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of Transportation
**Federal Highway
Administration**

FREEWAY MANAGEMENT AND OPERATIONS

HANDBOOK

FINAL REPORT

September 2003 (Updated June 2006)

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16. Abstract This document is the third such handbook for freeway management and operations. It is intended to be an introductory manual – a resource document that provides an overview of the various institutional and technical issues associated with the planning, design, implementation, operation, and management of a freeway network. The goal is to provide the user with a better understanding of the wide variety of potential strategies, tools, and technologies that may be used to support management and operation of the freeway network. The Handbook addresses the major changes in technology (e.g., ITS and architectures) that have occurred since the last Freeway Handbook was prepared. It also considers a broader view as well, including freeway management in the context of the entire surface transportation network, lane management concepts, roadway improvements (both geometric and operational), performance monitoring and associated measures, established processes for dealing with the risks associated with technology – intensive systems, and the role of freeway management during emergencies and evacuations. Specific chapters include Introduction (background on the freeway network, definitions, congestion, safety, mobility), freeway management and the surface transportation network (the various interdependencies during the facility's life –cycle, freeway management programs, performance monitoring and evaluation, roadway improvements, roadway operational improvements (e.g., signs and markings), ramp management, lane management, HOV facilities, traffic incident management, planned special event management, freeway management during emergencies and evacuations, information dissemination, transportation management centers, surveillance and detection, regional integration, and communications.			
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FOREWORD

Over the past three decades, the practice of freeway operations has matured. Strategies have evolved, techniques have been developed, and new technologies (ITS) have emerged. Traffic operation centers have reported successes and failures as lessons learned. The intelligent transportation community has quickly incorporated those lessons, and the resultant systems have progressed with each new generation of the freeway traffic management system.

The profession's view of freeway management and operations has also changed. Freeway management strategies and concepts were initially developed to counter congestion. That is still a major goal, along with enhance safety. But freeway practitioners are also beginning to view themselves as good stewards and responsible managers, managing not only the traffic flow on the network but also the being more proactive in addressing potential problems, rather than merely reactive. Moreover, part of this stewardship includes managing the elements of the network itself (e.g., asset management), not just the traffic flow. Another important consideration in this regard is that transportation is becoming increasingly customer-driven, with a need to view the network at more of a regional scale.

This expanded view of freeway operations and management is reflected in the key and recurring themes in this Handbook, including:

- Even though their primary responsibility may be the freeway network, practitioners must not address freeway management and operations in a singular, isolated manner. Accordingly, freeway managers must view the overall performance of the transportation network as a whole, and consider a vast array of potential actions to improve its performance. This may mean looking beyond the "typical" freeway management and operation alternatives and technologies.
- Freeway management and operations extends beyond ITS and electronic systems. Freeway managers must be familiar with all of the tools available to improve the safety and efficiency of the freeway system, including major roadway improvements, minor roadway improvements, and traditional traffic control devices (such as, static signing, pavement marking, and illumination systems); and look for appropriate opportunities to utilize these tools.
- Several processes have been instituted for developing transportation programs, planning and prioritizing potential improvements, and defining individual projects and strategies. Freeway management and operations should be an integral part of the established processes within an agency. Moreover, the freeway management practitioner must be cognizant of and, to the greatest extent possible (commensurate with his/her responsibilities), participate in these processes ensuring that freeway management and operations receives appropriate consideration.

REVISION HISTORY

The Freeway Management and Operations Handbook was developed in September 2003, and has since been updated to reflect current state of the practice. Updates to this handbook were coordinated by the Freeway Operations Committee Task Force.

The date of each chapter is listed in the footer of each page of the Handbook (e.g., September 2003). This will help to ensure that you have the most recent Handbook as individual chapters are updated. The most recent date of each chapter can be summarized as follows:

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Details of Revision History

Date	Author(s)	Summary of Update
March 2006	Les Jacobson Jason Stribiak	<p><u>Chapter 7 Update:</u></p> <p>Chapter 7 – Revised entire chapter to reflect current practice documented in the Ramp Management and Control Handbook (available at: http://ops.fhwa.dot.gov/freewaymgmt/freeway_ops.htm).</p>
June 2006	Les Jacobson Jason Stribiak	<p><u>Chapter 1 and Front Material Update:</u></p> <ul style="list-style-type: none"> • Front Cover – Added the words (Updated June 2006) to the date at the bottom of the page. • Form 1700, Box #5 - Added the words “(see Revision History page for chapter updates)” • Added a page after the Foreword and before the Table of Contents called “Revision History”. • Added the words “<i>Chapter 1 was revised in June 2006. For more information on the extent of revisions, see the Revision History Table at the beginning of this handbook.</i>” At the beginning of Chapter 1. • Chapter 1 - Revised the date in the footer to June 2006. • Updated Section 1.5.4.4. • Updated the definition of Ramp Management in Section 1.7 item #7 to be consistent with the definition provided in the Ramp Management Handbook.
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1. INTRODUCTION

Chapter 1 was revised in June 2006. For more information on the extent of these revisions, see the Revision History Table at the beginning of this handbook.

1.1 SCOPE OF FREEWAY MANAGEMENT AND OPERATIONS

Civilizations have become great in part because of their transportation systems. The Phoenicians used the seas as their transportation system. The Roman Empire built roads to connect the distant parts of their empire. The British Empire used the seas to maintain their empire. The United States civilization has become great and remains so, in a large part because of its transportation system, which has contributed to a robust economy. The ability to meet society's needs for mobility, access, goods movement, security, and overall quality of life is dependent on the ability to provide for safe, reliable, and sustainable travel in an ever-changing environment with varying demands. (8)

The nation's Interstate System and other expressways – totaling approximately 55,000 centerline miles – are an integral part of the surface transportation network. For example, urban freeways make up less than 2.4 % of the total urban highway mileage; yet carry approximately 20 % of the traffic nationwide (1). In essence, freeways provide the basic backbone of our roadway transportation system and the highest level of service when traffic flows smoothly and safely. "Service" in this context not only refers to the commuting, commercial, and recreational movement of drivers, riders and shippers; it also refers to the ability of the freeway network to support other government agencies (e.g., emergency service providers, first responders, military and security) as they plan, react to, and recover from weather-related, natural disasters, and human-caused emergencies.

Since the 1960's, population growth and economic prosperity have led to a steady increase in the number of vehicles using the roadways – particularly freeways – across the United States. The growth in highway travel by the public can be attributed to a number of factors including: population growth, an increased number of licensed drivers and auto ownership, an increase in the number of trips per household, growth in economic activity, changes in urban land use, and increase in freight activity. As shown in Figure 1-1, vehicle – miles traveled grew steadily during the last decade, with a minimal increase in lane-mileage.

This increase in demand has, unfortunately, resulted in more turbulent traffic conditions, increased congestion, and more frequent and longer traffic delays. Increased turbulence and increased vehicle demand leads to more conflicts and collisions, reducing safety. Today, the demand for freeway facilities is overwhelming, and problems have grown to an intolerable proportion in some metropolitan areas. A FHWA paper discussing TEA-21 Reauthorization (9) states: "It has become widely acknowledged that providing effective highway-based transportation consists of three component parts:

- Building the necessary infrastructure
- Preserving that infrastructure (e.g., maintenance & reconstruction), and
- Preserving its operating capacity by managing operations on a day-to-day basis.

Highway transportation can thus be likened to a three-legged stool that cannot effectively serve customer needs if any of these three parts (legs) is missing or is underemphasized (too short) relative to the others.” The focus of this document is the “operations leg”.

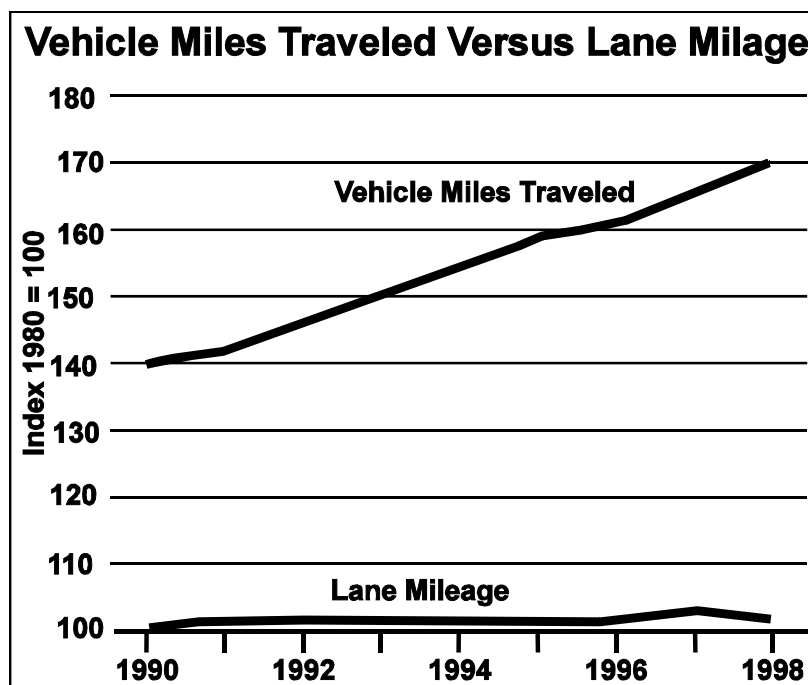


Figure 1-1: Vehicle Miles Traveled Versus Lane Mileage

(Reference 10)

Freeway traffic management and operations is the implementation of policies, strategies and technologies to improve freeway performance. The over-riding objectives of freeway management programs are to minimize congestion (and its side effects), improve safety, enhance overall mobility, and provide support to other agencies during emergencies. The TRB Freeway Operations Committee’s Millennium Paper (3) states: “Freeway operations, in its broadest context, entails a program to combat congestion and its damaging effects: user delay, inconvenience and frustration, reduced safety, and deteriorated air quality.” Moreover, this “context” includes a vast array of freeway uses – the daily commute, commercial vehicle operations, personal and recreational trips, emergency service response, and evacuations during emergencies.

1.1.1 Importance of Freeway Management & Operations

When discussing the quality of day-to-day freeway operations, the terms “congestion” and “safety” are commonly used. Traffic congestion means there are more people trying to use a given transportation facility during a specific period of time (i.e., “demand”) than the facility can

handle (i.e., “capacity”) with what are considered to be acceptable levels of delay or inconvenience. Safety is concerned with reducing the number of vehicle crashes and minimizing any injuries associated with crashes. Congestion – particularly unexpected congestion – and safety have very strong impacts on travelers’ attitudes. In a series of surveys carried out by FHWA (10), traffic flow and safety topped the list of highway characteristics that should receive the most attention (followed by pavement conditions and work zones).

Other equally important considerations include:

- **Mobility:** The ability and knowledge to travel from one location to another using a multimodal approach. (1)
- **Accessibility:** The means by which an individual can accomplish some economic or social activity. (1)
- **Reliability / Predictability:** How much the ease of movement varies from day to day, and the extent to which the traveler can predict these temporal variations.

In essence, motorists (and transit riders) want to know what to expect – such knowledge being a key attribute of “mobility”. Having accurate information about roadway performance significantly improves the perception of a trip because information allows motorists to make decisions that give them the perception of having more control over their life. Knowing the extent and duration of congestion not only gives the motorist better options, it removes a significant stress point, the unknown. (For example, a father trying to reach his daughter’s softball game realizes that the 10-minute delay won’t force him to miss the first pitch; therefore, he can relax and approach the accident site more cautiously, without any aggressive driving or “road rage”). Thus the perception of the congestion improves significantly. Conversely, when information is not available, the anxiety associated with the unknown reason for, and length of, the delay causes the motorist to perceive the delay as longer than it really is, perhaps leads to more erratic driving behavior, and creates a much more negative opinion of both the traffic congestion and, ultimately, how well the highway agency is using taxpayer resources. (2)

These considerations of mobility, accessibility, and reliability also apply to emergency and incident management agencies (i.e., Principal Responding Agencies – PRAs), and to motorists who are affected by an emergency (e.g., the need to evacuate from an area affected by a disaster of some sort). Under such extreme circumstances, these users also need to know their options and what to expect.

In theory, problems of congestion, safety, mobility, accessibility, etc. would dissolve with increases in capacity (i.e., adding more lanes, and new facilities) and the reconstruction of existing facilities (wider lanes and shoulders, improved alignment) to improve safety. Increasing capacity and reconstructing existing facilities, however, introduces significant economical, political and societal challenges, many of which cannot (and perhaps should not) be overcome. Moreover, increased capacity may create additional demand, eventually resulting in the same problems as before. Management and operations can provide practical and cost-effective alternatives (perhaps in concert with capacity improvements) for addressing freeway problems.

The need for and importance of freeway management and operations extends well beyond any constraints on building / reconstructing conventional infrastructure. Transportation agencies and authorities, and their staffs, have the responsibility to be good stewards and responsible

managers, being more proactive in addressing potential problems, rather than merely reactive. Moreover, part of this stewardship includes managing the elements of the network itself (e.g., asset management), not just the traffic flow.

Another important consideration in this regard is that transportation is becoming increasingly customer-driven, with a need to view the network at more of a regional scale. The public does not care which jurisdiction is responsible for the road on which they are currently traveling. They want and deserve a safe, reliable, and predictable trip, one that is safe from physical and mental harm, provides consistent service, and is predictable in terms of travel time that is within an acceptable variance.

Finally, technology – specifically Intelligent Transportation Systems (ITS) – is creating an environment where management and operations can take a major leap forward. The recent advances in surveillance, communications, processing, and information dissemination technologies, with an emphasis on “real time” applications, have proven a significant enabler of freeway management and operations. ITS allows for the rapid identification of situations with a potential to cause congestion, unsafe conditions, reduced mobility, etc.; and then to implement the appropriate strategies and plans for mitigating these problems and their duration and impacts on travel.

1.1.2 Wile E. Coyote and Freeway Performance

Reference 2¹ presents the “Wile E. Coyote Theorem of Freeway Performance” (including Figure 1-2) as follows:

“Freeway performance on congested and nearly congested roadways can perhaps best be explained by analogy to the Warner Bros. Road Runner cartoons. First, let’s talk about the cartoon. In a familiar Road Runner scene, Wile E. Coyote chases the Road Runner across the mesas of New Mexico. They run along a mesa until the Road Runner simply runs off the end, into thin air. Unaware, the Coyote follows him, running on thin air. Then something happens: he looks down. The Road Runner, safe as ever, whips out a taunting sign, and suddenly the Coyote realizes he is hanging in air. Zoom! Down he plunges for hundreds of feet... ending in a small puff of dust.

This same scenario is a very good description of urban freeway operations. Detection systems now measure freeway volumes that are 20 percent greater than what was once considered their theoretical maximum. However, under these volume conditions, when any type of disturbance in flow occurs, dramatic decreases in vehicle volumes and speeds result.

High volumes can be compared to the Coyote running along the top of the mesa. Volumes above about 2000 vehicles per lane per hour can be viewed as the Coyote running in air. As long as nothing happens to remind him that he is doing the impossible, he’s okay. And as long as nothing happens along the roadway, traffic will continue flowing.

The problem is, “things happen.” Accidents occur. Even small disruptions, such as a distraction on the side of the road (a catchy billboard, a police car pulled over) are

¹ Lomax, Turner, Hallenback, et al; “TRAFFIC CONGESTION AND TRAVEL RELIABILITY -- How Bad is the Situation and What is Being Done About It?”; September 2002

analogous to the Coyote looking down. At very high volumes, one vehicle's small hesitation can cause other vehicles to brake more heavily to avoid a collision. The disruption in flow then cascades, and suddenly both speed and throughput volume rapidly decrease. Like the Coyote, roadway performance plummets, and vehicle throughput vanishes in a small puff of dust.

And tomorrow, the Coyote will do it all again. Once again life imitates art."



Figure 1-2: Cartoon Analogy of Freeway Conditions

(Reference 2)

Freeway management and operations is all about keeping the Coyote from running off the cliff in the first place; and if (and when) he does, to keep him from looking down; and if (and when) he does look down, to minimize the impact of his fall (and the resulting dust plume), so he can resume his chase of the Road Runner as soon as possible thereafter.

1.2 PURPOSE

This document was prepared under FHWA Work Order SA80B010 as part of Contract DTFH61-01-C-00180. The original focus was to update the Freeway Management Handbook, reflecting the changes in the state-of-the-practice that had occurred since the Handbook was last updated in 1996. Per the original task order scope, “only an update and not a comprehensive revision is required to the Freeway Management Handbook”, and the “intent of this task order is to assess the current document, identify proposed changes, and perform the necessary revisions that ... are needed to represent the current state-of-the-practice in freeway management.” However, after a thorough review by the project team and a task force comprised of members and friends of the TRB Committee on Freeway Operations (see Table 1-1), it was determined that a complete and comprehensive revision to the Freeway Management Handbook was required – not just an “update” – to reflect the state of the practice, as well as to better address an expanded view of freeway management and operations. Annotated Outlines of each chapter were prepared, followed by several drafts reflecting review comments made by the aforementioned Freeway Operations Committee Task Force. It should be noted that the contributions made by this group of individuals was invaluable.

Table 1-1: Handbook Contributors – Freeway Operations Committee Task Force

- Jon Obenberger – FHWA Contract Manager
- Joel Marcuson – Task Force Leader
- Tom Urbanik – Project Team Reviewer
- Walter Kraft
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- Larry Corcoran
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This revised “Freeway Management and Operations Handbook” is intended to be an introductory manual – a resource document that provides an overview of the various institutional and technical issues associated with the planning, design, implementation, operation, and management of a freeway network. It is not intended to be an all-encompassing, “*Everything You Ever Wanted To Know About Freeway Management and Operations*”. Rather, it is intended to provide the user with a better understanding the wide variety of potential strategies, tools, and technologies that may be used to support management and operation of the freeway network. Additionally, beyond this obvious purpose of the Handbook, the document also attempts to address several broader issues, including:

- The concept of “operations” as a part of the overall mission (and some might regard as a relatively new one) for transportation agencies;
- Freeway management and operations activities (which often have a relatively short-term focus), within the context of the “life cycle” of the surface transportation network, such as relating freeway operations to a broader set of visions and goals, coordinating freeway operations with the longer – term policy making and transportation planning processes (and vice – versa), and expanding the view of freeway management and operations such that the transportation is considered.
- The numerous institutional relationships that impact the operation of the freeway and the infrastructure itself; and similarly, how individual “operational” actions relate to one another and how, when combined, can affect the institutional framework.
- Potential measures and procedures for evaluating the overall performance of the freeway, as well as evaluating freeway management strategies and improvements (both prior to and following their implementation).
- Planning and engineering processes for developing and updating freeway management programs, for developing individual projects to implement the program, and for managing the program after the projects are complete.

The Freeway Management and Operations Handbook relies heavily on other references for many of the concepts and some of the text included herein. As a general rule, the specific reference(s) is identified at the end of the associated sentence / paragraph / bullet list with a reference number in parenthesis. The references and their respective numbers are listed at the end of each chapter.

1.2.1 Why This Document Is Needed

In the late 1960s and early 1970s, highway agencies began to take steps toward active operation of the freeways that had been constructed during the intense building years of the Interstate Program. Emphases in highway transportation began to shift from building new facilities and enlarging existing ones to extracting the most from existing facilities. It was the dawn of the era of freeway operations and traffic management. Authorities began to realize that understanding how the public used freeways and how operating agencies managed that use was crucial to maintaining operational efficiency. Allowing unrestrained growth in the use of the freeway network produced congestion, which effectively reduced freeway capacity, lowered traveling speeds, reduced safety, and increased driver frustrations. Tools that could manage and reduce the congestion plaguing our highways were sorely needed. Researchers used

studies of highway usage to come up with the concepts and approaches that have since evolved into freeway traffic management programs. They realized that implementing these programs could cost-effectively influence the public's use of the highway system. (3)

Over the past three decades, the practice of freeway operations has matured. Strategies have evolved, techniques have been developed, and new technologies (ITS) have emerged. Traffic operation centers have reported successes and failures as lessons learned. The intelligent transportation community has quickly incorporated those lessons, and the resultant systems have progressed with each new generation of the freeway traffic management system.

The profession's view of freeway management and operations has also changed. Freeway management strategies and concepts were initially developed to counter congestion. That is still a major goal. But freeway practitioners are also beginning to view themselves as good stewards and responsible managers, managing not only the traffic flow on the network but also the physical elements of the network itself, addressing safety and security issues, and attempting to be more proactive in addressing potential problems rather than merely reactive.

Throughout this evolution, FHWA has sponsored the development of Handbooks to document the state of the practice in freeway management. A "Freeway Management Handbook" was originally developed in 1983. The first (and current) update was initiated in 1995, with the revised document published in 1997. The evolution will undoubtedly occur, and a new and revised "Freeway Management and Operations Handbook" will likely be required in another few years.

1.3 INTENDED AUDIENCE

The intended audience of the revised Handbook is transportation professionals that participate in or are responsible for any phase in the life cycle of a freeway network. This includes all public or private "practitioners" (e.g., managers, supervisors, engineers, planners, or technicians) that are involved with any issue or decision (e.g., legislation, policy, program, funding, project implementation, operational scenario) that may directly or indirectly influence the performance of a freeway facility. These activities may include, but not be limited to, planning and design of freeways and other transportation facilities within the same corridor, operational strategies, programs, and services that support continuous management of travel and control of traffic on freeway facilities, and the technology infrastructure to provide these capabilities.

It is emphasized that while this document focuses on the management and operation of freeway facilities, and views freeway practitioners as the primary audience, these practitioners must not consider freeways and their operation in a singular, isolated manner. All three of the aforementioned legs of the "transportation stool" (i.e., building, preserving, operating), are integral parts of the business of most transportation agencies, and freeways are just one element of the surface transportation network. The same planning, programming, and budgeting processes are applied to all of these facilities and management attributes. This is not to imply that they are necessarily in competition with one another; rather they should be viewed as complementary – for example, the application of freeway management and operational strategies on existing facilities may defer or eliminate the need for new infrastructure; new / expanded transit service may reduce the traffic flow on the freeway and other roadway facilities; the construction / reconstruction of freeway facilities can provide the opportunity to install ITS technologies and infrastructure (that support operations) in a most cost-effective manner; and

an intense program of freeway management and operations can help minimize the traffic flow impacts during reconstruction / maintenance activities.

1.4 OVERVIEW

1.4.1 The Problem

Demand for highway travel by Americans continues to grow as the population increases, particularly in metropolitan areas. Construction of new highway capacity has not kept pace with this growth. For example, between 1980 and 1999, route miles of highways increased 1.5 percent while vehicle miles of travel increased 76 percent. The effects of this disparity are captured in a number of measures and perceptions, including visible and consistent roadway congestion, the loss of personal and professional time, environmental degradation, and general traveler frustration – in essence, a reduction in overall mobility and accessibility. Some statistics are provided below:

- The Texas Transportation Institute (TTI) estimates that, in 2000, the 75 largest metropolitan areas experienced 3.6 billion vehicle-hours of delay, resulting in 21.6 billion liters (5.7 billion gallons) in wasted fuel and \$67.5 billion in lost productivity. (4)
- Each year, more than 42,000 people die on the nation's highways and 5 million are injured. A recent report from the National Highway Traffic Safety Administration put the economic costs of highway crashes at more than \$230 billion per year including medical and emergency services costs, lost productivity, legal costs, travel delay and property damage. Additionally, highway crashes are the leading cause of death of Americans 6 to 28 years of age. (13) The fatality rate on the Interstate System has been relatively steady after falling early in the 1990s. The number of fatalities on Interstate highways has increased over the past decade, but so has the level of traffic, as indicated by the number of vehicle miles traveled (VMT) (5).
- Congestion is growing in areas of every size. TTI's 2001 Annual Urban Mobility Report shows more severe congestion that lasts a longer period of time and affects more of the transportation network in 1999 than in 1982 in all urban population categories. The average annual delay per person climbed from 11 hours in 1982 to 36 hours in 1999. And delay over the same period quintupled in areas with less than 1 million people. The time to complete a trip during the congested period also continues to get longer. (2)
- Another measure of congestion—the travel time index—indicates how much more time it takes to travel during a peak period than at other times of day. This measure is based solely on the regular traffic congestion on the roadways. It provides a measure of how much of the change in traffic congestion is due solely to more cars using the roadways. During the past decade, the travel time index on Interstates increased by about 12 percent. This statistic provides information about drivers' experiences as well as the level of congestion on the road because it accounts for delays due both to the traffic demand on the road and to roadway incidents (e.g., crashes). (5)

The growth in demand has also impacted the temporal aspects of freeway operations. As discussed in Reference 2 and shown in Figure 1-3, traffic levels initially grow immediately before the start of the workday and immediately after the end of the workday (the green line). As traffic

reaches the roadway's capacity during those times, travelers begin to leave 10 or 15 minutes earlier or later in the day to avoid the resulting congestion or they allow more time for travel. This spread of travel demand soon creates a true "peak hour" of volume. As growth continues, like it has in most major cities, the "peak hour" becomes the "peak period," since limitations in roadway capacity allow growth in traffic to occur only at the beginning and end of the "peak period" (see the red line in the figure). The sharp morning or afternoon peak in travel thus becomes a wide mesa. In many areas, particularly suburban areas, these peak movements stop being one-directional (people traveling from the suburbs to the central city in the morning and back in the afternoon) and become two-directional as people travel among multiple suburban locations. As the evolution of congestion continues, travel on heavily used (and frequently congested) roads actually becomes almost constant throughout the day. Finally, as growth pressure continues, congestion in the peak periods can become so severe that average peak period volumes actually *decline* because congestion decreases the volume of vehicles a road can accommodate. (2)

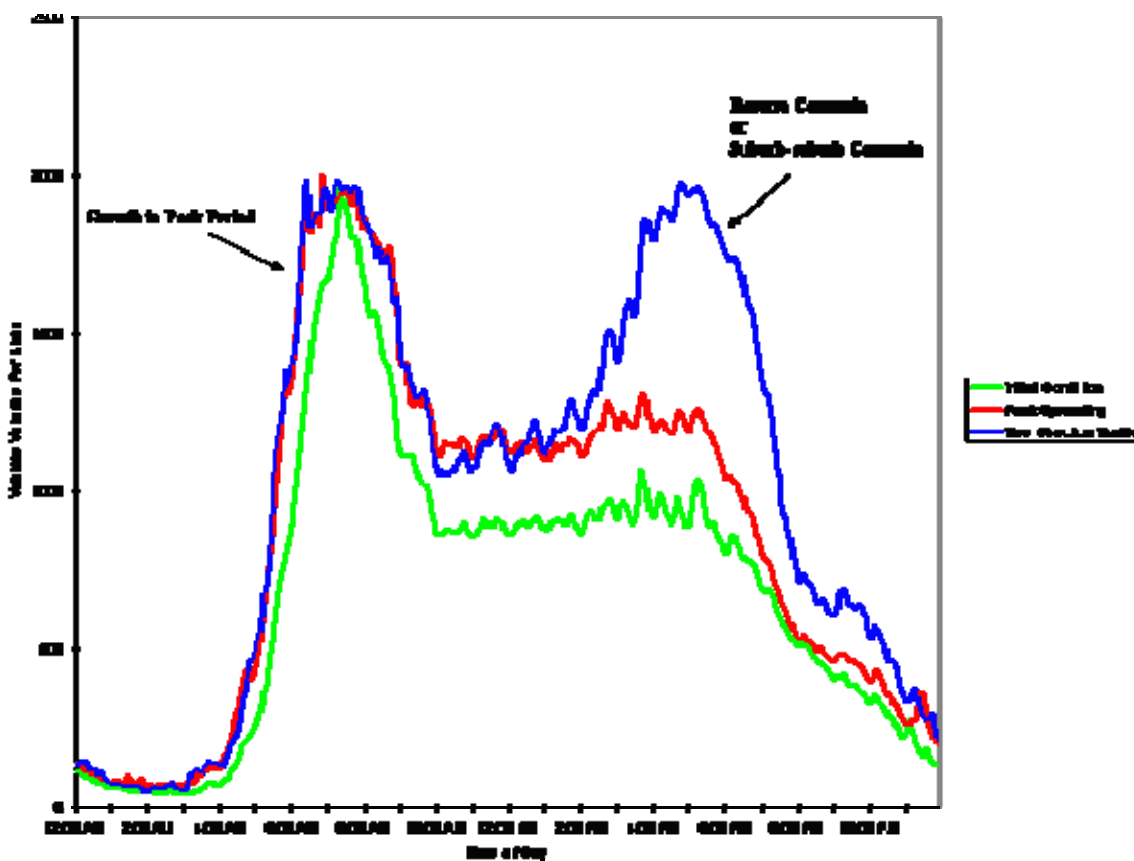


Figure 1-3: Typical Plots of Volume vs. Time-of-Day
(Reference 2)

Delays (resulting from freeway congestion) at particular locations in a transportation network are certainly aggravating to those using the system; but these delays are part of a much larger picture of how a transportation system allows people and goods to move around a metropolitan area. The consequences of congestion are much more serious to a community. For example:

- **Local Traffic Impacts:** When faced with congested conditions, many drivers quickly look for ways to bypass the freeway bottleneck. These often include making their way through arterial streets and residential neighborhoods not designed to handle through traffic. Such bypass traffic often becomes the focus of neighborhood complaints. (1)
- **Economic Growth:** Efficient transportation access to employment and shopping sites is an important consideration to business and developers when considering expansion opportunities. A good transportation system is an important selling point to communities that desire to attract development. In addition, good transportation is very important to the movement of goods and services and thus has a direct impact on sound economic growth and productivity. (1) With respect to the last point, commercial freight carriers notice the growing lack of travel reliability even more. These companies experience increasing costs from having to pay large quantities of overtime because their trucks are stuck in unexpected traffic. Costs also increase from an inability to schedule work for their vehicles over the complete workday, as the companies lengthen expected delivery times just to ensure that they don't have to pay overtime. Inefficiencies caused by unreliable roadway travel times add to the costs that slow moving traffic create by making each trip last longer. (2)
- **Quality-of-Life:** To some people, congested (and unsafe) highways are a symptom of deteriorating quality-of-life in a community. In many cases, and in particular in suburban communities, residents moved to their community to escape urban problems like traffic jams. Now facing this congestion has once again become part of their daily routine. Another aspect of this quality-of-life characteristic is the role transportation plays as a key element of getting and keeping a job. (1)
- **Environmental Quality:** Congested road conditions can have a detrimental effect on the environment, in particular air quality. Making improvements to the transportation system or trying to change travel behavior has been an important objective of those wanting to improve environmental quality. (1)

There is also an institutional and political aspect to all of this. Addressing the performance of the transportation network and the mobility needs of a community has become, in several cases, a litmus test for effective leadership. Because the public sector is viewed as having the major responsibility for solving transportation problems, community officials are often the focal point for citizens' interest concerning traffic congestion, safety, and mobility needs. (1)

1.4.2 The Future

There are a number of demographic trends that are likely to affect travel patterns and congestion in the future, including:

- **Rising affluence and increased income**—Rising incomes will likely translate into increased auto availability and use, increased number of trips per household, and increased average trip lengths. The rising affluence is partly due to the fact that many households now have

multiple workers. When multiple workers reside in a single household, it then becomes more difficult for each to live in close proximity to their work; thus the need to choose some compromise location that meets both workers' needs as well as the needs of other household members (e.g., good schools, nice parks, etc.).

- Democratization of mobility—Privately owned auto transportation is becoming more accessible to previously car-less households. This increased access to personal mobility via personal auto is mostly among Americans living in center cities. In many instances, this newfound personal mobility carries them to where employment is easy to find—the booming suburban areas that require longer vehicle trips. (2)

Traffic demand – both passenger and freight – is expected to increase. Estimates that FHWA uses indicate passenger traffic will increase by 17 percent from the end of 2001 through 2010—an increase from 2.7 trillion vehicle miles traveled to 3.1 trillion. In addition, states and FHWA data indicate that truck traffic is expected to increase in the future. Estimates used by FHWA show freight movement by truck increasing by 28 percent from the end of 2001 through the end of 2010. Finally, an alliance of primarily southern and southeastern states released a 2001 study that estimates a 6.9 percent annual increase in Latin American truck traffic in the United States (resulting in almost a doubling over the 10-year period). Ninety-six percent of this truck traffic will be on Interstates. (5)

1.4.3 Homeland Security and Other Emergencies

Another (and relatively new concern) is that of homeland security, which can be expected to exact new demands on the U.S. surface transportation system. Research by the Federal Transit Administration indicates that 58% of international terrorist attacks were on transportation targets, and of these 92% were on surface transportation. The ability of our system to cope with such contingencies requires capability to detect catastrophic incidents, to facilitate first responder communications, to quarantine roads, and to effectively route evacuations from major metropolitan areas; all while maintaining the appropriate balance between these transportation security needs and the efficiency of the transportation network. Freeway practitioners must be prepared to go beyond the normal day-to-day management activities to support emergency service providers and the military during large-scale response and recovery activities – not only terrorist attacks, but natural and weather related disasters such as hurricanes, forest fires, blizzards, earthquakes, etc.

1.4.4 Potential Solutions

As previously noted, providing effective highway-based transportation consists of three component parts: construction, preservation, and operations. In addition to these primarily “supply” – oriented solutions, there is also “demand” aspect; and numerous agencies have implemented solutions for managing the demand for the highway network.

1.4.4.1 Construction

Construction, whenever it is feasible, often seems to be the first choice of most politicians and many transportation agencies. It provides a visible increase in vehicular capacity. Whether it is politically popular depends on the cost of the construction project and its impacts on land uses and the environment. Construction does have several drawbacks. There isn't enough funding to address the growing demand. Moreover, construction is becoming increasingly difficult to do. In urban areas, where congestion tends to be greatest, land prices, public resistance, and

environmental mitigation requirements severely limit the size of capacity improvements. They also increase the time required to gain the necessary permits, thus raising costs dramatically. These problems limit both the public’s acceptance of new construction and their willingness to pay for those roads. Under these circumstances, new construction may only moderate existing congestion rather than eliminate it because building sufficient capacity to meet existing levels of demand is not feasible.

1.4.4.2 Operations

Since new construction is often not feasible or insufficient to significantly reduce congestion and improve mobility, transportation agencies are turning to operational improvements to reduce / limit the growth of congestion, improve safety, and / or increase the number of people the existing roadway will carry. A variety of strategies have been used successfully to improve roadway operation. Among the most common are: traffic incident detection and management, traveler information, managed lanes (e.g., preferential treatment to high-occupancy vehicles), ramp management, and Intelligent Transportation Systems.

Freeway management applications have had a positive effect on freeway operations leading to benefits such as increased safety, improved traffic flow, and reductions in traffic delays. A summary of measured benefits associated with freeway management is provided in Table 1-2. (More detailed information on the benefits and costs of freeway management strategies, and ITS technologies in general is available “Intelligent Transportation Systems Benefits and Costs – 2003 Update” (Reference 15). Information in that report is drawn from the ITS Benefits and Unit Costs Databases, a regularly updated repository of information, available at www.benefitcost.its.dot.gov.)

Table 1-2 Measured Benefits of Freeway Management

(Reference 6)

Measure	Benefit
Travel Time	Decrease 20% to 48%
Travel Speed	Increase 16% to 62%
Freeway Capacity	Increase 17%to 25%
Accidents	Decrease 15% to 50%
Fuel Consumption	Decrease of 41% in congested areas
Emissions	Decrease HC emissions 1400 tons annually
	Decrease NOx emissions 1200 tons annually

Each of the various operational strategies works effectively under specific conditions, but most improvements individually achieve only modest reductions in congestion. Their real contribution

is to significantly improve the efficiency of the existing infrastructure, while increasing the reliability and safety of the transportation system operation.

1.4.4.3 Demand Management

In the broadest sense, transportation demand management (TDM) is any action or set of actions intended to influence the intensity, timing, and spatial distribution of transportation demand for the purpose of reducing the impact of traffic or enhancing mobility options (1). A variety of government- and employer-sponsored programs can be designed to reduce vehicle trips during congested periods and in congested locations. These include flexible work schedules that allow employees to travel off-peak (or work at home), amenities to improve the safety and efficiency of biking and walking, ridematching services for vanpools and carpools, community-based carsharing, employer-subsidized transit passes, guaranteed emergency rides home for transit users, and incentives to decrease employer-paid parking.

1.4.4.4 Discussion

The transportation phenomenon is the result of demographic and market forces that are difficult to change. In addition to the supply and demand – oriented solutions noted above, there is also the issue of managing the land use and development patterns that influence when and where travel demand occurs over the long term. To be effective within this context, one needs to examine how the various actions complement one another over the long run.

A coordinated mobility, congestion reduction, and safety enhancement program should consist of several tools and elements from all of these categories of potential solutions. The specific structure of such a program depends, of course, upon funding and the feasibility of implementing such actions in the local political environment. Attributes of a mobility / congestion / safety program include:

- Provide the most cost effective transportation system improvements that enhance mobility, increase safety, and reduce traffic congestion while being consistent with community goals. The improvements can include operational changes to improve the performance of the existing network and services, and the physical expansion of the highway system or the addition of transit services.
- Examine better ways of managing transportation demand, especially if the opportunity for substantial gains in system performance through expansion or operational improvements is limited.
- Explicitly consider long-range strategies that will provide the foundation for avoiding similar problems in the future. This implies an important role for considering future land use/development patterns and their impact on travel.
- Deal with institutional arrangements and funding requirements for implementing the program. This is especially important where the transportation services are housed in separate units. (1)

It also bears mentioning that while all of these potential strategies can reduce congestion, enhance safety, and improve mobility; they will rarely be implemented in enough magnitude to completely eliminate congestion in urban areas. The goals, then, are more typically to manage congestion, provide travel options, and improve travel reliability and safety.

1.5 DEFINITIONS AND CONCEPTS

1.5.1 Freeways

The Highway Capacity Manual (HCM) (7) defines a freeway as a divided highway with full control of access and two or more lanes for the exclusive use of traffic in each direction. Freeways provide uninterrupted flow². Opposing directions of flow are continuously separated by a raised barrier, an at-grade median, or a continuous raised median (Figure 1-4). Operating conditions on a freeway primarily result from interactions among vehicles and drivers in the traffic stream and among vehicles, drivers, and the geometric characteristics of the freeway.



Figure 1-4: Freeway Interchange (I81 / I690 in Syracuse, NY)

(Courtesy of NYS DOT)

The AASHTO “Green Book” (13) defines freeways as “arterial highways with full control of access. They are intended to provide for high levels of safety and efficiency in the movement of large volumes of traffic at high speeds. With full control of access, preference is given to through traffic by providing access connections with selected public roads only and by prohibiting crossings at grade and private driveway connections”.

² “Uninterrupted” is used to describe the type of facility, not the quality of the traffic flow at any given time. A freeway experiencing extreme congestion, for example, is still an uninterrupted-flow facility because the causes of congestion are internal.

Several physical attributes of the freeway facility impact its capacity and operational characteristics as summarized in Table 1-3. Additional factors include level of enforcement, lighting conditions, pavement conditions, pavement markings and signing, and weather.

Table 1-3: Physical Factors Affecting Roadway Capacity and Operations

Category	Capacity / Design Element
Horizontal Alignment	<ul style="list-style-type: none"> • Degree of curvature • Superelevation
Vertical Alignment	<ul style="list-style-type: none"> • Grade • Length of grade • Vertical curves – sag and crest
Cross Section	<ul style="list-style-type: none"> • Number of lanes • Lane width • Lateral Clearance <ul style="list-style-type: none"> ○ Shoulder type and width ○ Median type and width ○ Clearance to obstructions
Other	<ul style="list-style-type: none"> • Interchange density • Ramps & ramp junctions • Weaving sections

A tollway or toll road is similar to a freeway, except that tolls are collected at designated points along the facility, either electronically, manually, or some combination. Although the collection of tolls may involve interruptions of traffic flow (Figure 1-6), these facilities should generally be treated as “freeways”, particularly with respect to strategies and technologies for management and operations. Special attention should be given to the unique characteristics, lane management opportunities, and constraints associated with toll collection facilities. Accordingly, the term “freeway” as used in this Handbook refers to any limited access facility, including the interstate system, expressways, toll roads, and connecting bridges and tunnels.

1.5.2 Congestion

The FHWA publication “Managing our Congested Streets & Highways” (10) documents the results of several surveys, with delays caused by traffic congestion topping the list of transportation issues that people reported as affecting their communities. But what is actually meant by the term “congestion”? To truly comprehend freeway management and operations strategies and supporting technologies, and to fully appreciate their potential to deal with congestion problems, it is important to understand both the nature of congestion and the events that occur in the traffic stream as congestion forms. There are multiple definitions and measures of congestion – both quantitative and qualitative, as discussed below.



Figure 1-5: Toll Plaza

1.5.2.1 Traffic Flow Theory

The generalized relationships between speed, density and flow rate are shown in Figure 1-6, with these parameters defined as follows:

- **Flow Rate**—the equivalent hourly rate (i.e., vehicles per hour) at which vehicles pass over a given point or section of a lane or roadway during a given time interval of less than one hour. (This is different from “volume”, which is the number of vehicles observed or predicted to pass a point during a specified time interval, such as annual or average daily traffic.) (7)
- **Speed** – defined as a rate of motion expressed as distance per unit of time, generally as miles per hour (mi/h). In characterizing the speed of a traffic stream, a representative value must be used, because a broad distribution of individual speeds is observable in the traffic stream. The curves in Figure 1-6 utilize “average travel speed”, which is computed by dividing the length of the highway segment under consideration by the average travel time of the vehicles traversing it (7).
- **Density** – the number of vehicles occupying a given length of a lane or roadway at a particular instant. For the curves shown in Figure 1-6, density is averaged over time and is usually expressed as vehicles per mile (veh/mi) (7).

The form of these curves depends on the prevailing traffic and roadway conditions on the segment under study. Moreover, while the diagrams in Figure 1-6 show continuous curves; in

reality there are likely discontinuities, with part of these curves not present. The curves illustrate the following significant points.

- A zero flow rate occurs under two different conditions. One is when there are no vehicles on the facility— density is zero, and flow rate is zero. The second is when density becomes so high that all vehicles must stop—the speed is zero, and the flow rate is zero, because there is no movement and vehicles cannot pass a point on the roadway (7).
- Between these two extreme points, the dynamics of traffic flow produce a maximizing effect. As flow increases from zero, density also increases, since more vehicles are on the roadway. When this happens, speed declines because of the interaction of vehicles. This decline is negligible at low and medium densities and flow rates. As the density further increases, these generalized curves suggest that speed decreases significantly just before capacity is achieved, with capacity being defined as the product of density and speed resulting in the maximum flow rate. This condition is shown as optimum speed S_o (often called critical speed), optimum density D_o (sometimes referred to as critical density), and maximum flow V_m . (7). In general, this maximum flow (i.e. capacity) occurs at a speed between 35 and 50 mph.

Efficient freeway operation depends on the balance between capacity and demand. In the simplest terms, highway congestion results when traffic demand approaches or exceeds the available capacity of the highway system. As vehicle demand approaches highway capacity, traffic flow begins to deteriorate. Flow is interrupted by spots of turbulence and shock waves, which disrupt efficiency. Then, traffic flow begins to break down rapidly, followed by further deterioration of operational efficiency. The result of this spiraling inefficiency can be observed during every weekday commute in almost every metropolitan area: Drivers push their way onto already crowded freeways to join thousands of others already caught in seemingly endless traffic jams. Unfortunately, by joining the already impeded traffic flow, drivers become part of the problem, creating even greater inefficiencies: more stop-and-go traffic conditions, longer delays, and greater potential for accidents.

While this is a simple concept, traffic demand is not constant. It can vary significantly depending on the season of the year, the day of the week, and even the time of day. Also, the capacity is not a constant – it can change (sometimes rapidly) because of weather, work zones, traffic incidents, or other events. It is not necessarily simple, either. The physical fact of finiteness and the principle of conservation underlies traffic stream behavior, as reflected in the smooth curves in Figure 1-6. However, the actual performance of a particular section of freeway at a particular point in time is more ambiguous, resulting from variations in individual human behavior and the mix of vehicle types using the facility. It may be possible to predict the average behavior and average capacity, and the variances about these averages for a traffic stream, but never the precise behavior.

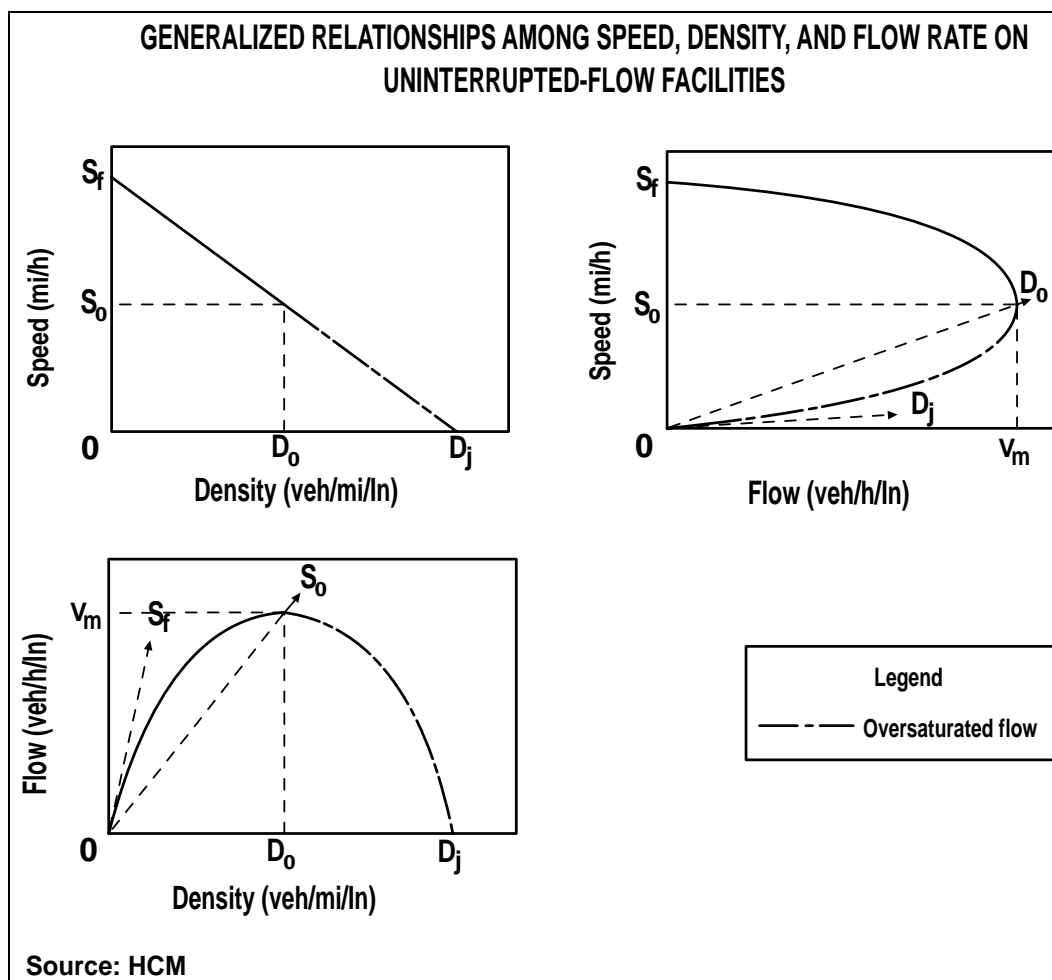


Figure 1-6: Generalized Relationships Between Speed, Density, and Flow Rate on Freeways
(Reference 7)

1.5.2.2 Quantifying Congestion

NCHRP Report 398 entitled “Quantifying Congestion” (Reference 16) identifies the following four components that interact in a congested roadway or system:

- **Duration** – the amount of time congestion affects the travel system.
- **Extent** – the number of people or vehicles affected by the congestion, and the geographic distribution of the congestion.
- **Intensity** – the severity of congestion (with concomitant measures such as person-hours of delay, average speed, etc.).
- **Reliability** – the variation of the other three elements.

The report states: “Any definition of congestion, and the congestion measures derived therefrom, should rely on concepts that are understandable by the intended audience. Travel time and its related quantities are widely understood and fundamentally useful in the definition

and measurement of congestion. However, the congested reflected in travel times and delays that are acceptable to travelers can vary by city size, location in the urban (or rural) area, and time of day or year. One method that may be used to resolve this issue is to define two quantities, congestion and unacceptable congestion.

- Congestion is travel time or delay in excess of that normally incurred under light or free-flow travel conditions.
- Unacceptable congestion is travel time or delay in excess of an agreed-upon norm. The agreed-upon norm may vary by type of transportation facility, travel mode, geographic location, and time of day, and should be derived taking into account the expectations for each portion of the transportation system as influenced by community input and technical considerations". (16)

Measures of congestion are discussed in Chapter 4.

1.5.2.3 Other Considerations

Perhaps "congestion" lies in the eye (and experience) of the beholder (Figure 1-7). As an example, in 2002, the ITS Forum of the "National Associations Working Group for ITS" (<http://www.nawgits.com/itsforum>) posted as the question of the month: "What should be our common definition of Congestion?" There were numerous replies and opinions, including:

- "Any definition needs to be understandable to the general public or to elected officials to be useful. Congestion occurs and is caused by bottlenecks. All other mechanisms for describing traffic flow are related to measures of effectiveness."
- "The speed-flow relationship is fundamental to traffic theory. In the Highway Capacity Manual this relation is given by a smooth curve, which yields a maximum flow at a speed between 35 and 50 mph. We tested this hypothesis using cross-sectional data. The test rejects the hypothesis that maximum flow occurs between 35 and 50 mph. The finding has some important implications. Congestion delay should be measured as the time spent driving below 60 mph, both because it is the most efficient speed and because drivers experience congestion below this speed."
- "A metric for congestion – total trip time at posted speeds compared to total trip time at operating speed and an accompanying index for setting service standards."



Figure 1-7: Another View of Congestion

- “Caltrans today measures congestion as the time spent driving under 35 mph continuously for 15 minutes.’
- “Transportation congestion has local / cultural and time-of-duration components to it that defy strict terminology.”
- “Congestion will always be relative.

With respect to the last point, congestion is typically viewed by travelers relative to their normal day-to-day experiences. Travelers accustomed to low speeds and congestion delays for 12 hours each day may not consider 10 minutes of delay per trip a problem. These travelers have learned to budget extra time or find other ways to cope with the delay. Travelers accustomed to light traffic and reliable trips might consider 5 minutes of delay per trip unacceptable and a problem worth noting at the next City Council meeting. A key aspect of a congestion management strategy is identifying the level of "acceptable" congestion and developing plans and programs to achieve that target. (2)

A major goal of freeway management and operations is to keep freeway capacity and the vehicular demand on a freeway in balance. The most effective way to combat congestion is to take action before traffic flow deteriorates and congestion forms. It would be ideal to manage the demand on the freeway to prevent traffic flow from ever breaking down and congestion from forming. This is usually not possible, and the best result is to delay the onset of congestion and speed the recovery from congestion, therefore minimizing the inefficiencies that congestion causes.

1.5.2.4 Recurrent and Non-Recurrent Congestion

Congestion is often classified as either recurrent or non-recurrent. The type of congestion depends on whether the capacity or the demand factor is out of balance.

- **Recurrent** congestion occurs when demand increases beyond the available capacity. It usually is associated with the morning and afternoon work commutes, when demand reaches such a level that the freeway is overwhelmed and traffic flow deteriorates to unstable stop-and-go conditions.
- **Non-recurrent** congestion results from a decrease in capacity, while the demand remains the same. This kind of congestion usually results when one or more lanes are temporarily blocked. A stopped vehicle, for example, can take a lane out of service, but the same number of vehicles expects to travel through. Speed and throughput drop until the lane is reopened, and then they return to full capacity. Capacity can also be decreased by weather events and events near the travelway (i.e., “rubber necking”), leading to non-recurrent congestion and reduced reliability of the entire transportation system.

Whereas recurrent and non-recurrent congestion have different causes, their solutions have many elements in common.

1.5.3 Safety

An individual highway crash is a rare, random, multifactor event, preceded by a situation in which one or more persons failed to cope with their environment. In the aggregate, however, traffic crashes are quite numerous and often follow certain patterns that can be identified.

Crashes reflect a shortcoming in one or more components of the driver-vehicle-roadway system. It is therefore very important for freeway practitioners to monitor traffic collision experience, and to use this information to identify, plan, implement, and evaluate corrective actions. Numerous approaches exist for improving safety and reducing crashes on highways. Many of these are beyond the scope of freeway management and operations, per se (e.g., enforcing seat belt laws, in-vehicle crash-avoidance technologies, geometric realignment); but others – such as improved signing and lighting, skid resistance pavement, adding shoulders and auxiliary lanes, and removing obstacles – are well within the realm of “operations”.

As previously noted, a major goal of freeway management and operations is to reduce congestion; and a reduction in congestion may also enhance safety. But how does congestion affect highway safety? The basic theory behind the interaction is that congestion leads to higher vehicle densities (i.e., more closely spaced vehicles on a roadway), which provides more opportunities for conflict. Congestion also reduces vehicle speeds, which implies that when vehicles are engaged in a crash, the collision forces are lower, thus reducing the injury to occupants. Another aspect of the model is the concept of “secondary” crashes—crashes that occur due to conditions produced by an existing crash. Some of these conditions—which wouldn’t exist without the occurrence of the first crash—include rapid backward queue formation (as vehicles suddenly stop to avoid the first crash), rubbernecking by drivers, and the maneuvers of emergency vehicles. Finally, the flow restrictions produced by crashes worsen existing congestion (2).

The details of the relationship between congestion and safety are not well understood (with the exception of lower crash severities, which have been documented in a general way for congested conditions, and the associated lower speeds). Based on the limited work that has been performed, a few tentative conclusions may be drawn:

- Crash potential (e.g., crashes per vehicle-mile traveled) probably increases as congestion increases.
- There is a lower proportion of single vehicle crashes (e.g., run-off-road, rollover, collision with fixed object) during congested conditions and a higher proportion of multiple vehicle crashes.
- Crash severities (extent and nature of personal injuries) are lower during congested conditions, due to lower vehicle speeds at the moment of crash impact.

In general, it can be assumed that any operational improvement that reduces congestion will lead to fewer crashes. The severity of crashes that occur will be higher, however, and it is likely that a greater proportion will be single vehicle crashes. Knowing these facts can target mitigation strategies to single vehicle crashes and higher severities—such as wider roadside recovery zones, protection of highway “furniture,” and coordination with emergency medical services. Moreover, an operations philosophy must take a systems-oriented view, where the consequences of a specific action (e.g., flow improvements) consider linked impacts such as safety (2).

1.5.4 Freeway Management and Operations

Freeway traffic management and operations is the implementation of policies, strategies and technologies to improve freeway performance. The over-riding objectives of freeway management programs include minimizing congestion (and its side effects), improving safety, and enhancing overall mobility. The TRB Freeway Operations Committee’s Millennium Paper

(3) states: "Freeway operations, in its broadest context, entails a program to combat congestion and its damaging effects: driver delay, inconvenience and frustration, reduced safety, and deteriorated air quality." Freeway traffic management entails:

- Understanding both the nature and magnitude of a particular congestion and / or safety problem, including current issues (i.e., reactive), and potential future ones (i.e., proactive);
- Combining various operational strategies, policies, and systems into a comprehensive program;
- Using technology, detection and verification systems, communication links, traffic operations centers, motorist information systems, and information sharing among systems;
- Implementing a high degree of interagency coordination and cooperation to provide emergency services and to restore accident scenes to normal operation in the shortest possible time;
- Deploying and implementing highly sensitive and sometimes controversial management strategies, such as ramp meters and high-occupancy lanes; and
- Managing extremely popular services such as tow trucks and patrols to rapidly remove disabled vehicles from freeways (3).

Freeway traffic management is all of this and more. Its components are aimed at providing some level of relief from congestion, improving safety and mobility for the traveling public, and meeting other related objectives. Strategies and technologies associated with freeway management and operations are summarized below.

1.5.4.1 Infrastructure Improvements

Freeway management and operations include "low-cost" (relative to constructing new facilities) improvements to the freeway infrastructure. Examples of such activities include adding auxiliary lanes, ramp widening, restriping to add an additional lane within the existing pavement, and similar improvements to eliminate bottlenecks. Enhancements to other attributes of the freeway infrastructure (e.g., signing, pavement markings, illumination) to increase safety and driver convenience / comfort are other possible improvements.

1.5.4.2 Traffic Incident Management

Traffic incident management is an operational approach designed to quickly detect, respond, and clear disabled vehicles and other "events" (such as debris) from the roadway that would detract from facility performance. Traffic incidents, such as crashes and disabled vehicles, reduce capacity (i.e., non-recurrent congestion) and decrease safety (along with the life-safety issues associated with responding to a crash scene with the proper medical personnel and equipment as soon as possible). Such incidents are the cause of 40 to 60 percent of all congestion in urban areas.

The primary intent of traffic incident management is to prevent incidents from reducing capacity; but when they do, the focus is to restore capacity as quickly as possible. This prevents backups and significantly decreases the occurrence and severity of congestion, and the possibility of secondary crashes. Traffic incident management programs vary from location to location. They can include: technologies and communications for rapidly detecting incidents and identifying their location and the appropriate response needs (e.g., networks of closed circuit television cameras, vehicle detection sensors, incoming 911 reports, incoming media reports, and mobile reports), systems and procedures for dispatching the appropriate emergency response personnel and equipment; service patrols (vehicles specifically intended to look for and help

disabled motorists), incident management teams (interagency working groups formed to develop faster and more efficient responses to accidents and other major incidents) traveler information systems.

1.5.4.3 Lane Management

The term “managed lanes” covers a variety of strategies and techniques, many of which have been used for years. The basic concept behind lane management is to employ operational tools to maximize the productivity of the available roadway. Lane management concepts can include the following:

- **HOV lanes** – to encourage more people to use high capacity modes of travel, thus moving more people in a single roadway lane
- **HOT lanes** – which allow vehicles to purchase access (through tolls) to underutilized HOV lane capacity, thus 1) maximizing vehicle use of HOV lanes without sacrificing HOV speed and reliability, and 2) providing revenue to help pay for HOV lane construction, maintenance, and operation, or other transportation needs.
- **Reversible and contra-flow roadways** – which allow increased use of underutilized lanes when traffic volumes in one direction far exceed traffic volumes in the opposite direction
- **Congestion pricing** – which uses tolls or other fees to shift travel demand from congested times and locations to other times of the day or to other facilities (or lanes) that are not congested
- **Truck-only facilities** – which both improve freight movement and limit truck/car interaction, thus increasing safety and decreasing the effect that heavy trucks have on passenger car performance. Lanes may also have truck restrictions.
- **Work zones** – providing efficient movement of traffic through areas of a highway construction, maintenance, or utility work activities; while protecting the safety of both workers and motorists.

1.5.4.4 Ramp Management

Ramp management, is the application of control devices, such as traffic signals, signing, and gates to regulate the number of vehicles entering or leaving the freeway, in order to achieve operational objectives. Most ramp management strategies lead to improved traffic flow and safety by 1) regulating the number of vehicles entering or exiting a freeway, or 2) smoothing out the rate at which vehicles enter the freeway facility. By employing either of these approaches, ramp management helps to balance freeway demand and capacity and maintain optimum freeway operation by reducing incidents that produce traffic delays, improve safety on adjacent freeways or arterial streets, or giving special treatment to a specific class of vehicles. Ramp management strategies are also often implemented with elements of other freeway management programs to create operational efficiencies and to assist in the delivery of overall transportation management goals and objectives.

Ramp management strategies may be used to control access to selected ramps, thus limiting the periods when vehicles may access the ramp or possibly restricting access to the ramp permanently. This significantly reduces, or may even eliminate, the potential for collisions that occur as a result of traffic entering or exiting the ramp facility and in turn smoothes the flow of traffic on segments of roadway where these collisions have occurred in the past.

Ramp management may also control the manner in which vehicles enter and exit a freeway. For instance, vehicles that enter the freeway in platoons introduce turbulence, which causes

vehicles on both the mainline and ramp to slow down to safely merge. This causes congestion around and upstream of ramp/freeway merge points. Ramp management strategies may be used to control the flow of vehicles entering a freeway, thus smoothing the rate at which vehicles are allowed to enter the freeway. Similarly, ramp management strategies and treatments may be implemented at the ramp-arterial intersection to better manage the flow of traffic exiting the freeway. Such treatments may reduce queues on exit ramps that extend out onto the freeway, helping to improve safety and mobility on the freeway.

1.5.4.5 Information Dissemination

This provides the information travelers need to effectively plan their trip prior to departure; and when en-route, the information may be used by drivers to avoid congestion and / or to adjust their driving behavior (e.g., in response to unsafe conditions). Traveler information provides choices for travelers – a key attribute of mobility. They can select different routes, different modes, different times, or even different destinations. They can avoid congested or unsafe routes (e.g., due to adverse weather conditions). Their ability to choose improves their trip. Such knowledge also reduces stress and limits risk taking behavior, thus producing better travel conditions. Pre-trip information is typically disseminated to the public via websites, media broadcasts, and mobile communication devices (e.g., personal digital assistants, pagers, and cell phones). En-route traveler information has traditionally been disseminated via commercial radio, changeable message signs (CMS) and highway advisory radio (HAR). With the emergence of wireless communication technologies, en-route traveler information can also be disseminated through wireless phones, web-enabled wireless phones, and a variety of personal digital assistants (PDA) equipped with wireless communication capabilities.

1.5.4.6 Intelligent Transportation Systems

Intelligent Transportation Systems (ITS) is the application of advanced electronics, computer, communications, and sensor technologies – in an integrated manner – to increase the efficiency and safety of the surface transportation network. ITS encompasses technologies that can lead to:

- Better management and operations of the existing highway, public transportation and railroad infrastructure to ease congestion and respond to crises.
- Safer and more convenient travel for people.
- More efficient and secure freight movements (14).

Used effectively, ITS opens the door to new ways of managing, operating, expanding, refining, reconfiguring and using the transportation system. ITS has proven itself as a significant enabler of freeway management and operations. Combined with ITS technologies, a **Freeway Management System** (FMS) consists of a set of resources (e.g., electronic systems, people, objects, and strategies) that are used to accomplish a set of goals to improve the operation of the freeway network. Several of these potential ITS components have already been mentioned above (e.g., CMS, HAR, ramp meters). Other elements of an ITS-based freeway management system that support these functions include:

- **Surveillance and Detection Systems** – These devices collect information on traffic flow and roadway performance, and allow operators to monitor conditions (in real time) on the freeway system. The sensors may collect data (volume, speeds, travel times), or provide video images via cameras. The data collected feeds the control and information dissemination functions, and allow operators to intervene when appropriate in those

functions. The data may also be stored (i.e., warehoused) for future analysis and performance evaluation. Sensor technology also allows the system to monitor roadway and environmental conditions, such as pavement temperature and weather. Roadway and environmental condition information are often used in deciding how best to allocate resources for functions such as snow and ice control.

- **Computer Systems and Systems Integration** – Freeway management systems are dependent upon the computer systems on which they operate. Selecting the appropriate hardware platforms and software programs for the desired functions, integrating the software and hardware subsystems into a complete system, and maintaining the complete system are critical elements of providing effective freeway management systems.
- **Transportation Management Center (TMC)** – The computer systems and associated software, the user interfaces and operators themselves, and associated resources are typically housed and operated from a traffic management center, although they can also be operated over a communication network without the need a formal center. In systems that include a TMC, it serves as the information “nerve center” for regional operations.
- **Communication Systems** – The effective operation of all of the functions mentioned above require communication of data, video, and voice. Communication systems transmit data and video from the field to a TMC or central location, transmit commands from the TMC or central location to the field equipment, transmit information among agencies, distribute traveler information to the systems that disseminate it, and allow personnel at any distance to communicate with one another.

1.5.5 Institutional Considerations

All of the attributes of a freeway management program – policies, funding mechanisms, strategies, systems and technologies, operational activities, etc. – take place within the institutional framework. This institutional fabric is multi-agency, multi-functional, and multi-modal. Moreover, the authority for transportation decision-making is dispersed among several levels, or “tiers”, of government (e.g., national, statewide, regional, agency, individual systems), and often between several agencies and departments within each governmental level. This institutional situation can lead to a fragmented delivery system for transportation services, resulting in an agency-specific and mode - specific focus, rather than an area-wide focus that considers the entire trip. After all, the customer’s perspective is that there is only one surface transportation system. The public generally does not care which jurisdiction or agency is responsible for the road or mode on which they are currently traveling. As taxpayers (and in some cases fare / toll payers), they want and deserve a safe, reliable, and predictable trip – one that is safe from physical and mental harm, provides a consistent level-of-service with minimal congestion, and is predictable in terms of travel time.

Achieving the safe, reliable, and secure operation of our Nation’s transportation network depends on collaboration and coordination across traditional jurisdictional and organizational boundaries. In other words, there must be “integration” (i.e., a term defined in the dictionary as making into a whole by bringing all parts together). In essence, integration is a bridging function between the various components of the surface transportation, and involves processes that focus on the sharing of information and the combining of resources in a manner that facilitates a more seamless operation. In addition to institutional integration (i.e., coordination between

various agencies and jurisdictions to achieve seamless operations), the surface transportation network needs to be integrated in other ways, including:

- Technical Integration (e.g., enabling different agencies and their TMCs to readily exchange information).
- Operational Integration (e.g., the exchanged information is combined to create a regional database for traveler information; or where signal timing is changed to accommodate increased traffic flow diverted from an adjacent freeway; or where plans are developed jointly in advance by all affected agencies (and then utilized) to manage traffic during special events and emergencies).
- Procedural Integration (e.g., combining planning and programming processes that address the surface transportation network as a whole and consider all possible improvements in a consistent manner).

Freeway management and operations must be addressed within this larger institutional context. Moreover, it is important that the practitioner have an understanding of the many external factors and dependencies that can impact the performance of the freeway network and influence how it should be managed.

1.5.6 Other Considerations

In addition to the broad concepts discussed above, the following items also warrant a brief discussion. As with most of the other items addressed in this introductory chapter, additional information and detail is provided in subsequent chapters.

1.5.6.1 Programs, Projects, and Process

A “program” is a coordinated, inter-related set of strategies, procedures, and activities, all intended to meet the goals and objectives articulated in vision statements and policies. “Projects” are well-defined, individual actions and activities that make up the program. The implementation of projects is how the program is realized. A program has a long – term temporal view, whereas individual projects generally have a shorter implementation period. Managing a program involves trade-offs between budget and timing, and determinations as to appropriate sequence and scope of the associated projects.

Practically every transportation - related program and project involves some sort of “process” – a series of actions – through which ideals and concepts are brought to fruition, implemented, and managed. There exists in every process an underlying structure that shapes and controls events. This framework consists of formal activities (e.g., written or unwritten policies agreed to in a collaborative fashion) and informal ones (e.g., human relationships), all relating to the ways options are created and decisions are made to improve the performance of the transportation network.

1.5.6.2 Performance Measures

Freeway management programs – consisting of operational strategies, low-cost roadway improvements, and / or ITS-based systems – are funded and implemented as a means to preserve mobility, improve reliability, enhance safety, and meet the public’s expectations for efficient and effective travel. It is important to ensure that the funds are spent wisely, that the agency makes the best use of its available resources, and that the full potential of past and

current investments is realized. This, in turn, requires that the performance of the freeway be continuously monitored and evaluated, including an assessment of the extent to which the implemented solutions achieve the intended objectives.

Performance measures provide the basis for evaluating the effectiveness of implemented freeway management strategies, as well as for identifying the location and severity of problems (such as congestion and high crash rates). This monitoring information can be used to track changes in system performance over time, identify systems or corridors with poor performance, identify potential causes and associated remedies, identify specific areas of a freeway management program or system that requires improvement, and provide information to decision-makers and the public. In essence, performance measures are used to measure how the transportation system performs with respect to the adopted goals and objectives, both for ongoing management and operations of the system, and for the evaluation of future options.

1.5.6.3 Concept of Operations

Usually associated with the development of a freeway management system, regional architecture, and other ITS deployments, a “Concept of Operations” is a document that defines the environment in which the freeway (and other elements of the transportation network) is to operate, and the needs of the users. This environment includes the relationships between the system and the owning agency’s policies, procedures and responsibilities; the interagency working relationships and agreements; the physical environment (i.e., the capabilities of the system); and the expectations (performance measures). The Concept of Operations is a tool by which regions, agencies, and traffic management centers – and the associated practitioners – identify (at a high level with few technical details) the optimal solution based on their preferred approach, their capabilities, and their constraints.

1.6 HOW TO USE THIS DOCUMENT

Section 1.3 identified the intended audience of the handbook as “transportation professionals that participate in or responsible for any phase in the life cycle of a freeway network.” Persons whose responsibilities are primarily policy development will find this introductory chapter, plus chapter 2, most pertinent. Those with the responsibility for program management and the development of freeway – oriented programs and / or projects should also review chapters 3 and 4.

Chapters 5 – 17 address topic-specific aspects of freeway management and operations, and are pertinent to all practitioners with day-to-day responsibilities for managing or operating a freeway facility, depending on their specific interests and needs. The most appropriate strategies, technologies, and services will vary based on the conditions unique to each metropolitan area, including the type and extent of problems, the political structure, the agencies’ experience with traffic management, and the level of cooperation between local agencies. Moreover, depending on regional needs, the overall freeway management goals, and the extent to which freeway management and operations are performed, will likely vary from region to region.

It is emphasized that this Freeway Management and Operations Handbook is not a design manual or a detailed technical reference. For many of the technical issues, excellent reference materials exist that provide more detailed information, in more of a “how-to” manner. These

include recent handbooks on Traffic Incident Management, Planned Special Event Management, Communications, HOV Lanes, and Detection and Surveillance Sensors. For the chapters covering these areas, the Handbook references these technical documents and provides only a brief summary.

1.6.1 State of the Art and State of the Practice

The FHWA White Paper “Freeway Management and Operations State of the Practice” (6) makes a distinction between the “practice” and the “art” – specifically:

- State of the Practice is defined as “*Proven practices in common use and the effective application of technologies commonly installed and operated in the freeway management and operations disciplines*”
- By comparison, the state-of-the-art is defined as “*Innovative and effective practices and the application of leading edge technologies that are ready for deployment in terms of operating accurately and efficiently, but are not fully accepted and deployed by practitioners.*”

Specific distinctions between the state of the practice and the state of the art are not addressed in this Handbook (as they are in Reference 6). The purpose of this Handbook is to provide the practitioner with a wide range of potentially useful alternatives for implementing freeway management programs and projects, thereby improving freeway operations. Some of these may be considered “practice”; while others may be deemed as “art”. Emerging trends will also be identified. Moreover, experience, lessons learned, and examples are provided in many instances.

Many of the items addressed in this Handbook are either technology or program-based, and therefore likely to change and/or become outdated at any time following the release of this Handbook. The reader should check the date of the Handbook. At the time of writing this document, the plan is for it to be more dynamic. The Internet is being used as one of the methods for distributing the Freeway Management and Operations Handbook. As technologies, operating practices, or programs change, as additional experience is gained and new lessons are learned, and / or as new reference documents are developed, the affected chapter(s) of the Freeway Management and Operations Handbook will either be modified and posted on the web, or announcements regarding new reference materials will be posted. For now, additional information on Congestion Mitigation activities can be found at the FHWA Congestion Mitigation web site at <http://www.fhwa.dot.gov/congestion>, the ITS Joint Program Office web site at <http://www.its.dot.gov>, or the Office of Operations web site at <http://www.ops.fhwa.dot.gov>.

1.6.2 Key Themes

Regardless of which chapter(s) the practitioner is perusing, there are a few key concepts that should always be kept in mind. Some of these have already been mentioned, while others will be discussed in subsequent chapters. They nevertheless apply to all aspects and processes involving the management and operation of a freeway facility. These key themes are highlighted in Table 1-4, and discussed in the following bullets.

- Even though their primary responsibility may be the freeway network, practitioners must not address freeway management and operations in a singular, isolated manner. All three of the aforementioned legs of the “transportation stool” (i.e., building, preserving, operating), are integral parts of the business of most transportation agencies, and freeways are just one

element of the surface transportation network. The same planning, programming, and budgeting processes are applied to all of these facilities and management attributes.

- Similarly, freeway practitioners must view transportation as a whole, consider a vast array of potential tools. This may mean looking beyond the “typical” freeway management and operation alternatives, and giving consideration to other types of improvements in concert with freeway management systems and strategies. These additional strategies and improvements may include new construction to increase the roadway capacity, enhancing other attributes of the freeway infrastructure (e.g., signing, pavement markings, illumination) to increase safety and driver convenience / comfort, and strategies to reduce travel demand.

Table 1-4: Key Themes for Freeway Management & Operations

- Practitioners must not address freeway management in a singular, isolated manner
- View the overall performance of the surface transportation network
- Consider how individual actions complement on another, and how, when combined as a program, contribute to regional goals
- Implement freeway management systematically on a regional basis, coordinating with all operational activities & organizations
- ITS is but a subset (“enabler”) of management and operations
- Consider all the available tools (e.g., roadway improvements, traffic control devices, ITS), looking at many potential improvements
- Freeway management should be an integral part of established process within agencies; with freeway practitioners participating in these processes.

- Practitioners must carefully consider how individual actions complement one another in the long run and how, when combined into an overall program, they relate to regional and community goals and objectives. Moreover, actions should be selected and implemented that, through sound engineering and planning analysis, are shown to improve problems in a cost effective, multimodal manner. Be realistic in the assessment of what is likely to be accomplished. Set performance targets; identify, collect, and store information for performance measurements; and report to the public and decision makers on system performance.
- Freeway management and systems are only one part of the many transportation management systems and operations activities that may exist within a metropolitan area, state, or multi state region. Freeway management should be implemented systematically on a regional basis and be coordinated with all the activities typically undertaken to operate the transportation network. This requires cooperation with neighboring governmental jurisdictions, regional transportation agencies, and organizations that provide or are involved with transportation – related services.

- Many of the later chapters deal with ITS technologies. It must be emphasized, however, that the deployment of Intelligent Transportation Systems is not the same as “operations”. ITS can be a significant subset / enabler of improved operations – for example ITS can provide real time information on the traffic flows; but operations is knowing what to do with this information to improve traffic flow, safety, and mobility.
- Similarly, freeway management and operations extends beyond ITS and electronic systems. Freeway managers must be familiar with all of the tools available to improve the safety and efficiency of the freeway system, including major roadway improvements, minor roadway improvements, and traditional traffic control devices (such as, static signing, pavement marking, and illumination systems). Moreover, practitioners should continuously look for opportunities to improve the performance and safety of freeway facilities with all of the available tools.
- Several processes have been instituted for developing transportation programs, planning and prioritizing potential improvements, and defining individual projects and strategies. Moreover, transportation agencies have adopted some of these – often with variations – as their formalized approach for making informed decisions regarding the investment of public funds for transportation improvements. Freeway management and operations should be an integral part of the established processes within an agency. Moreover, the freeway management practitioner must be cognizant of and, to the greatest extent possible (commensurate with his/her responsibilities), participate in these processes ensuring that freeway management and operations receives appropriate consideration.

1.7 DOCUMENT ORGANIZATION

Each of the 17 chapters that comprise the Freeway Management and Operations Handbook has been developed to “stand alone” within its specific topic area. Not lost on this, though, are the relationships and dependencies between various freeway management activities and other elements that comprise the surface transportation network. Thus, just as the freeway practitioners must view transportation as a whole, this Handbook should be looked at in a similar fashion. The chapters are not completely independent – for example, performance measures (discussed in Chapter 4) should be an integral part of the various processes (discussed in both chapters 2 and 3) by which transportation improvements are planned, developed, and implemented. Moreover, a freeway management program will encompass strategies and technologies from multiple chapters.

It is emphasized that the chapters only provide an “introduction” to their respective subjects. For additional details and design guidelines, the practitioner should consult a variety of references, many of which are identified (including web addresses) in the text of the chapter, along with the references section at the end of each chapter.

Chapters 7 through 17 – the ones that address specific freeway management strategies and technologies – utilize a common basic structure, starting with an introduction of the topic, the purpose of the chapter, and its relationship to other freeway management activities and Handbook chapters. The next section addresses “Current Practices, Methods, Strategies, and Technologies”, including an overview of the subject, benefits, key considerations during freeway

management program development, the relationship to the National ITS architecture, specific technologies and strategies, and emerging trends. This is followed by a section on “Implementation and Operational Considerations”. The chapter concludes with “Examples” and “References”. This format is not rigid. Depending on the chapter and its subject matter, these sections may have a different order, additional sections may be included, examples may be included throughout instead of in a separate section, and design considerations may be located in different sections; all to keep an appropriate flow of thought.

A brief summary of the material covered in the remaining chapters is provided below:

- **2 – Freeway Management and the Surface Transportation Network:** This chapter looks at freeway management and operations from the broader view of the entire surface transportation network, addressing the many external factors and dependencies (i.e., “cause & effect” interrelationships) that can impact the performance of the freeway network and how it should be managed. Information is provided regarding the types of constituencies that use and/or impact the surface transportation network, and the various organizational “tiers” where decisions affecting the surface transportation network are made. Several approaches are then discussed for meeting the challenges that these external factors and dependencies often present, thereby further improving the operation of the freeway as well as the entire surface transportation network. This “advice” applies to all potential freeway management activities and supporting technologies, and should therefore be duly considered when reading all subsequent chapters of this Handbook.
- **3 – Freeway Management Programs:** This chapter focuses on processes and activities specific to freeway management and operations. A series of activities are presented for establishing, enhancing, and managing a freeway operations program. These “steps” are not to be viewed as a separate process for developing a freeway management and operations program. Rather, they represent an amalgamation of important activities from other established processes. Intelligent Transportation Systems (ITS) have proven to be a significant enabler of operations, and many freeway management programs will include projects to design and implement ITS - based freeway management systems. Accordingly, this chapter also summarizes a number of published processes that are geared towards ITS deployment (e.g., systems engineering, configuration management, national and regional ITS architectures), with additional information provided in Chapter 14.
- **4 – Performance Monitoring and Evaluation:** Performance measures and the results of evaluations are important inputs to transportation planning and investment decision-making processes of public agencies. Moreover, the day-to-day operation and management of the freeway requires real – time knowledge how well the freeway is performing and the existence of any problems. This chapter addresses several related topics:
 - Performance measures, including discussions of why they are important, their relationship to the decision-making process, and important considerations when selecting performance measures. Several examples of performance measures that may be utilized for freeway management and operations are also provided, along with discussions on information gathering, data archiving, and reporting.

- Self-assessment tools developed by FHWA for evaluating how well the operations process is organized and administered, and how well it interacts with other agencies and affected stakeholders.
- Analytical tools (e.g., Highway Capacity Manual, simulation, before-and-after studies, estimating costs and benefits) for evaluating freeway performance and identifying problems, analyzing and prioritizing alternative solutions for correcting these problems, estimating the associated benefits and costs, and determining the actual improvement in performance and its cost effectiveness.
- **5 – Roadway Improvements:** This chapter provides an overview of potential actions that improve freeway performance by modifying the roadway itself, such as adding lanes to increase capacity (and thereby increase operational efficiency) at bottleneck locations, and making changes to the geometric configuration or physical characteristics of the roadway to enhance safety. After a brief overview of the types of problems that can be addressed by roadway improvements (and the potential benefits), and how these potential improvements should be addressed within the freeway management program, the following improvements are discussed: horizontal and vertical alignment; roadway widening (e.g., auxiliary lanes, shoulders); providing additional lanes without widening (e.g., restriping, use of shoulder as travel lane); interchanges (improvements to ramps and weaving sections); and other improvements such as treatment of obstacles and skid resistance.
- **6 – Roadway Operational Improvements:** Starting with this chapter, the rest of this Handbook is devoted to a discussion of operational strategies and enabling technologies. This particular chapter provides an overview of potential actions – specifically static signing, pavement markings, and roadway lighting – that do not modify the roadway footprint or geometry; nor are they usually considered in the context of “real-time” freeway management strategies and enabling technologies. Nevertheless, such improvements can improve the operation of the freeway, particularly in terms of safety and driver convenience and comfort. An overview of Travel Demand Management (TDM) strategies is also provided.
- **7 - Ramp Management and Control:** Ramp management is the application of control devices, such as traffic signals, signing, and gates to regulate the number of vehicles entering or leaving the freeway, in order to achieve operational objectives. Most ramp management strategies lead to improved traffic flow and safety by 1) regulating the number of vehicles entering or exiting a freeway, or 2) smoothing out the rate at which vehicles enter the freeway facility. This chapter describes various ramp management strategies, typical benefits, operational and design considerations, and provides case studies demonstrating agency experience with ramp management strategies.
- **8 - Managed Lanes:** A managed lane facility is one that increases freeway efficiency by packaging various operational and design actions. Lane management operations may be adjusted at any time to better match regional goals. This chapter addresses several managed lane concepts, including truck lanes, contraflow and reversible lanes, mainline metering, speed advisories and controls, work zone controls, toll facilities, and congestion pricing.

- **9 – High Occupancy Vehicle Treatments:** A form of managed lane, the preferential treatments for high occupancy vehicles (HOV), as a means for increasing the person-moving capacity of the transportation system, is covered in this chapter. Topics discussed include types of HOV facilities used on freeways (e.g., exclusive HOV lanes, concurrent flow HOV lanes, contraflow HOV lanes; operated either bi-directionally or reversible), park-and-ride facilities, HOV facility access, HOV strategies and operations (e.g., occupancy requirements, hours of operation, enforcement), and public awareness and marketing. High Occupancy Toll (HOT) lanes are also discussed.
- **10 - Traffic Incident Management:** Traffic incident management is the systematic, planned, and coordinated use of human, institutional, mechanical, and technical resources to reduce the duration and impact of traffic incidents, and improve the safety of motorists, crash victims, and traffic incident responders. This chapter provides a summary of the FHWA *Traffic Incident Management Handbook*, a document that treats traffic incident management in depth and is considered the primary reference on the subject.
- **11 - Planned Special Event Management:** A planned special event is a public attended activity or series of activities, with a scheduled time and location that may increase or disrupt the normal flow of traffic on affected streets or highways. The FHWA technical reference *Managing Travel for Planned Special Events* presents and recommends various planning initiatives, operations strategies, and technology applications that satisfy the special customer requirements and stakeholder performance requirements driving planned special event travel management. This chapter summarizes that reference, highlighting the essential elements involved in managing traffic during planned special events.
- **12 - Freeway Management During Emergencies and Operations:** Disaster planning, prevention, preparedness, response, and recovery fall into the category of emergency management. Natural disasters (e.g., hurricanes, forest fires, earthquakes, severe winter weather) and terrorist attacks are generally sudden and unexpected. Even those emergencies that can be anticipated have relatively short advance - response times amounting to, at best, a few days. The transportation network – particularly freeways – plays a major role during emergency management, including expediting evacuations from the affected area, and the return following the emergency. In some cases, emergency management also involves the restoration of transportation services. This chapter provides a high-level overview of procedures, institutional arrangements, and supporting documentation that are applicable to emergency management; many of which may be unfamiliar to the freeway practitioner, but nevertheless can have a major impact on the operation and management of the freeway during emergency situations.
- **13 – Information Dissemination:** The traveler information process extends well beyond the freeway, both in terms of where the information is obtained and how it is distributed. Information on freeway conditions and the dissemination of that information to freeway users should therefore be viewed as part of a broader, region-wide, advanced traveler information system (ATIS). This chapter covers the entire spectrum of ATIS, with the greatest emphasis being placed on those technologies and strategies that are directly related to the operation and management of the freeway itself (e.g., Changeable Message Signs (CMS) and Highway Advisory Radio (HAR)). Other topics include the “511” telephone – based system, traveler information dissemination over the Internet, and public – private partnerships.

- **14 – Transportation Management Centers:** The TMC is the hub or nerve center of most freeway management systems. It is here data about the freeway system is collected and processed, fused with other operational and control data, synthesized to produce “information”, and distributed to stakeholders such as the media, other agencies, and the traveling public. The information is used by TMC staff to monitor the operation of the freeway, and to initiate control strategies that affect changes in the operation of the freeway network. It is also where agencies can coordinate their responses to traffic situations and incidents. This chapter addresses several aspects of TMCs, including the physical design of the facility, operator workstations and user interfaces, other information displays, local area networks, central hardware and software, and TMC security. The “systems engineering” and “configuration management” processes are also discussed
- **15 – Detection and Surveillance:** Detection and surveillance technologies provide the information needed to perform nearly all traffic management functions and strategies. This chapter provides a summary of the FHWA document *Traffic Detector Handbook*, which addresses a number of technologies for measuring traffic flow. Other surveillance options (i.e., not addressed in the FHWA document) are also described, including probe-based surveillance, video surveillance (i.e., the use of real time video images of the freeway), and road-weather information systems (RWIS).
- **16 – Regional Integration:** The integration of multiple systems within a region provides for the real-time sharing of information between ITS based systems and the coordination of management activities between transportation agencies and emergency service providers, thereby enhancing system interoperability and enabling an areawide view of the transportation network. In essence, the goal of regional integration is to bring the operation and management of the surface transportation network into a unified whole, and to incorporate this singular management of the surface transportation network with the management of the broader transportation network. This chapter focuses on “technical integration”, including network topologies, database considerations, related elements of the National ITS Architecture, standards for message sets and protocols, etc. that enable different Management Centers (e.g., transportation, emergency services, information providers) to readily (and automatically) exchange, store, and access information from one another – a process known as “center-to-center” communications.
- **17 – Communications:** A communications network provides the means by which information is exchanged between all the entities and components that comprise a freeway management and operations program. There are multiple communications options (e.g., network architectures, technologies, standards, implementation strategies) available for meeting these needs. It is crucial that the most appropriate options be selected to best support the operational requirements of the freeway management program and the associated ITS – based systems. This chapter provides a summary of the FHWA document *Communications Handbook for Traffic Control Systems*.

1.8 REFERENCES

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2. FREEWAY MANAGEMENT AND THE SURFACE TRANSPORTATION NETWORK

Chapter 2 was revised in June 2006. For more information on the extent of these revisions, see the Revision History Table at the beginning of this handbook.

2.1 INTRODUCTION

The surface transportation network consists of physical elements, modes, services, management systems, and operational strategies that enable the transport of people and goods. Freeways (as defined in Chapter 1 to include all expressways, limited-access toll facilities, entrance and exit ramps, and connecting bridges and tunnels), along with their supporting traffic management strategies and technologies, comprise just one element of this larger system. Moreover, the basic institutional fabric of the surface transportation network is multi-agency, multi-functional, and multi-modal. This framework often leads to a fragmented delivery system for transportation service, resulting in an “agency” focus rather than a regional, system-wide perspective – one that considers the entire trip over the entire surface transportation network by a variety of different users and customers.

The perspective of the “customers” (i.e., the users of the surface transportation network) is that there is only one system. The public generally does not care which jurisdiction or agency is responsible for the road or mode on which they are currently traveling. As taxpayers (and in some cases fare / toll payers), they want and deserve a safe, reliable, and predictable trip – one that is safe from physical and mental harm, provides a consistent level-of-service with minimal congestion, and is predictable in terms of travel time. To achieve this singular vision of the surface transportation network, the involved agencies and practitioners must recognize and address the many customer, inter-facility, inter-jurisdictional, and inter-modal dependencies. As noted in the introduction to “Regional Planning for Operations Primer” (Reference 1), an introductory document that discusses a formal collaborative activity called “regional planning for operations”:

“More than ever, the safe, reliable, and secure operation of our Nation’s transportation systems depends on collaboration and coordination across traditional jurisdictional and organizational boundaries. Nowhere is this more apparent than in our metropolitan regions where numerous jurisdictions, agencies, and service providers are responsible for safely and efficiently operating various aspects of the transportation system. Many of these operations activities in a metropolitan region must cross agency and jurisdictional boundaries to be successful. They may include traffic incident management, emergency management, communications networks, traveler information services, response to weather events, and electronic payment services. These regional operations activities depend on collaboration, coordination, and integration to be effective and truly benefit those that use or depend upon the regional transportation system.”

The examples of operations activities provided in the above statement are integral parts of a freeway management program. Accordingly, the freeway practitioner has a significant role to play in achieving this vision of a “seamless” transportation network. At the same time, freeway practitioners must recognize that freeway management and operations represent but one “tool” for alleviating congestion, improving safety, and enhancing mobility; and other approaches merit due consideration. Additionally, in a pluralistic society such as ours with its numerous levels of government and organizational hierarchies, freeway practitioners must be cognizant of all the external circumstances that can impact the operation of the freeway network – either positively or negatively – thereby affecting how they define and pursue their individual responsibilities.

There are also temporal considerations. Decisions are made throughout the life cycles of transportation facilities – at a strategic level (i.e., long term), tactical level (i.e. shorter term), and operational level (i.e., real time). And all such decisions can affect the design, construction, operation, maintenance, and management of the transportation network.

2.1.1 Purpose of Chapter

This chapter looks at freeway management and operations from the broader view of the entire surface transportation network. Its goal is to provide the practitioner with an understanding of the many external factors and dependencies that can impact the performance of the freeway network and how it should be managed. These “cause & effect” interrelationships between the freeway and the overall surface transportation network include physical, technical, institutional, operational, procedural, and temporal considerations.

Following this introductory section, background information is provided regarding the types of constituencies and stakeholders that use and/or impact the surface transportation network in some fashion.³ The various organizational “tiers” where decisions affecting the surface transportation network are made (e.g., national, statewide, regional, agency), and the associated time frames of these decisions are then discussed.

The remainder of this chapter – and its primary objective – provides the practitioner with several approaches for meeting the challenges that these dependencies often present, thereby further improving the operation of the freeway as well as the entire surface transportation network. Specific considerations include awareness of and involvement in the various transportation planning and capital programming processes that impact freeway management and operations; having an expanded and integrated view of freeway management and operations, and clarifying the potential benefits of freeway management and operations. The program entitled “Regional Planning for Operations” and the importance of human relations are also discussed. This “advice” applies to all potential freeway management activities and supporting technologies, and should therefore be duly considered when reading all subsequent chapters of this Handbook.

2.2 BACKGROUND

A paradigm shift in transportation agencies’ missions has been underway for several years. These agencies had long been providers and maintainers of the surface transportation network. But with an increase in congestion and crashes, particularly in urban areas, the mission and services that these agencies support has been expanding to include “operations”. Moreover,

³ This discussion of stakeholders is at a very high level. Additional detail and discussion of stakeholders is provided in Chapter 3.

with increasing levels of congestion, and the ability to expand the existing roadway infrastructure becoming more difficult, the importance of operations has increased significantly (2).

This shift in mission of “service provider and operator” is continuing slowly. Most agencies now realize that they must also be operators to maintain and/or improve the performance and reliability of their surface transportation system. Such a paradigm shift also requires agencies to change the way they have been strategically planning, programming and allocating resources (to include management and operational considerations), working in partnership with all of their customers and with other jurisdictions and affected stakeholders. In essence, all of the various elements – physical, technical, institutional, decision-making, operational, etc. – must not only work better, but also together in an integrated fashion.

Successful management and operation of the surface transportation network (including freeways) requires that the perspectives and concerns of several different constituencies be considered. These “stakeholders” include anyone who has an interest in the operation of the transportation network (a “stake” as it were), and may be categorized as follows:

- **Users** are the primary customers of the surface transportation system. This includes those that use motorized transportation (e.g., motorcycles, automobiles, trucks, light and heavy rail, buses) as well as those that use non-motorized transportation, such as walking and bicycling. These customers are interested in safe, reliable, and predictable trips from their origin to their destination. They are generally not interested in the details of how the system operates, except when they encounter a system failure or disruption that influences the convenience or reliability of their trip. Additionally, users want real time and accurate travel condition information to guide them on their trip.
- **Decision Makers** (i.e., elected officials, agency heads, etc.) develop legislation and policies addressing the funding, implementation, and management of the surface transportation network. They also decide where public resources are allocated. They need to understand society’s needs and allocate available resources to best satisfy those needs. They also want to know the effects of their allocations.
- **Responders**, such as police, fire, and other emergency services, represent a “special user” category. They utilize the transportation network as part of their critical missions, and often have decision-making and operational responsibilities for the network, particularly during traffic incidents, special events, and emergencies.
- **Practitioners** (i.e., agency managers, planners, designers, implementers, operators, maintenance staff) are responsible for implementing the surface transportation network and for its day-to-day management and operation. In essence, they are the “providers” – providing the many functions and services requiring coordination and integration. They use the resources provided by the decision makers to provide travelers with the transportation services, travel modes and options, and information that meets the users’ needs. These practitioners represent many different types of transportation agencies, including federal, state, county, city, transit, and regional organizations.

- **Activity Centers and Service Providers**, such as private traveler information providers, airports and ports, private towing entities, stadiums, festivals, etc., can significantly impact the operation of the transportation facilities provided by transportation agencies.

As discussed throughout this Handbook, when developing a transportation – related program or project, it is important to identify the associated stakeholders, determine their needs and concerns, and engage them in the overall process as may be appropriate. As noted in Reference 1, such “collaboration and coordination” must be viewed as a “deliberate, continuous, and sustained activity that takes place when transportation agency managers and officials responsible for day-to-day operations work together at a regional level to solve operational problems, improve system performance, and communicate better with one another”.

2.3 DECISION MAKING

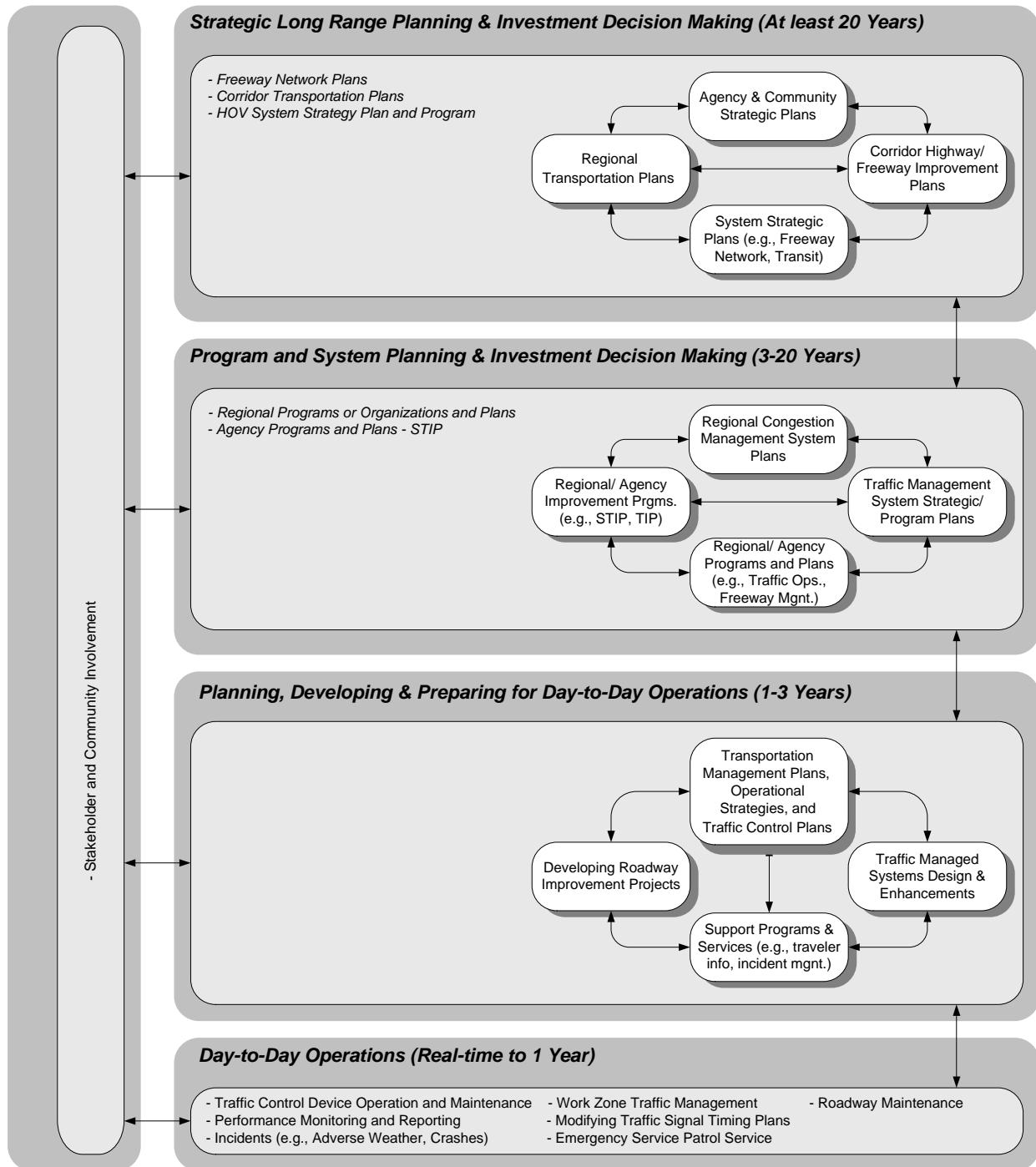


Figure 2-1: Freeway Management “Tiers” and Activities

2.3.1 Tier 1 - Strategic Long Range Planning and Investment Decision Making

Tier 1 involves long-term planning and decision making that guides the overall development and implementation of state/regional/and local transportation infrastructure. The focus of tier one is on the overall “big picture” of how transportation fits in with other elements of a state/region/local area to keep these areas in line with overall goals and objectives. Activities within this tier include:

- Regional transportation plans.
- Agency and community strategic plans.
- Modal/corridor strategic plans.

Generally speaking, these plans are generally prepared for urbanized areas of more than 50,000 population covering at least a twenty-year planning horizon. They also serve as input into programming specific investments over the mid- to long-term (see Tier 2). In other words, plans prepared under this tier set the stage for program planning and ultimately for identifying projects that satisfy regional goals and objectives. Plans of this nature should be updated every five years, or in the case of non-attainment or maintenance areas every three years.

2.3.2 Tier 2 -Program and System Planning and Investment Decision Making

Tier 2 involves relatively long – term planning and funding, as well as shorter term operations and management considerations. A major focus of Tier 2 is the strategic transportation planning, programming, and coordination efforts that include a longer-range time horizon (3–20 years). Statewide and regional transportation planning is the structured process followed by states, metropolitan planning organizations (MPOs), municipalities, and operating agencies to design both short and long-term transportation plans. This structured planning process often incorporates a Transportation Improvement Plan (TIP). A TIP describes specific projects that will be deployed and/or operated over the next three years at a minimum. The TIP must be prepared by each metropolitan area and state, and is to be updated at least every two years. The TIP is a prioritized program of transportation improvement projects or project segments, consistent with the Transportation Planning activities identified in Tier 1, and includes a financial element that constrains the TIP to be consistent with the available public and private funding sources. Development of the TIP must offer citizens, agencies, and other interested parties the opportunity to comment on the proposed program. Each metropolitan TIP automatically becomes part of the corresponding statewide TIP (the STIP). Freeway management projects need to be included in this document to receive Federal funds.

In addition to the TIP, key products of Tier 2 often include a freeway management program plan and an ITS strategic plan. These plans identify the key strategies and components of a freeway management program, the potential ITS technologies, areas of initial implementation, future initiatives to expand the functionality or area of coverage, and the resources needed to support all of the life-cycle phases of the system. It is important that the process to develop the freeway management strategic plan (or any such focused plan or project) support the overall transportation planning process; not compete with it. Moreover, the end products of these “focused” processes can and should be used to feed information back into the overall transportation planning process.

The development of these plans, especially the TIP, usually rests with the Metropolitan Planning Organization (MPO). The MPO provides the forum for cooperative transportation-decision making in which local elected officials and the communities they serve can identify shared goals and negotiate differences so that transportation plans and programs can be developed in an effective manner. Numerous transportation planning activities on a regional and local level feed information to the development of the Transportation Plan and TIP. These planning activities include ITS Strategic Plans, Corridor and Sub-area Studies, Major Investment Studies, Congestion Management Plans and others.

While these processes have historically focused on capital projects, it is now recognized that the statewide / regional transportation planning process must take management and operations of the transportation network, and the ITS – based systems that support operations, into consideration. The current trend to “mainstream” ITS (and operations) into the traditional decision-making process of transportation planning means that operations and ITS deployments will be increasingly funded through regular sources and compete with traditional transportation components, such as road widening and new construction. There is consequently a need to strengthen the ties between management and operations, ITS, and the transportation planning process.

The functions and responsibilities of Tier 2 are evolving to also include a management and operations element, with a much shorter time frame as compared to the transportation planning functions noted above. This includes the development of regional ITS architectures, HOV strategies, and similar strategic plans. It may also include regional and statewide operations as represented by an “**Integrated Transportation Management System**”.

The Freeway Operation Committee of the Transportation Research Board of the National Academy of Sciences defined an Integrated Transportation Management System as follows (Reference 3):

“An ‘integrated transportation management system’ (ITMS) provides for the automated, real-time sharing of information between ITS based systems and the coordination of management activities between transportation agencies, thereby enhancing system interoperability and enabling an area-wide view of the transportation network. These systems and agencies provide for the management and operation of a variety of different transportation facilities and functions, including freeways, arterial streets, transit (bus and rail), toll facilities (e.g., bridges, tunnels), emergency service providers and information service providers.”

Integrated transportation management systems and the associated statewide or regional organizations (where they exist) develop policies and plans intended to manage and operate the systems and programs – planned, funded, and deployed at other tiers – in a coordinated fashion (e.g., pre-planning for special events and major incidents). This requires the cooperation and involvement of the agencies and individuals that will be responsible for, or involved with, any life-cycle phase of the system. The general time frame associated with the process to initially develop traffic management plans and other items that support statewide / regional management and operations is typically one to three years. These plans and the issues addressed could include operational strategies; traffic control plans; regional / statewide traveler information; staff procedures and protocols to coordinate services; response plans; resource sharing or agency agreements; performance monitoring and evaluation reports; and operations manuals that are used for the actual operation of an ITMS.

There appears to be a general consensus that “operations is not adequately addressed by the transportation planning process. Most, if not all, planning models are incapable of evaluating the impact of improved operations on air quality and level of service. While investments in operations are becoming increasingly important, they cannot be justified as part of the planning process.” (1) Recognizing the need for a more formalized program for developing a transportation operations program, the FHWA Office of Traffic Management has developed a formal collaborative activity called “regional planning for operations”, which is discussed in a subsequent section of this Chapter.

2.3.3 Tier 3 – Planning, Developing & Preparing for Day-to-Day Operations

Tier 3 has programming, design, and operations responsibilities. From the perspective of freeway management and operations, it is in Tier 3 where the planning and designing of individual strategies, plans, or projects takes place. It is where the infrastructure comprising the surface transportation network (e.g., freeways, bridges, tunnels, surface streets, rail lines, rolling stock, traffic control / management devices) is typically owned. This level develops a multi-year program and budget that defines resources and commitments for a one-to-three year time frame, with updates every year or two. As noted in the introductory chapter to this Handbook, providing effective highway-based transportation consists of three component parts – building the necessary infrastructure (i.e. construction), effectively preserving that infrastructure (i.e. maintenance), and effectively preserving its operating capacity by managing operations on a day-to-day basis. All three of these “legs” that make up the “highway transportation stool” are defined and developed at the agency level; and it is at this tier where the relative balance between these parts are determined, and the associated priorities, budgets, and allocation of resources are established.

Another responsibility in Tier 3, and one that has become a priority, involves assessing the vulnerabilities of the infrastructure and physical assets; developing possible countermeasures to deter, detect, and delay the impact of threats to such assets; estimating the capital and operating costs of such countermeasures, and then budgeting the required resources; and improving security operational planning for better protection against future acts of terrorism.

2.3.4 Tier 4 – Day-to-Day Operations

Tier 4 (Day – to - Day Operations) deals primarily with the functions typically assigned to a Transportation Management Center (TMC). A TMC may be a physical structure, or it may be virtual. Regardless, the TMC is usually the heart of freeway management and operations program, providing the day – to – day operations of the transportation network. The TMC level performs several functions, including: gathering, synthesizing, and disseminating traffic and travel condition information; controlling a variety of field devices (Changeable Message Signs, ramp meters, cameras); and coordinating with other entities and stakeholders (e.g., emergency response providers). It is often an integral part of an ITMS, processing information that it receives from field devices and other TMCs, and sending out information. The TMC takes these data and then synthesizes, analyzes and stores the data. Information is then sent out to the sources that provided the information and other users of information. The users of information can be any of the customers discussed previously.

The TMC deals directly with all events that influence the actual operation of the freeway, including congestion, traffic incidents, special events, and emergencies. This is where the

freeway is operated and managed in real – time, via ITS devices and strategies, control plans, traveler services (e.g., freeway service patrols), operational procedures, and responses / actions taken based on a specific traffic event. Decisions at this TMC level (and their resulting outcomes) are made by operators, based on operations plans, which in turn are based on the policies and strategies developed at other tiers, adjusted to reflect real-time conditions.

2.3.5 Interaction Between Tiers

The Legislative, Regulatory and Research Tier in Figure 2.1 focuses on policy, direction, and support, and involves the authorizing legislation that establishes and provides priorities and resources for federal regulations, policies, programs, and research. The implementation of these regulations and associated programs are intended to positively influence the overall environment and how transportation management strategies and technologies are considered by the appropriate state, regional, and agency interests. These federal programs and rules, corresponding research programs, outreach and technology transfer programs, and results of the various initiatives (e.g., field operational tests, model deployments), are intended to introduce new and innovative technologies and practices, improve the capabilities of public agency staff, and advance the state-of-the-art and state-of-the-practice of local agencies – in essence, setting the bar for the minimum allowable performance of the transportation network, while encouraging agencies to go well beyond. Examples of how this can influence transportation programs and decision-making across tiers include:

- The programming, budgeting and resource allocation decisions made in Tier 2 will significantly impact the range of plans, services, level of automation, and options available to operate or support a TMC or ITMS.
- The aforementioned FHWA Rule 940 (requiring regional ITS architectures) could be the impetus for developing and deploying an ITMS, which in turn, will likely impact the system configuration and operation of one or more TMCs.
- An Agency-wide assessment of the vulnerability of critical assets may very well impact funding priorities for other transportation improvements (as identified in the TIP), resulting in implementation delays. It is not inconceivable that a TMC and / or ITMS may be designated a critical asset by the Agency, thereby affecting its daily operations (e.g., new procedures and checks by which operators can enter and leave the facility, restrictions on the type of information (e.g., video images) that operators can disseminate to the public).
- The design and subsequent implementation of a freeway reconstruction project (Tier 4) – particularly one that has inadequate provisions for maintenance and protection of traffic in the work zones; or that could disrupt system communications – will impact the operation of the TMC. At the same time, the freeway management system / TMC may enhance the maintenance and protection of traffic during the reconstruction (depending on the amount of coordination between the involved entities).

Freeway management strategies and systems need to be considered – better still, be an integral part – in the various decision-making processes in all tiers to ensure that the appropriate resources are provided for freeway management to succeed. This also requires a commitment on the part of these agencies to consider freeway management at the appropriate tiers within each state, region, and agency. Similarly, freeway management practitioners must

be cognizant of and, to the greatest extent possible (commensurate with their individual responsibilities), participate in these processes ensuring that freeway management and operations receives appropriate consideration.

2.3.6 Temporal Considerations

The various legislative, policy, programming, funding, management, and operational decisions are made throughout the “life – cycle” of the surface transportation network, potentially occurring during the planning, budgeting, design, implementation, operation, and evaluation of a program. Of all the activities that occur during the life cycle of the freeway network, the planning and programming activities are probably the most crucial to the long-term success of a freeway management program. In essence, the planning and programming processes distribute available funds and resources between the “3 legs” of the transportation stool (i.e., building the necessary infrastructure; effectively preserving that infrastructure through maintenance & reconstruction; and effectively preserving its operating capacity by managing operations on a day-to-day basis), and other societal needs.

As noted in the description of the various tiers, the various decisions can differ greatly in their respective time frames. Transportation planning typically deals with the strategic shaping of the transportation network, guiding the deployment of the system over long periods of time, perhaps decades. There is also a tactical consideration to planning – anticipating and responding to known events – which comprises a much shorter time frame. Operations, however, are ongoing. Operations planning guides the day – to – day functioning of the transportation network, and it is through operations planning that flexibility can be achieved. Operating situations are dynamic and driven by random factors. Real time is the temporal scale needed for operations, as the responses to changing conditions must be extremely fast if congestion, safety, and security hazards are to be ameliorated or avoided. (4)

Another consideration – everything is in a constant state of flux. For example, 20-year long range transportation improvement plans are updated every one to two years, Congressional reauthorization (with its changes in funding and policies) occurs approximately every 5 years (plus or minus depending on circumstances and the political landscape), rulings and standards can change or be updated at any time, and technology is continuously moving from emerging to state-of-the-art to state-of-the-practice to (on occasion) obsolete. The freeway practitioner must remain up-to-date on all decisions and plans that can impact operation and management of the freeway network.

2.4 ROLES AND RESPONSIBILITIES OF THE FREEWAY PRACTITIONER

At the very minimum, the freeway practitioner must be aware of and understand the overall framework in which freeway management and operations takes place. This includes:

- Recognizing that the freeway facility is just one component (albeit, a very important one) of the overall surface transportation network. Accordingly, freeway management must not be considered in a singular, isolated manner. Rather, it needs to be addressed in the context of an integrated and regional system.
- Being cognizant of all the dependencies and external circumstances that can impact – either positively or negatively – the operation of the freeway network. As discussed in the previous sections herein, this includes enabling legislation, policies and rules, transportation planning

processes and products, plans / designs for freeway reconstruction and maintenance, strategic plans, operating plans etc. These various processes and funding mechanisms must be understood in order to position freeway management and operations for inclusion and positive consideration.

- Acknowledging that a variety of perspectives exist towards freeway operations and its integration within the surface transportation network. These stakeholders and constituencies include users, decision makers, other freeway practitioners, and service providers; representing numerous entities (e.g., traffic, transit, police, fire, emergency management, activity centers) and “tiers” of decision-making. Never forget that freeway management and operations is an ongoing, iterative effort requiring regional collaboration and coordination.

These and other considerations for the freeway practitioner are discussed below.

2.4.1 Involvement

Awareness is important. But for a freeway management and operation program to be successful, proactive involvement is needed at (and across) all the decision-making tiers. Freeway management practitioners – be they operators, planners, designers, or managers – need to become involved in the various institutional frameworks and decision-making processes to the greatest extent possible, given their individual responsibilities. Examples of this involvement include:

- Becoming a “champion” within your organization for the concept that local, state and regional transportation agencies must make the daily, smooth operation of the surface transportation network a core mission; and promoting a more collaborative operations mentality within and among the organizations that manage and / or influence the surface transportation network.
- Understanding the capital planning process and developing a role within it, as this is the conduit by which funding for freeway management and operations is allocated. As previously noted, transportation planning is a continuing process, with plans updated on a regular basis (i.e., every 1 – 2 years). These plans (and the process to update them) provide freeway practitioners with the opportunity to:
 - Identify and influence the vision, goals and objectives for the region (e.g., mobility, safety, quality of life, security, etc.).
 - Introduce policy / decision makers of the benefits that freeway management strategies and other traffic management initiatives may have on the regions problems and constraints.
 - Select appropriate performance measures on which transportation alternatives may be compared, and the transportation plan and its components are subsequently evaluated. (Performance measures are addressed in Chapter 4)
 - Develop a regional “Concept of Operations” – addressing the role, responsibilities, operational strategies, and functions of a freeway management program and systems – in the regional / statewide planning documents.
- Obtaining funding for the deployment of freeway management systems, as well as funding for the ongoing management and operations of these systems. Understanding and becoming involved in the transportation planning process is important. But developing a role

within the programming processes is critical. Without being included in the programming decisions, there will be minimal (or no) funding for freeway management and operations.

- Engaging the appropriate stakeholders in every “process” that involves or impacts freeway management, thereby providing a framework for collaboration and cooperation. This constituency obviously includes the people responsible for policy decisions, overall management, and day-to-day operations of the transportation system and public safety services, including those involved in capital investment decisions. Nontraditional stakeholders also need a voice in regional transportation operations. These other stakeholders can include chambers of commerce, boards of trade, tourism and visitor agencies, the towing and recovery industry, major shippers and carriers, traffic reporting media, and major employers (or groups).
- Continuously coordinating and collaborating with other managers who are directly responsible for operating elements of the transportation system on a day-to-day basis, aiming to reach agreement on a shared operations vision, a concept for how regional activities should be operated over time, what measures to use to assess effectiveness, and how to make improvements to achieve desired expectations in operating performance.
- Understanding the political and institutional situation. After all, this is what establishes the framework and context in which freeway management and operations activities and systems are funded and implemented. The practitioner needs to be aware of the political and institutional sensitivities and opportunities, determining the associated needs and how much support may be forthcoming to meet these needs. The political / institutional situation should not necessarily be viewed as a negative. It may be, but it could also be a very positive factor that drives the program to success. Even if the program doesn’t have political and institutional support at the beginning, there is always the opportunity, through presentations, good management skills, and astute expectation management, to win people over as supporters.

2.4.2 An Integrated and Expanded View

Freeway practitioners must view the overall performance of the transportation network as an integrated whole, and not just focus on the operation of the freeway. The words “integration” and “integrated” are used throughout this Handbook. The term “integration” is defined in the 4th Edition of the American Heritage Dictionary as: “to make into a whole by bring all parts together; unite”. In the context of this Handbook, the term is used to describe a bridging function between all of the various components, activities, and related attributes that comprise and impact the surface transportation network. The goal of integration is to bring the management and operation of the surface transportation network into a unified whole, thereby making the various transportation modes and facilities perform better and work together.

The surface transportation network can be “integrated” in many ways, including:

- **Physical Integration** – The various components that comprise the surface transportation network – freeways and interchanges, arterial and local streets, parking facilities, sidewalks and crosswalks, bus and rail transit lines and stops, airports, inter-modal facilities, etc. – are all physically interconnected (e.g., arterial street – ramp – freeway). If they weren’t integrated in this fashion, movement could not take place. As such, improvements on one or more of these facilities – be they operational, physical / geometric, or some combination –

can affect the operation of the other elements of the surface transportation network (e.g., inadequate acceptance capacity of the arterial or other traffic absorber near an off-ramp can lead to traffic backing up onto the freeway). Perhaps more common is the scenario where a problem on one facility significantly impacts the operation of other nearby facilities (e.g., major accident on the freeway causes traffic to divert to the surface street, which can disrupt bus service and freight deliveries). Accordingly, the impacts on other facilities need to be considered whenever making freeway management decisions, and vice-versa.

- **Operational Integration** – As users travel from point A to point B along the surface transportation network, they typically use freeways, arterial streets and other elements of the system. Moreover, even if they stay on the same facility type (e.g., a freeway), they are likely moving from a facility owned and operated by one transportation agency to a facility owned and operated by another agency. Other entities and activities – such as the police, emergency services, roadway maintenance / construction, information service providers, etc. – may also impact the trip. As such, it is important to implement operational integration to promote information sharing and more coordinated operations between the various transportation entities. Examples include exchanging information between TMCs, and then combining the information to create a regional database for traveler information; changing signal timing to accommodate increased traffic flow diverted from an adjacent freeway; or all affected agencies jointly developing traffic management plans in advance, and then utilized to manage traffic during special events and emergencies.
- **Technical Integration** – This is closely associated with operational integration, providing the technical means by which information can be shared and the impacts of operational decisions can be immediately viewed and evaluated by the affected agencies. An example of technical integration is the adoption and use of standards enabling different TMCs to automatically exchange information.

Standards allow different systems or devices manufactured by different vendors to more easily share data. Specifically, they define how systems, products, and components can interconnect, exchange information and interact to deliver services within a transportation network. Standards help overcome the difficulties typically associated with proprietary systems/devices owned and operated by TMCs by offering open architectures that:

- Promotes integration and interoperability,
 - Encourages growth by minimizing development costs, and
 - Increases buyer and seller confidence in products.
- **Institutional Integration** – If physical integration makes operational integration necessary, then institutional integration is what enables such integration to take place. The “Background” section of the FHWA Rule 940 publication in the Federal Register (5) states: “*Institutional integration* involves coordination between various agencies and jurisdictions to achieve seamless operations and/or interoperability. In order to achieve effective institutional integration of systems, agencies and jurisdictions must agree on the benefits and the value of being part of an integrated system. They must agree on roles, responsibilities, and shared operational strategies. Finally, they must agree on standards and, in some cases, technologies and operating procedures to ensure interoperability. This coordination effort is a considerable task that will happen over time, not all at once.

Transportation organizations, such as transit properties, State and local transportation agencies, and metropolitan planning organizations must be fully committed to achieving institutional integration in order for integration to be successful. The transportation agencies must also coordinate with agencies for which transportation is a key, but not a primary part of their business, such as, emergency management and law enforcement agencies.”

- **Procedural Integration** – Institutional integration (as well as operational and technical integration) requires that those in authority make decisions to pursue integration of the surface transportation network, and then support this integration by providing the necessary resources. Decision-making is aided by a variety of procedures and processes – both formal and informal ones. Procedural integration focuses on the legislative, policy, planning, programming and budgeting environment in which the transportation infrastructure functions. The expanded mission of “operations” requires agencies to expand and better coordinate their procedures and processes for strategic planning, programming and allocating resources, managing, and operating the network, working in partnership with all of their customers, with other functional entities within their own agency, and with and other agencies.

These various types of integration are interrelated – for example, the existence of physical integration is often the impetus for exploring and instituting other forms of integration; operational integration can be more effective when technical integration has been implemented; procedural and institutional integration go hand-in-hand; while successful technical and operational integration typically require institutional integration (and the associated managerial support and funding) as a prerequisite.

In essence, organizations and practitioners that have previously operated independently need to consider themselves as part of an integrated team. They must cooperate with neighboring governmental jurisdictions, regional transportation agencies, and organizations that provide transportation in those situations where the transportation problem is an area-wide phenomenon. In many cases, because of the dispersed nature of travel patterns and the multitude of organizations providing transportation services, solutions to particular problems in a region or corridor will require a multi-jurisdictional approach. (6)

Coupled with this “whole” and integrated view of the surface transportation network, freeway practitioners must also consider a vast array of potential actions to improve its performance. This requires an expanded view of what constitutes “freeway management and operations”. For example:

- Recognize that traffic congestion is a more difficult problem than simply too many cars at a particular location. There are institutional and land use dimensions to the problem that make it complex. Transportation improvements can be considered from the perspective of enhanced transportation services (i.e., the “supply” of transportation), from the perspective of those who use these services (i.e., better managing the “demand” for the transportation system), from the perspective of influencing where and when this demand occurs (i.e., the land use dimension), or any combination of the above. Practitioners should carefully consider how individual actions relate to one another and how, when combined into an overall program, they relate to regional and community objectives. (6)

- The ITE Paper for the 2002 Theodore M. Matson Memorial Award (7) states: “there is a disconcerting tendency to confuse ITS technology with improved operations”. Freeway operations and management definitely includes extensive applications of Intelligent Transportation Systems (ITS) technologies and strategies. ITS can be a tremendous enabler of freeway management and operations, helping ensure that the investments in the roadway infrastructure are being used wisely and to the maximum efficiency. But projects to deploy these technology packages are not ends in and of themselves. Knowledgeable and trained staff must be placed in charge of these systems, use them proactively to accomplish well – articulated system goals and objectives, and maintain them.
- Reference 7 also states: “engineers must broaden their view of the profession to include new approaches that have not traditionally considered their responsibility”. This expanded view may mean incorporating freeway management and operation strategies (e.g., ramp management and control, lane management, HOV systems, traffic incident and planned special event management, information dissemination, surveillance); giving consideration to other types of operational improvements and enhancements (e.g., increasing the roadway capacity at bottleneck locations; improving static signing, pavement markings, illumination, etc. to increase safety and driver convenience / comfort); examining better ways of managing demand, such as congestion pricing and telecommuting; and considering long-range strategies (e.g., future land use / development patterns) that will provide the foundation for avoiding similar problems in the future. It is easy to claim that aggressive approaches are far beyond the scope of the profession. If the transportation professional does not take the lead, who will? (7)

2.4.3 Clarifying the Benefits

Traditional transportation projects that focus on adding new capacity introduce visible changes in local accessibility and level of service. The direct benefits of many operational improvements are often much less apparent and widely distributed. The benefits accrue to the users, but the costs – which are on going – are the responsibility of the providers, a scenario that may not always be highly valued in the political decision arena. A key precondition to generating support for an increased operations focus is a more widespread appreciation of the relatively high cost-effectiveness of most operations improvements. Accordingly, freeway management practitioners must document the success stories. These need not be traditional benefit/cost studies. It is more important to document real examples of how the quality of transportation operations has been improved with freeway management and related implementations. These success stories should involve innovative applications that cross traditional institutional structures and can be understood for their intrinsic value – for example, improving the response time of an ambulance through improved integrated operations, “amber alerts” via CMS, Internet sites showing real-time traffic conditions (graphically and / or via video feeds) are all benefits that do not require a benefit/cost ratio to be understood.

At the same time, freeway practitioners must be realistic in their assessment of what is likely to be accomplished from the implementation of freeway management and operations strategies and technologies. The “millennium paper” prepared by the TRB Committee on Freeway Operations (8) provides several excellent points in this regard, as summarized below:

- Traffic management does produce benefits, but one must be careful how these benefits are presented. The public must be given realistic expectations. For years, the public has been

told that technology will solve all of its problems. Practitioners must be vigilant to ensure that the view of the public toward freeway management and the associated technologies / systems is not influenced by overoptimistic expectations and longer-than-expected delivery times. The benefits of these systems are real, and the benefits of investing in freeway management are already being realized. However, industry insiders must remember that whereas the benefits for society as a whole are large, the benefits perceived by individual drivers on a daily basis may not be so impressive. We have the larger picture, and we must communicate realistic individual benefits to individual users.

- The safety benefits of traffic management always have been under-emphasized relative to congestion – reduction benefits, even though the two issues are related. Motorists appear to be increasingly concerned about safety and security. The safety benefits of roadway systems and improvements (e.g., ramp metering, variable speed limits, managed lanes, improved incident response) will require better documentation and publicity.
- How practitioners promote traffic management to elected officials, decision makers, and agency managers is another challenge. Again, one must be careful in expounding the benefits of freeway management and ITS – based systems. As a stand-alone program, freeway management will not solve congestion; however, working with the other pieces of the puzzle, it will help to mitigate congestion. Freeway management must work with traffic management on the arterial road network, traveler information providers, and regional planning to make an impact.

2.5 PLANNING FOR OPERATIONS

A recurring theme in this chapter has been the need for the freeway practitioner to understand the transportation planning process and to develop a role within programming processes, as this is the conduit by which funding for freeway management and operations is allocated. However, this may not always be easy. As stated in a White Paper prepared by FHWA (Reference 9), identifying significant areas of change to achieve an adequate emphasis on operations in Federal surface transportation programs: “effectively and proactively operating the highway system has not traditionally been of equal emphasis (to capital projects), and even where operations activities have been pursued, they have been typically carried out in a stove piped fashion within an individual jurisdiction (e.g. State, City, county), functional element (e.g. freeway, arterial, local street) or mode (e.g. passenger vehicle, highway-based transit) basis. A regional operations focus is largely lacking and the regional institutions that exist (e.g. MPOs) have not, with a few notable exceptions, traditionally championed operations at all.”

Reference 7 shares a similar sentiment, stating: “operations is not adequately addressed by the transportation planning process. Most, if not all, planning models are incapable of evaluating the impact of improved operations on air quality and level of service. While investments in operations are becoming increasingly important, they cannot be justified as part of the planning process”

Recognizing the need for a more formalized program for developing a transportation operations program, the FHWA Office of Traffic Management has published a document entitled “*Regional Planning for Operations Primer*” (1), an introductory document that discusses a formal

collaborative activity called “regional planning for operations”. The development of this primer was guided by three important principles:

- The value of regional operations collaboration and coordination results from having formalized and sustained activity between operators and service providers in metropolitan areas regarding regional operations policies and projects that cross agency and jurisdictional lines.
- Where regional operations collaboration and coordination takes place, institutionally, is not the question. What gets done is the important challenge. The focus is on improving operational performance for safe, reliable, and secure transportation systems across a region to better serve the customers.
- The regional operations collaboration and coordination activity must be closely linked to the metropolitan transportation planning and decision-making processes governed by Federal law. Stronger links between operations and planning will result in meaningful programs and investments as well as improved service to the customer across modes, agencies, and jurisdictions.

As envisioned in the primer, “regional operations collaboration and coordination is a deliberate, continuous, and sustained activity that takes place when transportation agency managers and officials responsible for day-to-day operations work together at a regional level to solve operational problems, improve system performance, and communicate better with one another” – much the same concept as discussed earlier in this Chapter. The document “encourages and enables regional operations collaboration and coordination for transportation managers and public safety officials from cities, counties, and States within a metropolitan region. These managers and officials may include traffic operations engineers and managers, transit operations managers, police officials, fire officials, emergency medical services officials, emergency response managers, and port authority (e.g., air and water) managers.” While not specifically mentioned, freeway practitioners are also part of this regional operations collaboration and coordination.

Figure 2-2 shows the framework on which “managers with day-to-day responsibilities for providing transportation and public safety services can build sustained relationships and create strategies to improve transportation system performance. The intent of the framework is to help institutionalize working together as a way of doing business among transportation agencies, public safety officials, and other public and private sector interests within a metropolitan region”.



Figure 2-2: Framework for Regional Collaboration & Coordination

(Reference 1)

This framework creates *structures* through which *processes* occur that result in *products*. It implies a commitment of *resources* needed to initiate and sustain regional collaboration and coordination and for implementing agreed upon solutions and procedures. The collaborative spirit is motivated by a desire for measurable improvement in regional transportation system *performance*. The five elements of the framework are interactive and evolving. A brief description of each element and the associated “action steps” (taken from Reference 1) is provided below:

2.5.1 Structure

The regional **structure** that supports collaboration and coordination within a region is the set of relationships, institutions, and policy arrangements that shape the activity. It provides the “table” at which operators and service providers sit with public safety and other key transportation constituencies. This “regional table” may range from an ad hoc loose confederation to a formal entity with legal standing and well-defined responsibilities and authorities. It may be facilitated by or emerge from existing entities or be newly formed. Associated action steps include:

- Identify key constituencies (e.g., employers, shippers, developers, communities) who support better transportation systems performance.
- Enlist regional champions/leaders who are committed to working together (and encouraging others to work with them) in support of better system performance.
- Develop a vision for regional transportation system performance that is shared by operators, service providers, and planners.
- Establish operations as a regular item on the regional planning agenda.

2.5.2 Processes

Processes are the formal and informal activities performed in accordance with written or unwritten, but collaboratively developed and accepted, policies involving multiple agencies and jurisdictions in a region. Processes describe how the “regional table” works to achieve its objectives. Associated action steps include:

- Make investments decisions based on the best combinations of capital investments and operations strategies (performance-based planning).

- Ensure that the solutions (project) selection process and criteria provide a level playing field for operational improvements and investments. Tools are available to show the benefits of operational improvements.
- Address operations activities (e.g., incident management, traveler information) in multimodal corridor planning.
- Use operations performance audits (e.g., corridor-wide) as a tool for guiding investment choices.
- Leverage operations to achieve regional goals (or meet other commonly sought outcomes).

2.5.3 Products

The **products** of collaboration and coordination are the results of processes, informing regional entities (public and private sector) about the operation of the regional transportation system over time (including planned improvements). These products include studies, evaluations, a regional concept of operations, baseline performance data, current performance information, and operating plans and procedures. Associated action steps include:

- Provide a current conditions baseline to calibrate long-range planning.
- Develop a regional concept of operations that sets performance expectations for regional operators (priorities, projects, improvements, processes, performance, resources).
- Get buy-in for the regional operations implementation agenda from public safety providers and agencies that operate elements of the transportation systems.
- Make the regional operations implementation agenda a necessary input into the transportation improvement plan/long-range plan (TIP/LRP).
- Use market research as the common link between operations (customer feedback) and planning (planning input).

2.5.4 Resources

Resources govern what is available within the region for sustaining and implementing the regional concept of operations and other operations plans on an ongoing basis. The resources include staff, equipment, and dollars. Also implied is the commitment on the part of organizations and individuals to allocate and share these resources. In essence, operations must be viewed as a resource priority to participating organizations. Associated action steps include:

- Ensure linkages to the overall regional transportation planning process for needed investment in operations.
- Use available funds to support convening activity for operators and planners.
- Ensure that everyone at the regional collaboration and coordination table perceives a return on investment of time and other resources.
- Make resources sufficiently available and flexible to effectively fund regional planning for operations activities and initiatives.

2.5.5 Performance

The **performance** element comprises how performance will be measured, and individual and collective responsibilities for monitoring and improving regional transportation system performance. Regional performance objectives, which are established collaboratively, most commonly address public safety, mobility, security, economic development, and environment. Associated action steps include:

- Agree on expected levels of performance and the need for improvement.

- Develop and accept relevant regional performance measures.
- Provide regular status reports on regional transportation system operations performance.
- Share, link, and provide system managers and system users with access to real-time and archived system performance data.

Freeway management and operations must be an integral part of regional planning for operations and the resulting strategies. These include a collective vision for how the region's transportation systems will operate in all situations, under a range of conditions, and with other related systems; a concept for how the system should be operated on a regional basis, and how to make changes to achieve desired improvements in system operating performance; and measures for assessing performance.

2.6 HUMAN RELATIONS

A recurring theme of the above discussions is that freeway management and operations is an ongoing, iterative effort requiring regional collaboration and coordination. The various agencies that are involved or impacted by the surface transportation network don't attend and participate in coordination meetings and decision-making processes, per se; rather, it is their representatives that discuss and (hopefully) resolve the numerous institutional, technical, and funding issues associated with regional operations. Freeway management and operations requires the talents of many people. In fact, most institutional challenges and barriers are really about human relations. As stated in the FHWA "Guidelines for Successful Systems" (Reference 10), "excellent human relations are therefore essential to a systems success. In fact, this may be the most critical aspect of the process. If the various participants cooperate, then a successful system is almost assured. On the other hand, when the relationships between individuals disintegrate and they start to work at cross-purposes, the success of the system is seriously endangered." The importance of personal relationships among leaders and staff members of key operating agencies and neighboring jurisdictions, who recognize common problems and opportunities and agree to work together to improve regional transportation systems performance, cannot be overemphasized.

The dependence on the social behavior of different individuals can be a bit unsettling. After all, the most critical element of the process to develop, implement, and operate a freeway a management program is also the least controllable. Reference 10 identifies a number of general principles that can help to promote and maintain good human relations, and therefore minimize many of the potential barriers to collaboration and coordination. These principles include:

- Good communications, preferably face to face.
- Appropriate knowledge and authority on the part of key individuals (agency representatives, managers)
- Empathy – viewing problems and issues as others do, which requires careful listening.
- Honesty – clearly presenting the facts and being truthful in all dealings.
- Individuality – approaching people as individuals, not as stereotypes.
- Thoughtfulness – showing respect for the opinions and talents of others.
- Positive Thinking – showing confidence in the concept of an ITMS
- Flexibility – recognizing that circumstances change, and being open to new ideas.

2.7 CLOSING

In closing, it is worthwhile highlighting similar “practitioner roles and responsibilities” identified in other sources. For example, according to the ITE publication “A Tool Box for Alleviating Traffic Congestion and Enhancing Mobility” (6), written by M.D. Meyers, “some of the most successful efforts at adopting the transportation programs have exhibited the following characteristics:

- Waging an aggressive campaign to inform the public of what is likely to occur if something is not done.
- Clearly stating what the average citizen will gain from these actions.
- Providing opportunities for citizens and interest groups to participate in the planning and decision making process.
- Actively pursuing business support for the proposed actions.
- Seeking media support in editorials and news reporting.
- Developing a cost effective program that appeals to a broad political base as possible”

The aforementioned FHWA White Paper (9), describing potential areas of change to achieve an adequate emphasis on operations in Federal surface transportation programs, proposes: “States be provided with a charge and the necessary resources to focus on regional operations collaboration and coordination. How this would be carried out in each State would vary, but the following functions would be performed:

- Establish and sustain a “table” where regional operations policies, protocols, activities, and projects are defined, discussed, debated, and coordinated by transportation system operators, including State and local transportation and public works agencies, public safety personnel and transit system operators. Representatives at the “table” should be those responsible for day-to-day management and operations activities;
- Develop, maintain, and monitor the effective implementation of a regional concept of operations;
- Set performance targets; identify, collect and store regional data for performance measurement, trend analysis, and monitoring; report to the public on system performance;
- Coordinate region wide operational improvement to enhance highway safety;
- Carryout regional collaboration for security and emergency transportation operations on key evacuation and military routes and the protection of critical NHS and STRAHNET infrastructure and provide for continued operations during an emergency;
- Prepare a Regional Operations Action Agenda; use performance data to identify operational problems, evaluate potential solutions and facilitate their accomplishment;
- Ensure the coordinated delivery of timely traveler and user information on transportation system operations to the full range of system users; and
- Provide substantive input to the Statewide and/or regional transportation planning process on necessary investments to improve system performance.

So long as all appropriate system operators are involved, performance of these functions could be led by an existing regional agency, such as an MPO; other existing agencies, such as State DOTs or large cities or counties; or an organization formed for the specific purpose of focusing on regional operations.”

FHWA’s “Self – Assessment process for Roadway Operations and System Management” (11) is a tool by which agencies with traffic operations responsibility can assess the effectiveness of their existing roadway operations processes, both in terms of its internal processes and the degree to which it serves its customers. This self-assessment reflects two important aspects of roadway operations: Organization (how well is the roadway operations process administered, directed, and evaluated) and Business Results (how well is the roadway operations process executed). Some of the assessment criteria – particularly those that mirror the discussions herein – are summarized in Table 2-1.

Table 2-1: Selected Criteria – “Self Assessment Process for Roadway Operations and System Management”

(Reference 11)

Area 1 – Organizational

Leadership - This category rates the senior leadership of an agency. It is a measure of the degree to which this leadership has personal involvement in creating and sustaining values, agency directions, performance expectations, customer focus, and a leadership system that promotes performance excellence in roadway operations. Specific areas include:

- Performance Criteria – The degree to which the agency has established objectives for roadway operations, including:
 - Have performance objectives been established that measure quality of service provided to motorists?
 - Have performance objectives been established for incident management services?
 - Have performance objectives been established for maintenance response times?
 - Are users involved in the identification of criteria?
- Personnel Understanding of Objectives
 - Do clear visions and goals exist for roadway operations?
 - Has management communicated and documented the visions and goals for roadway operations?
 - Were all levels of personnel involved in developing the visions and goals?
 - Have responsibilities for these goals been clearly communicated?
 - Are the visions and goals reviewed on a yearly basis and revised if appropriate?
- Outcome Orientation – The degree to which the agency relates the quality of its roadway operations performance to the impact on the community.
- Structure – The degree to which the agency has established an organizational structure that encourages effective leadership throughout the organization, including:
 - Does the agency have an appropriate mix of individuals to achieve agency goals?
 - Are training courses given in leadership?
 - Are potential leaders identified from less experienced personnel?
 - Are the potential leaders mentored?

Planning - This category rates the manner in which the agency develops its roadway operations strategies and plans, and the effectiveness with which it communicates them to its staff. Planning includes a broad spectrum of activities, including:

- Participation in the long-term strategic planning process that is typically conducted agency-wide
- Annual planning and budgeting cycles for the roadway operations function
- Planning of near-term activities such as allocation of staff to operations and maintenance functions
- Decisions for periodic operational updates and reviews such as signing, signal retiming, and preventive maintenance activities
- The manner in which the planning process is translated into an effective performance monitoring system to ensure that planning objectives are achieved.

Customer and Market Focus - This category considers the agency's relationship with its external customers including motorists, commercial vehicle operators, transit providers, transit riders, bicyclists, older drivers, hazardous material carriers, pedestrians, contractors, business owners and residents. It evaluates the agency's understanding and appreciation of its customers' needs and expectations, and the degree to which their needs are satisfied.

Table 2-1 (Continued)

Integration – This category evaluates how well the agency’s operations are coordinated and integrated with those of other modes and jurisdictions, and with “sister” organizations within the agency. Specific areas include:

- Coordination – The quality of your agency’s coordination with other agencies and organizations, including:
 - Does your agency meet regularly with other agencies and organizations?
 - During these meetings, do you discuss operational issues of common interest?
 - Do you discuss sharing of personnel and resource sharing (communications facilities, equipment required for emergencies, etc.)?
 - Have you executed memoranda of understanding defining responsibilities during periods for which operational coordination is required?
 - Have you practiced the coordinated operations under controlled conditions?
 - Do you review, discuss, and act upon the results of coordinated operations following major events or activities?
- Integration of Operations – The quality of your agency’s concept of operations, including:
 - Has your agency participated in the development of a regional concept of operations that defines the operational responsibilities of all agencies and organizations in the region under various types of incident and non-incident conditions?
 - Does this concept of operations describe the interactions between the agencies and organizations?
 - Is the concept of operations reviewed and updated periodically?
 - Have memoranda of understanding been executed by the participants that ensures management acceptance and support of the concept?
 - Is the concept of operations consistent with the regional ITS architecture if one has been developed?
- Integration and Coordination of Routine Operations – The degree to which the agency’s routine operations activities are coordinated with other agencies.
- Data and Information Integration – The degree to which your agency recognizes the importance of shared information, and takes steps to facilitate this sharing. (The various criteria within this category explore “technical integration”, which is discussed in Chapter 16)
- Integration of System Planning and Designs – The degree of integration that occurs during the planning, design, and implementation of new traffic management and/or dispatch systems, such as the inclusion of other agencies and organizations in the planning process; and the plans reflecting the requirements and services needed by other agencies.

Human Resources (Personnel) - This category evaluates the manner in which the workforce (including consultants and contractors) is enabled to develop and realize its full potential with regard to operations and system management. It also evaluates the alignment of the agency’s personnel policies with its other objectives. Specific areas include:

- Involvement and Commitment – How well all personnel are encouraged and enabled to contribute to achieving agency operations and system management goals and continually improving the agency, including soliciting inputs from all personnel (as appropriate) during the development of the strategic and annual plans.

Table 2-1 (Continued)

- Professional Development Programs – The quality of the programs and facilities available to agency personnel as appropriate for their job performance as well as advancement to the next job level, including training programs in the categories of traffic engineering, project management, leadership, and negotiating skills.
- Empowerment- Whether personnel are provided with the needed authority to permit them to interact with neighboring and other appropriate agencies.

Process Management - This category rates the processes of the agency uses to provide quality roadway operations, and the processes it uses to improve this quality. It deals with the degree to which processes are defined, monitored, evaluated and upgraded. A key criterion involves “Integration with Other Processes” – that is, the degree to which roadway operations is integrated with other elements of the agency and with other agencies; the extent to which roadway operations personnel are involved in the planning, design and inspection of new facilities; and participation of operations personnel in the activities of the appropriate Metropolitan Planning Agencies.

Data, Information and Knowledge – This category evaluates the effectiveness with which the agency collects data, processes the data, and creates the knowledge for effective decision-making at all levels of management.

Area 2 – Business Results

This area evaluates the current performance of the agency in a variety of areas, listed below, all of which are in the purview of the freeway practitioner.

- Safety Analysis
- Signing and Marking
- Debris Removal
- Snow, Sand, and Ice Control
- Emergency Evacuation
- Lighting
- Traffic Monitoring
- Vegetation Control
- Service patrols
- Ramp Metering
- System Performance Monitoring, Evaluation, and Reporting
- Construction Management
- Rest Areas
- Incident Response
- Incident Diversion Planning
- Incident Clearance
- Scheduled Incidents
- Motorist Notification (DMS, HAR)
- Media Interface
- Information Dissemination (Internet)
- Freeway / Arterial Coordination
- Interagency Coordination

2.8 REFERENCES

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3. FREEWAY MANAGEMENT PROGRAMS

3.1 INTRODUCTION

Practically every transportation-related program and the associated deployment projects involve some sort of “process” – a series of actions by which ideals and concepts are brought to fruition, implemented, and managed on a day-to-day basis. Within every process there exists an underlying structure that shapes and controls events. This framework consists of formal activities (e.g., written policies and operational guidelines agreed to in a collaborative fashion) and informal ones (e.g., human relationships), all relating to the ways options are created and decisions are made to improve the performance of the transportation network. An effective approach ensures that investment decisions include full consideration of operations strategies along with capital improvements; that operations activities are addressed from a regional and multimodal perspective; that the operations thinking addresses economic, environmental, and mobility objectives as well as any institutional issues; and that once implemented, the effects of these decisions can be measured and evaluated.

Several processes have been developed for planning and deploying transportation improvements such as new infrastructure, ITS-based systems, and operational activities. Moreover, many transportation agencies have adopted some of these – often with variations – as their formalized approach for making informed decisions regarding the investment of public funds for transportation improvements. Given that several such processes already exist, an additional (and separate) process for establishing, deploying, and managing a freeway operations program is not needed. Instead, freeway management and operations should be an integral part of the established processes within an agency. Moreover, as discussed in Chapter 2, the freeway management practitioner must be cognizant of and, to the greatest extent possible (commensurate with his/her responsibilities), participate in these processes ensuring that freeway management and operations receives appropriate consideration and funding.

3.1.1 Purpose of Chapter

Chapter 2 identified and summarized some of these processes – specifically, statewide and regional transportation planning for developing and updating long – range transportation improvement programs; and “regional planning for operations”, a more formalized program for developing a transportation operations program as recently developed by FHWA. This chapter focuses more on processes and activities specific to freeway management and operations. Following these introductory comments, a series of activities are presented for establishing, enhancing, and managing a freeway operations program. These “steps” are not to be viewed as a separate process for developing a freeway management and operations program. Rather, they represent an amalgamation of important activities from other established processes.

Intelligent Transportation Systems (ITS) have proven to be a significant enabler of operations. As such, many freeway management programs will include projects to develop, design, implement, and expand freeway management systems that incorporate advanced technologies and complex software. Accordingly, this chapter also summarizes a number of published processes that are geared towards ITS deployment (e.g., systems engineering, configuration management, regional ITS architectures). Finally, while not a process itself, the National ITS Architecture is also discussed herein as the associated conventions and terminology will often

affect how these other system processes are applied. Only a high - level overview of these system processes is provided in this Chapter. Additional information and details can be found in subsequent chapters of this Handbook, and in a variety of references, many of which are identified herein.

While reading about, and perhaps someday utilizing, the information and processes discussed in this chapter, it is important that the freeway practitioner keep in mind that ITS-based systems represent just one potential aspect of a freeway management and operations program, and that the freeway itself is just one element of the overall surface transportation network. Accordingly, freeway practitioners must view the overall performance of the transportation network as a whole, and consider a vast array of potential actions to improve its performance. Moreover, practitioners must carefully consider how individual actions complement one another in the long run and how, when combined into an overall program, they relate to regional and community goals and objectives.

3.2 ESTABLISHING A FREEWAY MANAGEMENT AND OPERATIONS PROGRAM

As defined in Chapter 1, a “program” is a coordinated, inter-related set of strategies, procedures, and activities (such as projects), all intended to meet the goals and objectives articulated in vision statements and policies. Figure 3-1 shows a series of activities that should be considered when establishing, enhancing, and managing a freeway operations program. This diagram and the “steps” shown therein should not be viewed as a separate, independent separate process for freeway management and operations. Rather, they represent a collection of important activities from other established processes, including the aforementioned planning for operations (Reference 1), systems engineering (References 2 and 3), regional ITS architectures (References 4 and 5), and incident management (Reference 15). This funnel diagram shows freeway management and operations within the context of the broader transportation planning process and the institutional environment as represented by the stakeholders. This becomes the basis for a vision, goals, objectives and strategies; and how these are used to identify required services, formulate the concept of operations, and help determine performance measures. These lead to decisions regarding the improvements, management systems, and staffing that are required. These operational tools are then implemented leading to the actions an operator takes on a day – to – day basis. These actions lead to results and outcomes, measured by the performance monitoring system, that consequently feed back and affect the formulation of the policies, goals, and objectives, and influence the planning and programming process. These various activities are discussed below.

3.2.1 Transportation Planning

As discussed in Chapter 2, statewide and regional transportation planning is the structured process followed by states, metropolitan planning organizations (MPOs), municipalities, and operating agencies to design both short and long-term transportation plans. Products are project-oriented, typically providing the Statewide and Regional (Constrained) Long Range Plan (LRP), Statewide Transportation Improvement Program (STIP), and regional Transportation Improvement Program (TIP). While the process has historically focused on capital projects, it is now recognized that the statewide / regional transportation planning process must take management and operations of the transportation network, and the ITS – based systems that support operations, into consideration.

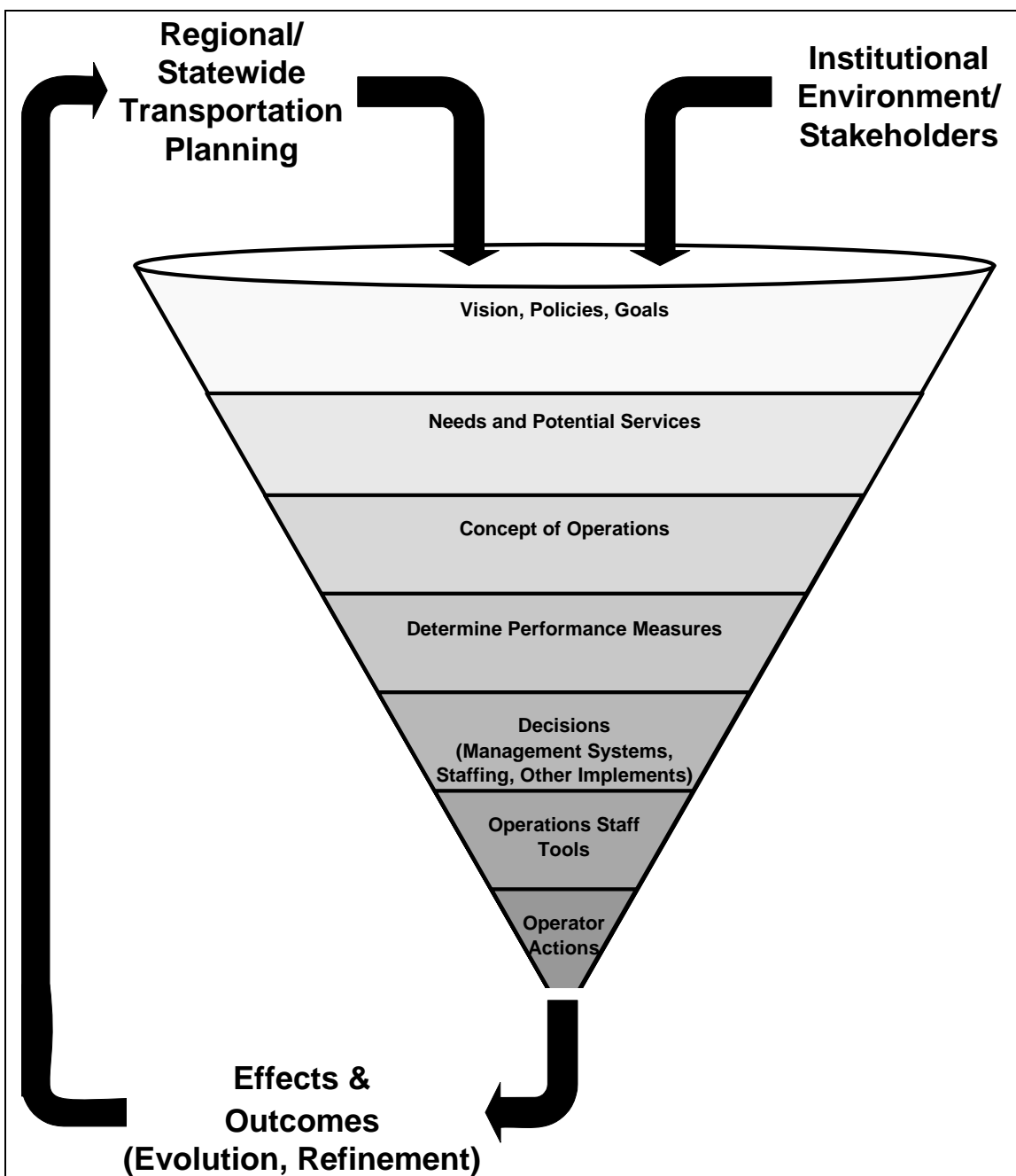


Figure 3-1: Activities That Comprise a Freeway Management & Operations Program

This concept of “mainstreaming” ITS and related management and operations activities into the traditional decision-making of planners and other transportation professionals is addressed in several documents, including NCHRP Project 8-35: “*Incorporating ITS into the Transportation Planning Process*” (Reference 7) and “*Integrating Intelligent Transportation Systems within the Transportation Planning Process: An Interim Handbook*” (Reference 8). The former has the stated goal of defining an integrated decision process where ITS and management and operations strategies are considered on equal basis with traditional elements of the transportation system. The latter “presents a framework for decision-making concerning ITS and aids practitioners in successfully deploying ITS in the context of the overall transportation program”.

The documentation for many of the processes noted and referenced above stress the importance of linking their efforts to the overall transportation planning process, and using their end product as part of the overall transportation planning process. For example, the FHWA rule regarding regional ITS architectures (Reference 4) states that the “development of the regional ITS architecture should be consistent with the transportation planning process for Statewide and Metropolitan Transportation Planning”. In general, any process used to develop and implement specific types of projects and activities (e.g., freeway management and operations, ITS – based systems, regional architecture) must support the overall transportation planning process; not compete with it. Moreover, the end products of these “focused” processes can and should be used to feed information back into the overall transportation planning process. As noted in the primer on planning for operations (Reference 1), “stronger links between operations and planning will result in meaningful programs and investments as well as improved service to the customer across modes, agencies, and jurisdictions”.

A freeway management and operations program must be an integral part of the regional and statewide transportation planning processes. These include a collective vision for how the region’s transportation systems will operate in all situations, under a range of conditions, and with other related systems; a concept for how the system should be operated on a regional basis, and how to make changes to achieve desired improvements in system operating performance; and measures for assessing performance. Additionally, the freeway management program (i.e., the associated improvements, systems, and operational tools) will provide information for updating both the Transportation Plan and the Transportation Improvement Program (TIP). The goal of the transportation planning process is on making quality, informed decisions pertaining to the investment of public funds for regional transportation systems and services. Using the freeway management and operations program to support these planning activities is an important step in the mainstreaming of operations into the traditional decision-making of planners and other transportation professionals.

3.2.2 Institutional Environment and Stakeholders

There are a number of institutional factors that can affect the requirements and decisions for a freeway management and operations program. These include (from Reference 9):

- **The Political Situation.** The political situation creates the context in which a freeway management and operations program is implemented. The people who created the political situation are usually key stakeholders and have needs that you must meet. It is important to determine what those needs are and how much support they’re willing to give to meet their

needs. In addition, some of the people involved in creating the political situation may be involved in the decision-making process that affects the freeway management program and associated projects. The political situation should not necessarily be viewed as a negative constraining the program. It may be, but it could also be a very positive factor that drives the program to success. Even if you, as a freeway practitioner, don't have the political support when you start, you always have the opportunity, through good project management and astute expectation management, to win people over as supporters.

- **Receptivity to Innovation and New Ways of Doing Business.** There are some who are receptive to innovation and change (the “early adopters”) and some who resist change all the way. Most people fall in the middle; they're not looking for change / new ways, but they'll accept it if it's presented to them in a positive way. Part of a freeway practitioner's job is to help the middle group, which is usually the largest one, accept the change by pointing out the positive aspects of freeway operations, by promising only what can be realistically delivered, and by keeping these promises. If there is resistance, the practitioner must look for the reasons, keeping personalities out of the picture. It could well be that the reason for the resistance is that some key requirement isn't being met for a group that considers themselves stakeholders.
- **Willingness to Invest in Freeway Management Solutions.** It may be necessary to provide information on the return on investment that the freeway management program offers the community it serves.
- **Local Laws and Regulations.** Laws and regulations are frequently the source of many key requirements. They set conditions that the program must meet and boundaries within which the program must operate.

Stakeholders are interest groups who are benefit from, or are otherwise impacted by, freeway management and operations (a “stake” as it were). This includes the various entities identified in Chapter 2 – including users, decision makers, responders (e.g., police, emergency services), practitioners, and activity centers and service providers; from all “tiers” – in essence, any persons or organizations with a strong material interest in success or failure of freeway management. The stakeholders are sources of the vision, goals and objectives, and requirements, and they are also ones who validate or verify the requirements. Stakeholders need to be brought into the picture early on to make sure their needs are considered and to determine how they will be involved in the process. In some cases it may be necessary to educate selected stakeholders, such as target the management levels in an organization where decisions can be made to commit valuable personnel resources to support the freeway management program effort.

The Regional ITS Architecture Guidance Document (5) provides an extensive list of the range of stakeholders that have participated in regional ITS architecture development efforts around the country. Reproduced in Table 3-1, the table makes a good checklist of *possible* stakeholders that may be involved in a freeway management program. This list should not be viewed as complete. As discussed in Chapter 11, additional stakeholders will become major participants during emergency situations and disaster management.

Table 3-1: Candidate Stakeholders

(Reference 5)

Transportation Agencies	Public Safety Agencies
<ul style="list-style-type: none"> •State departments of transportation (DOT) •Local agencies (City & County) <ul style="list-style-type: none"> ➢ Department of transportation ➢ Department of public works •Federal highway administration (FHWA) •State motor carrier agencies •Toll/Turnpike & Bridge / Tunnel authorities •Port authorities •Department of airport or airport authority 	<ul style="list-style-type: none"> •Law enforcement <ul style="list-style-type: none"> ➢ State police and/or highway patrol ➢ County sheriff department ➢ City/Local police departments •Fire Departments <ul style="list-style-type: none"> ➢ County/city/local •Emergency medical services •Hazardous materials (HazMat) teams •911 Services
Planning Organizations	Transit Agencies
<ul style="list-style-type: none"> •Metropolitan planning organizations (MPOs) •Council of governments (COGs) •Regional transportation planning agency (RTPA) 	<ul style="list-style-type: none"> •Local transit (city/county/regional) •Federal transit administration •Paratransit operations •Rail services (e.g., AMTRAK)
Other Agency Departments	Activity Centers
<ul style="list-style-type: none"> •Information technology (IT) •Planning •Telecommunications •Legal/Contracts 	<ul style="list-style-type: none"> •Event centers (e.g. sports, concerts, festivals, ski resorts, casinos, etc.) •National Park and US Forest Services •Major employers •Airport operators
Fleet Operators	Travelers
<ul style="list-style-type: none"> •Commercial vehicle operators (CVO) <ul style="list-style-type: none"> ➢ Long-Haul trucking firms ➢ Local delivery services •Courier fleets (e.g., US Postal Services, Federal Express, UPS, etc.) •Taxi companies 	<ul style="list-style-type: none"> •Commuters, residents, bicyclists/pedestrians •Tourists/Visitors •Transit riders, others
Other Agencies	Private Sector
<ul style="list-style-type: none"> •Tourism boards/visitors associations •School districts •Local business leagues/associations •Local Chambers of Commerce •National Weather Services (NWS) •Air and Water Quality Coalitions •Bureau of Land Management (BLM) •Academia interests, local Universities •National and statewide ITS associations (e.g. ITS America, ITE ITS members, etc.) •Military (including Coast Guard) 	<ul style="list-style-type: none"> •Traffic reporting services •Local TV & radio stations •Travel demand management industry •Telecommunications industry •Automotive industry •Private towing/recovery business •Mining, timber or local industry interest

3.2.3 Vision, Goals, and Objectives

The vision is a broad statement of the long-term goals of the program, such as “seamless traffic flow across jurisdictional boundaries”, “enhanced mobility through readily available information”, “safe and efficient movement of goods”, etc. Such themes enable all entities affected by freeway management to agree in simple layman’s terms regarding its purpose. Moreover, as the development of a vision should be a bottom-up process with input coming from the stakeholders, it offers the opportunity to bring all the stakeholders to the table early in the process, leading to a continuing dialog. Visioning also helps establish priorities and ensure that the freeway management program is fully responsive to participants needs. The vision sets the stage for the development of goals and objectives.

3.2.4 Needs and Services

This is the initial activity in determining how the freeway network should operate relative to how it operates today. The needs may be identified from discussions with stakeholders coupled with the results of analytical evaluations. This assessment should also include resources, institutional considerations, and potential constraints (funding, staffing availability, schedule, facilities). Services are the things that can be done to improve the efficiency, safety, and convenience of the freeway network through better information, advanced systems, new technologies, increased capacity, better guidance for drivers, improved institutional relationships, enhanced maintenance and operations, etc. Services are defined at a very – high level, and then prioritized, based on the needs evaluation and stakeholder input.

3.2.5 Concept of Operations

The Concept of Operations is a formal document that provides a user-oriented view of the freeway management and operations program. It is developed to help communicate this view to the other stakeholders and to solicit their feedback. In essence, the Concept of Operations lays out the program concept, explains how things are expected to work once it’s in operation, and identifies the responsibilities of the various stakeholders for making this happen. The vision, needs, and services are also documented. The process to develop a Concept of Operations should involve all stakeholders and serve to build consensus in defining the mission, goals, and objectives; provide an initial definitive expression of how functions are performed, thereby supporting resource planning; and identify the interactions between organizations (within and between “tiers”).

By definition, the Concept of Operations does not delve into technology or detailed requirements of the program. Rather, it addresses operational scenarios and objectives, information needs and overall functionality, where the program should be deployed, how users will interact with the various elements of the program, performance expectations, etc. The Concept of Operations must also address the “institutional” environment in which the freeway management and operations program is to be deployed, operated, and maintained. This environment includes all the potential users and providers (i.e., stakeholders) and their respective needs and perspectives, the relationships between the freeway management program and the policies / procedures of the affected public agencies and private entities, and the necessary coordination (working relationships and agreements) between the stakeholders.

Per the “IEEE Guide for Concept of Operations Documents”, the Concept of Operations:

- Provides a means of describing users' operational needs without bogging down in detailed technical issues

- Provides a mechanism for documenting a program's (and system's) characteristics and the users' operational needs in a manner that can be verified by the users without requiring them to have any technical knowledge beyond what is required to perform their normal job functions.
- Provides a place for users to state their desires, visions, and expectations without requiring them to provide quantified, testable specifications.
- Provides a mechanism for users and providers to express their thoughts and concerns on possible solution strategies. In some case, there may be technical or institutional constraints that dictate particular approaches. In other cases, there may be a variety of acceptable solution strategies.

3.2.6 Performance Measures

The performance measures provide the basis for evaluating the transportation system operating conditions and identifying the location and severity of congestion and other problems. The performance measures provide the mechanism for quantifying the operation of the network, and should also be used to evaluate the effectiveness of implemented freeway management strategies and to identify additional improvements. Another aspect of performance measurement is sharing and providing managers and users with access to real-time and archived system performance data. Additional information on performance measures is provided in Chapter 4 herein.

3.2.7 Decisions Regarding Improvements, Systems, etc.

In this stage, a determination is made – in a more detailed manner than in the Concept of Operations – what the freeway management program should do. This stage can run through several iterative cycles of defining, reviewing, and refining the requirements. A key point related to this phase is that the end product must be a set of requirements on whose meaning everyone agrees. In the parlance of “Systems Engineering” (which is discussed later in this Chapter), requirements are statements of the capabilities that the program strategies and supporting systems must have (i.e., “functions”), geared to addressing the mission-oriented objectives of the stakeholders. For requirements to be most useful, they should be statements of what is desired, not descriptions of how the need should be satisfied.

3.2.8 Implement Tools

This stage involves deciding “how” each requirement in the freeway management program is satisfied. It entails a determination of appropriate strategies, policies, actions, and systems and their components so as to satisfy the requirements. This will typically consist of several activities, including generating alternatives, assessing the alternatives (e.g., technical and operational feasibility, institutional compatibility, life-cycle costs, constraints), and considering the conditions that impact operations and maintenance (e.g., staff capabilities and availability, environment, available facilities, training and documentation needs). The evaluation of alternative strategies and system configurations / components should involve the following steps: estimate benefits or utilities for each alternative, estimate life-cycle costs of each alternative, perform comparative analysis, and select the alternative(s) offering the most potential. (Chapter 4 discusses some analytical tools for making such comparisons).

The freeway management and operations program will likely be implemented via many individual projects and initiatives that occur over years, or even decades. A sequence, or ordering, of projects must be defined. The first step is to review the regional transportation plans

(TIP, STIP), identify the freeway management projects that are already prioritized as short, medium and long term, and then use this as a starting point. Each freeway management project and initiative should be evaluated in terms of anticipated costs and benefits, and to determine whether there are any institutional or technical issues that will impede implementation. In addition, the evaluation may take into account the funding availability, agency and public support for each project, and other qualitative factors that will impact the actual sequence in which projects are deployed.

The projects and initiatives are then designed (e.g., preparation of plans, specifications, estimates, and other contract documents / work orders) and then implemented (including integration, testing, and acceptance activities, staff training, and documentation), making the freeway management and operations program real.

3.2.9 Operator Actions

The implementation of systems and other operational tools result in the actions an operator takes on a day – to – day basis. As discussed in Chapter 2, while the previous activities have been strategic and tactical in nature, operations are ongoing and performed on a real time temporal scale. This also includes maintenance of the freeway management and operations infrastructure (ensuring that it is functioning properly) and on-going configuration management (discussed later in this Chapter).

These actions lead to results and outcomes, measured by the performance monitoring system, that consequently feed back and affect the formulation of the policies, goals, and objectives, and influence the planning and programming process. This “feedback” element of the process allows practitioners to assess the effectiveness of their efforts, to identify areas for improvement, to demonstrate the benefits provided by the program, and to support requests for additional resources

A freeway management and operations program is a continuous process, one that must take into account changes in the local operational, technological, political, and funding environment. Based on the results of the evaluations, the freeway management program may be expanded (geographically and / or functionally), and the policies and operational strategies may be modified. It may also require developing a revised vision, new requirements, different approaches, etc. – in essence, continually exercising all the previous steps.

It is important that the operators understand that their actions directly contribute to achieving the program’s goals and objectives. The more successful the operations program in meeting the overall goals of the agency (as measured by performance monitoring), the more strongly supported it will be. The program is not simply operating the system, but providing the resources needed (equipment, software, tools, staffing, training, etc.) in a systematic approach (e.g., systems engineering) to develop an overall approach to support operations and make it as effective as possible.

Another important consideration is that freeway management and systems are only one part of the many transportation management systems and operations activities that may exist within a metropolitan area, state, or multi state region. Freeway management should be implemented systematically on a regional basis and be coordinated with all the activities typically undertaken

to operate the transportation network. This requires cooperation with neighboring governmental jurisdictions, regional transportation agencies, and organizations that provide or are involved with transportation – related services.

3.3 PROJECTS

“Projects” are well-defined, individual actions and activities that make up a substantial portion of a program (along with policies, procedures, and other actions). The development and implementation of projects is a how an on-going program is realized, and subsequently updated to reflect changes in the operating environment. Most, if not all, freeway management and operations programs incorporate some of the technologies and strategies associated with Intelligent Transportation System (although it is important to always remember that freeway management and operations is not limited to just ITS). As such, many freeway management programs will include projects to develop, design, implement, and expand freeway management systems that incorporate advanced technologies and complex software. This section summarizes a number of published processes that are geared towards ITS deployment – specifically, systems engineering, configuration management, and regional ITS architectures. While these processes are oriented towards ITS and individual projects, they nonetheless closely parallel the various “steps” identified in the previous section for establishing a freeway management and operations program.

3.3.1 Systems Engineering

The literature contains many definitions for “systems engineering”. The FHWA Technical Report “Building Quality Intelligent Transportation Systems Through Systems Engineering” (Reference 2) contains the following definition:

“Systems engineering is the process by which we build quality into complex systems. It uses a set of management and technical tools to analyze problems and provide structure to projects involving system development. It focuses on ensuring that requirements are adequately defined early in the process and that the system built satisfies all defined requirements. It ensures that systems are robust yet sufficiently flexible to meet a reasonable set of changing needs during the system’s life. It helps manage projects to their cost and schedule constraints and keeps realism in project cost and schedule estimates.”

Another way of describing system engineering is that it is a “requirements driven development process.” That is, user requirements are the overriding determinant of system design, component selection and implementation. There should be no “gold plating” and you only pay for what you really need. The Systems Engineering process is more than just steps in system design and implementation; is a life cycle process. It recognizes that most systems are built incrementally and/or expand over time. The basic steps in the process do not change, but are spread out over time. There is an even stronger need to provide feedback and assessment with each incremental deployment phase so that future phases build on and expand the system, rather than simply replace elements of the earlier phases.

Systems engineering helps accomplish four key activities that impact a project’s success. These are (2):

- Identify and evaluate alternatives – The feasibility of each alternative must be measured from three different points of view: technical feasibility, cost feasibility, and schedule feasibility. *Technical feasibility* addresses whether we can build, maintain, and operate a

system alternative, given the technology and people available to us. *Cost feasibility* looks at whether we can build, maintain, and operate a system alternative with the funds available for it. *Schedule feasibility* considers whether we can build a system alternative within the time frame allotted for its development. Usually we have to make trade-offs, deciding which alternative offers the better value.

- Manage uncertainty and risk in our systems – If we could accurately predict the future, it would be easy to avoid mistakes and problems. However, in real life, we need to deal with uncertainty and risk. Systems engineering focuses on three aspects of risk management: identification, analysis, and mitigation.
- Design quality into our systems – This is accomplished by addressing those factors that can negatively affect quality. Paraphrasing the International Organization for Standardization (ISO), we can define quality as “the totality of features of a system that bear on its ability to satisfy stated or implied needs.” Among the factors that can negatively affect the quality of a system are its *complexity*, its *inflexibility*, its *lack of standardized components*, and its *reliability and availability*.
- Handle program management issues that arise – this requires a good project plan – one that is complete, comprehensive, and communicated. It should including all tasks that must be performed, accurately estimate the resources required to accomplish each task, assign the appropriate resources to each task, define all dependencies among tasks, identify all products or other criteria whose completion signifies that a task is done, and determine how to measure progress against plan when managing the project.

References 2 and 6 utilize the ‘V’ (or ‘VEE’) model as a way of showing the systems engineering process and relating the different stages in the system life cycle to one another. The ‘V’ model, illustrated in Figure 3-2 shows the early stages in building a system as steps along the left leg of the ‘V,’ the decomposition leg of the process. The steps on this decomposition leg break the system down into its pieces, proceeding from development of a Concept of Operations for the system, through the definition and refinement of the system’s requirements (going from high-level to detailed requirements), to the system design stage, which also goes from high-level to detailed design. At the bottom of the ‘V’ is the Implementation stage, which represents the transition from decomposition (the conceptual level) to re-composition (the physical level). During this stage, the system’s design is transformed into actual products. On the right-hand leg of the ‘V’ are the re-composition steps, where all the parts of the system are tested and put together. As one proceeds up the right-hand leg, the system’s building blocks are combined into larger and larger pieces, resulting in a finally assembled and installed (i.e., complete) system.

The ‘V’ model helps to emphasize the importance of evaluation in all stages of a system project. In the early stages of the system life cycle (the left leg of the ‘V’ model), one is using mostly inspection and analysis as evaluation tools. In the later stages of the system life cycle (the right leg of the ‘V’ model), the primary evaluation tool is testing. Regardless of which leg of the ‘V’ model one is on, evaluation efforts are combined with system development activities. Additional information regarding the individual steps that comprise the ‘V’ systems engineering model is provided in Chapter 14.

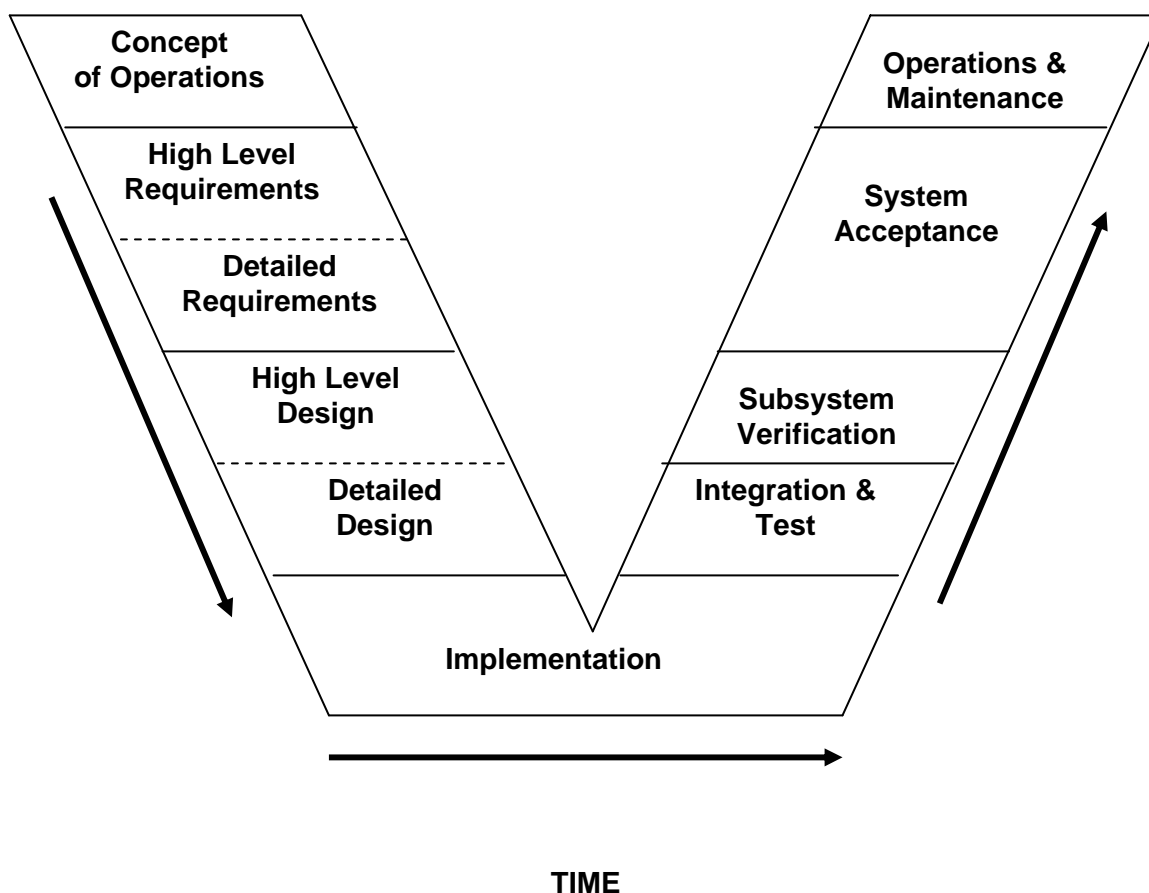


Figure 3-2: V - Diagram
(Reference 2)

As previously noted, one of the key activities of the systems engineering process is to manage risk. This means ferreting out the issues and potential problems that can affect the end - project. Table 3-2 contains a set of questions – listed by each step shown in the “V” diagram – that can be asked to help identify issues and potential problems. The questions are at a high level. As you answer them, other, more detailed questions will arise.

Table 3-2: Key Systems Engineering Questions

(Reference 2)

Area	Key Questions
Needs Analysis	<ul style="list-style-type: none"> • What is wrong with the current situation? • What needs does the ITS project fill? • Have we clearly articulated the need? • Do all ITS project stakeholders have a common understanding of the project's goals and objectives?
Concept of Operations	<ul style="list-style-type: none"> • Is our concept consistent with any Architecture(s) with which it must interact? • Have we identified all intended users of the ITS system? • How will each intended user interact with the ITS system? • How is this different from the current situation, if at all? • Do the intended users understand their role in the ITS system? • Have we coordinated with all other agencies affected by this ITS system?
Requirements	<ul style="list-style-type: none"> • What specific functions will this ITS project perform? • Have we defined each function in detail? • Have we identified all system interfaces? • Are all system interfaces well defined? • Have we defined our required system performance in quantifiable terms? • Have we reviewed all requirements with stakeholders? • Have we considered system availability requirements? • Have we assessed our reliability and maintainability requirements? • What derived requirements must we validate with our customer(s)? • Have we considered what security our system needs?
System Architecture	<ul style="list-style-type: none"> • What are the components of the ITS (e.g., TMC, ATIS)? • How does this ITS system fit in with other ITS systems in the region? • Is there an existing regional or project architecture based on the National ITS Architecture?
Allocated Requirements	<ul style="list-style-type: none"> • Which components address which requirements? • Is this allocation appropriate? • Is this allocation complete? • Are there any unaddressed requirements?
Detailed Design	<ul style="list-style-type: none"> • Do the details meet the requirements? • Is each component buildable? • Are the interfaces satisfied? • Are the details well documented? • Do the details of the design map to all allocated requirements? • Have we built sufficient redundancy into all mission-critical components?

Area	Key Questions
Implementation (includes system integration)	<ul style="list-style-type: none"> • What is the overall plan for building this ITS system? • If capability will be phased in, what is our overall schedule? • Can the ITS project be completed within cost and schedule? • Have we considered human factors? • Have we assessed the maintainability of the final system? • Can we re-use/integrate existing components or capabilities?
Test	<ul style="list-style-type: none"> • How will we know when a test is successful? • Are all mission-critical functions thoroughly tested? • What areas will we not test and why? • Have we scheduled a full end-to-end test, integrating all interfaced systems?
System Acceptance	<ul style="list-style-type: none"> • Do we have clear criteria for system completion? • Have all users agreed with our completion criteria? • Will our customers be satisfied with the system? • Will we have adequate system documentation for all users and maintainers?
Operation and Maintenance	<ul style="list-style-type: none"> • Have we assessed the full life-cycle costs of the system, including training, operation, and maintenance? • Have we identified who will maintain the system? • Do we have the system maintainer on-board? • Do we have a schedule for upgrades and/or enhancements to this system? • What growth in demand have we planned for?

3.3.2 Configuration Management

Freeway management programs (and their associated freeway management systems) are ongoing endeavors. More often than not, the program and systems are implemented in small increments, with functions and areas of coverage being added over time. The institutional landscape – which influences policy and funding decisions – is also subject to change during the life – cycle. Changes in program and system requirements are therefore inevitable. A goal of a freeway management practitioner should not be to avoid making changes, but to keep the requirements change process under control through a process known as “Configuration Management.” Configuration Management includes procedures and techniques that allow the practitioner to consider and evaluate the impacts of proposed changes, and then to track and document those changes that are made.

Configuration management is a part of the systems engineering process and a critical element in the life of any system. It is particularly important in those systems that are software intensive. But configuration management principles and procedures are also applicable in the broader context of a freeway management program. The concept can and should be expanded to include operations and management strategies – not just technical systems. In other words, the term “configuration” in configuration management can refer to the entire set of items that make up a freeway management program, including policies, system hardware and software, documentation, operational procedures, freeway geometrics and associated infrastructure (e.g.,

signing and lighting), incident management strategies, work zone procedures, and anything else that makes up the description and embodiment of a the program.

The process is described in more detail in the document “*Configuration Management (CM) for Transportation Management Systems*” (Reference 10), the contents of which are summarized below and in Chapter 14. It is noted that the processes and procedures of CM have been developing in the information technology community for many years. Accordingly, Reference 10 makes use of a standard developed and refined in the IT industry – the Electronic Industries Alliance (EIA) Standard 649 *National Consensus Standard for Configuration Management* (ANSI/EIA-649/-1998), referred to EIA 649. Reference 10 is oriented towards ITS – based transportation management systems. But as is the case with other “systems” processes described herein, by changing a few key terms (e.g., “system” into “program”, “TMS’ into ‘freeway operations”) and expanding the context, the CM process can be “converted” and used for the overall freeway management and operations program.

There are two fundamental purposes of Configuration Management (CM) – to establish system integrity, and to maintain system integrity. A system with integrity is one in which:

- All components are well defined and documented
- A working baseline is always available to implement and provide transportation management services
- Integration with other regional systems can readily be accomplished
- A high degree of traceability exists, allowing one to easily identify how system functions are provided.

In other words, a system with integrity is one that is available and functional.

CM provides a holistic approach for effectively controlling system change. It helps to verify that changes to subsystems are considered in terms of the entire system, minimizing adverse effects. Changes to the system are proposed, evaluated and implemented using a standardized, systematic approach that ensures consistency. All proposed changes are evaluated in terms of their anticipated impact on the entire system. CM also verifies that changes are carried out as prescribed and that documentation of items and systems reflects their true configuration. A complete CM Program includes provisions for the storing, tracking and updating of all system information on a component, subsystem and system basis. This provides TMS managers with an up-to-date baseline of their system.

The CM process may be (and ideally should be) applied throughout the system life cycle. This allows TMS management to track requirements throughout the life cycle through acceptance and operations and maintenance. As changes are inevitably made to the requirements and design, they must be approved and documented, creating an accurate record of the status of the system. The general CM process is described graphically in Figure 3-3. Additional information regarding these CM activities is provided in Chapter 14.

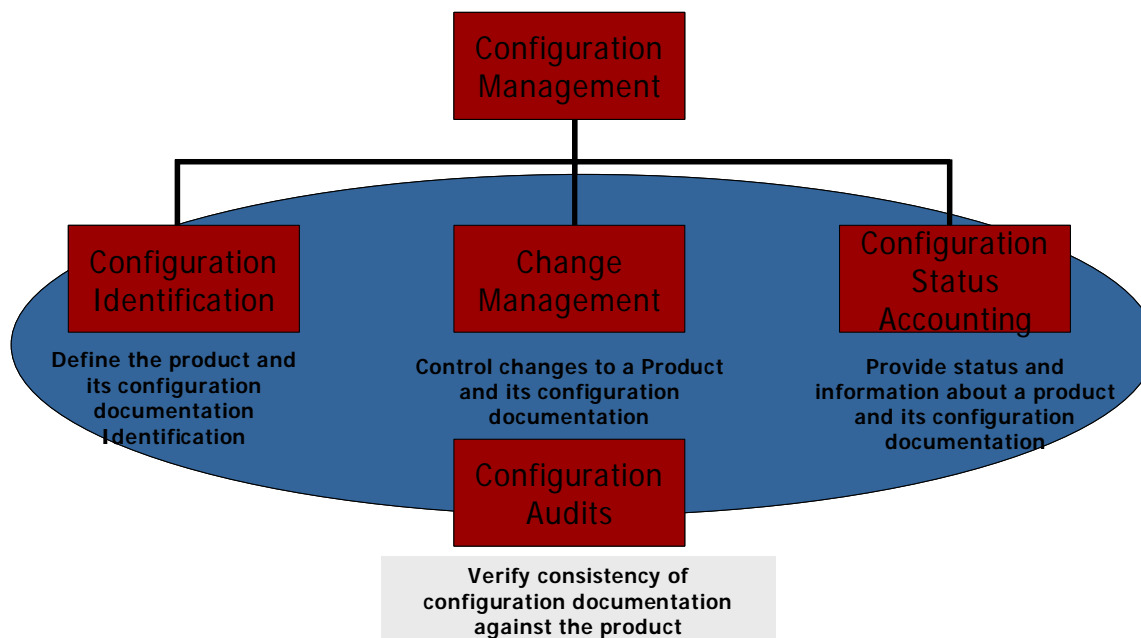


Figure 3-3: Configuration Management Process
(Reference 10)

3.3.3 FHWA Rule on Regional ITS Architectures

FHWA Rule 940 (4), which became effective in 2001, implements section 5206(e) of the Transportation Equity Act for the 21st Century (TEA-21), and requires ITS projects to conform to the National ITS Architecture and standards. The rule states that “conformance with the National ITS Architecture is interpreted to mean the use of the National ITS Architecture to develop a regional ITS architecture, and the subsequent adherence of all ITS projects to that regional ITS architecture.” Per the rule, “ a regional ITS architecture shall be developed to guide the development of ITS projects and programs and be consistent with ITS strategies and projects contained in applicable transportation plans. The National ITS Architecture shall be used as a resource in the development of the regional ITS architecture. The regional ITS architecture shall be on a scale commensurate with the scope of ITS investment in the region. Provision should be made to include participation from the following agencies, as appropriate, in the development of the regional ITS architecture: Highway agencies; public safety agencies (e.g., police, fire, emergency/medical); transit operators; Federal lands agencies; State motor carrier agencies; and other operating agencies necessary to fully address regional ITS integration.”

Freeway practitioners interact with many of the agencies noted above. Moreover, given that freeway management systems will often be a major component of a regional ITS architecture⁴, and that freeway management system projects funded in whole or in part with the highway trust fund must conform to this rule, it is important that freeway practitioners be cognizant of the rule and be involved in any process for developing a regional ITS architecture.

⁴ Regional integration is discussed in Chapter 16.

While not identifying a process, per se, Rule 940 identifies what the regional architecture shall include as a minimum – specifically:

- A description of the region;
- Identification of participating agencies and other stakeholders;
- An operational concept that identifies the roles and responsibilities of participating agencies and stakeholders in the operation and implementation of the systems included in the regional ITS architecture;
- Any agreements (existing or new) required for operations, including at a minimum those affecting ITS project interoperability, utilization of ITS related standards, and the operation of the projects identified in the regional ITS architecture;
- System functional requirements;
- Interface requirements and information exchanges with planned and existing systems and subsystems (for example, subsystems and architecture flows as defined in the National ITS Architecture);
- Identification of ITS standards supporting regional and national interoperability; and
- The sequence of projects required for implementation.

Additionally, the rule states that all ITS projects (funded with highway trust funds) shall be based on a “systems engineering analysis”, and that this analysis shall include identification of participating agencies, requirements definition, analysis of alternative system configurations and technology options, procurement options, identification of applicable standards and testing procedures, and procedures and resources necessary for operations and management of the system.

The Regional ITS Architecture Guidance Document (5) describes a process for creating a regional ITS architecture with supporting examples of each architecture product. This document is a guide for transportation professionals who are involved in the development, use, or maintenance of regional ITS architectures. The guidance is structured around the following process:

- **Step #1: Get Started**
 - Identify Need
 - Define Region
 - Identify Stakeholders
 - Identify Champions
- **Step #2: Gather Data**
 - Inventory Systems
 - Determine Needs and Services
 - Develop Operational Concept
 - Define Functional Requirements
- **Step #3: Define Interfaces**
 - Identify Interconnects
 - Define Information Flows
- **Step #4: Implementation**
 - Define Project Sequencing

- Develop List of Agency Agreements
- Identify ITS Standards

- **Step #5: Use the Architecture**

- **Step #6: Maintain the Architecture**

Each of these steps and associated activities are discussed in Chapter 16 herein (Regional Integration). As is the case with the other system – oriented processes, these steps parallel many of the activities identified in the “funnel” diagram in Figure 3-1.

3.3.4 National ITS Architecture

As previously noted, FHWA Rule 940 (4) requires ITS projects to conform to the National ITS Architecture and standards. The rule states that “conformance with the National ITS Architecture is interpreted to mean the use of the National ITS Architecture to develop a regional ITS architecture, and the subsequent adherence of all ITS projects to that regional ITS architecture.” Since most, if not all, freeway management programs incorporate some of the technologies and strategies associated with Intelligent Transportation Systems, a basic knowledge and understanding of the terms and concepts of the National ITS Architecture is important for freeway management practitioners. This section provides an overview of the National ITS Architecture. Additional information on the National ITS Architecture as well as information on available training can be found at the FHWA’s ITS Joint Program Office website: www.its.dot.gov and then clicking on ‘Architecture’ at the top of the page. A link to <http://iteris.com/itsarch/> is provided where the many documents describing the National ITS Architecture (11) may be found.

3.3.4.1 Background

A system architecture is a framework that describes how system components interact and work together to achieve the system’s goals. The architecture – or framework – describes the system operation, what each component does and what information is exchanged among the components. While it may be somewhat abstract, the architecture provides the tool for defining interfaces between systems, subsystems, and system components, and identifying the communications necessary to achieve integration of the systems and subsystems.

The National ITS Architecture provides a common structure for the design of intelligent transportation systems. It is not a system design nor is it a design concept. It is the framework around which multiple design approaches can be developed, each one specifically tailored to meet the individual needs of the user, while maintaining the benefits of a common architecture (e.g., compatibility and interoperability between systems, products, and services; without limiting design options). The architecture defines the functions that must be performed to implement a given service, the physical entities or subsystems where these functions reside (e.g., the roadside or the vehicle), the interfaces/information flows between the physical subsystems, and the communication requirements for the information flows (e.g., wireline or wireless). The National ITS Architecture also provides a common vocabulary to facilitate internal and external communications with colleagues and others involved in transportation planning. In addition, it identifies and specifies the requirements for the standards needed to support national and

regional interoperability, as well as product standards needed to support economy of scale considerations in deployment.

3.3.4.2 Attributes

The National Architecture utilizes a layered framework consisting of three layers—transportation, communications, and institutional. The transportation and communications layers are “technical” layers in which the actual components reside. The institutional layer is a non-technical layer that establishes the policies, funding incentives, working arrangements, and jurisdictional structures that support the technical layers – in essence, where the aforementioned planning for operations and associated collaborations take place.

Figure 3-4 provides a high-level view of the framework of the *physical architecture*.

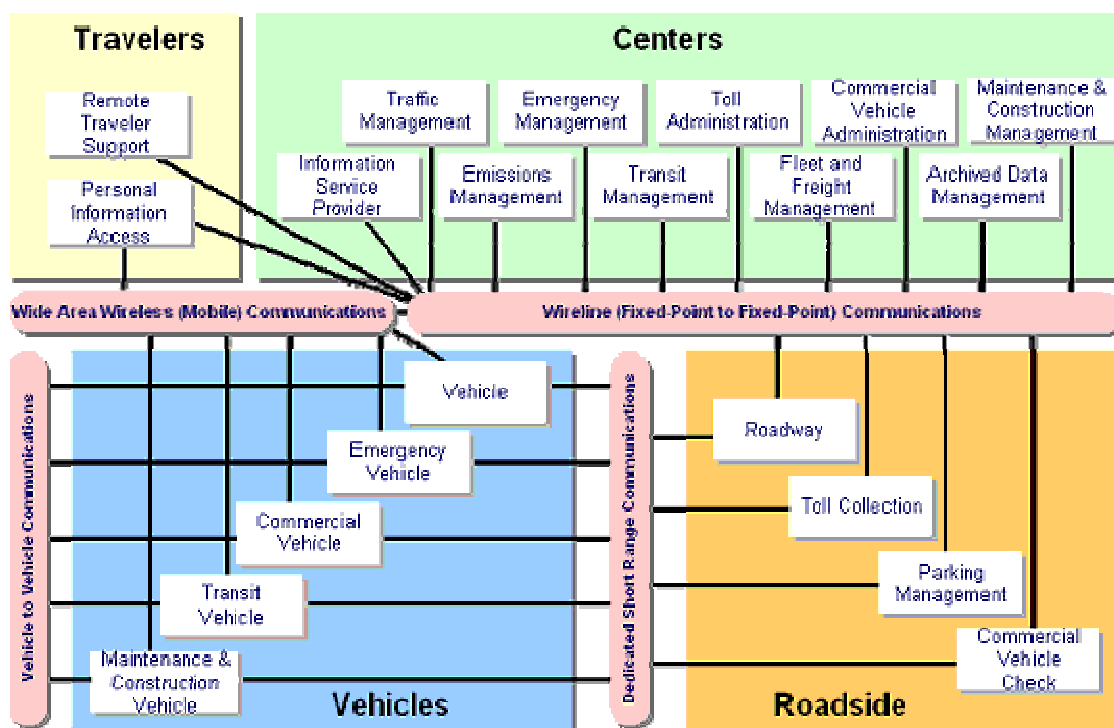


Figure 3-4: High Level Architecture Diagram
 (Reference 11)

This “links-and-sausages” diagram includes both the transportation and communication layers of the Architecture. The transportation layer includes 21 interconnected *subsystems* (depicted as rectangles), distributed among four *classes* – *Traveler*, *Center*, *Roadside*, and *Vehicle* – depicted as larger, colored encompassing rectangles.

- **Center Subsystems** deal with those functions normally assigned to public/private administrative, management, or planning agencies. It is emphasized that the Center Subsystems are functionally, not physically defined. They should not be viewed as “brick

and mortar” facilities. Rather, they represent a cohesive set of functional definitions with required interfaces to other Subsystems. The implementation of a physical Transportation Management Center will often collocate the functions and capabilities from several of the Center Subsystems.

- **Roadside Subsystems** include functions that require convenient access to a roadside location for the deployment of sensors, signals, changeable message signs or other interfaces with travelers and vehicles of all types.
- **Vehicle Subsystems** are installed in a vehicle. They include such functions as advanced vehicle control and safety systems, and in-vehicle signage and information.
- **Traveler Subsystems** represent platforms for ITS functions of interest to travelers or commercial vehicle operators in support of multimodal traveling.
- **Communication Links** support the exchange of information (referred to as either *information flows* or *architecture flows*) between the subsystems. The National ITS Architecture has identified four communication media types (shown as ovals) to support the communications requirements between the 21 subsystems – *wireline* (fixed-to-fixed), *wide area wireless* (fixed-to-mobile), *dedicated short-range communications* (fixed-to-mobile), and *vehicle-to-vehicle* (mobile-to-mobile).

In addition to the physical architecture, the National ITS Architecture includes a *Logical Architecture* that presents a functional view of the ITS *User Services*. This perspective is divorced from likely implementations and physical interface requirements. It defines the functions or process specifications that are required to perform ITS user services, and the *data flows* that need to be exchanged between these functions. The logical architecture groups processes and data flows to form particular transportation management functions (e.g., manage traffic), which are represented graphically by data flow diagrams (DFDs), or bubble charts, which decompose into several levels of detail.

3.3.4.3 User Services

User Services identify what ITS should do from the user's perspective. A broad range of users are considered, including the traveling public as well as many different types of system operators. The concept of user services allows system or project definition to begin by establishing the high level services that will be provided to address identified problems and needs. The user services have been bundled into the following eight categories:

- Travel and Traffic Management
- Public Transportation Management
- Electronic Payment
- Commercial Vehicle Operations
- Emergency Management
- Advanced Vehicle Safety Systems
- Information Management
- Maintenance and Construction Management

New or updated user services have been and will continue to be added over time.

3.3.4.4 Market Packages

Some of the user services are too broad in scope to be convenient in planning actual deployments. Additionally, they often don't translate easily into existing institutional environments and don't distinguish between major levels of functionality. In order to address these concerns (in the context of providing a more meaningful evaluation), a finer grained set of deployment-oriented ITS service building blocks – called *Market Packages* – were defined from the original user services. Market packages, are tailored to fit – separately or in combination – real world transportation problems and needs. They provide another method for entering into the National ITS Architecture, and can be used as a starting point for defining functional requirements and system specifications. Market packages are not intended to be tied to specific technologies, but of course depend on the current technology and product market in order to actually be implemented. As transportation needs evolve, technology advances, and new devices are developed, market packages may change and new market packages may be defined. Several of the market packages associated with freeway management and operations are identified in subsequent chapters.

3.3.5 Standards

The International Standards Organization (ISO) defines standards as documented agreements containing technical specifications or other precise criteria to be used consistently as rules, guidelines, or definitions of characteristics, to ensure that materials, products, processes and services are fit for their purpose. The National ITS Architecture identifies standard requirements based on the interfaces between subsystems in the physical architecture, the associated information flows and data flows that pass across those interfaces, and some indications of the class of technology suitable for each interface. An actual standard would dictate a *specific* interface (or interfaces), *specific* message sets and protocols, and *specific* technology for implementation.

The USDOT ITS Standards website (<http://www.standards.its.dot.gov>) provides current status on the ITS Standards Program. It also contains resource documents, fact sheets, testing, deployment contacts, training and application area information as well as an interactive ITS Standards Forum.

3.3.5.1 NTCIP

Of particular interest to the freeway practitioner involved in ITS is the NTCIP (National Transportation Communications for ITS Protocol) suite of standard communications protocols and data definitions that have been designed to accommodate the diverse needs of various subsystems and user services of the National ITS Architecture. NTCIP standards are intended to handle these needs in the following two areas:

- The first type of communications is between a management system or center and multiple control or monitoring devices managed by that system or center, such as a freeway management system communicating with detectors and ramp meters on freeways, and a traffic management system controlling CCTV cameras, dynamic message signs, advisory radio transmitters, environmental sensors and traffic count stations on roadways. Since most applications of this type involve a computer at a management center communicating with various devices at the roadside or on agency vehicles, this type is referred to as center-to-field (C2F) communications.

- The second type of communication involves messages sent between two or more central management systems, such as an emergency management system reporting an incident to a freeway management system and a traveler information system, and a weather monitoring system informing a freeway management system of ice forming on the roadway so that the freeway management system is able to post appropriate warning messages on dynamic message signs. This type of communication is referred to as center-to-center (C2C) communications. Even if two or more of the various center subsystems are located within the same “center” or building, they are still considered logically separate. C2C involves peer-to-peer communications between any number of system computers in a many-to-many network. This type of communication is similar to the Internet, in that any center can request information from, or provide information to, any number of other centers. Additional information regarding C2C standards is provided in Chapter 16.

NTCIP provides the mechanism whereby interchangeability and interoperability amongst the various components of transportation systems can be achieved, where “interchangeability” is defined as the capability to exchange devices of the same type (e.g., a signal controller from different vendors) without changing the software; and “interoperability” is defined as the capability to operate devices from different manufacturers, or different device types on the same communications channel. Specific NTCIP standards are discussed in more detail in subsequent chapters. Additional information regarding NTCIP may be found on the NTCIP website (www.ntcip.org), including the NTCIP Guide (12).

3.4 MAINTENANCE CONSIDERATIONS

The processes and the associated steps summarized above focus on planning, developing, implementing, operating, and managing a transportation management system. This includes freeway management strategies, which are addressed in more detail in subsequent chapters. Another crucial element of a system’s life cycle is maintenance. Freeway Management Systems (FMS) are complex, integrated amalgamations of hardware, technologies and processes for data acquisition, command and control, computing and communication. Accordingly, FMS maintenance can be a complex proposition as well, requiring sophisticated approaches and advanced technology. Maintenance of the FMS is a necessity to ensure reliability and proper operation, thereby protecting the investment and enabling the system to respond to changing conditions. Failure to function as intended could negatively impact traffic safety, reduce system capacity, and ultimately lead the traveling public to lose faith in their transportation system. Failure of the system also has the potential to cause measurable economic loss and increase congestion, fuel consumption, pollutants, and traffic accidents. In essence, loss of a device due to a malfunction is an operations issue. Maintenance is part of management and operations.

There are several references that address maintenance of transportation management systems and components, including the ITE publication “Traffic Control System Operations – Installation, Management and Maintenance” (Reference 13) and “Guidelines For Transportation Management Systems Maintenance Concepts and Plans” (Reference 14). Both documents discuss maintenance management (e.g., organizational structure, personnel and staffing), options for performing maintenance (e.g., in-house, contract), and guidelines for performing maintenance on a variety of system components – the former document addressing field devices, computers, and communications; the latter focusing more on Transportation Management Centers.

Maintenance considerations must be an integral part of any process to develop a freeway management program and / or system, and must be part of all the steps and activities in that process – for example, involving maintenance stakeholders, developing a maintenance concept, including maintenance and replacement costs in the life cycle analyses of alternative technologies / components, identifying maintenance functional requirements, including resources to carry out maintenance functions in the resource allocation process, etc. In this manner the freeway management program and any enabling systems will include the necessary resources, environment, and procedures to maintain the infrastructure associated with the program / system; transportation management center and its associated infrastructure.

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4. PERFORMANCE MONITORING AND EVALUATION

4.1 INTRODUCTION

Freeway management programs – consisting of operational strategies, low-cost roadway improvements, and ITS-based systems – are implemented as a means to enhance safety, preserve mobility, improve reliability, increase productivity, and meet the public's expectations for efficient and effective travel. Moreover, freeway management initiatives are planned, designed, deployed, operated, and maintained with public funding. It is therefore important to ensure that these funds are spent wisely, that the agency makes the best use of its available resources, and that the full potential of past and current investments is realized. This, in turn, requires that the performance of the freeway be continuously monitored and evaluated, and that appropriate analytical tools and measures be used to identify and quantify problems, to evaluate alternative solutions, and to assess the extent to which the implemented solutions achieve their objectives.

Another consideration is that freeway management and operations – particularly ITS-based improvements – are increasingly funded through the use of regular sources (i.e., not specific to ITS or operations). The move to “mainstream” funding mechanisms necessitates the integration of freeway management and operations into the established transportation planning process, where freeway management strategies and systems can be evaluated both against, and in combination with, conventional transportation components such as major road widening and new facility construction. It is critical that the associated benefits and costs are known and compared in an equitable manner (i.e., using the same set of performance measures and criteria), thereby providing an economic justification for the implementation of freeway management systems and operational strategies.

Increased customer expectation and public sector accountability have helped to focus attention on performance measurement as one of the essential tools at the practitioner's disposal. To be held accountable, one needs a clear understanding of what they are trying to accomplish and how to assess the results in such a way that they can continue to improve. Indeed, this is why performance measurement in government has become such a hot topic. Osborne and Gaebler (1992) summed it up well in their landmark work, *Reinventing Government*.

- If you don't measure results, you can't tell success from failure.
- If you can't see success, you can't reward it.
- If you can't see failure, you can't correct it.

Freeway practitioners work to achieve results. Performance measures are indicators of work performed and results achieved (1).

4.1.1 Chapter Scope & Objectives

The use of performance measures in transportation planning and investment decision-making processes of public agencies has increased significantly. This demand has led to the need for information and guidance on how to integrate the consideration of freeway performance into these processes. Moreover, the day-to-day operation and management of the freeway requires real – time knowledge how well the freeway is performing and the existence of any problems. There is general agreement among transportation practitioners that freeway system

performance monitoring, evaluation, and reporting should be performed and continuously supported by operating agencies.

Performance measures are the primary focus of this chapter, including discussions of why they are important, their relationship to the decision-making process, and important considerations when selecting performance measures. Several examples of performance measures that may be utilized for freeway management and operations are then provided. The section on performance measurement concludes with discussions on information gathering, data archiving, and reporting.

There are several attributes of a freeway management program – such as how well the operations process is organized and administered, and how well it interacts with other agencies and affected stakeholders – that are difficult to quantify in terms of a performance measure. Several self-assessment tools have been developed by FHWA for this purpose, and are discussed herein.

Evaluation of a freeway management and operations program (and other transportation improvements) must occur throughout the life cycle of the facility, including identifying problems and segments with less-than-desired performance, analyzing and prioritizing alternative solutions for correcting these problems, estimating the associated benefits and costs, and determining the actual improvement in performance and its cost effectiveness. An overview of such methods and analytical tools (e.g., Highway Capacity Manual, simulation, before-and-after studies, estimating costs and benefits) is also provided in this chapter.

4.1.2 Relation to Other Freeway Management Activities

Performance monitoring and evaluation is a continuous process that occurs throughout the life cycle of the freeway facility. Moreover, as shown in the “funnel diagram” in the previous chapter (Figure 3-1), determining performance measures” is one of the key activities when establishing, enhancing, and managing a freeway operations program. Reiterating the description of the performance measure “step” from Chapter 2:

“The performance measures provide the basis for evaluating the transportation system operating conditions and identifying the location and severity of congestion and other problems. The performance measures provide the mechanism for quantifying the operation of the network, and should also be used to evaluate the effectiveness of implemented freeway management strategies and to identify additional improvements. Another aspect of performance measurement is sharing and providing managers and users with access to real-time and archived system performance data.”

Performance measures and analytical tools need to be considered and/or utilized in other freeway management activities, including:

- **Stakeholders** – Stakeholders are interest groups who benefit from, or are otherwise impacted by, freeway management and operations (e.g., the various transportation providers, transportation system users, and other persons or organizations with a strong material interest in success or failure of freeway management). The stakeholders should be involved in the processes to define performance measures and how they are used.

- **Needs** – This is an initial assessment of how the freeway network should operate relative to how it operates today. Needs are embodied in the vision, goals, and overall public policy. They may be further defined in a variety of ways, including performance evaluations (e.g., comparing actual operational measures to performance criteria) and analytical assessments of freeway performance (e.g., before and after studies).
- **Implementation** – Using the broad description of this step from Chapter 3, this activity includes design – deciding “how” each need and the corresponding requirements will be satisfied. Performance measures and analytical tools identified in this chapter may be useful in evaluating alternatives and selecting the most cost – effective one (e.g., simulation, estimate benefits or utilities for each alternative, estimate life-cycle costs of each alternative, perform comparative analysis). A type of performance measures is also used during the actual implementation of freeway improvements – criteria for the various component and system tests.
- **Evaluation** involves the routine collection and analysis of appropriate data, comparing the results with the previously – established performance measures, and evaluating the performance of the strategies, policies, systems, and operator procedures that comprise the program. This “feedback” element of the process allows practitioners to assess the effectiveness of their efforts, to identify areas for improvement, to justify these improvements (e.g., configuration management process), to demonstrate the benefits provided by the program, and to support requests for additional resources.

The collection of data is an important element of a performance monitoring and evaluation process. An ITS – based Freeway Management System (FMS) represents a potentially valuable data source in this regard. Accordingly, in addition to the other functions of a surveillance subsystem (discussed in Chapter 15), it should be developed and deployed to automatically collect, store and analyze data associated with performance measures to the greatest extent possible. FMS -generated data will not only benefit the transportation operations and planning communities by allowing them to access more and better data. It will also enhance the appeal of FMS deployment by significantly broadening its originally intended benefits.

4.2 PERFORMANCE MEASURES

4.2.1 Overview

Performance measurement may be defined as follows (from Reference 2):

“Performance measurement is a process of assessing progress toward achieving predetermined goals, including information on the efficiency with which resources are transformed into goods and services (outputs), the quality of those outputs (how well they are delivered to clients and the extent to which clients are satisfied) and outcomes (the results of the program activity compared to its intended purposes), and the effectiveness of government operations on terms of their specific contributions to program objectives”

Performance measures provide the basis for identifying the location and severity of problems (such as congestion and high accident rates), and for evaluating the effectiveness of the implemented freeway management strategies. This monitoring information can be used to track

changes in system performance over time, identify systems or corridors with poor performance, identify the degree to which the freeway facilities are meeting goals and objectives established for those facilities, identify potential causes and associated remedies, identify specific areas of a freeway management program or system that requires improvement / enhancements, and provide information to decision-makers and the public. In essence, performance measures are used to measure how the transportation system performs with respect to the overall vision and adopted policies, both for the ongoing management and operations of the system, and the evaluation of future options.

Agencies have instituted performance measures and the associated monitoring, evaluation, and reporting processes for a variety of reasons – to provide better information about the transportation system to the public and decision makers (in part due, no doubt, to a greater expectation for accountability of all government agencies); to improve management access to relevant performance data; and to generally improve agency efficiency and effectiveness, particularly where demands on the transportation agency have increased while the available resources have become more limited.

A rather succinct view of performance measures is provided by Wolf (Reference 3) in a paper prepared for the 4th Integrated Transportation Management System (ITMS) conference held in 2001. The author describes the California performance measurement effort, stressing that it “was critical throughout the process to remind partners what performance measurement was and still is:

- A standard management function to help understand accomplishments
- A planning tool to improve investment analysis
- Customer-oriented as opposed to service provider-driven
- A genuine system perspective, as modally blind as possible
- A lengthy, evolving process
- Very effective if there is a clear purpose and simple set of metrics based on readily obtainable data;

And what performance measurement isn't:

- A panacea
- An isolated exercise
- A magical “Black Box”
- Naive over-simplification
- Usurpation of regional authority”

Finally, it should be emphasized that performance measures for transportation operations are not a fleeting trend; but a permanent way of doing business that eventually will be used at all levels of transportation agencies.

4.2.2 Performance Measures and Decision Making

Chapter 2 describes several “tiers” amongst which the authority for transportation decision-making is dispersed. Performance measures are necessary at each of these tiers. However, as Meyer (Reference 4) points out, “at each level, there could be measures desired by the corresponding decision makers that are specific to that decision context. At the very highest level, this could imply that decision makers might be interested in issues and performance measures not directly linked to information surfacing from the other levels.”

A Transportation Management Center (TMC) requires an accurate real - time monitoring of the freeway's performance, and how that performance compares to "normal" (using performance measures over time to define "normal"). The TMC manager and operators monitor the performance of the facility to assess existing conditions for short-term non-recurring events and for longer term recurring congestion, determine and implement operational plans, and inform freeway users of existing and predicted near-term conditions. The freeway manager also uses the results of the performance monitoring to identify deficiencies in the physical freeway system, and provides planners and designers with the necessary information and input to incorporate into the planning and design of future improvements to the facility.

Similarly, an Integrated Transportation Management System (ITMS) also requires real-time monitoring information, aggregated over the entire region, to address the performance of the entire surface transportation network (with data obtained from multiple TMCs and other sources). The real time information may be used to implement and monitor region-wide response plans. The data may also be archived and evaluated later to either modify existing response plans or create new ones.

The Agency tier requires performance measures for resource allocation and programming (i.e., making choices among alternatives) and for trade-off analyses – for example, setting appropriate performance targets for a policy or system plan when the trade-offs involve different objectives (safety and system preservation). The use of performance measures to help define the implications of these choices and trade-offs can be one of the most powerful ways to use performance measures to influence decisions.

Another common application of performance measures is in long-range planning at the Regional / Statewide tier. As noted in Chapter 2, State DOT's and regional agencies (metropolitan planning organizations - MPOs) maintain long-range planning activities to determine how to build and manage the transportation system to meet the stated needs and goals of the relevant customer group. In this context, performance measures must be sufficiently specific to permit distinguishing the effect of investment in one modal system or program of activities versus another. The objective is to give decision makers better information about the likely impact and outcome of different mixes of investment (or budget) among different programs. In a broader context, performance measures are needed at the statewide / regional level to help drive policies, goals, and objectives. They may also be useful for identifying the need for increased revenue and influencing the associated legislation (e.g., increased fuel tax).

Performance measures can also be used at the National tier to assist with policy making, goal setting, developing and justifying legislation, and developing reports for Congress. Even at this high level, measures can be identified that are consistent with broad policy and goals and that specify the desired outcome in unambiguous, quantifiable terms. The actual measures selected must sum up the net effect at the agency, ITMS, and TMC levels of many smaller, discrete actions. The time frame of the effect of such actions may be relatively long – some measures might not show marked change until a given policy has been implemented for several years.

Another important consideration is the need to improve the links between resource allocation decisions, system conditions, and performance results. Pickrell and Neuman (Reference 5)

identify the following factors as contributing to the desire to link performance data to decisions about system investment:

- **Accountability:** Publicly funded agencies have come under increasing pressure to be accountable to “customers.” Performance measurement provides a means of determining if resources are being allocated to the priority needs, as identified through performance monitoring and reported to external or higher-level entities.
- **Efficiency:** Setting performance targets that are aligned with an agency’s goals and mission help staff, management, and decision-makers stay focused on the priorities, thereby increasing efficiency. It improves internal management and the ability to direct resources where needed, to track results, and to make adjustments with greater confidence that the changes will have the desired effect.
- **Effectiveness:** Performance measurement may help an agency to better achieve objectives that have been identified through the planning process, and to improve the correlation between agency objectives and those of the system users or the general public. It reflects a shift in agency thinking away from simply output (e.g., “tons of salt applied”) to outcome (e.g., “reduction in ice-related fatalities”) and allows progress to be tracked explicitly.
- **Communications:** As an adjunct to accountability, a good performance measuring program cannot help but improve communications with an agency’s customer base and constituency, including other agencies and entities that are involved with the operation and management of the surface transportation network.
- **Clarity:** Performance measurement can lend clarity of purpose to an agency’s actions and expenditures, forcing clear thinking about the purposes of planning, programming actions, and investments in the transportation system.

One of the key discussion points from Chapter 2 is that freeway practitioners must become more involved and “provide substantive input to the Statewide and/or regional transportation planning process on necessary investments to improve system performance”. Developing performance measures and collecting the associated data represent a potential approach for increasing one’s involvement in the transportation planning and resource allocation process.

Performance measures should be viewed as a tool to improve, guide, and enhance the decision-making process; not as the means to replace or “automate” it. As noted in Reference 5, “much has been said about the undesirability of creating a “black box” approach to planning or decision making. Practitioners have commented that in some cases, decision makers tend to overapply performance data and absolve themselves of the responsibility to apply professional judgment or take responsibility for decisions. The emphasis should be on improving the transparency of the planning and programming processes rather than further cloaking them in quantitative language understandable to only a few. It should encourage participants to be clear about their objectives and more explicit about how they will work to achieve those objectives.”

4.2.3 Developing Performance Measures

The development of performance measurement systems is a dynamic and incremental process. There is neither one right set of performance measures nor one right process to develop a

performance measurement system. References 1, 2, 3, 5, 6, 7 and 8 provide guidelines for developing performance measures and the attributes of good performance measures as summarized below:

- **Goals and objectives** – Performance measures should be identified to reflect goals and objectives, rather than the other way around. This approach helps to ensure that an agency is measuring the right parameters and that “measured success” will in fact correspond with actual success in terms of goals and objectives. Measures that are unfocused and have little impact on performance are less effective tools in managing the agency. Moreover, just as there can be conflicting goals, reasonable performance measures can also be divergent (i.e., actions that move a particular measure toward one objective may move a second measure away from another objective). Such conflicts may be unavoidable, but they should be explicitly recognized, and techniques for balancing these interests should be available.
- **Data needs** – Performance measures should not be solely defined by what data are readily available. Difficult-to-measure items, such as quality of life, are important to the community. Data needs and the methods for analyzing the data should be determined by what it will take to create or “populate” the desired measures. At the same time, some sort of “reality check” is necessary – for example: are the costs to collect, validate, and update the underlying data within reason, particularly when weighed against the value of the results; can easier, less costly measures satisfy the purpose – perhaps not as elegantly, but in a way that does the job. Ideally, agencies will define and, over time, implement the necessary programs and infrastructure (e.g., detection and surveillance subsystems) for data collection and analysis that will support a more robust and descriptive set of performance measures.
- **Decision-making process** – Performance measures must be integrated into the decision-making process; otherwise, performance measurement will be simply an add-on activity that does not affect the agency’s operation. Performance measures should be based on the information needs of decision makers, with the level of detail and the reporting cycle of the performance measures matching the needs of the decision makers. As previously noted, different decision making tiers will likely have different requirements for performance measures. One successful design is a set of nested performance measures such that the structure is tiered from broader to more detailed measures for use at different decision-making levels.
- **Facilitate Improvement** – The ultimate purpose of performance measures must clearly be to improve the products and services of an agency. If not, they will be seen as mere “report cards”, and games may be played simply to get a good grade. Performance measures must therefore provide the ability to diagnose problems and to assess outcomes that reveal actual operational results (as compared to outputs that measure level of effort, which may not be the best indicator of results).
- **Stakeholder Involvement** – Performance should be reported in stakeholder terms; and the objectives against which performance is measured should reflect the interests and desires of a diverse population, including customers, decision makers, and agency employees. Buy-in from the various stakeholders is critical for initial acceptance and continued success of the performance measures. If these groups do not consider the measures appropriate, it will be impossible to use the results of the analysis process to report performance and negotiate

the changes needed to improve it. Those who are expected to use the process to shape and make decisions should be allowed to influence the design of the program from the beginning. Similarly, those who will be held accountable for results (who are not always the same as the decision makers) and /or will be responsible for collecting the data should be involved early on to ensure that they will support rather than circumvent the process or its intended outcome. The selected performance measures should also reflect the point of view of the customer or system user. An agency must think about who its customers are, what the customers actually see of the department's activities and results, and how to define measures that describe that view.

- **Other Attributes** – Good performance measures possess several attributes that cut across all of the “process” issues noted above. These include:
 - **Limited number of measures** – All other things being equal, fewer rather than more measures is better, particularly when initiating a program. Data collection and analytical requirements can quickly overwhelm an agency's resources. Similarly, too much information, too many kinds of information, or information presented at too fine a level of disaggregation can overwhelm decision makers. The corollary is to avoid a performance measure that reflects an impact already measured by other measures. Performance measures can be likened to the gauges of a dashboard – several gauges are essential, but a vehicle with too many gauges is distracting to drive.
 - **Easy to measure** – The data required for performance measures should be easy to collect and analyze, preferably directly and automatically from a freeway management (or other) system.
 - **Simple and understandable** – Within the constraints of required precision, accuracy, and facilitating improvement, performance measures should prove simple in application with consistent definitions and interpretations. Any presentation of performance measures data must be carefully designed such that it is easy for the audience to understand the information, and that the data analysis provides the information necessary to improve decision making.
 - **Time frame** – The decision-making “tiers” can have significantly different time frames, both for the making of the decision and for the effect of that decision to take place. Using performance measures to monitor the effectiveness of a policy plan requires measures that can reflect long-term changes in system usage or condition. Similarly, performance measures for the operation of a TMC should reflect changes within a “real – time” context. Once established, performance measures should be in place long enough to provide consistent guidance in terms of improvements and monitoring to determine whether the objectives are being met.
 - **Sensitivity** – Performance measurement must be designed in such a way that change is measured at the same order-of-magnitude as will likely result from the implemented actions.
 - **Geographically appropriate** – The geographic area covered by a measure varies depending on the decision-making context in which it is used. The scope of measures used to evaluate progress on broad policies and long-range planning goals and

objectives often are region-wide, statewide, and even nation-wide. To be effective in an operations context, measures may need to be focused on a specific geographic area (e.g., corridor, system).

4.2.4 Examples of Performance Measures

This section identifies several potential performance measures from a number of different references. It is not the intent of this section to suggest that the practitioner should utilize all of these performance measures (several of which are repeated between different references). Quite the opposite. The number of performance measures should be kept to a manageable minimum number, provided that they conform to the attributes discussed in the previous section, and answer the following key questions regarding the freeway network:

- How many people/vehicles are using the system?
- Where and when are they being delayed and / or subject to unsafe conditions?
- How frequently do those delays / unsafe conditions occur?
- How bad are the delays / unsafe conditions?
- What are the reasons for these delays / unsafe conditions?
- Can I measure the effect of operational improvements on the delays / unsafe conditions?

4.2.4.1 Overview

Performance measures are often described as input, output, or outcome measures. *Input measures* look at the resources dedicated to a program; *output measures* look at the products produced; and *outcome measures* look at the impact of the products on the goals of the agency. For example, with respect to increasing roadway capacity, an input measure might be materials consumed; output measures could include lane – miles added; while an outcome measure might include the reduction in hours of user delay, resulting from the increased capacity. Outcome measures are preferred because they directly relate the agency’s strategic goals to the results of the activities undertaken to achieve them. Outcome measures are also generally more difficult to define and measure. In deciding which measures to use, the agency needs to consider whether data can be collected to allow a measure to be calculated accurately and with sufficient frequency for it to be a useful tool in guiding decisions (7).

4.2.4.2 Background

A paper by Meyer (Reference 4) developed for the October 2000 Conference on Performance Measures and Performance Based Planning and Programming, provides the following short history of the use of performance measures.

“The primary developmental period for the systematic approach toward transportation planning that characterizes much of current practice occurred in the 1960s and 1970s. Transportation planning then was concerned with many issues, but primarily the focus was on system expansion to meet the growing demands for automobile travel and the corresponding characteristics of high speed and safe use of the road systems. Average vehicular speed, estimated usage of the system or network links (such as volume to capacity), number of crashes, and costs became the most used criteria for evaluating alternative transportation system plans. Because these were the criteria used for plan evaluation, they also tended to be the measures used in monitoring the “effectiveness” of transportation system performance. As the nation’s urban road system expanded in response to unprecedented population and employment growth, congestion on this system and the concomitant effects on the environment

and on people's daily lives became important issues to system users, decision makers, and analysts. Congestion, the effects of congestion, and measuring congestion levels were thus some of the major system performance issues that drew the interest of transportation professionals in the 1980s and 1990s. However, much of this professional interest focused on measures that had been developed in the mid-1950s by engineers and planners who were interested in the impacts of congestion on vehicle flow. Suggested measures of congestion during this earlier period focused on three major factors:

- Operational characteristics of traffic flow, which included speed, delays, and overall travel times;
- Volume-to-capacity characteristics, which required a comparison of actual volumes with road capacity; and
- Freedom of movement characteristics, which required a determination of the percentage of vehicles restricted from free movement and the durations of such restrictions.”

Meyers concludes this brief review of the background on performance measurement with the observation that “many of the measures proposed today to monitor system performance are similar to those proposed 50 years ago at the beginning of comprehensive transportation planning in the United States. In many ways, these measures carry a value judgment about what the system user, or perhaps society in general, perceives as acceptable or desirable performance. The measures have become entrenched as current and accepted practice for the monitoring of system performance, even though they were originally used for alternatives evaluation or design standards. For the road users, however, there may be different measures that reflect actual trip patterns and trip characteristics. If transportation is one of the empowering factors that allows economic development, affects environmental quality, and influences perceptions of quality of life, then decision makers will presumably want to know how system performance over time relates to these purposes.”

4.2.4.3 Examples – Performance Based Planning

Table 4-1 illustrates the types of performance measures that have been proposed as part of the performance-based transportation planning⁵. These measures are linked to the types of goals that are often part of the transportation planning process; although not that all of these measures will necessarily be part of the process. As previously discussed, the more measures there are, the more likely it is that their use for decision making will be confusing and ineffective. Rather, Table 4-1 is simply an illustration of the different types of measures that could be considered for each goal.

⁵ Table 4-1 is from Reference 4, edited to reflect those measures most applicable to freeway operations. Reference 4 itself is a summary of performance measures developed by Cambridge Systematics.

Table 4-1: Performance Measures

(Source – Reference 4)

Accessibility

- Average travel time from origin to destination
- Average trip length
- Percentage of employment sites within x miles of major highway
- Number of bridges with vertical clearance less than x feet

Mobility

- Origin-destination travel times
- Average speed or travel time
- Vehicle miles traveled (VMT) by congestion level
- Lost time or delay due to congestion
- Level of service or volume-to-capacity ratios
- Vehicle hours traveled or VMT per capita
- Person miles traveled (PMT) per VMT
- Customer perceptions on travel times
- Delay per ton-mile
- PMT per capita or worker
- Person hours traveled
- Passenger trips per household

Economic Development

- Economic cost of crashes
- Economic cost of lost time
- Percentage of wholesale, retail, and commercial centers served with unrestricted (vehicle) weight roads

Quality of Life

- Lost time due to congestion
- Accidents per VMT or PMT
- Tons of pollution generated
- Customer perception of safety and urban quality
- Average number of hours spent traveling
- Percentage of population exposed to noise above certain threshold

Environmental and Resource Consumption

- Tons of pollution
- Number of days in air quality noncompliance
- Fuel consumption per VMT or PMT
- Number of accidents involving hazardous waste

Safety

- Number of accidents per VMT, year, trip, ton mile, and capita
- Number of high accident locations
- Response time to accidents
- Accident risk index
- Customer perception of safety
- Percentage of roadway pavement rated good or better
- Construction-related fatalities

Operating Efficiency (System and Organizational)

- Cost for transportation system services
- Cost-benefit measures
- Average cost per lane-mile constructed
- Origin-destination travel times
- Average speed
- Percentage of projects rated good to excellent
- Volume-to-capacity ratios
- Cost per ton-mile
- Customer satisfaction

System Preservation

- Percentage of VMT on roads with deficient ride quality
- Percentage of roads and bridges below standard condition
- Remaining service life
- Maintenance costs
- Roughness index for pavement

4.2.4.4 Examples – Mobility Measures

Providing individual mobility and accessibility to urban activities is an important goal for transportation planning, and therefore a critical precursor to the types of societal outcomes desired. Several efforts have been made to develop system level mobility indices. The Texas Transportation Institute (as reported in Reference 4) has developed several mobility measures that could be applied at the metropolitan level. Travel time plays a leading role in almost all of these measures, including the following:

- Travel Rate (minutes per mile) = travel time (in minutes) / segment length (miles)
- Delay Rate (minutes per mile) = actual travel rate – acceptable travel rate
- Reliability Factor = percentage of time that a person's travel time is no more than 10% higher than average
- Total Delay (vehicle – minutes) = [actual travel time (min.) – acceptable travel time (min.)] x vehicle volume.

The “acceptable travel time” is the total time it would take to travel a segment during expected conditions. This travel time is generally calculated assuming travel at the posted speed limit, although it may also be calculated using a congestion threshold speed established from local performance goals for mobility.

4.2.4.5 Examples – FHWA Mobility Monitoring Program

The Mobility Monitoring Program, a performance monitoring application sponsored by the Federal Highway Administration, attempts to quantify two key performance attributes of the transportation system – mobility and reliability. In non-technical terms, the mobility measures attempt to answer the question “how easy is it to move around?” and the reliability measures attempt to answer the question “how much does that ‘ease of movement’ vary?” For both mobility and reliability concepts, the monitoring approach is built upon travel-time based measures. Travel time concepts are well understood and used daily by non-technical audiences (e.g., commuters, travelers, passengers) and private sector transportation businesses (References 9 & 10)

The Program reports several measures each for mobility and reliability. Each of the measures attempts to quantify slightly different components of mobility and reliability. The primary mobility measures included in the program reports (9,10) are:

- **Travel time index** – a ratio of travel conditions in the peak period to a target or acceptable travel condition (typically free-flow conditions are used). The travel time index indicates how much longer a trip will take during a peak time. For example, a travel time index of 1.3 indicates that the trip will take 30 percent longer (1.3 times longer).
- **Percent of congested travel** – this is primarily a system measure that quantifies the extent of congestion. A free-flow speed is used as a congestion “benchmark” and any travel on a road section for a time period that is less than the free-flow speed is determined to be congested. The congested travel is summed and then divided by total travel estimates.
- **Delay per person** – expressed in person-hours per year, this measure is used to reduce the total travel delay value to a figure that is more relatable to user experience. It also normalizes the impact of mobility projects that handle much higher demand than other alternatives.

These mobility performance measures reflect the *average level* of congestion and mobility. However, a number of empirical studies have demonstrated that travelers value not only the time it usually takes to complete a trip but also the reliability in travel times. For example, many commuters will plan their departure times based on an assumed travel time that is greater than the average to account for a lack of reliability.

During the first year of the Program, three reliability performance measures were tracked:

- **Buffer index** – this measure expresses the amount of extra “buffer” time needed to be on-time 95 percent of the time (late one day per month). Travelers could multiply their average trip time by the buffer index, then add that buffer time to their trip to ensure they will be on-time 95 percent of all trips. An advantage of expressing the reliability (or lack thereof) in this way is that a percent value is distance and time neutral.
- **Percent variation** – also known as the coefficient of variation, this is the amount of variability in relation to average travel conditions. It is calculated as the standard deviation divided by the mean. A traveler could multiply their average travel time by the percent variation, then add that product to their average trip time to get the time needed to be on-time about 85 percent of the time (one standard deviation above the mean). Higher values indicate less reliability.
- **Misery index** – this measure attempts to quantify the intensity of delay for only the worst trips. The average travel rate is subtracted from the upper 20 percent of travel rates to get the amount of time beyond the average for some amount of the slowest trips.

Of the three, the buffer index rose above others as the preferred measure, and it seemed to resonate with most audiences. There is no single agreed-upon reliability measure, and no customer/user market research has been performed. Even for these measures, it is not certain what level of reliability or variability (e.g., 85 percent, 90 percent, 95 percent, a combination) should be examined.

Data from transportation operations centers in 10 cities were used to develop and test the procedures and the performance measures. Individual city reports are available on the study website: <http://mobility.tamu.edu/mmp>.

4.2.4.6 Examples – NCHRP Synthesis 311

This Synthesis (Reference 2) examined the use of performance measures for the monitoring and operational management of highway segments and systems. More than 70 performance measures were identified. These were evaluated against the following criteria (adapted from many of the same references identified in Section 4.2.3 herein, and paralleling the attributes discussed in Section 4.2.3):

- Clarity and simplicity (e.g., simple to present and interpret, unambiguous, quantifiable units, professional credibility)
- Descriptive and predictive ability (e.g., describes existing conditions, can be used to identify problems and to predict changes)
- Analysis capability (e.g., can be calculated easily and with existing field data, techniques available for estimating the measure, achieves consistent results)
- Accuracy and precision (e.g., sensitive to significant changes in assumptions, precision is consistent with planning applications and with an operation analysis)

- Flexibility (e.g., applies to multiple modes, meaningful at varying scales and settings)

Table 4-2 lists those measures that received the highest scores (at least 75 % of the possible maximum points) and were consistently reported in the synthesis of practice. These measures were also recommended based on “their ability to serve as a foundation for other commonly reported measures, such as congestion index”.

Table 4-2: Recommended Performance Measures from NCHRP #311

(Reference 2)

Outcomes (Operational) Performance Measures

- Quantity of travel (users’ perspectives)
 - Person-miles traveled
 - Truck-miles traveled
 - VMT
 - Persons moved
 - Trucks moved
 - Vehicles moved
- Quality of travel (users’ perspectives)
 - Average speed weighted by person-miles traveled
 - Average door-to-door travel time
 - Travel time predictability
 - Travel time reliability (% of trips that arrive in acceptable time)
 - Average delay (total, recurring, & incident – based)
 - Level of Service (LOS)
- Utilization of the system (agency’s perspective)
 - Percent of system heavily congested (LOS E or F)
 - Density (passenger cars per hour per lane)
 - Percentage of travel heavily congested
 - V/C ratio
 - Queuing (frequency and length)
 - Percent of miles operating in desired speed range
 - Vehicle occupancy (persons per vehicle)
 - Duration of congestion (lane-mile-hours at LOS E or F)
- Safety
 - Incident rate by severity (e.g., fatal, injury) and type (e.g., crash, weather)
- Incidents
 - Incident induced delay
 - Evacuation clearance time

Outputs (agency performance)

- Incident response time by type of incident
- Toll revenue
- Bridge condition
- Pavement condition
- Percent of ITS equipment operational

4.2.4.7 System and Maintenance Measures of Performance

In addition to measuring the performance of the transportation network (including freeways), managers of freeway management systems will likely need additional performance measures as related to the performance of the FMS itself and its components. As discussed in Reference 11 (“Guidelines for transportation Management Systems Maintenance Concepts and Plans”) the following parameters are useful data when evaluating products, “however, the reader of product specifications should be warned about hyperbole”:

- Mean time between failures (MTBF) – defined in Reference 14 as the average time between hours of exposure for all like products divided by the number of failures.
- Mean time to repair – number of hours to make good the failed item
- Average cost to repair
- Design life

Reference 11 emphasizes that “design life and MTBF is not the same thing for all ITS devices. In some cases equipment can last decades if it is well maintained and necessary repairs are made. A hard drive, that may have a MTBF of 50 years, a design life of 5 years and a warranty for 2 years will cause an ITS system to crash and usually cannot be repaired. When considering the spares and replacements of ITS devices the developer of the plan needs to consider the most appropriate measure for that device on their facility.”

Measuring the performance of the system maintenance program provides information both on organization and management issues in addition to the reliability of various FMS devices. Having metrics of the system provides the system with continual feedback on how well the system and its individual components are operating. The metrics associated with the structure of the plan could include:

- Down time of the entire system (e.g., aggregated over a specified period of time)
- Number of times the system is down
- Time to detect failure
- Time to handle responsive maintenance
- Time to handle emergency maintenance
- Time to bring system back on-line
- Negative calls from the public
- Adverse press

4.2.5 Information Gathering

Obviously, a direct relationship exists between the performance measures selected and the data needed in the performance measurement process. The data and information used in decision-making must be of high quality. They must originate from reliable, consistent sources and meet the needs of the decision makers. Moreover, the decision makers must have confidence in the information, or it will not be used.

The most common data problems are acquiring the required information and in ascertaining the quality of the data. The “garbage in, garbage out” concept applies to the data used in a performance measurement system. If the data gathered are highly uncertain, then the conclusions drawn by converting those data into performance measures also will be highly

uncertain and will have reduced value in managing the agency. For this reason, great care needs to be taken in data collection. Investments in accurate, high-quality data collection systems are essential to successful performance measurement and, by extension, to achieving the overall strategic goals of the agency. In reality, however, some things either cannot be measured accurately or cannot be measured accurately at an acceptable cost. Transportation agencies need to consider the uncertainty introduced by inaccurate data when taking action based on their system of performance measures (7).

References 3 and 8 discuss the concept of a “Performance Monitoring Plan” as a mechanism for collecting the data needed to quantify performance measures. Such a plan is essential for coordinating and allocating resources and for controlling the quality of the information that is used for evaluations. The monitoring plan specifies such things as:

- The data to be collected
- Frequency of data collection / schedule
- Data collection locations
- Data collection responsibilities
- Data analysis techniques and responsibilities
- Database management requirements
- Performance analysis reporting

Once the desired data are in hand, the focus shifts to the analysis and reporting of results. In this stage, the most challenging problem is often separating the impact of the activities of the transportation agency from the impacts generated from beyond those activities. For example, highway crashes are influenced by many factors besides highway design. If an agency uses the total number of highway crashes as a performance measure, does an increase in crashes indicate that the agency’s safety programs are ineffective? Before that conclusion is drawn, the impact of changes in other causal factors (e.g., weather) clearly needs to be understood.

The necessity of separating the impacts of external factors has direct implications for data collection. Even though statistical techniques might be available to allow the impacts of several factors to be isolated, the techniques require large numbers of observations to be used reliably. Thus, it is necessary to have a data collection system that increases the number of observations by maintaining data with some degree of disaggregation in both time and space. (7).

As noted in the overview section at the beginning of this chapter, the detection and surveillance subsystem of a Freeway Management System represents a potentially valuable data source for performance monitoring. Typically, the FMS generates massive amounts of data about the state of travel that are used by transportation authorities to effectively operate and manage their transportation systems, including traveler information. As a general rule, this information is collected and used in real time at a TMC to continually improve the operational performance of the system. The increasing deployment of FMS and the amount and variety of FMS-generated data throughout the nation offer great potential for longer-term transportation planning and performance monitoring. The same information collected at the TMC may also be used – but no longer in the context of real time applications – at the ITMS and agency tiers to identify deficiencies, and then to design and establish short term operational improvements such as incident response plans. These same data may also be applied at the state / regional tier, being incorporated into the transportation planning process for analyzing and evaluating alternative transportation improvements.

In order to monitor the long – term performance of the transportation network, the real time operations data collected by the FMS and /or ITMS must be systematically retained and reused – a process known as “data archiving” or data warehousing.

4.2.5.1 Data Archiving

The primary reasons for archiving FMS - generated data are:

- Provide more and better information for managing and operating the system — The first step in proactive management is knowing where problems are likely to occur before they actually do, then preventing or mitigating the impacts of those problems. Archived operations data can be used to predict when and where problems may occur again, as well as helping to evaluate alternative strategies for preventing or mitigating the problem.
- Maximize cost-effectiveness of data collection infrastructure — Data archiving permits transportation agencies to maximize their investments in data collection infrastructure by re-using the same data for numerous transportation planning, design, operations and research needs.
- Much less expensive than manual data collection — Data archiving is significantly less expensive than having a planning or design workgroup re-collect even a small percentage of the data using manual methods or special studies.
- Established business practice in other industries — The retention and analysis of operational data is an established practice in most competitive industries that use data to manage their business activities. (12).

Given that archived FMS-generated data can provide a valuable longer-term resource for a variety of stakeholders, the Archived Data User Service (ADUS) was incorporated into the National ITS Architecture in September 1999 to help realize the potential usefulness of ITS data. A U.S. Department of Transportation multi-agency, 5-year ITS Data Archiving Program Plan was developed based upon the vision of “*improving transportation decisions through the archiving and sharing of ITS generated data.*”

Attempting to use data to meet information needs for which the data were not originally intended can be a challenging endeavor. In the context of ADUS, data issues are multi-faceted and complex, including data quality, format, integrity, compatibility, and consistency. Moreover, with ITS-generated data being so temporally extensive (e.g., collected every 30 seconds) but spatially limited (e.g., covering 30 miles of roads), ADUS data sometime need to be integrated with data from traditional sources in order to be useful.

The “Guidelines for Developing ITS Data Archiving Systems” (Reference 13) provides a number of basic principles that can be applied regardless of archive size or design, including:

- Determine the workgroup(s) or agency(ies) that should have primary responsibility for operating and maintaining the data archive. This may seem like a simple matter; in many cases, though, data archiving systems have not been further developed because no one has taken responsibility for their operation and maintenance.

- Discussion and dialogue in early stages among all stakeholders should assess the demand for archived data as well as the strengths and weaknesses of which agency or workgroup in a region maintains data archives. In some cases, there may be several agencies that each operate their own data archive, but which are connected and integrated through a “virtual data warehouse”. In other cases, it may be logical for a regional planning agency with strong information management capabilities to warehouse data that can be shared among other agencies in the region. In any case, sharing data between agencies will be necessary, and will require some level of agreement on data definition and geographic units. (Refer to Chapter 16 on Regional Integration).
- Start small but think long-term, and begin with modest prototypes focused on a single source of data (e.g., freeway detector data).
- Develop the data archiving system in a way that permits ordinary users with typical desktop computers to access and analyze the data. Effective data archiving systems make large operations data archives available to ordinary computer users without requiring them to have specialized database or programming skills. These systems use a “point-and-click” interface, either through a Windows-based application or a web browser, to provide access to the data archives.
- Provide access to and distribution of archived data through the Internet or portable storage devices such as CDs or DVDs. Internet-based access and distribution of data are some of the most common and effective means to share archived data. CDs or DVDs are used as an alternative to Internet-based data archives, permitting the data archiving agency to maintain greater control and security over the data.
- Save original data as collected from the field for some specified period of time, but make summaries of this data available for most users. Many data archiving systems aggregate data to a consistent time interval (5 minutes is most common) for loading into a data archive. Because there will always be some users interested in the original data, a mechanism should be developed to store this for a short period of time or to store it permanently off-line.
- Use quality control methods to flag or remove suspect or erroneous data from the data archive. The rigor of the quality control ultimately depends upon how and for what purpose the data will be used. Two different philosophies exist for what to do with data that has failed quality control:
 - Simply identify or flag the data records that have failed quality control; or
 - Remove the data records that have failed quality control and replace with better estimates.These business rules (for how to deal with data failing quality control) will depend upon who will be using the data and for what purpose. There is no single correct answer for quality control.
- Provide adequate documentation on the data archive and the corresponding data collection system. With data archiving systems, many data users will be from outside the operations workgroup or agency that collected the data. Thus, they may have little knowledge about the operations data that is collected, how it is collected, and how it is processed by operations before it is archived. Adequate documentation for data archives primarily includes (but is not

limited to) an “audit trail” of how the data have been processed since they were collected in the field (e.g., information about the results of quality control, any summarization or aggregation steps, and any estimates or changes that have been made to original, field-collected data), and information on the data collection system (e.g., the type, location, and other identification for detectors, the detectors that were considered “online” for a particular hour or day, and information about equipment calibration and maintenance).

4.2.5.2 Examples of Data Archiving

California PeMS Data Archiving

The Operations Division in Caltrans’ Headquarters office has worked with researchers at the University of California at Berkeley in creating PeMS, a freeway Performance Measurement System. PeMS gathers raw freeway detector data in real-time from several of Caltrans’ districts, including Los Angeles, Orange County, and Sacramento. The detector data for these participating districts are summarized and processed as follows:

- Aggregates 30-second flow and occupancy values into lane-by-lane, 5-minute values;
- Calculates the *g*-factor for each loop, and then the speed for each lane. (Most detectors in California are single loop, and only report flow and occupancy. PeMS adaptively estimates the *g*-factor for each loop and time interval.
- Aggregates lane-by-lane values of flow, occupancy, and speed across all lanes at each detector station. PeMS has flow, occupancy, and speed for each 5-minute interval for each detector station (one station typically serves the detectors in all the lanes at one location);
- Computes basic performance measures such as congestion delay, vehicle-miles traveled, vehicle-hours-traveled, and travel times.
- The data archives are then made available through the Internet (<http://transacct.eecs.berkeley.edu>) for anyone that has access privileges (i.e., the site is password-protected).

PeMS has several applications and built-in data summary and reporting tools on the web site. One of these involves trip travel time estimates and shortest routes. A user can bring up the district freeway map on the Web browser, and select an origin and destination. PeMS displays 15 shortest routes, along with the estimates of the corresponding travel times. PeMS also provides travel time predictions – for example, what will be the travel time 30 minutes from now. The travel time prediction algorithm combines historical and real time data.

Another application, called “plots across space,” can assist in identifying bottleneck locations for more detailed investigation. To use the application, the engineer selects a section of freeway, a time, and a performance variable such as speed, flow, or delay. PeMS returns a plot of the variable across space. Having quickly determined the existence of these bottlenecks, the engineer can go on to determine their cause, such as the location of interchanges, the highway geometry, large flows at ramps, etc, and propose potential solutions to alleviate the bottleneck. Furthermore, any scheme implemented to relieve a bottleneck can be rigorously evaluated by a thorough before-and-after comparison.

The impetus for this data archive was state legislation that required Caltrans to monitor the performance of their transportation system. Because Caltrans has extensive detector coverage on freeways in several districts, they chose to archive existing data rather than manually re-collect system performance data. Caltrans’ PeMS data warehouse is unique because it is one of the few statewide operations data archives in existence. Time and experience will reveal how

useful a centralized statewide data archive is to local agencies and workgroups at the district level.

Washington State DOT

WSDOT has been archiving freeway detector data since 1981 in some shape or form, although early efforts were difficult because of the expense of data storage and the difficulty of data transfer (pre-Internet). The agencies have made numerous improvements to their data archive over the years and, for the most part, the data archives have been institutionalized within WSDOT. Freeway detector data (i.e., vehicle volumes and lane occupancy by direction) are collected every 20-seconds from field controllers as part of the Seattle area freeway management system. The data are converted into estimates of vehicle speed and travel time, and summarized to the 5-minute level in the data archive. Quality control is also performed before the detector data is loaded into the archive, and the archive documents the number of data records that have failed quality control.

The Washington State DOT and the Washington State Transportation Center (TRAC) at the University of Washington have developed a CD-based data archive for the Seattle freeways, which they use to distribute the archived operations data. Each data archive CD contains data extraction and summary tools.

An analysis process developed by TRAC produces facility performance information based on these data. This process also fuses the basic freeway surveillance data with independently collected transit ridership and car occupancy data to estimate person throughput. The data are used for a wide variety of purposes, including answering key policy questions and evaluating operational improvements such as ramp metering or HOV lanes, freeway performance monitoring, pavement design, and freight performance analysis.

A paper by Mark Hallenbeck, Director of TRAC (Reference 14), summarizes the experience and lessons learned from this data archiving system as follows:

- “The good news is that ITS surveillance systems being built for traffic management purposes provide much of the data needed to perform these types of analyses; therefore, lots of “new” data are not necessary. Instead, the data already collected must be retained, analyzed, and reported.”
- “Storing and analyzing the data are not free. However, a large number of potential users exist for the information that the surveillance system generates. The key is to work with potential users to fund the modest costs of storing, analyzing, and reporting the data already collected. The agency must also determine who will operate the database.”
- “It is important to recognize that not all surveillance data are “good.” Therefore, the analytical procedures must be able to identify and handle “unreliable” data. Mechanisms should also be in place to repair and calibrate unreliable sensors. (After all, unreliable data also hinder the operational control decisions that are based on those data.)”
- “Because most traffic management systems have limited equipment maintenance budgets, repair activities have to be prioritized. A key to consider when balancing cost versus data availability is that obtaining useful performance information does not require all detectors to be operating. (Does an agency really need to report volumes based on continuous data

collection at 300 locations in the urban area, or will 12 to 20 sites spread strategically around the region reveal the important facts?) The reality is that necessary data can be obtained with a moderate amount of planning and cooperation.”

- “When this cooperation occurs, it becomes truly possible to manage the roadway system. This is because an agency now has the data necessary to understand how the roads are actually performing and how that performance changes as a result of various management and operations activities.”

4.2.5.3 Field Measurements / Manual Data Collection

As previously discussed, Freeway Management Systems (FMS) offer the potential to automate much of the data collection required for performance – based evaluations. That said, the reality is (as of the date of this writing) that less than one-third of the freeways in the nation’s urban areas are instrumented with surveillance subsystems, the data collected by many of these systems does not include all the information required by outcome – based performance measures, detectors don’t always function properly, and some information just cannot be collected without some sort of manual activity.

The “*Manual of Transportation Engineering Studies*” (Reference 15) is an updated and expanded version of the 4th edition to the Manual of Traffic Engineering Studies. It is designed to “aid transportation professionals and communities to study their transportation problems in a structured manual, following procedures accepted by the profession.” The primary focus is on “how to conduct ”transportation engineering studies in the field”. Each chapter introduces a type of study and describes the methods of data collection, the types of equipment used, the personnel and level of training needed, the amount of data required, the procedures to follow, and the techniques available to reduce and analyze the data. Applications of the collected data or information are discussed only briefly. Individual chapters include volume studies, spot speed studies, travel-time and delay studies, inventories, transportation planning data (e.g., origin – destination), traffic accident studies, traffic control device studies, roadway lighting, and goods movement studies. Additionally, there are appendices covering statistical analysis, written reports, and presentations. Another valuable reference is the “*Travel Time Data Collection Handbook*” (TTI, Report FHWA-PL-98-035, March 1998).

4.2.6 Reporting

As previously discussed, a good performance measuring program cannot help but improve communications with an agency’s customer base and constituency, including decision makers and other agencies and entities that are involved with the operation and management of the surface transportation network. To achieve this improved communications, however, requires that the performance measure data be translated into reports for dissemination to stakeholders. Many of the criteria discussed for performance measures are directly applicable to performance reporting, including reporting results in stakeholder terms, that the information necessary to improve decision making is conveyed in these reports, and that the information is presented in a manner that is easy for the audience to understand and interpret.

Visual depictions of the data can assist users in understanding trends, operational performance, and the meaning of complex data interactions. As an example, the Washington State DOT and the Washington State Transportation Center (at University of Washington) convert their archived data (previously discussed in section 4.2.5.2) into a variety of presentation graphs – showing

congestion problems, benefits from operational improvements, comparisons of alternatives, etc. – as a means of discussing freeway operations and the associated policy issues with managers and other decision makers. A few examples are shown and described below in terms of possible policy and operational questions (from References 14 and 16).

What does the congestion picture really look like?

This basic “volume-by-time-of-day” graphic can be extended to illustrate when congestion occurs and its effect on vehicle speed and throughput. Average speed is color coded to indicate how conditions routinely change by time of day. Then, because conditions vary considerably from day to day, reliability at this point in the roadway can be examined by defining “congestion” (in this case, the occurrence of LOS F conditions) and reporting on the frequency with which that congestion occurs. Graphically, it is possible to lay the “frequency of congestion” over the same graphic that illustrates vehicle volumes and average speeds. This is shown in Figure 4-1 (read “Vehicle Volume Per Lane” on the left axis, and “Frequency of Congestion” on the right axis.) This graphic shows that this specific location experiences LOS F conditions more than 80 percent of all weekdays (four times a week). It is also possible to see the slight decrease in vehicle throughput, caused by congestion, which occurs in the heart of the morning peak period.

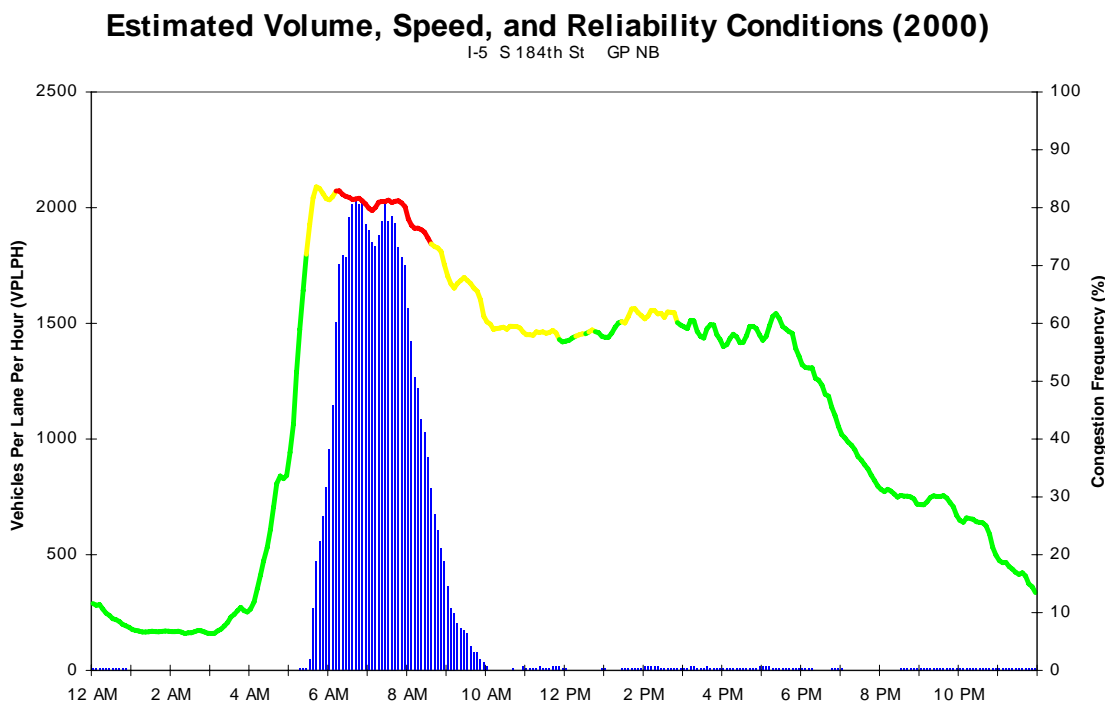


Figure 4-1: Estimated Frequency of Congestion, Volumes and Speeds
(Reference 14)

Another approach is to produce an average daily corridor profile to depict lane-occupancy percentage at each location along a corridor for a specified direction of travel. As shown in Figure 4-2, the resulting graph is a contour map, color – coded according to the estimated congestion level.

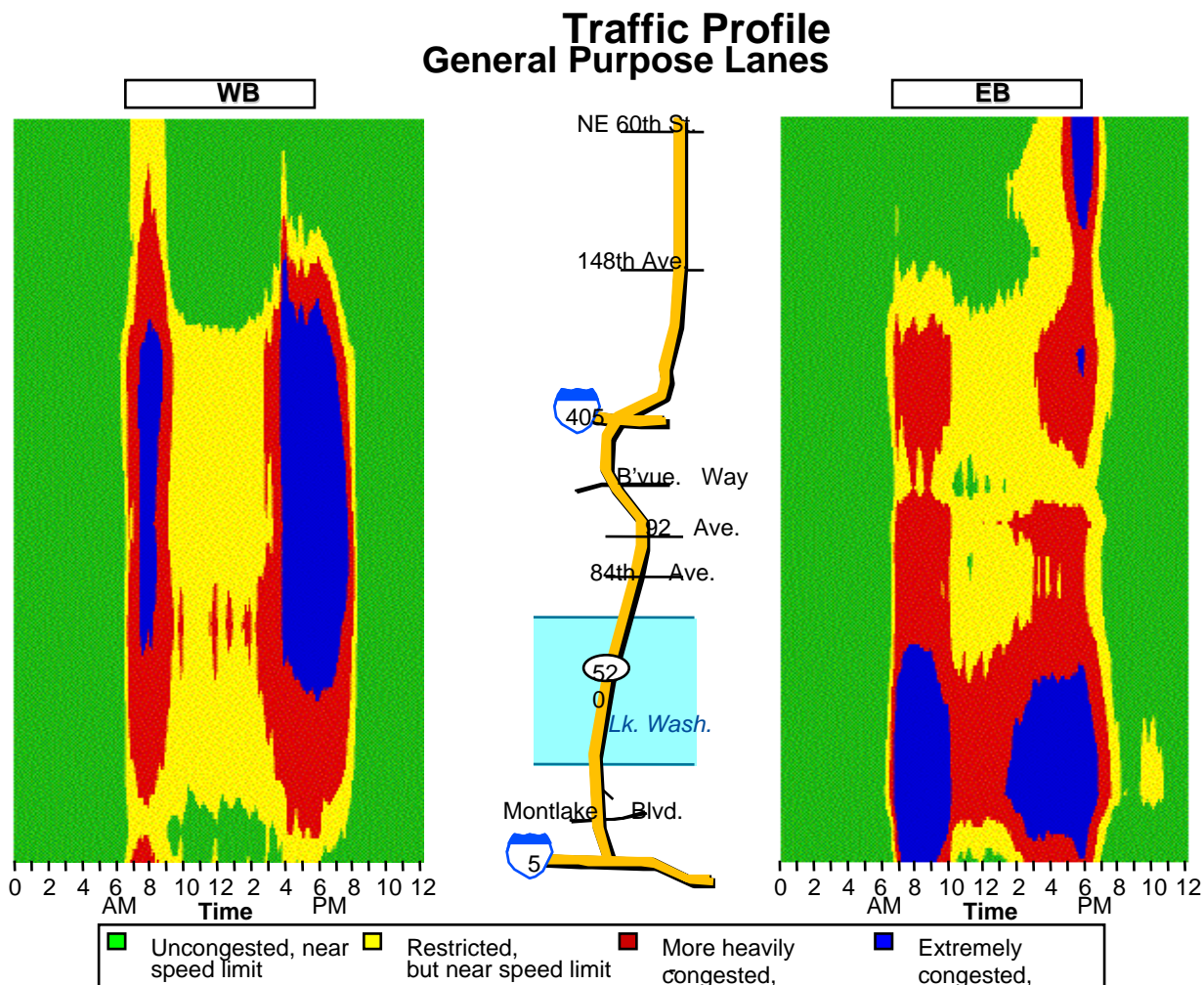


Figure 4-2: “Temperature” Diagram of Traffic flow Conditions
(Reference 18)

What delays are the public experiencing?

Using vehicle speed data that can be obtained from the freeway surveillance system, it is possible to estimate vehicle travel times throughout the day. Again, by saving these data, it is possible to describe not only today’s travel times (excellent for measuring the effects of an incident), but also an entire year’s travel times. Graphics like Figure 4-3 allow the analysis and reporting of travel conditions throughout the day.

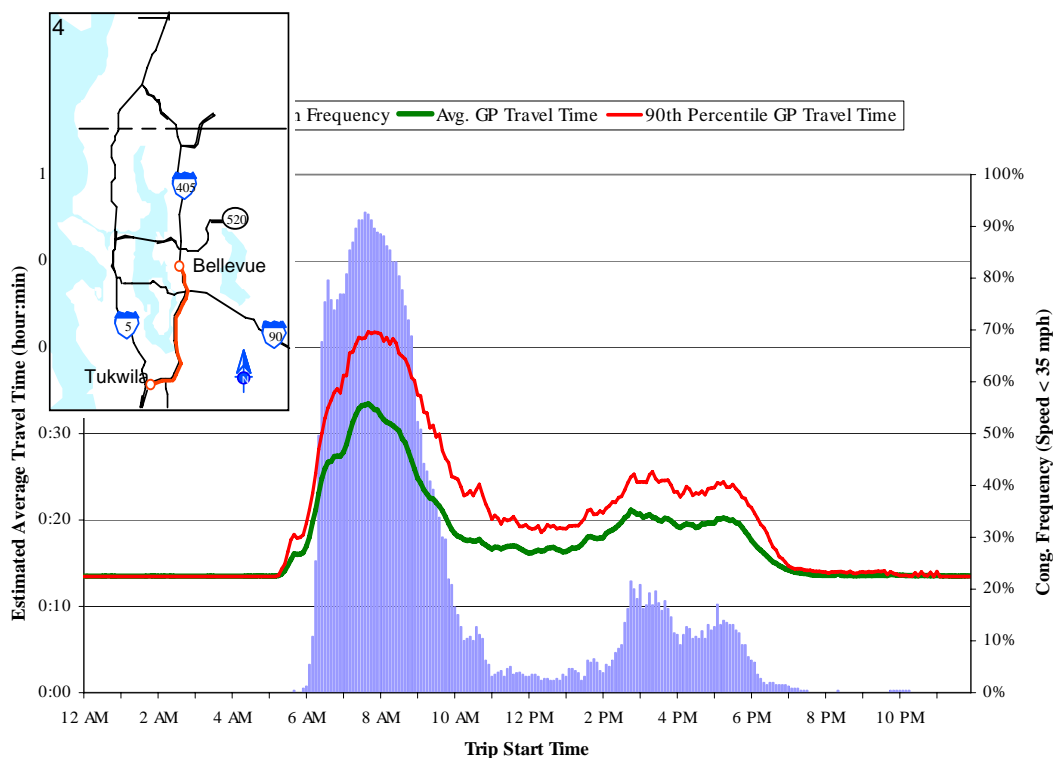


Figure 4-3: Travel Times (by time of day) for a Specific Route
 (Reference 14)

The graphic illustrates the actual travel times experienced (by time of day) for a specific route of interest (in this case the northbound trip using the southern half of the I-405 corridor). The green line represents the average travel time for a trip starting at a given time. The red line illustrates the 90th percentile trip. This is essentially the worst travel time a motorist could expect to experience once every two weeks. (As previously discussed, the Mobility Monitoring Program uses the “Buffer Index” as a measure of travel reliability. Changing the graphic to illustrate the 95th percentile trip time would represent the Buffer Index.)

Figure 4-3 also includes a measure of “congestion frequency.” In this case, “congestion” is defined as the average speed for a trip of less than 35 mph. The blue histogram describes the frequency with which a motorist can expect to experience a trip that averages less than 35 mph for the entire trip duration.

Statistics such as the ones presented in the Figure 4-3, when tracked over time, allow freeway operations personnel to measure and present the broad, overall effects of the traffic control strategies they implement. These statistics also lead to more informed discussion of the travel conditions that exist (e.g., How bad is off-peak congestion? Is off-peak operation of the service

patrol program necessary?), which in turn leads to more informed debate about the need for and relative merits of alternative operations strategies.

What improvements have ramp metering produced?

Any time significant operational changes are implemented within the surveillance area, the resulting changes in vehicle throughput and performance can be measured. WSDOT has operated ramp meters in the afternoon on SR 520 in Seattle for a number of years. Until recently, the ramp meters were not used in the morning. When morning metering was implemented, significant improvements in freeway performance occurred. Those improvements, illustrated in Figure 4-4, included an increase of over 170 vehicles per lane per hour and a decrease in the occurrence of LOS F conditions of one day per week. Ramp meters may not have “solved” the congestion problem; but they did make a considerable improvement.

Volume and Congestion on Eastbound SR-520 on the Viaduct

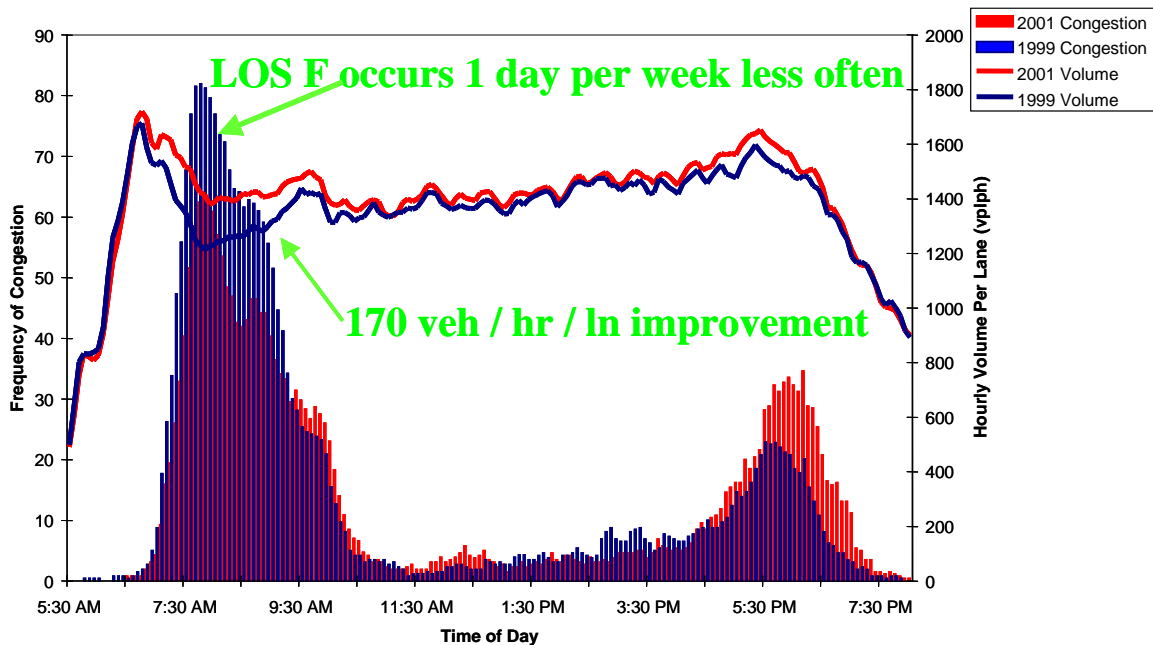


Figure 4-4: The Effect of Ramp Meters on Vehicle Volume (per lane) Throughput and Frequency of LOS F Operations

(Reference 14)

4.2.7 Emerging Trends and Needs

The use of performance measures – particularly those that measure “outcome” – for operating and managing the transportation network, and for longer-range planning and decision making, is itself an emerging trend. The same holds true for data archiving. A recent problem statement developed by the TRB Committee on Freeway Operations, entitled “Freeway Performance Monitoring, Evaluation, and Reporting”, states: “a consensus does not exist and technical guidance has not been developed regarding the appropriate measures, methods, data requirements, evaluation tools, procedures, level of effort, and resources required to properly support the monitoring, evaluation, and reporting of freeway performance. Research and technical guidance is needed to provide direction and ensure that transportation professionals are effectively integrating the performance of freeways into the appropriate planning and decision making processes of agencies.”

References 2, 3, 5, 6 and 10 address future issues and research needs, as summarized below:

- Gather examples, case studies, and tools to effectively communicate performance measures to policy makers, legislatures, and the public. Information is needed on how performance measurement is effectively communicated to decision makers to allow them to make informed decisions.
- Clarify (standardize) terminology and differences between organizational or managerial measures and system measures. Align the definition of goals across the industry to the extent possible, then standardize the measures used. Create consistent standards, so that performance measures can be reliably compared across agencies. Reporting standard errors or confidence intervals should be included.
- Develop training for managers and policy makers to apply and use performance measurement systems. Provide tools for managers and policy makers in applying and using performance measures.
- Gather information on how to incorporate community or society goals (or “soft” measures) into the performance measurement process. Create quality-of-life and sustainability performance indicators.
- Operational performance measures that address evacuations from man-made or natural disasters are needed, particularly for use during the operations of these events and tailoring strategies to maximize / optimize performance based on these measures.
- The maximum benefits will not be realized until considerable integration is achieved. Performance measurement can and should be the *lingua franca* for such integration, with mutually acceptable and well-defined outcomes acting almost like common denominators.
- With respect to archived data, significantly enlarge roadway sensor coverage (i.e., freeways and arterials) and experiment with data sources; transit operating data should be added to get a more complete system picture; encourage the local use of the archived data; improve the calibration and maintenance of data collection equipment; and add “event” databases (e.g., incidents, weather and work zone locations, which have significant impacts on roadway travel times).

4.3 SELF ASSESSMENT

The goal of performance measures is to describe the past, present, and future operation of the operation of the transportation network in quantifiable terms, be they direct outputs (e.g., travel times, tons of pollutant), costs, indices (e.g., accident risk and accessibility), or other surrogates that reflect broad system performance outcomes. Nevertheless, there will always be certain attributes of a freeway management program – such as how well the operations processes are organized and administered, and how well it interacts with other agencies and affected stakeholders – that may never be directly quantified in terms of a performance measure.

Several self-assessment tools have been developed by FHWA for this purpose. To date (spring, 2003), the following self – assessment process have been developed:

- Roadway Operations and System Management, by which state and local transportation agencies can assess the effectiveness of their roadway operations and system maintenance activities. (Some of the assessment criteria are summarized in the previous chapter in Table 2-1).
- Work Zone, to provide a clear indicator of how well transportation agencies are doing in mitigating the impact of work zones on congestion and crashes. (Some of the assessment criteria are summarized in chapter 8)
- Traffic Incident Management, to allow local stakeholders to assess how well they manage traffic incidents and identify areas for improvement. (Some of the assessment criteria are summarized in Chapter 10).

The self-assessment tools have been developed based upon what is known at the time of their development. FHWA plans to update and improve them as they go through the self-assessment process each year. The self-assessment tools are designed for internal use. They are intended to help an agency evaluate its operational effectiveness, both in terms of its internal processes and the degree to which it serves its customers. They will not necessarily provide a basis for comparison with other agencies, but instead serve as a guidance document to highlight areas in which improvements can be made. The self-assessment process should be repeated periodically to gage the degree to which agency performance is changing.

Self-Assessment is intended as a group exercise and as such, should be conducted with as many stakeholder representatives as possible, including representatives from other agencies as appropriate. Ideally, those participating in the self-assessment should represent every aspect of the particular subject or focus of the tool. Agency management should also be represented. Management's participation is essential if the results are to lead to implementation of needed changes. It is important that the participants reflect the organizational assignments of responsibility.

4.4 ANALYSIS TECHNIQUES

Evaluation of a freeway management and operations program (and other transportation improvements) must occur throughout the life cycle of the program and the associated facility. This includes identifying segments with less-than-desired performance and other operational deficiencies, analyzing alternative solutions for correcting these problems, estimating the associated benefits and costs, and determining the actual improvement in performance and its cost effectiveness. Performance measures and self-assessments are just part (albeit a

significant one) of this ongoing evaluation process. Other analytical tools and evaluation methods, as summarized in this section, may also be necessary and appropriate.

The FHWA document entitled “Decision Support Methodology for Selecting Traffic Analysis Tools” (Reference 17) has the stated objective to “assist traffic engineers and traffic operations professionals in the selection of the correct type of traffic analysis tool for operational improvements”. These tools include sketch planning, travel demand models, analytical tools based on the Highway Capacity Manual, and simulation. (Several of these tools are discussed below). Reference 17 identifies the following criteria that a user should consider when selecting a type of analysis tool:

- Identification of the analysis context for the task at hand – planning, design, or operations/construction.
- Analyzing the appropriate geographic scope or study area for the analysis, including isolated intersection, single roadway, corridor, or a network.
- Capability of modeling various facility types, such as freeways, high-occupancy vehicle (HOV) lanes, ramps, arterials, toll plaza, etc.
- Ability to analyze various travel modes, such as single-occupancy vehicles (SOV), HOV, bus, train, truck, bicycle and pedestrian traffic.
- Ability to analyze various traffic management strategies and applications such as ramp metering, signal coordination, incident management, etc.
- Capability of estimating traveler responses to traffic management strategies including route diversion, departure time choice, mode shift, destination choice, and induced/ foregone demand.
- Ability to directly produce and output performance measures such as safety measures (crashes, fatalities), efficiency (throughput, volumes, vehicle-miles of travel (VMT)), mobility (travel time, speed, vehicle-hours of travel (VHT)), productivity (cost savings) and environmental measures (emissions, fuel consumption, noise).
- Tool/cost effectiveness for the task at hand, mainly from a management or operational perspective. Parameters influencing cost-effectiveness include tool capital cost, level of effort required, ease of use, hardware requirements, data requirements, animation, etc.

The document also helps identify under what circumstances a particular type of tool should be used, and contains guidance on how to use this information to select the appropriate type of tool. It is emphasized that Reference 17 is intended to assist practitioners in selecting the *category* of tool for use; it does not include an assessment of the capabilities of specific tools within an analysis tool category.

4.4.1 Highway Capacity Manual

The Highway Capacity Manual (Reference 18) provides analytical techniques for quantifying operational problems on freeways (e.g., capacity analysis and level of service for freeway segments, weaving areas, ramps and ramp junctions, and interchange ramp terminals). The HCM utilizes Level of service (LOS) as a quality measure to describe operational conditions within a traffic stream, generally in terms of such service measures as speed and travel time, freedom to maneuver, traffic interruptions, and comfort and convenience. The analytical methods in the HCM attempt to establish or predict the maximum flow rate for various facilities at each of the following levels of service:

- LOS A describes free-flow operations. Free-flow speeds prevail. Vehicles are almost completely unimpeded in their ability to maneuver within the traffic stream. The effects of incidents or point breakdowns are easily absorbed at this level.
- LOS B represents reasonably free flow, and free-flow speeds are maintained. The ability to maneuver within the traffic stream is only slightly restricted, and the general level of physical and psychological comfort provided to drivers is still high. The effects of minor incidents and point breakdowns are still easily absorbed.
- LOS C provides for flow with speeds at or near the free flow speed of the freeway. Freedom to maneuver within the traffic stream is noticeably restricted, and lane changes require more care and vigilance on the part of the driver. Minor incidents may still be absorbed, but the local deterioration in service will be substantial. Queues may be expected to form behind any significant blockage.
- LOS D is the level at which speeds begin to decline slightly with increasing flows and density begins to increase somewhat more quickly. Freedom to maneuver within the traffic stream is more noticeably limited, and the driver experiences reduced physical and psychological comfort levels. Even minor incidents can be expected to create queuing, because the traffic stream has little space to absorb disruptions.
- At its highest density value, LOS E describes operation at capacity. Operations at this level are volatile, because there are virtually no usable gaps in the traffic stream. Vehicles are closely spaced, leaving little room to maneuver within the traffic stream. Any disruption of the traffic stream, such as vehicles entering from a ramp or a vehicle changing lanes, can establish a disruption wave that propagates throughout the upstream traffic flow. At capacity, the traffic stream has no ability to dissipate even the most minor disruption, and any incident can be expected to produce a serious breakdown with extensive queuing. Maneuverability within the traffic stream is extremely limited, and the level of physical and psychological comfort afforded the driver is poor.
- LOS F describes breakdowns in vehicular flow; and with such stop-and-go conditions, it is difficult to predict a flow rate. These conditions generally exist within queues forming behind breakdown points. Breakdowns occur when the ratio of existing demand to actual capacity or of forecast demand to estimated capacity exceeds 1.00. The various reasons for these breakdowns (as identified in the HCM) include traffic incidents, which can cause a temporary reduction in the capacity of a short segment; and points of recurring congestion, such as merge or weaving segments and lane drops.

The HCM provides methodologies for determining the performance and LOS for undersaturated conditions based on a number of variables, including number of lanes, lane widths, pavement conditions, users familiarity with the facility, clearance between the edge of the travel lanes and the nearest obstructions (i.e. shoulder width), type of terrain / grade, percentage of heavy vehicles in the traffic stream, base free-flow speed, interchange spacing, and peak-hour factor⁶.

⁶ The analysis of LOS is based on peak rates of flow occurring within the peak hour. Most of the procedures in this manual are based on peak 15-min flow rates. The relationship between the peak 15-min flow rate and the full hourly volume is given by the peak-hour factor (PHF).

HCM procedures are closed-form (i.e., they are not iterative). The practitioner inputs the data and parameters and, after a sequence of analytical steps, the HCM procedures produce a single answer. Moreover, HCM procedures are macroscopic (i.e., inputs and outputs deal with average performance during a 15-minute or a one-hour analysis period), deterministic (i.e., any given set of inputs will always yield the same answer), and static (i.e., they predict average operating conditions over a fixed time period and do not deal with transitions in operations from one state to another).

4.4.2 Simulation

Capacity and LOS analyses are useful tools for gauging the expected operating conditions along freeway segments, and for determining the “order-of-magnitude” changes that will result from major freeway improvements (e.g., widening, reconstructed interchanges, bottleneck improvements). However, improvements provided by freeway management strategies and systems are typically not reflected in such procedures. Moreover, information on performance measures (e.g., vehicle delays, fuel consumption, emissions) is not provided by capacity analysis techniques. It may therefore be worthwhile to utilize traffic simulation models, which can examine the manner the freeway network performs under various sets of simulated conditions.

As implied by the name, traffic simulation models examine the manner in which the roadway network performs under various sets of “simulated” conditions. They provide an excellent means of estimating changes in freeway performance metrics (e.g., average speeds, travel time, delays, emissions) resulting from freeway management strategies and improvements. Simulation models have been successfully used to evaluate the impacts of adding HOV lanes, auxiliary lanes, and truck climbing lanes; freeway widening and reconstruction; modifications to interchanges and weaving sections; ramp metering; incident management (e.g., the reduced time to respond and clear a capacity-reducing incident); and traveler information (by inputting an assumed level of diversion resulting from the information).

Traffic simulation models can be divided into the following two general classes:

- **Macroscopic simulation models** – Macroscopic simulation models are based on deterministic relationships of flow, speed, and density of the traffic stream. The simulation in a macroscopic model takes place on a section-by-section basis rather than tracking individual vehicles. Macroscopic simulation models were originally developed to model traffic in distinct transportation networks, such as freeways, corridors (including freeways and parallel arterials), surface street grid networks, and rural highways. They consider platoons of vehicles and simulate traffic flow in small time increments. Macroscopic simulation models operate on the basis of aggregate speed/volume and demand/capacity relationships. Validation of macroscopic simulation models involves replication of observed congestion patterns. Macroscopic models have considerably less demanding computer requirements than microscopic models. They do not, however, have the ability to analyze transportation improvements in as much detail as microscopic models, and do not consider trip generation, trip distribution, and mode choice in their evaluation of changes in transportation systems. (19). Examples include TRANSYT-7F and FREQ.

- **Microscopic simulation models** – Microscopic simulation models simulate the movement of individual vehicles, based on theories of car-following and lane-changing. Typically, vehicles enter a transportation network using a statistical distribution of arrivals (a stochastic process), and are tracked through the network on a second-by-second basis. Upon entry, each vehicle is assigned a destination, a vehicle type, and a driver type. The traffic operational characteristics of each vehicle are influenced by vertical grade, horizontal curvature, and superelevation, based on relationships developed in prior research. The primary means of calibrating and validating microscopic simulation models is through the adjustment of driver sensitivity factors. Computer time and storage requirements for microscopic models are large, usually limiting the network size and the number of simulation runs that could be completed (19). Examples include CORSIM, INTEGRATION, PARAMICS, VISSIM, and Synchro/SimTraffic.

Simulation tools are effective in evaluating the dynamic evolution of traffic congestion problems on transportation systems. By dividing the analysis period into time slices, a simulation model can evaluate the buildup, dissipation, and duration of traffic congestion. Simulation models, by evaluating systems of facilities, can evaluate the interference that occurs when congestion builds up at one location and impacts the capacity of another location.

The individual models vary in their capabilities, limitations, and ease of use (a discussion of which is beyond the scope of this Handbook). Moreover, several models can also show results in real time on a computer monitor by a 2-dimension or 3-dimensional illustration. Simulation models are available from a variety of sources. Information about ordering several of the models mentioned herein is available at

http://www.fhwa.dot.gov/environment/cmageat/descriptions_traffic_simulation_models.htm. A number of firms specialize in the application of simulation models. Some have their own proprietary simulation software that can be used to analyze special scenarios such as toll plaza operation (e.g., varying combinations of cash and electronic toll lanes) and border crossings.

Reference 19 (Guidelines for Applying Traffic Microsimulation Modeling Software) identifies the following tasks as being typically required to develop, calibrate, and apply a microsimulation model to a typical traffic analysis project:

- Identification of project purpose, scope, and approach
- Data Collection - Microsimulation models require significant input data, including geometry (lengths, lanes, curvature); controls, existing demands (volumes, OD table), calibration data (capacities, travel times, queues), and future demands
- Coding – Each microsimulation model has a set of user-adjustable parameters that enable the practitioner to calibrate the model to specific local conditions. In the absence of good guidance on the appropriate procedures for determining these calibration parameters, it is possible for different practitioners to arrive at different or incorrect conclusions.
- Error Checking – The coded transportation network and demand data are reviewed for errors. This step is necessary to weed out coding errors before proceeding with calibration.
- Calibration – An initial calibration is performed to identify the values for the capacity adjustment parameters that cause the model to best reproduce observed traffic capacities in

the field. If the microsimulation network includes parallel streets, then route choice will be important. In this case, a second calibration process is performed, but this time with the route choice parameters. Finally, the overall model estimates of system performance (travel times and queues) are compared to field measurements of travel times and queues. Fine-tuning adjustments are made to enable the model to better match the field measurements.

- Alternatives Testing -- In order to avoid biasing the results, it is important to ensure that the microsimulation model for each alternative contains ALL of the traffic congestion associated with it. The model should start the analysis period with no congestion on the network, and it should end the analysis period with no congestion present on the network. Insufficiently long analysis periods and insufficient geographic coverage result in “missed” congestion that is not properly tabulated by the microsimulation model. Microsimulation models typically produce two types of output, including animation displays and numerical output in text files. The animation display shows the movement of individual vehicles through the network over the simulation period. Text files report accumulated statistics on the performance of the network. It is crucial that the analyst reviews both numerical and animation outputs, and not just one or the other, in order to gain a complete picture of the results.
- Documentation and presentation of the results

A significant amount of effort generally is required to learn to use traffic simulation models, including setting up the appropriate inputs and parameters. Simulation tools also require a plethora of input data – the data requirements being generally proportional to the extent of the network being modeled. The required data can include characteristics of each link (e.g., length, number of lanes, auxiliary / HOV lanes, ramps, grade, speed limits, lane widths, pavement condition), link traffic flow information (e.g., entering / exiting volumes, ramp volumes, travel times, prevent heavy vehicles and buses, lane changing characteristics) and other types of information such as detector locations, incident characteristics (e.g., effect of lane blockage on capacity), and ramp metering operations. Additionally, considerable error checking of the data is required, along with manipulation of a large amount of potential calibration parameters. Simulation models cannot be applied to a specific facility without calibration of those parameters to actual conditions in the field.

Simulation models generally require a non-trivial analysis effort. Moreover, any model-specific limitations should be taken into consideration when interpreting the outputs of simulation. Sensitivity analyses are important to developing an understanding of how reasonable the simulation estimates are, and how much confidence the analyst should place in them.

In a FHWA survey of 40 state DOT and local agencies, the following were the top answers to the question: “What are the major barriers to your use of traffic analysis tools?”

- Lack of trained staff
- Lack of time
- Intensive data gathering requirements
- Cost of software
- Lack of confidence in results

These potential issues notwithstanding, simulation should be strongly considered as a key element of any process to evaluate freeway performance, particularly during the alternatives

analysis and design stages. As an example, a presentation to the TRB Freeway Operations Committee in January 2002 (Reference 20) identified 111 recent simulation experiences involving several models, including CORSIM, FREQ, INTEGRATION, PARAMICS, and VISSIM. Applications of these models included analyses / evaluations of ramp metering, HOV lanes, truck climbing lanes, auxiliary lanes, interchange modifications, design alternatives, widening, growth impacts, weaving sections, reconstruction planning, ITS strategies, and overall operations. In closing, the presentation identified the following keys to successful model applications:

- Well designed work plan
- Strong internal support
- Model and technical training
- Good input and output data
- Model and technical support
- High – quality calibration
- Design of investigations
- Documented results

4.4.2.1 Future Trends

FHWA has been a leader in the area of traffic simulation model development, including the development of the NETSIM and FRESIM models, and their integration into the CORSIM model. Today, FHWA continues to develop, maintain, and support the CORSIM model (now part of the Traffic Software Integrated System (TSIS) package⁷), including bug fixes, training courses, and guidance documentation. When FHWA undertook this leadership role there were no commercial traffic simulation packages in the market – a situation that no longer exists. Accordingly, FHWA is now assuming more of a “market facilitator role”. FHWA will not be a traffic simulation model developer, but will provide resources to stimulate the existing simulation market. Deployment will be facilitated through a combination of outreach, training, guidance, and technical support.

Development activities are focused on developing new tools and improving the analytical foundation of existing tools. The NGSIM program (Next Generation SIMulation) is part of this activity. The goal of the NGSIM Program is to ensure the needs of the model users are met through improving the capability of commercial models. The products of the NGSIM program will include:

- Validation data sets – the sets of real-world traffic data with its corresponding data descriptions that may be used to validate the core algorithms.
- Core algorithms – the set of algorithms necessary to describe the fundamental behavioral models associated with the driver-vehicle-highway systems (e.g., lane change logic, gap acceptance logic, and response to traffic control devices)
- Documentation of the core algorithms and the validation data sets.

Another trend in simulation is the development of real time models that can estimate and predict traffic conditions, thereby allowing freeway management systems to operate in more of a proactive mode. As an example, FHWA is supporting the Center for Transportation Studies at the University of Virginia in the development and evaluation of two prototype traffic estimation

⁷ TSIS also includes a graphical input editor and an animation output processor.

and prediction systems. One of these, DynaMIT, is a real-time simulation model that estimates and predicts traffic conditions, generates traveler information, and provides route guidance. The performance of DynaMIT is being evaluated using real world data from the Hampton Roads Smart Traffic Center.

4.4.3 Before and After Studies

Whereas simulation models provide estimates of changes in performance measures (quite a useful tool when evaluating alternatives prior to selecting the specific freeway improvement for design and deployment); after the selected strategies have been implemented, the actual changes in performance can be measured. The most common method of evaluating this actual effectiveness is a Before-and-After study. With Before-and-After studies, the performance of the freeway network is evaluated prior to implementation of the freeway management strategies and / or system. The same performance measures are then taken again after the strategies / system have been implemented. The effectiveness of the system is then determined by comparing the performance of the freeway during the “before” and “after” conditions.

Potential limitations of a Before-and-After analysis include the following:

- The effects of individual improvements are difficult to distinguish when more than one improvement is made at a time.
- It may take some time for drivers to adjust their travel behavior after the strategy / system has been implemented. Therefore, depending upon when the “after” data are collected, the true effect of the changes may not be measured.
- There is often a long time lag between the “before” condition and the “after” condition, which causes this approach to be susceptible to errors caused by time- related factors (such as changes in travel patterns, population growths, economic fluctuations, etc.).
- Some performance measures (like the number of crashes, or demand) can fluctuate considerably over time. There is a tendency for these performance measures to return to more typical values after an extraordinary value has been observed. This tendency is called *regression to the mean*. It is possible that either the “before” condition or the “after” condition could fall at one of these extreme values, thereby, hiding the true performance of the system.

4.4.4 Alternatives Analysis

In very general terms, an alternatives analysis involves estimating the benefits and costs for each alternative, comparing these alternative -specific benefits to its costs, comparing this “cost-efficiency” for all alternatives, and then selecting the one that offers the greatest potential.

4.4.4.1 Benefits

Freeway management strategies (i.e., operational improvements, low-cost geometric improvements, ITS) can produce a number of benefits, often significant in their magnitude. An overview of some of these benefits is included in Chapter 1, with additional information provided in subsequent topic-specific chapters. Several benefits can be quantified as performance measures (e.g., reduction in travel time, reduced delay, reduced emissions, reduced fuel consumption, reduced incidents) and associated indices; whereas others cannot (e.g., improvement in driver perception of the transportation agencies in the region). Furthermore, while some of the quantifiable benefits can be readily converted to a monetary value (e.g., fuel consumption, person delay), other benefits, such as emission reductions, do not easily lend themselves to monetary conversions (at least not without some significant assumptions).

Another consideration when estimating benefits (and in developing alternatives) is to fully recognize the synergies that can develop from implementing certain combinations of freeway management elements and / or ITS components. For example, if deployed independently, ramp widening, ramp metering, and retiming of signals at nearby intersections would likely improve operations; but combined, the benefits could be significant. Similarly, implementation of closed-circuit television may not only assist in the verification and response - determination of an incident, but also prove useful in verifying whether a traffic message is properly displayed on a nearby changeable message sign. At the same time, it is important to realistically assess how certain elements or components will actually perform, given the presence of other improvements and subsystems. In some cases, the interrelationships are such that the benefits of stand-alone elements may not be additive, as in the case of automated incident detection algorithms (and the associated surveillance infrastructure) combined with a toll free telephone number established for cellular telephone users to call in and report incidents – quickly detecting the same incident twice (once by each subsystem) does not double the benefits.

The freeway practitioner must also recognize the fact that whereas freeway management costs are “real dollars” obligated by a government agency and ultimately funded by taxpayers; the benefits, while very real in terms of improved operations and safety, may not always translate well into dollar equivalents – that is, the monetary value of the benefits does not represent actual funds that accrue back to an agency or that are recognized by individual travelers. Moreover, these benefits may not be as highly valued in the political decision arena as more traditional highway improvements involving significant amounts of concrete and asphalt. As discussed in Chapter 2, the freeway practitioner must endeavor to promote a more widespread appreciation of the relatively high cost-effectiveness of freeway management and operations.

Information on benefits can be obtained from a variety of sources, including:

- Simulation (as discussed in section 4.4.2)
- ITS Deployment Analysis System (IDAS, discussed in section 4.4.4.6)
- Other similar improvements and systems (e.g., www.benefitcost.its.dot.gov for ITS-related benefits) with the caveat that great care must be taken when using representative benefits of similar systems and programs. The user must consider potential differences in the features and functionality of the programs, location and topography, the existing traffic conditions before implementation, the existence and stability of working relationships between agencies, the specific combination of elements and subsystems incorporated into the overall freeway management program – all of which contribute to its overall success and impact of a freeway management and operations program.

4.4.4.2 Costs

Costs associated with freeway management improvements may be classified as follows:

- **Capital costs** include all costs associated with the implementation of the freeway management strategies and systems, including planning, design, right-of-way, equipment, construction, maintenance & protection of traffic during construction, software development and licensing, system integration, and testing.
- **Continuing costs** are those associated with ongoing operations of the freeway management program, including equipment and infrastructure maintenance costs, equipment replacement, staffing costs to operate the system (operations personnel, clerical

personnel, public information personnel, etc.), utilities costs, software updates, and leasing costs (communications, control center space, etc.).

Continuing costs are just as important as, if not more important than, capital costs. Adequate funding for operations and maintenance, including funding to replace system components when their useful lives have expired, is essential for successful freeway management.

It is crucial that the life – cycle costs of the program must be determined in terms of its complete implementation and operating schedule, recognizing that a freeway management and operations program will likely entail many separate steps, with elements that are deployed and become operational at various points in time. In developing life – cycle costs, the time stream of capital and operating / maintenance costs must be determined and net present worth techniques applied (e.g., discount the annual recurring costs and sum with capital costs to derive the net present value.)

Information on costs can be obtained from a variety of sources, including:

- ITS Deployment Analysis System (IDAS, discussed in section 4.4.4.6)
- Experience of other programs and systems (e.g., www.benefitcost.its.dot.gov for ITS – related costs, and selected DOT web sites), with the caveat that great care must be taken when using representative costs of similar systems and programs. The user must consider potential differences in methods of construction and integration, timing (i.e., inflation), location and topography, and what all is included in a particular item (e.g., does the DMS cost include the support structure).

4.4.4.3 Benefit – Cost Analysis

The Benefit-Cost (B/C) analysis technique is perhaps the most widely accepted methodology for evaluating transportation improvement alternatives. The B/C ratio is simply the equivalent benefit of an alternative divided by the equivalent cost of that alternative:

$$B/C = (\text{benefits of alternative } i) / (\text{costs of alternative } i)$$

Benefit-cost comparisons are possible when the benefits of an improvement can be assigned a monetary value. If the benefits of an alternative exceed its costs, the improvement is economically justifiable. Furthermore, the ratio of each alternative provides a convenient basis for comparison, providing a measure of the dollars of expected benefit of an alternative for each dollar spent on that alternative.

If system alternatives being analyzed build upon each other in terms of the costs, quantities, complexities, etc. of components that meet the system goals and objectives, it may be more appropriate to consider an incremental benefit-cost analysis. For this approach, the benefits and costs considered for each alternative are not the totals, but rather the additional benefits achieved and costs incurred over the next expensive (and presumably effective) alternative. This analysis considers, in effect, whether an investment necessary to achieve the next incremental step in the system can be justified in terms of the incremental benefits that would be achieved.

The benefit-cost (or incremental benefit cost) analysis methodology provides an objective means of comparing the quantifiable and monetarily-based benefits of an alternative to the

costs of that alternative. However, as already discussed, some freeway management benefits are not easily quantified, and not all quantifiable benefits are easily converted to a monetary value. Because of this, alternative analyses are often needed to help assess which alternatives systems or subsystems meet their objectives in the most economical manner. One such analysis approach is utility cost.

4.4.4.4 Net Present Value

Computation of an alternative's net present worth involves a conversion of all costs and benefits of an alternative that are incurred at the alternative's initiation and throughout its useful life (life-cycle) to an equivalent current value. The current value of the equivalent costs is subtracted from the current value of the equivalent benefits of the alternative. If the benefits exceed the costs, the alternative can be justified economically. Furthermore, comparisons among alternatives are straightforward; the alternative that provides the greatest additional benefits over costs (sometimes referred to as "excess benefits") is said to have the greatest net present worth.

4.4.4.5 Utility – Cost Analysis

Although a benefit-cost (or incremental benefit-cost) analysis is a direct method of determining whether a freeway management alternative is economically viable, such an analysis can be performed only if the benefits to be accrued can be estimated in monetary terms. For many goals and objectives of freeway management, this is not possible. In these cases, a utility-cost analysis approach is commonly utilized. The term cost-effectiveness is sometimes used interchangeably with the term utility-cost analysis.

In a utility-cost analysis, utility measures of performance goals or objectives are created to estimate system benefits. Typically, a project team or expert panel subjectively rates (from 0 to 10 or on a similar scale) how well an alternative is expected to achieve each of the objective or performance criteria. Weighting factors (summing to unity) are also estimated for each of the objective or performance criteria, and multiplied by the rating given to that objective/criterion. These "utilities" of each of the objective/criteria are then summed to determine the total system utility. Dividing the system utility by total system cost represents the utility-cost factor for a particular system. The basic steps in a utility-cost analysis are as follows:

- Define goals and subgoals (done as part of the decision process).
- Weigh each goal.
- Weigh each subgoal.
- Rate the utility of each alternative in satisfying each goal/subgoal.
- Multiply the rating by the weight for each goal / subgoal, and sum over all goals for each alternative (i.e., calculate the utility)
- Compute utility-cost ratio.

4.4.4.6 ITS Deployment Analysis System (IDAS)

The ITS Deployment Analysis System (IDAS) is software developed by the Federal Highway Administration that can be used in planning for Intelligent Transportation System (ITS) deployments. It is a modeling tool at the sketch planning level that enables the user to conduct systematic assessments and quantitative evaluations of the relative benefits and costs of more

than 60 types of ITS investments (at the time of this writing), in combination or in isolation. IDAS has a number of useful features. For example, IDAS:

- Works with the output of existing transportation planning models;
- Compares and screens ITS deployment alternatives;
- Estimates the impacts and traveler responses to ITS;
- Develops inventories of ITS equipment needed for proposed deployments and identifies cost sharing opportunities;
- Estimates life-cycle costs including capital and O&M costs for the public and private sectors;
- Provides documentation for transition into design and implementation.

The model utilizes network and trip data from the regional transportation model. Strategies are applied either for links in the transportation network or at the traffic analysis zone level. Strategies that affect the time or cost of travel affect mode choice, temporal choice, and induced/foregone demand through a "pivot-point" model, which is based on coefficients from the regional travel model. Other strategy impacts are based on findings from various empirical studies. Changes in trips by mode, time of day, and origin/destination subsequently affect vehicle speeds and volumes.

Required data include transportation network and trip tables by mode and/or purpose, which can be obtained from the regional travel model, and deployment of ITS strategies by type and location on the transportation network. The outputs include changes in vehicle-trips, VMT, emissions; travel time savings and improvements in travel time reliability; energy consumption, noise impacts, safety impacts, and monetary values of these changes; and lists of ITS equipment and costs.

IDAS requires some time investment to learn and some user skills – in particular, it is helpful to have familiarity with travel model data in setting up the model. Data entry and alternatives analysis are conducted in a user-friendly Windows environment. Run time is non-trivial (anywhere from a few minutes to a few hours, depending on the number of zones and other factors.)

4.5 CLOSING, AND A LOOK FORWARD

Performance measures are important and valuable indices for evaluating the transportation system operating conditions, identifying problems (e.g., congestion and delays, poor operating speeds, crashes, large fluctuations in travel times / average speeds), and their locations and severity. As discussed in Chapter 2, having identified the problems, the next step for the freeway practitioner is to develop alternative improvements and strategies for alleviating (or at least reducing the impact of) these problems, and then analyzing and evaluating these alternatives (using one or more of the tools and techniques described in Section 4.4) to determine the optimum alternative or combination of alternatives.

The remainder of this Freeway Management and Operations Handbook (i.e., Chapters 5 – 17) describes numerous alternatives for improving the operation and safety of a freeway facility. What is "best" for a particular location is dependent on a number of factors and considerations specific to that location, including the roadway geometrics, signs and markings, weather, lighting, driver population and their behavior, the mix of vehicles in the traffic flow, locations and characteristics of major traffic generators, the institutional environment and the associated goals

and policies of decision makers, the extent of any ITS deployment, the features and functionality of any existing management systems, just to name a few. It is the responsibility of the practitioner to consider all such variables in the analysis.

Moreover, as discussed in Chapter 2, when identifying potential operational improvements and enhancements, the practitioner must consider a wide range of possibilities and perspectives – including the perspective of enhanced transportation services (i.e., the “supply” of transportation), the perspective of those who use these services (i.e., better managing the “demand” for the transportation system), the perspective of influencing where this demand occurs (i.e., the land use dimension), or any combination of the above. Practitioners should also carefully consider how individual actions relate to one another and how, when combined into an overall program, they relate to area, regional and statewide objectives.

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5. ROADWAY IMPROVEMENTS

5.1 INTRODUCTION

An oft-repeated axiom of this Handbook is that freeway practitioners must view the overall performance of the transportation network as a whole; broadening their view of “management and operations” to include other approaches for improving freeway performance that have not traditionally been considered their responsibility. This expanded view means looking beyond the “typical” freeway management and operation alternatives (e.g., ramp management and control, managed lanes and HOVs, traffic incident and planned special event management, traveler information dissemination, traffic management centers, surveillance, etc; as discussed in subsequent chapters), and giving consideration to other types of improvements in concert with freeway management systems and strategies. These additional strategies and improvements may include increasing capacity at bottleneck locations, altering the geometrics to eliminate safety hazards, enhancing various attributes of the freeway environment (e.g., signing, pavement markings, illumination) to increase safety and driver convenience, and implementing strategies to reduce travel demand.

The introductory chapter to this Handbook uses the analogy of a three – legged stool to describe effective highway transportation. This stool consists of three component parts – building the necessary infrastructure, effectively preserving that infrastructure, and effectively preserving its operating capacity by managing operations on a day-to-day basis – with all three parts, or legs, existing in the appropriate proportion to one another. Thus, the freeway practitioner needs to somewhat “blur” any distinction between these “legs”, considering improvements to the infrastructure to be within the broad realm of “operations”.

5.1.1 Purpose of Chapter

This chapter provides a high-level overview of potential actions that improve freeway performance by modifying the roadway itself, such as adding lanes to increase capacity (and thereby increase operational efficiency) at roadway bottlenecks, ramps, interchanges, or other roadway locations; and making changes to the geometric configuration or physical characteristics of the roadway to enhance safety. After a brief overview of the types of problems that can be addressed by roadway improvements (and the potential benefits), and how these potential improvements should be addressed within the freeway management program, the following improvements are discussed: horizontal and vertical alignment; roadway widening (e.g., auxiliary lanes, shoulders); providing additional lanes without widening (e.g., restriping, use of shoulder as travel lane); interchanges (improvements to ramps and weaving sections); and other improvements such as treatment of obstacles and skid resistance.

It is emphasized that this chapter provides only an introduction to possible roadway improvements in support of freeway operations. For additional details and design guidelines, the practitioner should consult a variety of references, many of which are identified at the end of this chapter. Moreover, new freeway facility construction, major 3R projects (resurfacing, restoration, rehabilitation), and significant freeway infrastructure construction (e.g., new interchange, widening over a stretch of several miles) are not addressed herein; although the practitioner should nonetheless be cognizant of the potential of such major improvements, and consult the appropriate references as required.

5.2 BACKGROUND AND OVERVIEW

Chapter 1 discusses the concept of “recurrent congestion” – a situation that occurs when demand increases beyond the available capacity of the roadway. It is usually associated with the morning and afternoon work commutes, when demand reaches such a level that the freeway is overwhelmed and traffic flow deteriorates to unstable stop-and-go conditions. The obvious solution to this problem – and often the most effective – is to increase the capacity of the affected segment.

Several physical attributes of the freeway facility impact its capacity and operational characteristics as summarized in Table 5-1. Additional factors effecting capacity include percentage of heavy trucks, level of speed enforcement, lighting conditions, pavement conditions, pavement markings and signing, and weather. By enhancing one or more of these roadway elements, the capacity will be increased thereby improving traffic flow. As an example, using the methodologies and tables contained in the Highway Capacity Manual (Reference 1), increasing the number of freeway lanes from 2 to 3 will increase the “service volumes”⁸ at Level of Service D from 3840 vph to 5850 vph – an increase of a little over 50 %. Another example – cited in Reference 2 – involves increasing the distance to obstructions on both sides of the freeway (having two 12-foot lanes in each direction) from one foot to six feet could increase the capacity by about 10 %.

Table 5-1: Physical Factors Affecting Roadway Capacity and Operations

(Source – Reference 1)

Category	Capacity / Design Element
Horizontal Alignment	<ul style="list-style-type: none"> • Degree of curvature • Super elevation
Vertical Alignment	<ul style="list-style-type: none"> • Grade • Length of grade • Vertical curves – sag and crest
Cross Section	<ul style="list-style-type: none"> • Number of lanes • Lane width • Lateral Clearance <ul style="list-style-type: none"> ○ Shoulder type and width ○ Median type and width ○ Clearance to obstructions
Other	<ul style="list-style-type: none"> • Interchange density • Ramps & ramp junctions • Weaving sections

Roadway improvements can also enhance traveler safety by improving hazardous locations. In fact, the ITE Document “A Toolbox for Alleviating Traffic Congestion and Enhancing Mobility” (Reference 2) includes a table listing the “design elements that can influence safety. It is

⁸ For urban conditions, 12-foot lanes, 6-foot shoulders, level terrain, 5% heavy vehicles, and 1 interchange per mile.

essentially identical to Table 5-1 above (with the addition of sideslopes, roadside traffic barriers, and ditch design). A few examples of roadway improvements enhancing traveler safety include:

- In certain cases, an improperly aligned highway with sharp curves may have five times as many accidents compared to a highway with good alignment. (Reference 2)
- As reported in Reference 3, Caltrans has evaluated many of its safety projects to determine what has been effective. On average, curve correction was found to reduce 50 % of all accidents, superelevation correction reduced 50 % of run-off-road accidents, and truck escape ramps reduced 75% of run-away truck accidents.
- Longitudinal grooving of pavements has shown dramatic reductions in wet pavement accidents. The FHWA Report “Effectiveness of Alternative Skid Reduction Measures” (Reference 4) references two California studies from the early 1970’s where grooving resulted in reductions in the wet pavement accident rates of 70 and 73%, with the largest decreases in sideswipe, fixed object, and rear-end accidents. The same reference summarizes 77 grooving projects in 13 states that showed an overall decrease of 75% in wet pavement accidents.

5.2.1 Key Considerations During Freeway Management Program Development

It is important for freeway practitioners to regularly address and evaluate a full array of freeway improvements – from large-scale projects to “low cost” roadway enhancements⁹ as potential elements of a freeway management and operations program. As such, they should be considered throughout the various activities that comprise the development and management of a freeway operations program (refer to Chapter 3).

A critical issue (or “step” as shown in previous Figure 3-1) is that of the “institutional environment”. One of the major differences with many of the actions discussed in this chapter compared to the operational improvements discussed in subsequent chapters is that, in almost all cases, roadway improvements that add capacity are subject to planning and environmental requirements¹⁰ that must be followed to secure financial support (2). This may include:

- A Major Investment Study (MIS), where a major transportation investment is identified through the planning process as satisfying a need and where federal funds are potentially involved. A major investment includes “high-type highway improvements of substantial cost that are expected to have a significant impact on capacity, traffic, level of service, or mode share at the transportation or sub-area scale” (2).
- An environmental impact statement (EIS) or environmental assessment will have to be undertaken if the proposed improvement is expected to have significant environmental impacts.
- If the urban area is in non-conformance with air quality standards, a conformity analysis must be undertaken to show no additional degradation of air quality due to the proposed improvement.

⁹ Low cost relative to building a new roadway or widening long stretches of existing facilities

¹⁰ Some freeway practitioners have indicated that, in their experience, the installation of auxiliary lanes for freeway entrances and exits, and the widening of entrance ramps have not been subject to these requirements; or when they are, the result is a “Negative Declaration”, allowing the roadway improvement to move forward without going through a time consuming environmental study.

The proposed roadway improvements should also be correlated with State and Regional Long-Range Plans, TIPs, etc. As these improvements are generally considered capital projects, they may already be programmed or budgeted; or the proposed improvement might be readily incorporated into another programmed capital project in the same geographic area. Other procedural considerations include:

- Stakeholders should include those agencies, departments, and staff responsible for designing, building, and maintaining roadway improvements.
- Performance measures (discussed in Chapter 4) should include indices for identifying locations with recurrent congestion and safety problems, and for determining the nature of the problems and severity.
- When analyzing and making decisions regarding potential improvements, it is important to remember that changes in traffic and operational patterns resulting from roadway improvements often have an impact that goes beyond the immediate facility that is being improved. For example, additional capacity provided in one corridor could very well influence demand on adjacent arterials or nearby freeways, while eliminating a bottleneck at one location could exacerbate congestion somewhere downstream. Such issues must be considered in the analysis that precedes a decision to improve the roadway and increase capacity. In other words, when looking at alternative roadway improvements, the concept of systemwide performance (as compared to segmental throughput) must be the foremost consideration. As discussed in chapter 4, simulation models have proven very useful in this regard.
- Geometric design standards contribute to improved freeway safety and throughput. These criteria and guidelines should be incorporated into the design of roadway improvements. Applicable references include (but are not limited to) the AASHTO *“Policy on geometric Design of Highways and Streets”* (Reference 5), the AASHTO *“Highway Safety Design and Operations Guide”* (Reference 6), and the TRB *“Geometric Design and the Effects of Traffic Operations”* (Reference 7). It is also noted that, at the time of writing this Handbook, ITE is preparing a Freeway and Interchange Geometric Design Handbook.

5.2.2 Relationship to Other Freeway Management Activities

Roadway improvements and more traditional operations improvements – including ITS – based solutions – should work in concert with one another. Moreover, roadway improvements often enhance the application of the strategies addressed in subsequent chapters. For example:

- Ramp metering (as discussed in Chapter 7) may be more effective, particularly with respect to minimizing back-ups onto the surface street network and / or providing preferred treatment for HOVs, by widening the ramp to provide additional lane(s) or HOV bypass lanes.
- Truck restrictions (as discussed in Chapter 8 on Managed Lanes) on upgrades may require the addition of a climbing lane to enhance the operation.
- Incident management (Chapter 10) may be enhanced by the construction of wider shoulders or refuge areas for disabled vehicle.

- During special event management (Chapter 11) and major evacuations (Chapter 12), the use of shoulders as travel lanes – thereby increasing roadway capacity – may be an appropriate and effective strategy.

5.3 HORIZONTAL AND VERTICAL ALIGNMENT

Horizontal and vertical alignments are considered “permanent design elements” (5). It is extremely difficult and costly to correct alignment deficiencies after a highway is constructed. Nevertheless, such changes to the roadway infrastructure may prove a cost – effective and possibly necessary solution, particularly if there are safety issues. Projects to improve horizontal and / or vertical alignments are typically not within the realm of “operational improvements”, but are considered highway reconstruction (i.e. the preservation leg of the aforementioned 3-legged stool).

The ITE “Toolbox for Alleviating Traffic Congestion and Enhancing Mobility” (2) defines highway reconstruction as the process of replacing or rehabilitating a road. Reconstruction projects include modernizing geometric and structural standards, improving the quality of operation and safety, increasing capacity, and extending the life of facilities. Importantly, the reconstruction of a facility provides an opportunity to correct or improve operational problems that developed since the facility was built. These improvements could include changes in alignment, improved interchange design, new interchanges, and widening.

While not typically in the realm of “operations”, these actions impact freeway operations and should be considered as part of the “toolkit” the practitioner draws from when analyzing and recommending actions to address operational deficiencies. Freeway management practitioners should also be cognizant of and, to the greatest extent possible, directly involved in the planning and design of major reconstruction projects to:

- Ensure that the projects address identified deficiencies in freeway operation
- Ensure that disruption to the traveling public is minimized through carefully planned and coordinated construction sequences and work zone management strategies, including the implementation of transportation management strategies and technologies minimize this disruption during reconstruction (e.g., incident management, surveillance, traveler information)
- Identify the potential impact of reconstruction on existing field components of an ITS-based freeway management system (e.g., conduit and communications cable, CCTV, detectors), and prepare plans for keeping these components operational during reconstruction)
- Identify elements (e.g., conduit network, foundations) that can be provided in the reconstruction design for system implementation at a later date.

5.4 ROADWAY WIDENING

The number of lanes on a freeway segment influences congestion and safety. Widening a freeway to provide additional lanes over several miles falls into the category of a major

reconstruction. There are also “bottleneck” situations (i.e., insufficient capacity for just a short distance) where a low-cost roadway improvement can add lanes to eliminate these constraints.

5.4.1 Auxiliary Lanes

An auxiliary lane is defined by AASHTO (5) as the portion of the roadway adjoining the traveled way for speed change, turning, weaving, truck climbing, maneuvering of entering and leaving traffic, and other purposes supplementary to through-traffic movement. Auxiliary lanes are used to balance the traffic load and maintain a more uniform level of service on the highway. They facilitate the positioning of drivers at exits and the merging of drivers at entrances. AASHTO (5) provides the following guidance regarding auxiliary lanes:

- The width of an auxiliary lane should be equal to the through lanes. Where auxiliary lanes are provided along freeway main lanes, the adjacent shoulder should desirably be 2.4 to 3.6m [8 to 12 ft] in width, with a 1.8m [6 ft] wide shoulder being the minimum considered.
- Operational efficiency may be improved by using a continuous auxiliary lane between the entrance and exit terminals where interchanges are closely spaced; the distance between the end of the taper on the entrance terminal and the beginning of the taper on the exit terminal is short; and/or local frontage roads do not exist. An auxiliary lane may be introduced as a single exclusive lane or in conjunction with a two-lane entrance.
- When interchanges are widely spaced, it might not be practical or necessary to extend the auxiliary lane from one interchange to the next. In such cases, the auxiliary lane originating at a two-lane entrance should be carried along the freeway for an effective distance beyond the merging point. An auxiliary lane introduced for a two-lane exit should be carried along the freeway for an effective distance in advance for the exit.

Figure 5-1 illustrates an example of adding an auxiliary lane (8). The Dallas district of the Texas Department of Transportation, in conjunction with the City of Richardson, TX, developed and implemented this solution to improve merging / weaving at the entrance to southbound US 75 from the recently constructed President George Bush Turnpike. The cause of the bottleneck was a forced merge of the ramp traffic onto the southbound main lanes of I-75. Texas Transportation Institute (TTI) conducted an evaluation. Before and after data established that each vehicle using the ramp connection averaged one minute in travel time savings, with a peak savings of over three minutes. At the same time, main lane traffic maintained or experienced a slight increase in speed. The TTI report (6) further states that, in general, the benefit – to – cost ratio for these types of projects are typically high, averaging 20:1 for a ten-year life.

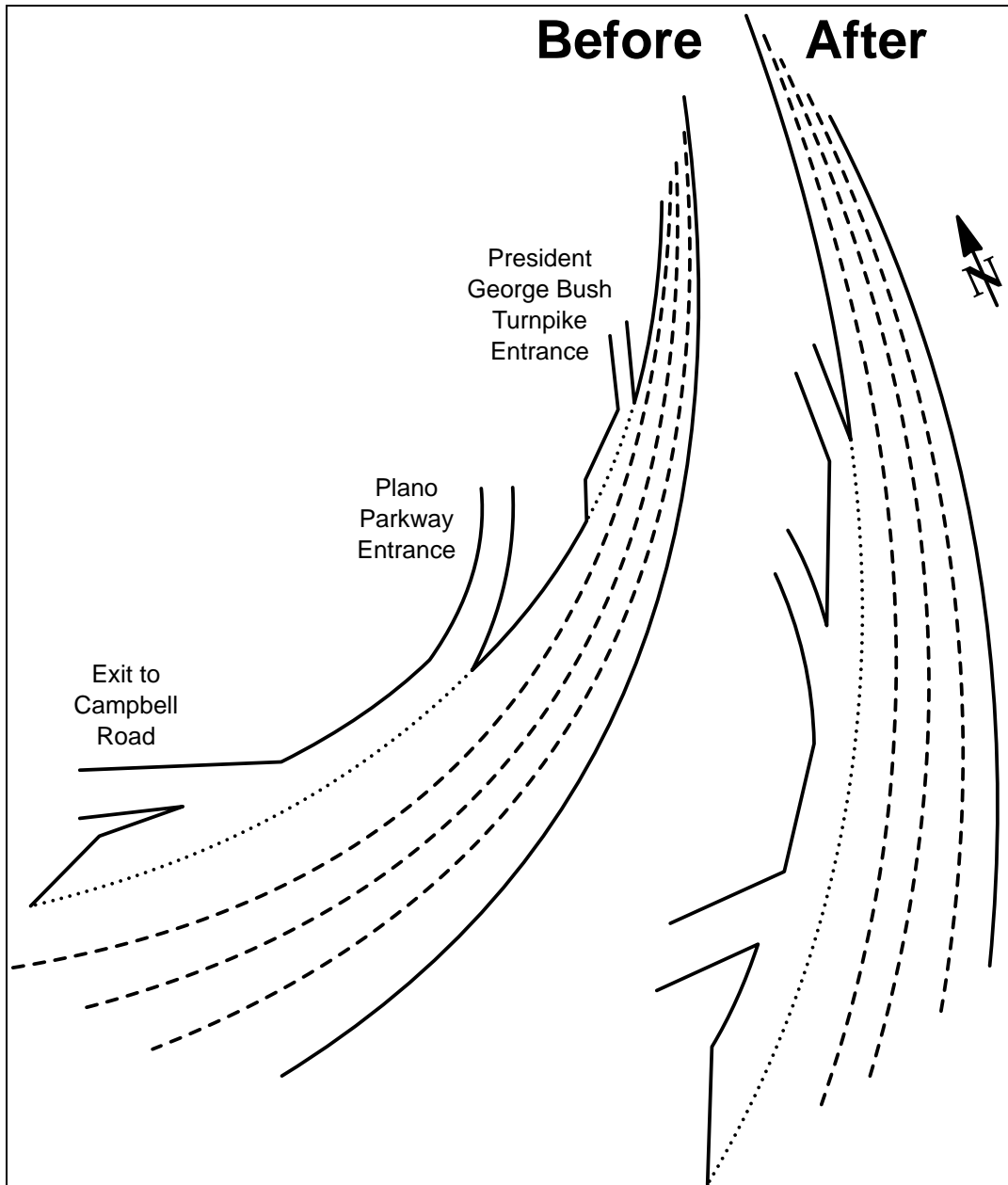


Figure 5-1: Example of Adding an Auxiliary Lane
(Reference 8)

5.4.2 Speed - Change Lanes.

Drivers leaving a freeway at an interchange are required to reduce speed as they exit on a ramp. Drivers entering a freeway accelerate until the desired highway speed is reached. Because the change in speed is usually substantial, AASHTO (5) recommends that provision should be made for acceleration and deceleration to be accomplished on auxiliary lanes to minimize interference with through traffic and to reduce crash potential. Such an auxiliary lane, including tapered areas, may be referred to as a speed-change lane. The terms “speed-change lane,” “deceleration lane,” or “acceleration lane”, as used in Reference 5, apply broadly to the “added lane joining the traveled way of the freeway with that of the turning roadway and do not necessarily imply a definite lane of uniform width. This additional lane is a part of the elongated ramp terminal area.”

A speed-change lane should have sufficient length to enable a driver to make the appropriate change in speed between the freeway and the turning roadway in a safe and comfortable manner. Moreover, in the case of an acceleration lane, there should be additional length to permit adjustments in speeds of both through and entering vehicles so that the driver of the entering vehicle can position himself opposite a gap in the through-traffic stream and maneuver into it before reaching the end of the acceleration lane. This latter consideration also influences both the configuration and length of an acceleration lane. (5)

5.4.3 Climbing Lanes

Per AASHTO (5), climbing lanes offer a comparatively inexpensive means of overcoming reductions in capacity and providing improved operation where congestion on grades is caused by slow trucks in combination with high traffic volumes. Although typically applied in rural areas, there are many instances where climbing lanes are needed and appropriate for urban areas. Criteria presented in AASHTO (5) include the following:

- Critical length of grade – this is the length of a particular upgrade that reduces the speed of low-performance trucks 15 km/h (10 mph) below the average running speed of the remaining traffic. Charts for determining this critical length of grade are provided in the reference (e.g., just under 1000 ft for a 5% upgrade grade). If the critical length of grade is less than the length of grade being evaluated, consideration of a climbing lane is warranted.
- Existence of a low level of service on the grade. Generally, climbing lanes should not be considered unless the directional traffic volume for the upgrade is equal to or greater than the service volume for LOS D.
- The location where the climbing lane should begin depends on the speeds at which trucks approach the grade and the extent of sight distance restrictions on the approach. Where there are no sight distance restrictions or other conditions that limit speeds on the approach, the added lane may be introduced on the upgrade beyond its beginning because the speed of trucks will not be reduced beyond the tolerable level to following drivers until they have traveled some distance up the grade. The ideal design is to extend the climbing lane to point above the crest, where a typical truck could attain a speed that is within 15 km/h (10 mph) of the speed of other vehicles. Climbing lanes on multilane roads are usually placed on the outer or right-hand side of the roadway.

5.4.4 Widening Without Adding Lanes

Widening the roadway, but not adding lanes can also improve operations. The potential for an increase in capacity and improved safety (i.e., providing a safe refuge for disabled vehicles) via shoulder widening has already been mentioned.

AASHTO (5) discusses widening the traveled way on horizontal curves to make operating conditions on curves comparable to those on tangents. On earlier highways with narrow lanes and sharp curves, there was considerable need for this widening. On modern highways (12 ft lanes) and high-type alignment, the need for widening has lessened considerably. But for some conditions of speed, curvature, and width, it remains appropriate to widen travel ways. Widening is needed on certain curves for one of the following reasons:

- The design vehicle occupies a greater width because the rear wheels generally track inside front wheels (off tracking) in negotiating curves, or
- Drivers experience difficulty in steering their vehicles in the center of the lane.

Design values are provided in this reference for various values of roadway width, design speed, radius of curve, and design vehicles. A minimum widening of .6 m / 2 ft is recommended (5).

5.5 PROVIDING ADDITIONAL LANES WITHOUT WIDENING THE FREEWAY

Using freeway shoulders as travel lanes has occurred in some cities since the late 1960s, with many of these lanes being devoted to HOV use. These modifications include using one or more shoulders as travel lanes (this is often done only during peak hours and in the peak direction); and reducing lanes widths to provide additional lanes within the existing pavement. The following discussion of this strategy is taken from the ITE "Toolbox for Alleviating Congestion and Enhancing Mobility" (2).

5.5.1 Benefits/Cost

Significant increases in capacity (up to as much as 30 percent and more) are possible. These capacity increases however, have often been achieved with some increase in accident rates. Thus, the design of such lanes must clearly take into consideration the safety aspects of the particular freeway section. Even though such treatments should be considered temporary, an FHWA staff study found that in cities with populations over one million, almost 32 percent of the urban freeway mileage could experience reduced congestion through such low-cost measures.

A 1995 study of freeway shoulder lanes (Reference 9) found:

- Freeway capacity in excess of 2,200 passenger car per hour per lane were observed at these sites.
- Modified sites have a greater tendency to fall into more congested conditions at high volumes than unmodified sites.
- The range of observed speeds along an unmodified freeway section will be somewhat greater than along a comparable modified section.
- Accident rates at modified freeway actions are somewhat higher than rates for unmodified sections.
- Truck accident rates are almost always higher on modified sections.

Another study¹¹ examined the northern Virginia I-95 use of shoulder lanes for the entire day. This 8 mile / 12.9 km section of Interstate has a left lane designated for 3+ HOV vehicles, two general purpose lanes, and a right shoulder which is used as a conventional travel lane. This study concluded:

- The use of shoulder lanes increased freeway capacity significantly. Analysis indicated that removing the shoulder lanes from general purpose use would increase queue lengths by 140 percent and system delays by 929 percent. The HOV and shoulder lanes carried 47 percent of road vehicles and 63 percent of total travelers on the freeway.
- No adverse impacts on general traffic accident frequency were found. Fatality rates were lower than the “before” situation.
- Importantly, in keeping with the concern mentioned earlier about safety, several modifications were made in the corridor to maintain operational and enforcement activities. In particular, emergency pullouts were built and signed to allow for safe storage of disabled vehicles.

The primary advantages and disadvantages in implementing this tool are summarized below (from Reference 9)

Design Alternative	Advantages	Disadvantages
Use of Left Shoulder	<p>Left shoulder not used as much for emergency stop or emergency enforcement.</p> <p>Lease expensive if width is available.</p> <p>Trucks often restricted from left lane.</p>	<p>Usually requires restriping.</p> <p>Sight distance problem with some median treatments.</p>
Use of Right Shoulder	<p>Often the easiest to implement.</p>	<p>Right should is preferred area for emergency stops and enforcement.</p> <p>Sight distance changes are merge and diverge areas of ramps.</p>
Use of Both Shoulders	<p>Not recommended.</p> <p>Use ONLY in extreme cases.</p>	<p>Requires restriping</p> <p>Safety concerns</p> <p>Enforcement difficult</p> <p>Incident response longer</p> <p>Maintenance more difficult and expensive</p>

¹¹ Chen, C. “Evaluation of HOV and Shoulder Lane Travel Strategy for I-95”, ITE Journal, September 1995

5.5.2 Implementation

Whenever improvements are made to a highway, the level of safety should be improved. As noted in the AASHTO 1997 "Highway Safety Design and Operations Guide":

"The need to accommodate more traffic within existing or limited additional right-of-way on high volume urban freeways has led some agencies to increase capacity by exchanging full-lane or shoulder widths for additional travel lanes with reduced widths. Any proposed use of less than full standard cross section must be studied carefully on a case-by-case basis. Experience indicates that 12ft- lanes can operate safely if there are no other less-than-standard features; however, combined with shoulder width reductions, substandard sight distance, and other features, (these) lanes may not provide the same operation"

This means that when shoulder use is being considered for traffic flow, careful planning and design should occur to avoid any potential safety problems. In addition, structural capacity of a highway varies across the cross section. The shoulder is not often constructed to accommodate traffic loads. Pavement failures and subsequent repair under traffic conditions will have an effect on both capacity and safety.

Cooperation and coordination between the state highway agency and the traffic enforcement officials responsible for enforcement (i.e., "stakeholders") is essential. Because the use of breakdown lanes is not consistent with federal design criteria, federal approval will be required if the highway facility is on the federal-aid system.

When this action is being considered, it typically generates opposition from traffic enforcement agencies and motorists who are mainly concerned about safety (i.e. the emergency lane is used for traffic flow rather than by emergency vehicles or breakdowns). Also, there is concern that the flow from entrance ramps will be adversely affected. There are all legitimate concerns that should be addressed. The response to these concerns includes the following from the AASHTO 1997 "Highway Safety Design and Operations Guide" (Reference 6):

- Where shoulders are converted to travel lanes, removing the left-side shoulder is preferable.
- Horizontal and vertical curvature should be checked for adequate stopping sight distance, particularly in those instances where the median shoulder is being considered as a travel lane, and the highway has a narrow median and median barrier.
- Systems for rapid incident detection and response should be considered for sections with substandard lanes and shoulder widths. (This includes removing disabled vehicles from the shoulders before the peak period when the shoulder becomes a traveled lane).
- If both shoulders are removed; mitigating measure should include adequate advisory and regulatory signing, constructing frequent emergency pullouts, active overhead and side-mounted changeable message signs and signals, continuous lighting, truck lane use restrictions, dedicated service patrols and continuous enforcement.
- For sections greater than 1.5 kms where inadequate shoulders are provided emergency pullouts should be considered where feasible.

5.6 INTERCHANGES

Interchanges are where traffic enter and exit the freeway. The merging and weaving associated with interchanges affect traffic flow. Improvements can be made to increase the capacity and safety of the weaving sections and the ramps that comprise the interchange.

5.6.1 Weaving Segments

The Highway Capacity Manual (1) identifies three geometric variables that influence weaving segment operations (i.e., configuration, length, and width) as discussed below:

- Configuration – The configuration of the weaving segment (i.e., the relative placement of entry and exit lanes) has a major effect on the number of lane changes required of weaving vehicles to successfully complete their maneuver.
- Weaving Length – Because weaving vehicles must execute all the required lane changes for their maneuver within the weaving segment boundary from the entry gore to the exit gore, the parameter of weaving length is important. The length of the weaving segment constrains the time and space in which the driver must make all required lane changes. Thus, as the length of a weaving segment decreases (configuration and weaving flow being constant), the intensity of lane changing, and the resulting turbulence, increase. Similarly, by increasing the length of the weaving area, capacity is increased.
- Weaving Width – The third geometric variable influencing the operation of the weaving segment is its width, which is defined as the total number of lanes between the entry and exit gore areas, including the auxiliary lane, if present. As the number of lanes increases, the throughput capacity increases. At the same time, the opportunity for lane changing also increases for discretionary lane changes that may take place within the weaving segment.

Another variable is volume. The weaving geometrics of an interchange may work quite well under one combination of through and entering / exiting volumes, and lead to congestion and safety problems under another (e.g., higher volumes).

Depending on the interchange layout and the distances between adjacent interchanges, capacity may be increased, safety improved, and weaving operations improved by the addition of auxiliary lanes and other widening efforts as previously discussed.

5.6.2 Ramp Components

The term “ramp” is used by AASHTO (5) to include all types, arrangements, and sizes of turning roadways that connect two or more legs on an interchange. Figure 5-2 illustrates several types of ramps and their characteristic shapes. Various configurations are used; however each can be broadly classified as one of the types shown. The different ramp patterns of an interchange (i.e., the different types of interchange configurations) are made up of various combinations of these types of ramps.

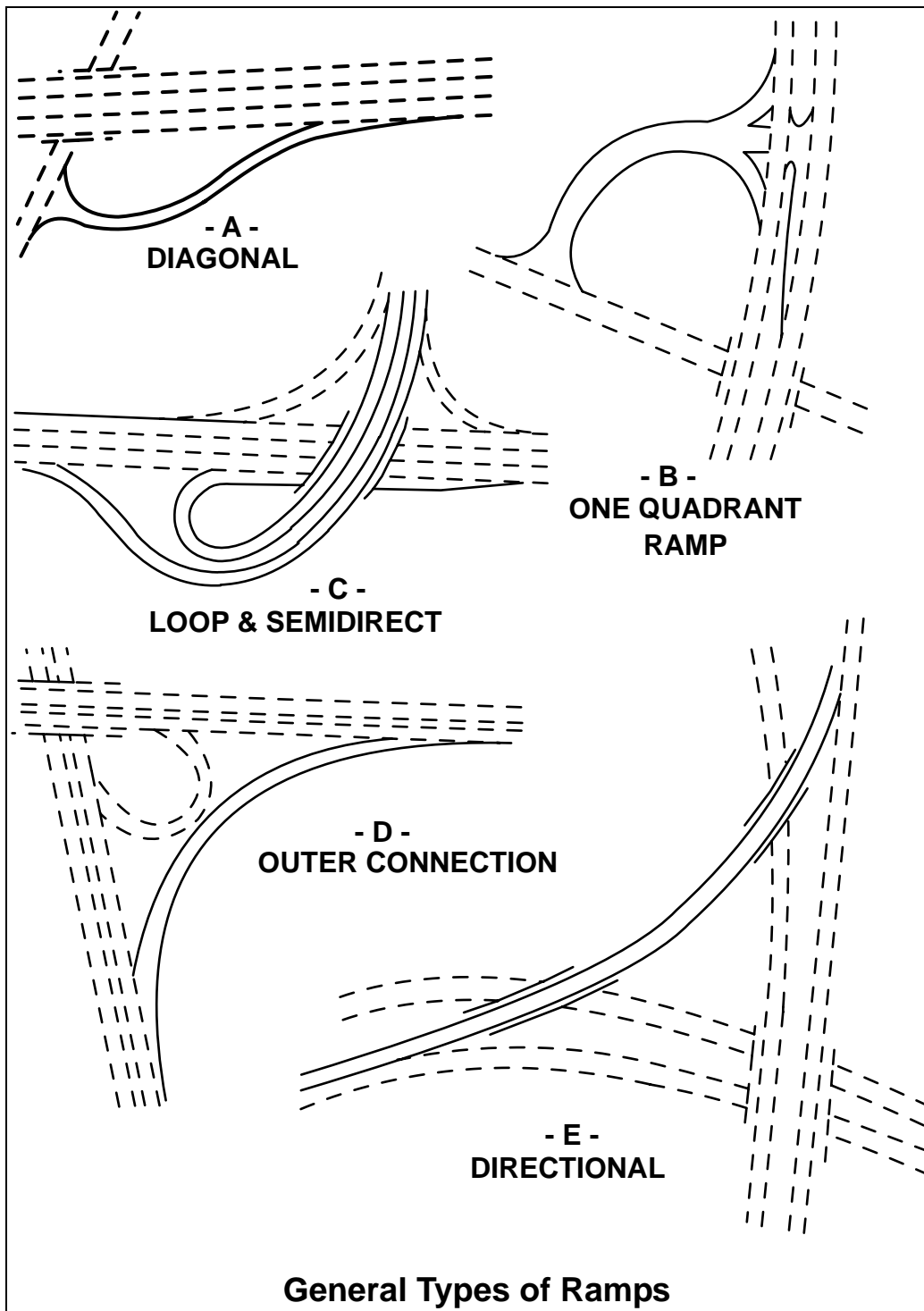


Figure 5-2: Types of Freeway Ramps

(Reference 5)

There are a number of variables that influence the operation of ramp-freeway junctions. They include all of the attributes affecting basic freeway segment operation (e.g., number of lanes and lane widths, lateral clearances, terrain and grades, degree of curvature) There are additional parameters of particular importance to the operation of ramp-freeway junctions, including length and type (taper, parallel) of acceleration/deceleration lanes, sight distances, speed, and lane distribution and free flow speeds of upstream freeway traffic.

The length of the acceleration or deceleration lane has a significant effect on merging and diverging operations. Short lanes provide on-ramp vehicles with restricted opportunity to accelerate before merging and off-ramp vehicles with little opportunity to decelerate off-line. The result is that most acceleration and deceleration must take place on the mainline, which disrupts through vehicles. Short acceleration lanes also force many vehicles to slow significantly and even stop while seeking an appropriate gap in the traffic stream. The free flow speed of the freeway is also an influential factor, since it determines the speed at which merging vehicles enter the acceleration lane and the speed at which diverging vehicles must enter the ramp. This, in turn, determines the amount of acceleration or deceleration that must take place.

Like the freeway, enhancements to many of these ramp parameters (e.g., length, grade, curvature, sight distance) will require major reconstruction. Other ramp and interchange attributes – such as number of ramp lanes and lane widths, and the length of acceleration and deceleration lanes – may be modified through relatively low cost projects (similar to those discussed above for the freeway) to improve operations.

5.7 OTHER IMPROVEMENTS

Certain types of collisions may be reduced and / or their severity lessened by the implementation of specific corrective measures. This section provides an overview of some of these that may be considered in the overall context of freeway management and operations.

5.7.1 Roadside Obstacles

AASHTO (5) recommends the following priorities for treatment of roadside obstacles on existing highways:

- Remove the obstacle or redesign so it can be safely traversed
- Relocate the obstacle to a point where it is less likely to be struck
- Reduce the severity of impact with the obstacle using an appropriate breakaway device
- Redirect the vehicle by shielding the obstacle with a longitudinal traffic barrier and / or crash cushion
- Delineate the obstacle if the above alternatives are not appropriate

It is noted that the design of guardrail and barrier systems has had considerable research. References include the AASHTO Roadside Design Guide and NCHRP Report 350 (“Recommended Procedures for the Safety Performance of Highway Features”). These publications note that the treatment of end sections of guardrail or a barrier is of particular concern.

5.7.2 Skid Resistance

Skidding crashes are a major concern in highway safety. It is not sufficient to attribute skidding crashes merely to “driver error” or “driving too fast for existing conditions.” The roadway should

provide a level of skid resistance that will accommodate the braking and steering maneuvers that can reasonably be expected for the particular site.

Highway geometrics affect skidding. Therefore, skid resistance should be a consideration in the design of all new constructions and major reconstruction projects. Vertical and horizontal alignments can be designed in such a way that the potential for skidding is reduced. Also, improvements to be vertical and horizontal alignments should be considered as a part of any reconstruction project (5).

Pavement types and textures also affect a roadway's skid resistance. The four main causes of poor skid resistance on wet pavement are rutting, polishing, bleeding, and dirty pavements. Rutting causes water accumulation in the wheel tracks. Polishing reduces the pavement surface microtexture and bleeding can cover it. In both cases, the harsh surface features needed for penetrating the thin water film are diminished. Pavement surfaces will lose their skid resistance when contaminated by oil drippings, layers of dust, or organic matter. Measures taken to correct or improve skid resistance should result in the following characteristics: high initial skid resistance durability, the ability to retain skid resistance with time and traffic, and minimum decrease in skid resistance with increasing speed (5).

Tining during placement leaves indentations in the pavement surface and has provided to be effective in reducing the potential for skidding on wet roadways with Portland cement concrete surfaces. The use of surface courses or overlays constructed with polish-resistant coarse aggregate is the most widespread method for improving the surface texture of bituminous pavements. Overlays of open-graded asphalt friction courses are quite effective because of their frictional and hydraulic properties. For further discussion, refer to the AASHTO Guidelines for Skid Resistant Pavement Design.

5.7.2.1 Grooving

Another potential solution to correcting a pavement surface with low skid resistance may be modification of the existing surface rather than the application of a new surface. Grooving is a technique of altering the existing pavement surface to greatly increase the texture, thereby facilitating the displacement of water by tires. When a tire rolls over a rain-soaked surface, water forms a layer between the tire and pavement, and a portion of the tire is raised off the surface. The water pressure increases with the speed of the vehicle, lifting more and more of the tire, until the tire loses contact with the pavement. This situation – where the tire (and vehicle) floats above the road surface on a layer of water – is known as hydroplaning. If the tire is not actually touching the road or runway surface, it's impossible to steer or brake, significantly increasing the chance for a crash or other accident. The grooved pavement provides escape routes for water compressed between the tire tread and the road. The grooves restore friction performance to worn or smooth pavement surfaces, enhancing braking and cornering under wet conditions because more of the tire's surface is on the pavement rather than on water. Various specifications for grooving can be found on the website for the International Grooving and Grinding Association (www.igga.org).

In addition to the often-dramatic reduction in wet weather accidents, grooving can be accomplished with minimal disruption to traffic –only one lane needs to be closed at a time, and traffic can use the grooved pavement shortly thereafter. There are some potential disadvantages to grooving, including (5):

- Grooving can't be used for bituminous concrete unless the asphalt is well cured; otherwise spalling of the grooves occurs.
- Use of studded ties and chains reduces the service life of the grooved pavement
- Motorcyclists and drivers of small cars may have a sensation of instability

It is also noted that while grooving reduces wet weather accidents, the pavement skid resistance as measured by conventional means does not increase significantly.

5.7.3 Emergency Escape Ramps

The AASHTO publication "A Policy on Geometric Design of Highways and Streets" (5) discusses emergency ramps at length. The following is a summary taken from the AASHTO document.

- Need for Emergency Escape Ramps – Each grade has its own unique characteristics. Highway alignment, gradient, length, and descent speed contribute to the potential for out-of-control vehicles. For existing highways, law enforcement officials, truck drivers, or the general public will often report operational problems on a downgrade. A field review of a specific grade may reveal damaged guardrail, gouged pavement surfaces, or spilled oil indicating locations where drivers of heavy vehicles had difficulty negotiating a downgrade.
- Location of Escape Ramps – Ramps should be located to intercept the greatest number of runaway vehicles, such as at the bottom of the grade and at intermediate points along the grade where an out-of-control vehicle could cause a catastrophic crash. Escape ramps generally may be built at any practical location where the main road alignment is tangent. They should be built in advance of horizontal curves that cannot be negotiated safely by an out-of-control vehicle and in advance of populated areas. Escape ramps should exit to the right of the roadway.
- Design Considerations –The alignment of the escape ramp should be tangent or on very flat curvature to minimize the driver's difficulty in controlling the vehicle. The width of the ramp should be adequate to accommodate more than one vehicle because it is not uncommon for two or more vehicles to have need of the escape ramp within a short time. The entrance to the ramp should be designed so that a vehicle traveling at a high rate of speed can enter safely – an auxiliary lane may be appropriate to assist the driver to prepare to enter the escape ramp. Access to the ramp should be made obvious by advance signing to allow the driver of an out-of-control vehicle time to react, so as to minimize the possibility of missing the ramp. Regulatory signs near the entrance should also be used to discourage other motorists from entering, stopping, or parking at or on the ramp.

5.8 REFERENCES

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6. ROADWAY OPERATIONAL IMPROVEMENTS

6.1 INTRODUCTION

In theory, the problems of congestion, safety, mobility, etc. would dissolve with increases in capacity (i.e., adding more lanes, and new facilities) and the reconstruction of existing facilities (wider lanes and shoulders, improved alignment and geometrics) to improve safety. However, such major roadway improvements (briefly discussed in the previous chapter) introduce significant economical, political, financial, and societal challenges, many of which cannot (and perhaps should not) be overcome. Operational improvements often provide alternative, less expensive, and more practical approaches for addressing freeway problems.

The rest of this Handbook is devoted to a discussion of these operational strategies and the enabling technologies, including ramp management and metering (Chapter 7), managed lane concepts (Chapter 8), HOVs (Chapter 9), traffic incident management (Chapter 10), planned special event management (Chapter 11), freeway management during emergencies and evacuations (Chapter 12), traveler information (Chapter 13), transportation management centers (Chapter 14), surveillance and detection (Chapter 15), regional integration (Chapter 16), and communications networks (Chapter 17). As noted in Chapter 1, each of these operational approaches and strategies works effectively under specific conditions. And while most improvements individually achieve only modest reductions in congestion, when combined together in an overall freeway management program, they can provide significant improvements. Moreover, they can significantly improve the efficiency of the existing network, while increasing the reliability and safety of the transportation system operation.

It is interesting to note that all of the operational strategies and technologies discussed in the subsequent chapters of this Handbook have some relationship with the National ITS Architecture¹², whether it be user services, market packages, subsystems / links in the architecture diagram, or some combination. But as emphasized in earlier chapters, Intelligent Transportation Systems should not be confused with improved operations. ITS can be a significant subset / enabler of improved operations – for example ITS can provide real time information on the traffic flows; but operations is knowing what to do with this information to improve traffic flow, safety, and mobility. Moreover, several other strategies – that have little or nothing to do with ITS – can be implemented to enhance the operation of the freeway. Examples include low – cost roadway improvements (as discussed in Chapter 5); and the actions discussed in this Chapter.

6.1.1 Purpose of Chapter

This chapter provides a high-level overview of potential actions – specifically static signing, pavement markings, and roadway lighting – that do not modify the roadway footprint or geometry; nor are they usually considered in the context of “real-time” freeway management strategies and enabling technologies. Nevertheless, such operational improvements can improve the operation of the freeway, particularly in terms of safety and driver convenience and comfort. An overview of Travel Demand Management (TDM) strategies is also provided at the

¹² Additional information regarding the National ITS Architecture, including references, is provided in Chapter 3 herein.

end of this chapter. It is emphasized that this chapter only provides an introduction to these other operational improvements and strategies. For additional details and design guidelines, the practitioner should consult a variety of references, many of which are identified at the end of this chapter.

6.2 BACKGROUND AND OVERVIEW

Static signing, pavement markings, and roadway lighting can enhance the safety of the freeway and overall driver convenience. Signs and markings, by their very nature and purpose, serve to regulate, to guide, to warn, and to channelize traffic into proper position on the roadway; and this contributes to safer operation of the freeway. Improved visibility – as provided by illumination – can also contribute to safety and driver comfort.

6.2.1 Key Considerations During Freeway Management Program Development

Static signing (including speed zoning), pavement markings, and roadway lighting are all integral parts of the initial process to plan, design, and construct (or reconstruct / rehabilitate) a freeway facility. In many respects, they may be considered a “prerequisite” for freeway operations, as the freeway infrastructure really can’t be opened to traffic without including the appropriate signing, markings, lighting, etc. However, just because they have been in place and operating since “day 1”, does not preclude the need to routinely evaluate the performance of these attributes (and all freeway management and operation strategies for that matter), and to identify and implement improvements as may be required.

It is therefore important that the freeway performance monitoring effort (discussed in Chapter 4) include measures that can help identify problems associated with inadequate signing, markings, and / or lighting. For example, a large number of night-time accidents might indicate the need for improved lighting; a large number of accidents involving single vehicles running off the road can indicate the need for better signage (e.g., chevron alignment signs) and edge treatments (e.g., markings, rumble strips); and a history of collisions and / or a wide variance in speeds in the vicinity of and interchange might point to problems with guide signing.

6.2.2 Relationship to Other Freeway Management Activities

Static signing, markings, and lighting are integral parts of the other operational improvements discussed in this Handbook. For example:

- The Manual on Uniform Traffic Control Devices (MUTCD – Reference 1) includes specific sections on signing for preferential lanes and HOV lanes (2B.48 – 50), signing for emergency management (2I), markings for preferential lanes and HOV lanes (3B.22 – 23), as well as signing for ramp metering.
- Signing is an important element of many incident management programs, such as overpass names and 0.1- mile markers to help cellular phone users in identifying the specific location of crashes and other incidents that they report.
- In an area of inadequate geometrics that is experiencing a significant number of collisions, signing (speed and / or warning) may prove effective as an interim solution until the geometric deficiencies can be corrected.

6.3 TRAFFIC CONTROL DEVICES

Communication with the freeway motorist is a complex problem. The Manual on Uniform Traffic Control Devices (MUTCD – Reference 1) is the national standard for traffic control devices and their application. The Manual presents criteria for the design and uniform application of signing, signalization, painted channelization, and pavement markings. This Manual's text also specifies the restriction on the use of a device if it is intended for limited application or for a specific system.

The purpose of traffic control devices, as well as the principles for their use, is to promote highway safety and efficiency by providing for the orderly movement of all road users on streets and highways throughout the Nation. Traffic control devices notify road users of regulations and provide warning and guidance needed for the safe, uniform, and efficient operation of all elements of the traffic stream. To be effective, a traffic control device should meet five basic requirements:

- Fulfill a need;
- Command attention;
- Convey a clear, simple meaning;
- Command respect from road users; and
- Give adequate time for proper response.

The following aspects of traffic control devices should be considered to ensure that the above criteria are met: design; placement and operation; maintenance; and uniformity. Vehicle speed should be carefully considered as an element that governs the design, operation, placement, and location of various traffic control devices. (1)

6.3.1 Static Signs

Section 2 of the MUTCD addresses traffic signs¹³, defined as a device mounted on fixed or portable support whereby a specific message is conveyed by means of words or symbols placed for the purpose of regulating, warning, or guiding traffic. The MUTCD defines signs by their function as follows – regulatory, warning, and guide.

6.3.1.1 Regulatory Signs

Regulatory signs give notice of traffic laws or regulations, the violation of which constitutes a misdemeanor or felony. Freeway examples include speed limit signs, lane use control signs, truck prohibitions, DO NOT ENTER, and preferential (Diamond / HOV) lane signs.

One of the most common regulatory signs on freeways is the speed limit. For those segments where the statutory speed limit (e.g., 55, 65, or 70 mph, depending on the State) is inappropriate, a reasonable speed limit must be established and posted via speed zoning. These speed zones are based on normal traffic conditions and favorable weather. Drivers have the responsibility to adjust their speed in adverse conditions (or variable speed limits may be implemented as discussed in Chapter 8 on Managed lanes).

Reference 2 (Fundamentals of Traffic Engineering) addresses speed zones, stating that (per state vehicle codes) a systematic survey of physical and traffic conditions on the highway

¹³ Signs for work zones are addressed in a Section 6 of the MUTCD.

section is required before a speed zone is established. The following items should be considered in the survey:

- *Spot Speed Distribution.* The behavior of traffic provides one indication of the appropriate speed limit on a highway section. Speed limits are typically set at the 85th percentile speed (subject to the maximum speed established by state law).
- *Standard Deviation of the Speed Distribution.* The dispersion or spread of its speeds is a good indicator of the efficiency and safety of a traffic stream. Locations with broad speed distributions often indicate an artificially low speed limit and the need to modify the limit.
- *Accident Experience.* Crash patterns on a road segment may indicate the need for a lower or higher speed limit. For example, a higher limit may result in a more uniform traffic flow, increasing some speeds at the low end of the distribution and reducing the speed of some fast drivers because of the more reasonable limit; while excessive speed is often cited as a contributing factor to single-vehicle run-off-the-road crashes.
- *Traffic Volumes.* At higher volumes it is especially important that the speed distribution's spread be as low as possible, both for capacity and safety reasons.

Other factors to be considered include interchange frequency and spacing, the simultaneous impacts of horizontal and vertical curve alignment, and the roadside environment and potential distractions (e.g., advertising signage).

6.3.1.2 Warning Signs

Warning signs call attention to unexpected conditions on or adjacent to a highway that might not be readily apparent (e.g., physical features such as curves, grades, low clearances, etc., and intermittent conditions such as gusty winds and icy roads). Warning signs alert road users to conditions that might call for a reduction of speed (i.e. speed warning) or an action in the interest of safety and efficient traffic operations. In addition to the "diamond" - shaped warning signs, chevron alignment signs are often appropriate on sections of roadway and ramps where curvature requires additional warning.

The MUTCD (1) states that "the use of warning signs should be kept to a minimum as the unnecessary use of warning signs tends to breed disrespect for all signs. In situations where the condition or activity is seasonal or temporary, the warning sign should be removed or covered when the condition or activity does not exist." Additional guidance is provided as summarized below:

- The use of warning signs shall be based on an engineering study or on engineering judgment.
- Warning signs should be placed so that they provide adequate PIEV time, where PIEV time represents the total time needed to perceive and complete a reaction to a sign; the sum of the times necessary for **P**erception, **I**dentification (understanding), **E**motion (decision making), and **V**olition (execution of decision). A table of advance placement distances is provided for various posted speed limits and conditions (e.g., stopping required, high judgment required, deceleration to a posted advisory speed).

- Minimum spacing between warning signs with different messages should be based on the estimated PIEV time for driver comprehension of and reaction to the second sign.
- Warning signs should not be placed too far in advance of the condition, such that drivers might tend to forget the warning because of other driving distractions, especially in urban areas.
- The effectiveness of the placement of warning signs should be periodically evaluated under both day and night conditions.

In many instances, it may be possible to have “activated” warning signs – that is, signs coupled with surveillance devices that automatically indicate to a driver that he or she is moving faster than the recommended speed or is overweight (as indicated on the warning sign).

6.3.1.3 Guide Signs

Guide signs show route designations, destinations, directions, distances, services, points of interest, and other geographical, recreational, or cultural information that may help drivers on their trips. The MUTCD (1) states that guide signs on freeways and expressways should serve distinct functions as follows:

- Give directions to destinations, or to streets or highway routes, at intersections or interchanges;
- Furnish advance notice of the approach to intersections or interchanges;
- Direct road users into appropriate lanes in advance of diverging or merging movements;
- Identify routes and directions on those routes;
- Show distances to destinations;
- Indicate access to general motorist services, rest, scenic, and recreational areas; and
- Provide other information of value to the road user.

The 15th edition of “Fundamentals of Traffic Engineering” (2) addresses directional signing on high-speed highways as follows: “High traffic speeds and the complex interchanges found on modern freeways present a special directional signing problem. Control devices must guide motorists to the correct lane or off-ramp, and must begin this guidance sufficiently early to minimize last-minute lane changes. Unfamiliar drivers must rely almost entirely on signing to reach their destination.” The MUTCD (1) further notes that “route signs and directional signs should be used frequently because they promote safe and efficient operations by keeping road users informed of their location”. Examples of directional signing include:

- Signed route numbers. The MUTCD (1) now requires that all numbered routes be identified with signs.
- Cross-street names, required in larger cities to inform motorists of their approximate location. Freeways often lack clearly distinguishable landmarks adjacent to the roadway.
- Numbered Interchanges. The MUTCD (1) requires the numbering of interchanges on freeways, and recommends kilometer (mile) post numbering rather than consecutive numbering.

- Kilometer (Mile) posts must be placed on all freeways (Ref. 1). Numbering begins at the south or west state border, or at the south or west beginning of the route. The MUTCD (1) also states that Reference Posts (e.g., mile markers at 0.1 mile intervals) may be installed along any section of a highway route to assist road users in estimating their progress, to provide a means for identifying the location of emergency incidents and traffic accidents, and to aid in highway maintenance and servicing.
- Use of diagrammatic signs (i.e., guide signs that show a graphic view of the exit arrangement in relationship to the main highway, as shown in Figure 6-1) has been shown to be superior to conventional guide signs for some interchanges. (1)

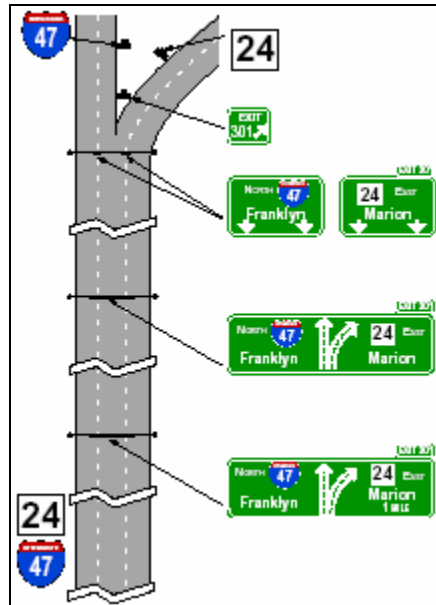


Figure 6-1: Example of Diagrammatic Signing (Figure 2E-7 from MUTCD)

- Motorist service signs provide directions to food, fuel, lodging, hospitals, telephones, and similar services. This type of guidance is essential in advance of freeway exits because the business themselves may not be visible from the roadway.
- Recreation and cultural interest area signs guide road users to a general area and then to specific facilities or activities within the area. Recreational or cultural interest areas are attractions or traffic generators that are open to the general public for the purpose of play, amusement, or relaxation. Recreational attractions include such facilities as parks, campgrounds, gaming facilities, and ski areas, while examples of cultural attractions include museums, art galleries, and historical buildings or sites.

6.3.1.4 Sign Location and Placement

The standard placement for most signs is on the right-hand side of the roadway facing approaching traffic; supplementary signs in other locations may be used. Signs should be placed to be visible only to the traffic for which they are intended. The following principles should govern the longitudinal and lateral placement of signs.

Longitudinal Placement – The longitudinal placement of a sign must be coordinated with roadside features, including existing guardrail and other signs.

- Regulatory signs are normally placed at or near the location where the regulation exists or begins (e.g., truck restriction, speed zone); additional signs may be used where a regulation (e.g., speed limit) continues over an extended section of highway.
- Warning signs are typically placed in advance of the hazard. Guidance for the longitudinal placement of warning signs (e.g., PIEV time) is discussed in previous section 6.3.1.2.
- Guide signs are often placed in advance of an intersection or junction; others, such as street name signs and kilometer (mile) posts, are located at the point where they apply.

Positive guidance principles require that messages be spread over time and distance, with preference normally given first to regulatory, then to warning, and finally to guidance messages. Within these categories, priority should be given to more critical upcoming elements (e.g., CURVE AHEAD) rather than general warnings (e.g., DEER CROSSING).

Lateral Placement -- Laterally, signs should be placed within the driver's cone of vision, but not so close that they constitute a hazard to an errant vehicle. The MUTCD (1) states that overhead signs should be used on expressways, where some degree of lane-use control is desirable, or where space is not available at the roadside. Overhead signs have value at many locations. The factors to be considered for the installation of overhead sign displays are not definable in specific numerical terms. The following conditions (not in priority order) may be considered in an engineering study to determine if overhead signs should be used:

- Traffic volume at or near capacity
- Complex interchange design
- Three or more lanes in each direction
- Restricted sight distance
- Closely spaced interchanges
- Multilane exits
- Large percentage of trucks
- Street lighting background
- High-speed traffic
- Consistency of sign message location through a series of interchanges
- Insufficient space for ground-mounted signs
- Junction of two freeways
- Left exit ramps

Overhead sign installations should be illuminated unless an engineering study shows that retroreflectorization alone will perform effectively.

The freeway practitioner needs to be careful not to end up with too many signs. Regulatory and warning signs should be used conservatively because these signs, if used to excess, tend to lose their effectiveness (1). Additionally, locations with potential for information overload should be identified and corrected (3). Urban freeways and expressways are prime candidates for information overload. The MUTCD (1) identifies the following special sign treatments that may be desirable in these instances:

- Use of Interchange Sequence signs instead of the Advance Guide signs for the affected interchanges. (Figure 6-2)

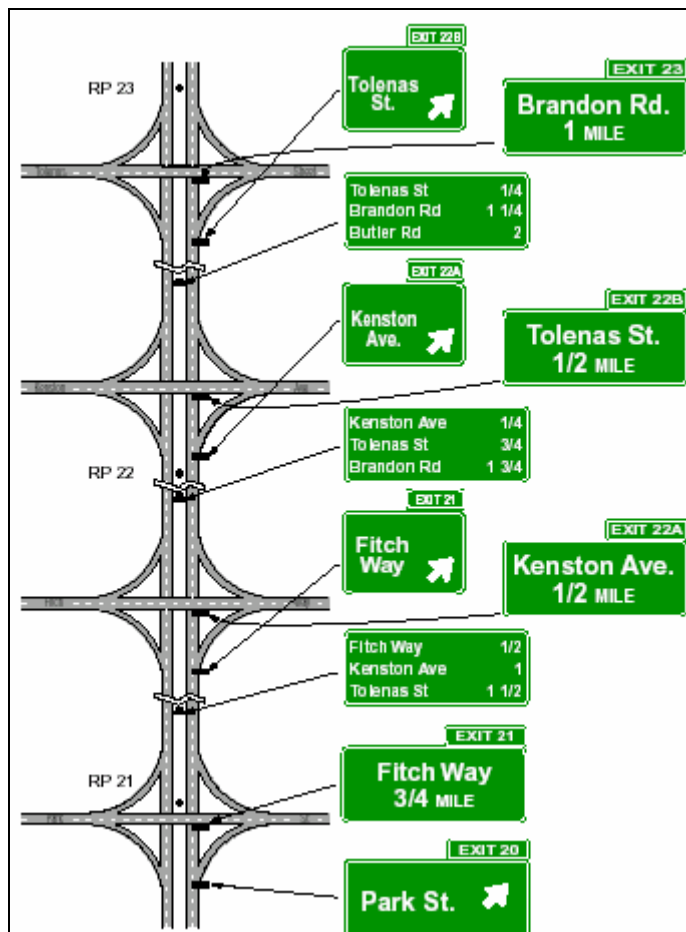


Figure 6-2: Interchange Sequence Signs (Figure 2E-21 from MUTCD)

- Use of sign spreading to the maximum extent possible (Note – Sign spreading is a concept where major overhead signs are spaced so that road users are not overloaded with a group of signs at a single location.)
- Elimination of service signing (e.g., fuel, telephone)

- Display of advance signs at distances closer to the interchange, with appropriate adjustments in the legend
- Use of overhead signs on roadway structures and independent sign supports
- Use of diagrammatic signs in advance of intersections and interchanges

Finally, the practitioner must recognize that signs are easily damaged due to impact or vandalism. Over time their visual quality will degrade due to dirt and normal reflectivity deterioration. An agency's decision to install signs must also include a commitment to continually maintain the device.

6.3.2 Pavement Markings

Markings on highways have important functions in providing guidance and information for the road user. Major marking types include pavement and curb markings, object markers, delineators, barricades, channelizing devices and islands. In some cases, markings are used to supplement other traffic control devices such as signs, signals and other markings. In other instances, markings are used alone to effectively convey regulations, guidance, or warnings in ways not obtainable by the use of other devices (1). Specifically, markings are used to:

- Display regulation (e.g., no passing)
- Supplement signs and other devices (e.g., symbol arrows, stop bars at metered ramps).
- Guide traffic (e.g., lane lines and edge lines)
- Warn traffic (e.g., delineate gore areas).

The standards and recommendations contained in Section 3 of the MUTCD (1) provide a basis for achieving uniformity of markings. Those markings most applicable to freeways are summarized below:

- **Lane lines** are helpful in guiding traffic and in achieving efficient utilization of the roadway. They are required on all freeways and Interstate highways. Lane lines are normally broken white lines, but a single solid line may be used to discourage lane changes. Where crossing the lane line markings is prohibited, the lane line markings shall consist of two normal solid white lines.
- **Lane reduction transition** markings should be used whenever the number of lanes decreases. The transition is accomplished using a taper with a length given by equations included in the MUTCD.
- **Pavement edge lines** are required by the MUTCD on all freeways and expressways. Pavement edge lines on the right side of the road are white and those on the median side are yellow.
- **Channelizing lines** (often referred to as gore striping) may be used to form channelizing islands where traffic traveling in the same direction is permitted on both sides of the island. A channelizing line shall be a wide or double solid white line, and other pavement markings in the channelizing island area shall also be white. New striping can provide more visible patterns in ramp gore areas. Gore striping can be very important on urban freeways, especially on drop lanes. As shown in Figure 6-3, channelizing lines at exit ramps define the

neutral area, direct exiting traffic at the proper angle for smooth divergence from the main lanes into the ramp, and reduce the probability of colliding with objects adjacent to the roadway. At entrance ramps (Figure 6-4) they promote safe and efficient merging with the through traffic. White chevron markings may be placed in the neutral area for special emphasis. These markings need to be highly visible, wear well, and often have some type of tactile element to them (e.g., raised markers) to alert drivers that they are crossing the neutral zone

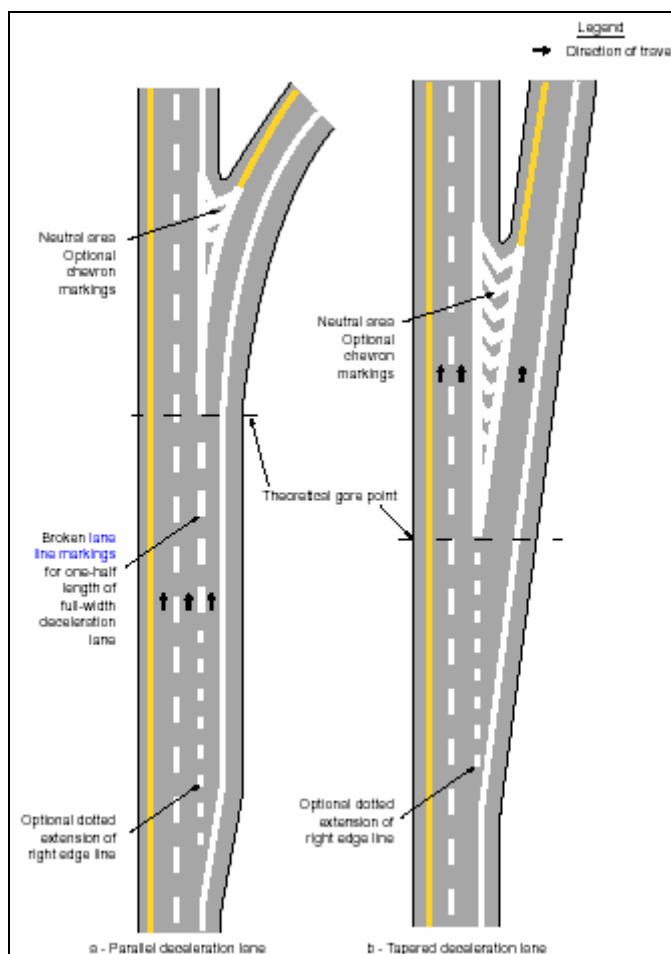


Figure 6-3: Exit / Lane Drop Markings (Figure 3B-8 / Sheet 1 from MUTCD)

Markings have limitations. Visibility of the markings can be limited by snow, debris, and water on or adjacent to the markings. Marking durability is affected by material characteristics and traffic volumes. Accordingly, markings must be maintained and replaced on a recurring basis. In fact, an important consideration for freeway management and operations is the material used in markings. Paint, while the least expensive material, wears the quickest and requires the most frequent renewal. Moreover, moving painting operations can only occur at night on heavily traveled freeways. The cost of renewed pavement markings and the potential for collisions

during these repainting operations can make paint less attractive than methyl – methacrilite or thermo-plastic.

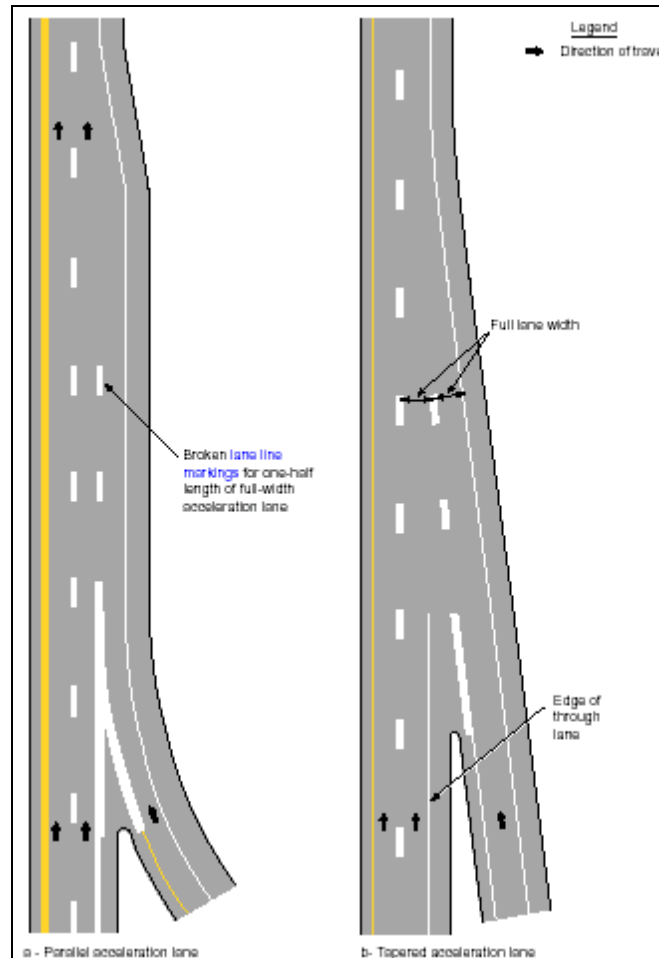


Figure 6-4: Entrance Ramp Markings (Figure 3B-9 from MUTCD)

6.3.2.1 Other Markings

In addition to pavement markings, other forms of marking are addressed in Section 3 of the MUTCD (1) that can enhance roadway delineation and hazard awareness. These include:

- **Raised pavement markings** are defined as devices with a height of at least 10 mm (0.4 in) mounted on or in a road surface that are intended to be used as a positioning guide, or to supplement or substitute for pavement markings. The MUTCD addresses several applications, including their use as vehicle positioning guides with longitudinal markings, as a supplement to other markings, and as a substitute for pavement markings. With respect to the latter application, retroreflective or internally illuminated raised pavement markers, or nonretroreflective raised pavement markers supplemented by retroreflective or internally illuminated markers, may be substituted for markings of other types; although raised pavement markers should not substitute for right edge line markings.

- **Object markers** are used to mark obstructions within or adjacent to the roadway. These markers may consist of yellow retroreflectors mounted symmetrically, horizontal, or vertically on a panel; or a striped marker consisting of a vertical rectangle with alternating black and retroreflective yellow stripes sloping downward at an angle of 45 degrees toward the side of the obstruction on which traffic is to pass.
- **Delineators** (also referred to as guideposts) are retroreflective devices mounted above the roadway surface and along the side of the roadway in a series to indicate the alignment of the roadway. They are considered guidance devices rather than warning devices. Delineators are particularly beneficial at locations where the alignment might be confusing or unexpected, such as at lane reduction transitions and curves. Delineators are effective guidance devices at night and during adverse weather. An important advantage of delineators in certain locations is that they remain visible when the roadway is wet or snow covered. The color of delineators must conform to the color of edge lines. The MUTCD requires that single delineators be provided on the right side of expressways and freeways and on at least one side of interchange ramps, except in a few cases (e.g., on sections of roadways where continuous lighting is in operation between interchanges). Guidance on delineator placement and spacing for tangent and curved sections is also provided in the MUTCD.

6.3.3 Rumble Strips

Addressed in Part VI of the MUTCD, rumble strips may be considered another form pavement marking. Rumble strips are raised or grooved (indented) patterns installed on the pavement surface of a travel lane or a shoulder intended to alert inattentive drivers through vibration and sound that their vehicles are leaving the travel lane. On divided highways, they are typically installed on the median side of the roadway as well as the outside (right) shoulder.

Run – off – the road (ROR) crashes account for almost one – third of the deaths and serious injuries each year on the Nation’s highways. Inattentive driving (due to distractions or fatigue) has been identified as a significant causal factor in many of these crashes. A number of studies have demonstrated the benefits of shoulder rumble strips in reducing death and serious injury caused by inattentive drivers in ROR crashes (8). For example (as reported in Reference 2), Caltrans has evaluated many of its safety projects to determine what has been effective. On average, rumble strips resulted in a 50 % reduction in “drift off road accidents”.

Rumble strips will not eliminate ROR crashes caused by excessive speed, sudden turns to avoid on-road collisions, or high-angle encroachments. Because they are intended to alert drivers "drifting" off the road, rumble strips are most effective when installed near the edge line adjacent to relatively wide shoulders. This placement provides motorists leaving the traveled way at a shallow angle with both time and space to steer back onto the roadway safely. Most states offset shoulder rumble strips just outside the edge line of the travel lane by a distance of 100 mm (4 in) to 300 mm (12 in). This keeps the strip elements some distance from the construction joint between the travel lane and shoulder; helps reduce the number of inadvertent hits from passing traffic, especially larger trucks; and allows for a substantial width of the paved shoulder to remain available for other users of the shoulder. Rumble strips installed at the outside edge of a shoulder with no useable recovery area beyond the shoulder are of

questionable value. Long sections of relatively straight roadways that make few demands on motorists are the most likely candidates for the installation of shoulder rumble strips (8).

Reference 8 (FHWA Technical Advisory on Roadway Shoulder Rumble Strips) provides additional information regarding rumble strip types (e.g., milled – in, rolled – in, formed, raised), design practices (e.g., location, spacing), installation, and other references on the subject. It also provides the following recommendations:

- Continuous, milled shoulder rumble strips should be installed on rural freeways and expressways as an effective means of reducing single vehicle, run-off-road crashes caused primarily by any form of motorist inattention. While they may be installed on a project-by-project basis, economies of scale and timely implementation of shoulder rumble strips make system-wide installation projects highly desirable.
- Regardless of the type of rumble strip element installed, shoulder rumble strip usage should be coupled with continuing driver behavior safety programs aimed at educating the general driving public on the dangers of drowsy and inattentive driving.
- Rumble strips should not normally be used in urban or suburban areas or along roadways where prevailing speeds are less than 80 km/h (50 mph).
- Where rumble strips are being installed for the first time or where their use might be unexpected, appropriate signs and pavement markings alerting both motorists and cyclists to their presence are advisable.

6.4 ROADWAY LIGHTING

The modern freeway provides an alignment and profile that, together with other factors, encourages high operating speeds. Although improved design has produced significant benefits, it has also created potential problems. For example, driving at night at high speeds may lead to reduced forward vision – that is, the inability of headlights to illuminate objects in the driver's path in sufficient time for some drivers to respond. (4).

The addition or enhancement of roadway lighting can improve seeing conditions and visibility at night, thereby improving throughput (higher night speeds are possible) and safety. The objectives of roadway lighting are as follows:

- Promotion of safety at night by providing quick, accurate, and comfortable seeing for drivers and pedestrians.
- Improvement of traffic flow at night by providing light, beyond that provided by vehicle lights, which aids drivers in orienting themselves, delineating roadway geometrics and obstructions, and judging opportunities for overtaking.
- Illumination in long underpasses and tunnels during the day to permit drivers entering such structures from the open to have adequate visibility for safe vehicle operation.

- Reduction of crime after dark (While not an issue, per se, on a freeway itself; it is an important consideration in the design of rest areas and crash investigation sites along the freeway).

In 1989, a task force of the Illuminating Engineering Society of North America, reported on a study made to determine the benefits of roadway lighting. Essentially, this report concluded: adequate lighting that is properly designed, installed, and maintained can usually significantly reduce night accidents. AASHTO's "Informational Guide for Roadway Lighting" (4) states, "many researchers have shown roadway lighting to reduce accident occurrence and incidences of crime and vandalism." As reported in Reference 2, Caltrans has evaluated many of its safety projects to determine what has been effective. On average, lighting resulted in a 15 % reduction in night accidents.

Industry development and general experience on lighting of roadways has resulted in a reasonably well-developed technique for the design of lighting systems. For a given condition to be lighted (e.g., width of roadway / interchange area) and a known level of illuminance or luminance to be provided, there are accepted methods permitting ready analysis of different alternates in lamps, luminaires, mounting height, luminaire spacing and positioning, energy consumption, etc. to determine a preferred design (4). Guidance and criteria for designing lighting systems are provided in References 4 and 5, as well as other documents published by the Illuminating Engineering society of North America (www.iesna.org). Accordingly, the focus of this section of this Handbook is to provide an overview of definitions, criteria, and the potential issues associated with roadway lighting – basic information of which the freeway manager and operations practitioner should be cognizant.

6.4.1 Background and Definitions

The purpose of roadway lighting is to attain a level of visibility that enables the motorist (and pedestrian) to see quickly, distinctly, and with certainty all significant detail, notably the alignment of the road and any obstacles on or about to enter the roadway. Most aspects of traffic safety as related to roadway lighting involve visibility. The basic factors that influence visibility include: size, shape, and texture (i.e., identifying detail) of an object; general brightness of the roadway background; contrast between an object and its surroundings, and the contrast between pavement and its surroundings as seen by the observer; time available for seeing; vision capability of the observer / driver (and is often affected by age); the condition of the windshield; and glare.

With respect to the last item, glare may be defined as any light, either direct or indirect, which reduces the ability to see or produces a sensation of ocular discomfort. Many roadway lighting factors can affect glare, including the size of the light source, displacement angle of the source from the line of sight, illuminance at the eye, adaptation level, and exposure time and motion.

General definitions of several technical terms used in roadway lighting design are provided below:

- **Luminous Flux** – the rate of emission of luminous energy from a light source measured in all directions. The unit of measurement is the *lumen*.
- **Illuminance** – the density of luminous flux incident on a surface. The unit of illuminance is *lux*.

- **Luminance** (Photometric Brightness) – the luminous intensity of any surface in a given direction per unit of projected area of the surface as viewed from that direction. The term brightness usually refers to the intensity of sensation resulting from viewing surfaces or spaces from which light comes to the eye.
- **Luminaire** – a complete lighting unit consisting of a light source together with the parts (reflector and/or refractor) used to distribute the light, a socket to support and position the light source, amps, wiring terminals, and a housing.
- **Lighting Standard** – the complete assembly of a lighting standard (i.e., pole), bracket(s) or mast arm(s), and luminaire(s).
- **Light Loss Factor** – A depreciation factor which is applied to the initial average luminance or illuminance to determine the value of depreciated average luminance or illuminance at a predetermined time in the operating cycle (e.g., just prior to relamping). It reflects the decrease in effective light output of a lamp and luminaire over its life. It is made up of several factors, including decrease of lamp lumen output with burning hours, frequency and effectiveness of luminaire cleaning, specific equipment being used, and operation of the light source at other than rated current or voltage.
- **Uniformity of Illuminance** – the ratio of average illuminance on the pavement area to the minimum illuminance on the pavement. It is commonly called the uniformity ratio.
- **Reflectance** – the ratio of the light flux reflected by a surface to the incident flux. In the case of roadways it is affected by the surface characteristics and the viewing angle.

6.4.2 Lighting Criteria and Warrants

AASHTO (4) identifies several warranting conditions for the purpose of establishing a basis on which lighting for freeway sections may be justified. The warrants provide “minimum conditions which are to be met whenever an agency is contemplating lighting for new or existing projects. Meeting of the warrants does not obligate the highway agency to provide lighting.” Moreover, the warrants are not to be construed as the only criteria for justifying lighting. Local conditions, such as frequent fog, ice, snow, roadway geometry, ambient lighting, sight distance, signing, etc. could justify modification of these warrants in either a positive or negative way.”

Continuous Freeway Lighting – Continuous freeway lighting is considered to be warranted for the following cases:

- Sections in or near cities where the current ADT is 30,000 or more
- Sections where three or more interchanges are located with an average spacing of 1 ½ mile or less, and adjacent areas outside the right-of-way are substantially urban in character
- Sections with a length of two or more miles that pass through a substantially developed suburban or urban area in which one or more of the following conditions exist: (a) local traffic operates on a complete street grid having some form of street lighting, parts of which are visible from the freeway; (b) the freeway passes through a series of developments (e.g., residential, commercial, industrial, colleges, parks, terminals) which include roads and/or parking areas that are lighted; (c) separate cross streets, both with and without connecting ramps, occur with an average spacing of ½ mile or less, some of which are lighted; and (d)

the freeway cross section elements are substantially reduced in width below desirable sections used in relatively open country.

Complete Interchange Lighting – Complete interchange lighting is defined as the lighting of the freeway through traffic lanes through the interchange, the traffic lanes at all ramps, the acceleration and deceleration lanes, all ramp terminals, and the crossroad between the outermost ramp terminals (4). Such lighting is considered to be warranted for the following cases:

- Total current ADT ramp traffic entering and leaving the freeway within the interchange area exceeds 10,000 for urban conditions, 8,000 for suburban conditions, and 5,000 for rural conditions.
- Current ADT on the crossroads exceeds 10,000 for urban conditions, 8,000 for suburban conditions, and 5,000 for rural conditions.
- On unlighted freeways where existing substantial commercial or industrial development is located in the immediate vicinity of the interchange, and which is lighted during hours of darkness; or where the crossroad approach legs are lighted for ½ mile or more on each side of the interchange.
- Where the ratio of night to day accident rate within the interchange area is at least 1.5 or higher than the statewide average for all unlighted similar sections, and a study indicates that lighting may be expected to result in a significant reduction in night accident rate.
- Wherever there is continuous freeway lighting

Underpasses – An underpass is a portion of a roadway extending through or beneath some natural or man-made structure. Supplementary lighting might be required during the daytime as well as at night. Guidance provided by AASHTO (4) is summarized below:

- Length to height ratios of 10:1 or lower will not, under normal conditions, require underpass lighting during the daytime. When this ratio is exceeded, it is necessary to analyze the specific geometry and roadway conditions, including penetration of daylight on the roadway, to determine the need for daytime lighting. The transition from bright daylight to tunnel lighting, and back again to daylight must also be considered.
- Underpasses that are part of a freeway section with continuous lighting warrant the use of (nighttime) illumination; with the lighting levels and uniformities duplicating, to the extent practical, the lighting values of the adjacent roadways. If continuous lighting is not provided along the adjacent freeway sections, underpass lighting may still be warranted for nighttime conditions where unusual or critical roadway geometry occurs under or adjacent to the underpass area.

Special Situations

- Long tunnels¹⁴ require the use of artificial lighting or equivalent means to provide adequate roadway and tunnel user visibility necessary for safe and efficient traffic operation.

¹⁴ Reference 4 defines a tunnel as “long” if its portal-to-portal length is greater than the wet pavement minimum stopping distance.

- Any Rest Area offering complete rest facilities (including comfort station and picnic facilities) should be lighted, including the entrance and exit, the interior roadways, parking areas, and activity areas.
- Lighting of other specialized areas should be considered with respect to the needs of the motorist as well as the requirements of others interacting with the motorist. These other specialized areas include truck weighing stations, inspections and enforcement areas, park-and-ride lots, toll plazas, and escape ramps.

6.4.3 Roadway Lighting Design

For many years, roadway lighting was designed on the basis of pavement illuminance – the amount of light or luminous flux falling on the pavement surface. In 1983, the Illuminating Society of North America introduced a new design concept, that of luminance. Pavement luminance is more realistic in that it considers the luminous flux reflected per unit of pavement surface in the direction of a standardized observer. The current American National Standard Practice for Roadway Lighting (RP-8-00: Reference 5) allows the use of both the illuminance and luminance design methods, and also introduces the new concept of small target visibility (STV). STV permits an even more realistic consideration of the driving task, because it is based on the calculation of the visibility of a field of 180 x 180 mm targets located on an area of the pavement. It even considers the contrast between the target and the immediate background, the transient adaptation characteristics of the eye, and the visual capability of the driver.

The basic goal of roadway lighting design is to provide the appropriate levels and uniformity of luminance (or illuminance) of the pavement and of objects on or near the pavement. These depend on several items, including the following:

- **Lamps** – Various types of lamps may be used for roadway lighting, each with varying characteristics (e.g., initial light output as measured in lumens, light loss factor, color rendition, and lamp life). Lamp alternatives include fluorescent (used only for tunnel and sign lighting), mercury (blue-white color), and high-pressure sodium (golden-white color output) has been replacing the mercury lamp.
- **Luminaire Distribution Pattern** – The luminaire includes a reflector and usually a glass or plastic lens or refractor. The function of the reflector and refractor is to gather the light from the source, direct it toward the roadway, and shape it into a desired pattern on the roadway. Proper distribution of the light flux from the luminaire is an essential factor in good roadway lighting
- **Pavement Classification** – The texture and color of each type of pavement determines its reflectance, which affects the luminance produced by a given level of lighting.
- **Mounting Height** – The height of luminaires above the roadway surface varies from 5 m to more than 50 m. The lower mounting heights are used for tunnel and underpass lighting, and roadways located near or crossing aircraft approach zones. Conventional roadway lighting utilizes mounting heights of 9 to 15 m. The highest mounting heights involve groups of luminaires mounted on free standing poles or towers at 25 m (80 feet) to 55 m (180 feet) or more. This high mast lighting is used for area lighting such as freeway interchanges, roadways with wide cross sections, toll plazas, rest areas, and other complex road areas.

- **Luminaire Spacing** – It is usually in the interest of both good lighting and good economics to use larger lamps at reasonable spacing rather than smaller lamps at closer spacing and lower mounting heights. On wide roadways, pairs of luminaires opposite each other, mounted outside the roadway or in the median, may be required. The physical roadside conditions (e.g., sign structures, overpasses, guardrail, curvature, gore clearances) may restrict the placement and spacing of lighting poles. In general, sharp curves and steep grades require closer luminaire spacing in order to provide uniform pavement brightness. Specific location decisions must also consider access to luminaires for maintenance, visibility of traffic control devices, potential distracting shadows cast by overhead signs, and aesthetics (i.e., a pleasant daytime appearance). Safety must also be considered in determining lighting pole locations. It is desirable to place poles outside the roadside clear zone whenever practical; and if not, they should be designed with a breakaway feature.
- **Uniformity Ratios** – It is noted that the same average level of luminance (or illuminance) can be obtained by several different arrangements of these variables – for example, a few high-output light sources mounted relatively high, or a greater number of low-output sources mounted relatively low. A major factor of concern in comparing such alternative arrangements is the uniformity of luminance (or illuminance) over the traveled way to be lighted.

Other lighting design issues include cost, power consumption, and maintenance requirements (e.g., lamp replacement, access, electrical apparatus, skill levels). Moreover, the luminance (or illuminance) values should be regularly monitored and the lighting effectiveness evaluated as part of the on-going performance monitoring effort.

6.5 TRAFFIC DEMAND MANAGEMENT (TDM) CONSIDERATIONS

Based on principles adopted through the regional planning process, the goal of traffic operations functions may include redirecting traffic demand (from the freeway) through Traffic Demand Management (TDM) methods. Several TDM actions are an integral part of freeway management and operations (e.g., managed lanes), and are discussed in subsequent chapters. Other TDM actions go well beyond the scope of this Handbook. Nevertheless, freeway management practitioners should be acquainted with the entire TDM spectrum.

In its broadest sense, demand management is any action or set of actions intended to influence the intensity, timing and spatial distribution of transportation demand for the purpose of reducing the impact of traffic or enhancing mobility options. Such actions can include offering commuters one or more alternative transportation modes and/or services, providing incentives to travel on these modes or at non-congested hours, providing opportunities to better link or “chain” trips together, and/or incorporating growth management or traffic impact policies into local development decisions (6).

The traditional perspective of TDM was characterized as getting commuters away from driving alone and into carpools, vanpools, public transit, bicycles, walking, etc. This primary mission was supported through the provision of incentives and support services to enable this transition to occur. These support services included: guaranteed ride home, alternative / flexible work hours, preferential parking, and/or transit and vanpool benefit programs. A related mission was

to eliminate some commute trips entirely through the application of telecommuting, either at home or at a satellite center located near home, or implementing compressed week programs.

As discussed by Berman (7), a new, more contemporary model of TDM is emerging and needs to be recognized. TDM should now be viewed as the policies, programs and actions implemented to:

- Increase the use of commute alternatives
- Spread the timing of travel to less congested periods
- Reduce the need to travel, and/or
- Shift the routing of vehicles including trucks and single occupant vehicles to less-congested facilities or systems

This definition addresses mode choice, time choice, location choice, and route choice.

“Managing travel demand today is about providing travelers, regardless of whether they drive alone, with choices of location, route, and time, not just mode” (9).

This broader definition of TDM encompasses three key trends or enablers:

- **Information** in an accessible and timely format, including construction updates, incidents, emergencies, weather, real-time conditions on all transportation modes, real-time transit schedules, and transit – carpool availability
- **Technologies** that support the dissemination of this information, including navigation devices, Internet, GPS, and wireless communications.
- **Financial Incentives** such as tax incentives and credits, direct subsidies, cost sharing, and variable pricing.

These elements help enable the various aspects of TDM, including mode choice (how to travel) via preferential parking, transit / vanpool benefits, guaranteed ride home, traveler Information, and electronic road and parking pricing strategies and systems; time choice (when and how fast) via flexible schedules, compressed work weeks, express bus service, HOV lanes and high occupancy toll lanes, and road pricing; location choice (where and whether to travel) as supported by telecommuting; and route choice (which way to travel).

In the broadest sense, transportation demand management (TDM) is any action or set of actions intended to influence the intensity, timing, and spatial distribution of transportation demand for the purpose of reducing the impact of traffic or enhancing mobility options (1). A variety of government- and employer-sponsored programs can be designed to reduce vehicle trips during congested periods and in congested locations. These include flexible work schedules that allow employees to travel off-peak (or work at home), amenities to improve the safety and efficiency of biking and walking, ridematching services for vanpools and carpools, community-based carsharing, employer-subsidized transit passes, guaranteed emergency rides home for transit users, and incentives to decrease employer-paid parking.

6.6 REFERENCES

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7. RAMP MANAGEMENT AND CONTROL

Chapter 7 was revised in March 2006. For more information on the extent of these revisions, see the Revision History Table at the beginning of this handbook.

7.1 INTRODUCTION

If designed, operated, and maintained effectively, ramps allow motorists to make connections between different facilities in a safe, convenient, and comfortable fashion with little or no delay or impact on traffic. However, conditions on ramps seldom represent the conditions for which they were initially designed. Instead, ramps are often too closely spaced, do not offer adequate acceleration distances for posted speeds, or are simply overwhelmed by the increasing number of motorists that use them on a daily basis. When conditions like these exist, impacts may develop that affect the efficient and safe operation of traffic on ramps and/or the facilities to which they are connected (i.e., freeways and arterials). Despite poor conditions, however, agencies can proactively manage traffic on ramps to obtain desired benefits, to satisfy pre-determined goals and objectives, and improve safety and efficiency of freeway operations.

Ramp management is the application of control devices, such as traffic signals, signing, and gates to regulate the number of vehicles entering or leaving the freeway, in order to achieve operational objectives, such as (1):

- Improved safety.
- Improved mobility.
- Improved perception of transportation management agencies and staff.
- Reduced environmental impacts.

Ramp management also helps to achieve these objectives by smoothing the rate at which vehicles enter and exit the freeway.

Ramp management typically encompasses the following four strategies:

- Ramp metering.
- Ramp closure.
- Special use treatments.
- Ramp terminal treatments.

Other than freeway-to-freeway interchanges, freeway entrance and exit ramps represent the only opportunity for vehicles to legally enter or exit a freeway and, therefore, represents the only location which control can be exercised.

7.1.1 Purpose of Chapter

The primary purpose of this Chapter is to improve the operation of freeways and their associated ramps by providing support, information, guidance, and recommended practice to practitioners responsible for freeway management and operations. This chapter summarizes the Federal Highway Administration's (FHWA) *Ramp Management and Control Handbook* (1), by providing an overview of the essential elements of an effective ramp management program. The use or application of these recommended practices, contained in this Chapter and in the *Ramp Management and Control Handbook* (1), will in time serve to enhance the use and effectiveness of various ramp management strategies and techniques.

The *Ramp Management and Control Handbook* (1) describes ramp management in depth and is considered the primary reference on the subject. This Handbook can be accessed using the following URL: <http://ops.fhwa.dot.gov/freewaymgmt/index.htm>.

7.1.2 What is Ramp Management?

Ramp management, is the “application of control devices, such as traffic signals, signing, and gates to regulate the number of vehicles entering or leaving the freeway, in order to achieve operational objectives”(1). Most ramp management strategies lead to improved traffic flow and safety by 1) regulating the number of vehicles entering or exiting a freeway, or 2) smoothing out the rate at which vehicles enter the freeway facility. By employing either of these approaches, ramp management helps to balance freeway demand and capacity and maintain optimum freeway operation by reducing incidents that produce traffic delays, improve safety on adjacent freeways or arterial streets, or giving special treatment to a specific class of vehicles. Ramp management strategies are also often implemented with elements of other freeway management programs to create operational efficiencies and to assist in the delivery of overall transportation management goals and objectives.

Ramp management strategies may be used to control access to selected ramps, thus limiting the periods when vehicles may access the ramp or possibly restricting access to the ramp permanently. This significantly reduces, or may even eliminate, the potential for collisions that occur as a result of traffic entering or exiting the ramp facility and in turn smoothes the flow of traffic on segments of roadway where these collisions have occurred in the past.

Ramp management may also control the manner in which vehicles enter and exit a freeway. For instance, vehicles that enter the freeway in platoons introduce turbulence, which causes vehicles on both the mainline and ramp to slow down to safely merge. This causes congestion around and upstream of ramp/freeway merge points. Ramp management strategies may be used to control the flow of vehicles entering a freeway, thus smoothing the rate at which vehicles are allowed to enter the freeway. Similarly, ramp management strategies and treatments may be implemented at the ramp-arterial intersection to better manage the flow of traffic exiting the freeway. Such treatments may reduce queues on exit ramps that extend out onto the freeway, helping to improve safety and mobility on the freeway.

7.1.3 Relation to Other Freeway Management Activities

There are many freeway management activities that are related to or dependent upon ramp management. To understand the role of ramp management within the freeway management spectrum, it is important to understand the relationships that exist between these activities.

Ramp management is a single element or function that falls under an agency's freeway management "umbrella". With that said ramp management should be viewed as an element of the overall transportation management system - not as a program that operates in parallel to or separate from it (1). In this regard, the relationship between ramp management and freeway management can be likened to puzzle pieces, with ramp management representing just one piece of the entire freeway management program puzzle (see Figure 7-1). Ramp management elements must work together with elements of other freeway management programs to deliver freeway management and surface transportation system goals and objectives (e.g., minimize freeway congestion and its side effects, to improve safety, to enhance mobility, etc.). The freeway management functions that comprise a freeway management program are identified in Figure 7-1, and their relationship with regard to ramp management is described below.

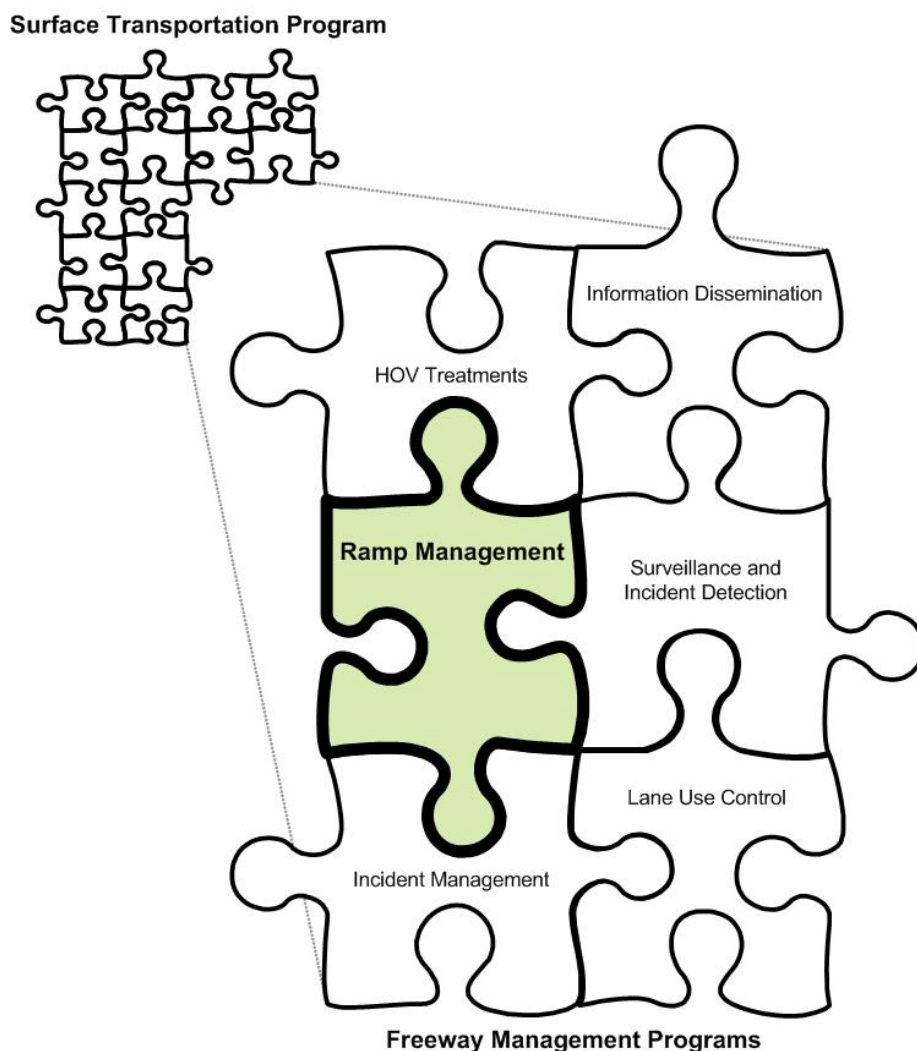


Figure 7-1: Freeway Management Programs and Their Relationships with the Surface Transportation Program (Reference 1)

The freeway management programs presented in Figure 7-1 are often integrated with other freeway management programs, including ramp management. Relationships that exist between ramp management and other freeway management programs are briefly summarized in Table 7-1.

Table 7-1: Freeway Management and Operations Activities and Their Relationship to Ramp Management

Activity	Relationship
<p>Managed Lanes (Chapter 8)</p>	<p>Lane use controls may be used to direct motorists to use certain lanes and to merge out of other lanes. Lane use controls are usually used either in reversible lane operations or to close lanes because of road work or incidents. Ramp management strategies can be used in conjunction with lane use controls to manage the demand, leading to freeway sections where lane use controls are active.</p>
<p>High Occupancy Vehicle Treatments (Chapter 9)</p>	<p>Preferential treatment of HOVs and other vehicle classes have been successfully used to bypass single-occupant vehicle (SOV) queues at ramp entrances (metered and non-metered). Similarly, ramps dedicated solely for the use by HOVs have been implemented to lessen travel times to and from the freeway by avoiding congestion on ramps and surface streets.</p>
<p>Incident Management (Chapter 10)</p>	<p>Incident management procedures and plans may be integrated with ramp management to improve safety and restore operations on ramps and the mainline in a more timely fashion. Through active management of ramp meters and other devices, operators may monitor freeway operations during emergencies and clear ramp queues to allow a more timely response to emergencies.</p>
<p>Planned Special Event Management and Control (Chapter 11)</p>	<p>Ramp management can improve operations on ramps, freeways and surface street during special events, helping to minimize the impacts that special event traffic has on neighborhoods and through traffic near the special event. Ramp management may be applied to reduce the length of queues on ramps, allowing queues to be fully contained to the ramp instead of flowing back onto the freeway and adjacent arterial. This not only improves safety on these facilities, but also improves the flow of traffic that uses them. Ramp management may also be used to minimize the impacts on neighborhoods near the special event by restricting access to ramps in the areas, requiring special event traffic to use upstream and downstream ramps, where traffic will have less of an impact.</p>
<p>Information Dissemination (Chapter 13)</p>	<p>Information dissemination techniques employed by other freeway management functions may be used to inform to motorists en-route or pre-trip about the current operational status of ramp meters. Additionally, motorists may be alerted to planned ramp closures as well as construction activities on or near the ramp.</p>
<p>Detection and Surveillance (Chapter 15)</p>	<p>Surveillance and incident detection systems are used to determine and adjust freeway and ramp operational conditions. Data from detectors installed on the ramp and/or mainline can be used to set or adjust ramp metering parameters. Closed circuit television (CCTV) can be used to visually verify that ramp meters are functioning properly or to observe the effects of ramp metering on traffic flow.</p>

Although it does not have a direct relationship to ramp management, tolling may indirectly affect operations on ramps, freeways and adjacent arterials in a manner similar to ramp metering. Toll booths and gates located on entrance ramps can play a similar role to ramp meters because the toll operation can break up platoons as drivers slow or stop to pay tolls. In this regard, toll booths stagger the release of vehicles, which helps to smooth the flow of vehicles entering the tollway facility. Additionally, toll booths restrict excess demand to the ramp so vehicle platoons do not form as vehicles enter. However, with toll booths and gates no attempt is made to control the number of vehicles that are released to reflect traffic conditions. Therefore, toll booths and gates should be viewed as only a strategy that produces effects similar to that of ramp metering and should not be viewed as a ramp management strategy in itself. In some cases, the operational effects of tolling can serve as input into the development of operational strategies for locations where toll booths and gates have been deployed or are planned.

With the advent of automated toll collection systems and the trend toward open road tolling, toll collection acts less like a ramp management strategy than it once did. In the future, the affect of toll collection on dispersing platoons or regulating entering traffic will be even more limited.

7.2 CURRENT PRACTICES, METHODS, STRATEGIES & TECHNOLOGIES

7.2.1 Overview

Simply speaking, freeway entrance and exit ramps connect high-speed, limited-access freeways to other high-speed, limited-access freeways or lower-speed, principal arterials/highways, and vice versa. Additionally, ramps are the only facilities motorists may use to legally make connections to and from limited access facilities and as such represent the only locations where traffic entering and exiting a limited access facility can be controlled (1).

Ramp management strategies can balance freeway demand and capacity, maintain optimum freeway operation by reducing incidents that produce traffic delays, improve safety on adjacent freeways or arterial streets, or give special treatment to a specific class of vehicles. The balance between freeway demand and capacity is achieved by controlling the manner in which vehicles enter a freeway. For instance, vehicles that enter the freeway in platoons introduce turbulence, which causes vehicles on both the mainline and ramp to slow down to safely merge. This causes congestion around and upstream of ramp/freeway merge points. Ramp management strategies may be used to control the flow of vehicles entering a freeway, thus smoothing the rate at which they are allowed to enter the freeway.

Ramp management strategies may be used to control access to selected ramps, thus limiting the periods when vehicles may access the ramp or possibly restricting access to the ramp permanently. This significantly reduces, or may even eliminate, the potential for collisions that occur as a result of traffic entering or exiting the ramp facility and in turn smoothes the flow of traffic on segments of roadway where these collisions have occurred in the past.

7.2.2 Benefits

Before and after evaluations of ramp management strategies offer strong evidence that ramps, freeways, and even adjacent arterials operate better once strategies are implemented. Typical benefits of ramp management strategies include:

- **Safety** - Ramp management strategies, such as ramp metering, reduce stop-and-go driving behavior, resulting in fewer rear-end collisions. Ramp metering also breaks up platoons entering a freeway, resulting in fewer side-swipe and merge-related collisions. During periods of severe weather, ramps may be closed to prevent motorists from accessing freeways that are impassable. Ramp-arterial treatments (e.g., signal timing improvements, canalization, widening, and striping) may also improve safety by containing vehicle queues to the ramp, preventing queues from spilling back onto the freeway or adjacent arterial. Safety benefits from ramp metering programs across the county are presented in Table 7-2.
- **Mobility and Productivity** - Ramp management strategies may increase travel speeds while reducing travel time and delay. Freeways that have metered entrance ramps usually carry more traffic than they did before metering began, while attaining the improvements mentioned previously. A ramp metering study in Minneapolis showed a 25-percent increase in peak period traffic volumes while increasing average speeds by 5 km/h (3 mi/h) (2).
- **Environmental Effects** - The improved speeds, reduced stop-and-go traffic, and reduced delays that result from ramp management strategies also result in reduced emissions and fuel consumption. An evaluation of ramp meters in Minneapolis identified a net annual saving of 1,160 tons of emissions (3).
- **Traveler Perception and Satisfaction** - Ramp management and improved operations on freeways demonstrate to the public that agencies responsible for transportation facilities are doing something about congestion and safety problems. As a result, travelers and the public in general will be more satisfied with transportation agencies and the job they are doing. Higher public satisfaction makes it easier for agencies to acquire the needed resources to develop, implement, operate and maintain transportation improvements.
- **Promotion of Multi-modal Operation** - Ramp management promotes the use of transit, carpools, vanpools, and other multi-occupant modes of transportation by giving preferential treatment to these modes.

More information on the benefits of the Minneapolis/St. Paul ramp metering program, as well as a summary of a ramp closure project conducted in Honolulu, Hawaii is provided in Section 7.4.

7.2.3 Key Considerations During Freeway Management Program Development

Ramp management systems and strategies can be an important part of a freeway management and operations program. Ramp management goals, objectives and strategies should be consistent with regional transportation goals and objectives and must support the mission and vision of the agency responsible for implementing them (1,4). Ramp management goals, objectives and strategies should be defined at the regional level and should fit into the context of the broader transportation planning process, including the freeway management program.

Agencies should not implement ramp management strategies if their associated improvements do not support local, regional, and statewide surface transportation system goals and objectives. If policies are not in place and resources are not available to operate and maintain strategies, deployment may actually result in public contempt for the strategies that are implemented. This in turn will impede the agency's ability to effectively manage traffic.

**Table 7-2: Summary of Ramp Metering Benefits
(Reference 2)**

Location	Traffic Flow Benefits	Safety Benefits	Approximate Time of Implementation or Evaluation
Portland, Oregon	A 173% increase in average travel speed.	43% reduction in peak period collisions.	1981
Minneapolis/St. Paul, Minnesota	A 16% increase in average peak hour travel speed and a 25% increase in peak period volume.	24% reduction in peak period collisions.	Initial implementation in 1970. Evaluation in 1989.
Seattle, Washington	A 52% reduction in average travel time and a 74% increase in traffic volume.	39% reduction in collision rate.	1981-1987
Denver, Colorado	A 57% increase in average peak period travel speed and a 37% decrease in average travel time.	50% reduction in rear-end and side-swipe collisions.	1981-1989
Detroit, Michigan	An 8% increase in average travel speed and a 14% increase in traffic volume.	50% reduction in total collisions and 71% reduction in injury collisions.	1984
Long Island, New York	A 9% increase in average travel speed.	15% reduction in collision rate.	1991

When properly planned and implemented, ramp management can be an important element of a freeway management program. However, ramp management strategies are not appropriate for all situations, nor does their implementation eliminate the need to pursue other complimentary strategies. The potential use of ramp management strategies should be examined thoroughly before any such improvements are made. A comprehensive approach in planning, designing, implementing and operating ramp management strategies can help ensure successful projects. The *Ramp Management and Control Handbook* provides a comprehensive overview of the steps involved in planning, designing, and implementing ramp management strategies. Some of these key considerations for planning and developing a ramp management program are discussed in the following sections:

7.2.3.1 Planning Considerations

To be effective, ramp management strategies often need to take into consideration aspects of ramp management strategy implementation that indirectly affect overall outcomes. For instance, ramp management implementation and operation may be perfect, but if ramp management strategies are not enforced, the overall objectives of strategies may not be achieved. Similarly, if issues affecting equity are ignored, strategies may viewed unfavorably by certain groups of individuals, ultimately limiting the positive impacts that strategies offer. Last but not least, maintenance of strategies must be taken into consideration during the planning process to ensure that strategies can be actively maintained and that malfunctioning equipment does not confuse motorists.

Enforcement is one key to effective ramp management and control. This is especially true for ramp metering because compliance is critical to its operational success. Therefore, enforcement issues associated with ramp management strategies must be taken into consideration during the planning process so appropriate actions are taken to ensure that ramp management strategies are enforceable. This includes a coordinated effort with law enforcement to ensure that issues such as an appropriate enforcement strategy, safe enforcement areas, adequate staff, and support by the courts are addressed.

Similar to enforcement, equity and environmental justice issues are also key considerations for ramp management projects. The direct involvement of diverse cultural and economic communities in the development of transportation projects will help to ensure that projects fit harmoniously within their communities without sacrificing safety and mobility.

Planning is also required for maintenance, especially if new systems are implemented. Therefore, it is important to include the maintenance staff in the planning stages of a project, as they will have recommendations on the types and manufacturers of equipment to procure, equipment location, and other issues that are an integral part of their jobs.

7.2.3.2 Inter- and Intra-Agency Coordination

Practitioners responsible for ramp management should coordinate with individuals inside and outside their respective agencies, first to ensure that ramp management strategies can be supported and secondly, to develop effective procedures to implement and operate these strategies. The key is to break down barriers that exist within and between agencies and institutionalize working together as a way of doing business among transportation agencies, public safety officials, and other public and private sector interests within the region. Practitioners responsible for ramp management may choose to use inter- and intra-agency coordination as a means to obtain consensus on how ramp management will operate and how it fits into the overall traffic management program.

Inter-agency coordination will help the ramp management practitioner identify and exploit possibilities for improving day-to-day operations. The continual coordination between agencies may foster the development of strong relationships and tactics that, over time, equate to measurable improvements in the safety, efficiency, and quality of service associated with regional transportation facilities, including freeways and ramps. Inter-agency coordination, however, is not an easy process. The ramp management practitioner should expect to make several attempts to obtain the level of inter-agency coordination needed to support ramp management activities, especially if this is a first attempt to coordinate with individuals from these outside agencies. Adding to this difficulty are institutional barriers, such as resource constraints, internal stovepipes in large agencies, and the often narrow jurisdictional perspective of governing boards. As such, initial attempts to coordinate with outside agencies should begin early in the planning process to allow enough time to ensure that coordination can occur.

Inter-agency coordination covers a broad set of agencies and stakeholders. The agencies and disciplines that are critical to ramp management include:

- **Enforcement agencies** - to ensure that motorists obey signing, striping, barricades, and ramp signals to maximize the benefits of these investments. City or state traffic ordinances may need to be amended to ensure that ramp management strategies can be enforced and to dictate penalties for non-compliance.
- **Local traffic engineering or public works departments** - to ensure that ramp management operations fit well with arterial operations. Coordination with traffic engineering or public works departments may also be needed to define agency roles and responsibilities. For example, agreements may be needed to distinguish which agency will operate traffic signals located near metered ramps.
- **Transit agencies** – to determine if ramp management strategies can support or improve transit operations, and if impacts on transit operations are acceptable. Coordination with transit agencies should occur throughout the life cycle of ramp management strategies.
- **Local transportation planning agencies** - to incorporate regional transportation data into the ramp management decision-making process and to program ramp management projects into the regional transportation planning program.
- **Media** – to establish solid relations with the media in the initial stages of ramp management. The media can provide practitioners with a means to gain positive support for ramp management strategies from groups impacted by, and involved in their implementation. However, the media can also be obstructive if not handled properly. If the benefits of ramp management strategies are oversold and unrealistic, credibility of the implementing agency may be questioned.

Similar to inter-agency coordination, intra-agency coordination will help individuals within an agency work together to solve operational problems, improve system performance, and communicate successfully with one another through deliberate collaboration and coordination. This coordination will allow managers to coordinate their activities with others that comprise the broader traffic management program. As mentioned earlier, ramp management is one element of the traffic management program and needs to further the goals and objectives of that program. However, internal coordination goes beyond the traffic management program. Personnel responsible for ramp management activities must also coordinate with the following set of internal staff:

- **Planning staff** - to make sure ramp management needs are incorporated into the agency plans.
- **Design staff** - to make sure that ramp management needs are incorporated in project designs.
- **Maintenance staff** – to determine if ramp management strategies can be adequately maintained. If ramp management strategies cannot be adequately maintained, with existing agency resources, the practitioner must work with maintenance staff to determine the resources that are needed to maintain systems and equipment and options for acquiring them.
- **Public information staff** - who are responsible for informing the public of activities related to ramp management.
- **Senior management** – to keep these individual abreast of any issues arising from ramp management activities.

Development of a regional traffic management program Concept of Operations (Con Ops) presents a good opportunity for inter- and intra-agency coordination in defining how ramp management fits into the larger traffic management program. In short, the process of

developing a Con Ops should involve all stakeholders and serve to build consensus in defining the mission, goals, and objectives of ramp management. It should also provide an initial definitive expression of how functions are performed (thereby supporting resource planning), and identify interactions between organizations (5).

7.2.3.3 Staffing

Successful ramp management requires skilled, well-trained staff in sufficient numbers to operate and maintain the strategies at effective levels. Staff who operate and maintain ramp management strategies should have knowledge, skills, and abilities (KSAs) similar to staff who operate and maintain other traffic management elements. The needed KSAs will differ based on the functions that staff are intended to perform – planning/design, operations, or maintenance.

Staff assigned to ramp management must be properly trained and have the knowledge to operate strategies effectively. Training is available from in-house sources, national transportation organizations (e.g., the National Highway Institute), and educational institutions.

The appropriate staffing level will depend on a number of factors including the size of the system, the system complexity, the hours of operation and the specific ramp management strategies chosen. For example, ramp metering will usually require more operations staff in a traffic management center, whereas time-of-day ramp closure will take more field staff.

The ramp management practitioner should determine the impacts that ramp management and control activities will have on existing staff levels. Practitioners must also assess the effect that changes to staffing have on current funding allocations. Budgeting for training usually falls into an agency's overhead budget and is 100-percent agency-funded. This is often overlooked during the planning stage, yet can be costly if training new staff is required or inadequate training is provided.

7.2.3.4 Performance Monitoring

Effective ramp management relies on the ability to monitor the effects of any action taken to manage the movement of vehicles on ramps, regardless of whether it is on an exit or entrance ramp. Along with the ability to monitor is the ability to implement actions to change the conditions under which the ramp is operating, such as varying the ramp meter timing, adjusting the time of day a ramp is closed, or adjusting signal timing at the ramp-arterial intersection. Practitioners must seek to understand the impact (positive or negative) ramp management strategies have on furthering the region's transportation goals. Based on this understanding, practitioners must correct problems and seek ways to maximize the benefits of the strategies that have been implemented.

For each objective associated with the ramp management program, the appropriate measure(s) of effectiveness should be identified, along with the desired threshold level of change that will be used to determine if the strategy has met the objective. Objectives of a ramp management program typically include (6):

- Improve traffic flow and travel time reliability for selected corridors.
- Improve safety for selected corridors.
- Improve neighborhood impacts.
- Improve transit operations.

Typical measures of effectiveness that correspond to the above objectives include:

- Change in travel time.
- Change in travel time reliability.
- Change in the total number of crashes.
- Change in the severity of crashes.
- Change in traffic volumes on adjacent surface streets.
- Change in transit travel times.
- Change in transit ridership levels.

Various types of equipment (e.g., CCTV, detection) can be installed to conduct performance monitoring and streamline the data collection process. This equipment may be installed before ramp management strategies become operational. They may also be programmed into other freeway management projects scheduled to be completed before ramp management strategies are planned to be in place.

7.2.4 Relationship to National ITS Architecture

The National ITS Architecture (7) “Freeway Control” market package includes ramp metering. This market package supports ramp meter controls on the freeway, traffic data flow from the freeway to the traffic management center (TMC), the control of ramp meters from the TMC, the control of sensor and controller equipment, and status and performance monitoring.

7.2.5 Technologies and Strategies

As previously mentioned earlier in this chapter, there are four general classifications of ramp management strategies. The advantages and disadvantages of each strategy differ, thereby requiring practitioners to closely analyze each to determine their appropriateness for satisfying existing problems and conditions. Before selecting a strategy, it is important that practitioners understand the purpose of each strategy and its advantages and disadvantages. This understanding will help narrow the focus and to identify the one strategy, or set of strategies, that is most appropriate given a set of unique issues and characteristics.

Ramp management strategies are not all mutually exclusive and in certain cases may be combined to maximize their potential advantages. For example, high-occupancy vehicle (HOV) ramps or bypass lanes - a special use treatment, are often implemented with ramp metering. Ramp terminal treatments are often combined with any one or combination of the other three. A brief overview of the available ramp management strategies is provided in the following section. The four ramp management strategies are discussed in the order they are presented below.

- Ramp metering.
- Ramp closure.
- Special use treatments.
- Ramp terminal treatments.

Readers should refer to the *Ramp Management and Control Handbook* (1) for a detailed discussion of ramp management strategies.

7.2.5.1 Ramp Metering

Ramp metering is the use of a traffic signal(s) deployed on a ramp to control the rate at which vehicles enter a freeway (see Figure 7-3). By controlling the rate at which vehicles are allowed to enter a freeway, the flow of traffic onto the freeway becomes more consistent, smoothing the flow of traffic on the mainline and allowing more efficient use of existing freeway capacity. Ramp metering can be an effective tool to address congestion and safety concerns that occur at a specific point or along a stretch of freeway.

There are several aspects associated with ramp meter operation that practitioners should be aware of prior to making the decision of whether or not to implement ramp meters. These aspects affect how a ramp meter or system of ramp meters control traffic based on agency goals and objectives and on local conditions. Aspects of ramp metering that need to be considered are briefly discussed below.

- **Metering Strategy** – The control decision made that best addresses the specific goals and objectives of the metering system.
- **Geographic Extent** - the area that will be covered by ramp metering and whether the meters in that area will be operated in an isolated manner or as part of a larger system of meters.
- **Metering Approaches** - local or system-wide and pre-timed or traffic responsive.
- **Metering Algorithms** - the specific logic and calculations used to select or determine a metering rate.
- **Queue Management** - how the metering rate will be affected by ramp queues and how the agency will keep queues at a manageable and acceptable level.
- **Flow Control** - how traffic will be released from the meter, one at a time or two at a time in one lane or multiple lanes.
- **Signing** - how drivers will know that a ramp meter is on or off.



Figure 7-2: Ramp Metering Signals



Figure 7-3: Metered Ramp

7.2.5.2 Ramp Closure

Ramp closure has the greatest potential impact on existing traffic patterns and is rarely implemented as a long-term strategy. The potential for significant impact is especially true for full or permanent ramp closures, where access to the ramp is no longer provided, requiring traffic to seek alternative routes to access the freeway. In many cases, full ramp closure involves the physical removal of the ramp pavement so as not to give the false impression that the ramp will be re-opened. Other types of ramp closures that affect traffic to a lesser degree include temporary and scheduled closures. These types of closures usually involve deploying automatic gates or manually placing barriers at the ramp entrance to prevent access to the ramp. Due to the relatively high impact on existing traffic patterns, ramp closures are seldom considered for deployment if other viable options are available. Full ramp closure is best applied as a last resort for severe safety problems. Temporary or scheduled closures may be applicable for reducing potential vehicle conflicts that may result from construction, major incidents, emergencies, or special events.



Figure 7-4: Ramp Closure Gate

7.2.5.3 Special Use Treatments

Special use treatments for ramp management give “special” consideration to a vehicle class or classes to improve safety, improve traffic conditions, and/or encourage specific types of driving behavior. Special use treatments require that the necessary policies (e.g., HOV, special events) be in place before strategies are implemented and funding requirements can be met.

Special use treatments include:

- HOV bypass lanes.
- HOV exclusive ramps.
- Construction, delivery, or emergency vehicle exclusive ramps.



Figure 7-5: HOV Ramp

7.2.5.4 Ramp Terminal Treatments

Ramp terminal treatments are solutions to specific problems that occur at the ramp/arterial intersection or have the potential to affect operations on the ramp, adjacent arterial, or freeway. Typically, ramp terminal treatments focus on managing queues that form on the ramp that spill back onto an adjacent arterial or the freeway facility. Ramp terminal strategies implemented at entrance ramps will provide better flow of arterial traffic not destined for the freeway and will improve the flow and handling of traffic on the ramp. Ramp terminal treatments implemented at exit ramps may reduce queue spillback from the ramp terminal signal, reducing the potential for collisions on the freeway at the back of the queue. There are at least six treatments that can be implemented at ramp terminals that can improve traffic conditions (e.g., traffic flow and safety) on or near ramp facilities:

- **Ramp widening** - to increase capacity, provide additional storage, or to provide a separate lane adjacent to the general-purpose lane so that HOV vehicles can bypass queues at meters.
- **Channelization** – to delineate and separate traffic movements.
- **Signal timing adjustments** - to reduce queuing on the ramp and to prevent queues from backing up into the intersection (entrance ramps), onto the freeway facility (exit ramps).
- **Turn restrictions** - to restrict volumes on the arterial downstream of the interchange, similar to signal “gating” methods.
- **Geometric improvements** - to improve sight distances, reduce horizontal and vertical curves in the roadway, or fix any other geometric deficiencies that cause motorists to take corrective measures.
- **Signing and pavement marking improvements** - to inform or provide guidance to motorists of downstream conditions or to delineate traffic and facilitate vehicle movements.



Figure 7-6: Advance Ramp Control Warning Sign

7.2.6 Design and Related Considerations

There are a variety of considerations for the design of the systems and field elements within any capital improvement project that supports a ramp management strategy. Every project must be reviewed to ensure that it is consistent with the operational objectives and that all pieces of the project are consistent with one another.

The *American Association of State Highway and Transportation Officials (AASHTO) Design Guidebook* (8) and the *Manual on Uniform Traffic Control Devices (MUTCD)* (9) provide design guidelines for freeways. Some agencies also have their own design guides. Sections 10.6 through 10.9 of the *Ramp Management and Control Handbook* (1) addresses the design considerations for ramp closures, special-use ramps, ramp terminal treatments, and ramp metering. The equipment, signing, and pavement markings needed are outlined for each.

With many ramp management strategies, ITS elements are typically required. Section 10.8 of the *Ramp Management and Control Handbook* (1) offers guidance in following a systems engineering approach, whereby the agency can guide their ITS procurement through a step-by-step process from the Concept of Operations and detailed requirements and design to implementation and system acceptance.

7.2.7 Emerging Trends

Ramp meter operation is likely to be improved in the future in the following ways:

- Current research into an improved understanding of traffic flow in the region of flow breakdown is likely to result in improved ramp metering control strategies. For example, different metering strategies might be employed for sustained operation in the free flow region as compared with recovery from the congested flow regions.
- Improved estimation of the tail of the ramp queue will lead to better control of the queue. Improved estimation is likely to come about through improved estimation algorithms and through the increased use of wider area detection technologies (10,11).
- Improved recognition of the multi-objective applications of ramp metering (e.g., freeway flow optimization, corridor flow optimization, safety improvement, merge flow smoothing, and limitation of queue waiting time) and the design of systems that accommodate these functions at the required locations.
- Improvement in the ease of tuning ramp metering systems to accomplish their objectives. The use of fuzzy logic and emphasis on evaluation of performance data are steps in this direction (11).
- More frequent use of real-time performance monitoring to gain a better understanding of how ramp meters are performing and to make needed adjustments more quickly (1).

7.3 IMPLEMENTATION AND OPERATIONAL CONSIDERATIONS

Ramp management strategy implementation is a delicate process that begins well before strategies are physically deployed, and concludes only when deployed strategies have been successfully tested and initially operated. Before ramp management strategy implementation is seriously considered and systems or equipment are purchased, practitioners must coordinate internally with upper management to determine the feasibility of and support for ramp management strategy implementation. This includes close examination of the minimum requirements to successfully deploy and operate ramp management strategies, such as staffing levels and needs, hardware and software needs, budgetary constraints and resources, and policy directives.

7.3.1 Intra-Agency Readiness

Agencies preparing to implement ramp management strategies should take steps to ensure that strategies can be implemented successfully. Ramp management strategies should not be implemented until agencies are ready to implement, operate, and maintain selected strategies. Implementing the selected strategies requires planning to ensure that the needs of the agency and the public will be met. Key aspects of this effort include:

- **Systems Implementation** – Ramp meter instrumentation (loops, signals, signs, controllers, etc.) need to be installed well in advance of when ramp metering is slated to begin.
- **Software Implementation** - Software that is used to establish communications in the field and that allow operators to monitor and control systems need to be developed or procured and tested before implementation can take place.
- **Data Collection** – Before ramp management strategies are implemented data need to be collected to evaluate the performance of ramp management strategies in delivering pre-determined goals and objectives. Traffic volumes, travel times, and other appropriate performance measures should be collected, modeled, and analyzed to estimate the benefits of implementing the ramp management strategy. Improvements to travel time and travel speeds in a specific corridor, as well as changes in congestion on the mainline and ramps, may be measures of effectiveness that can be used to prioritize locations where equipment will be installed. Depending on the scope of ramp management deployment, this action may need to be completed as much as one year in advance of when the strategy is slated to begin.
- **Testing** - It is critical to make sure all detection, communication, field controller firmware, and central system software is well tested before ramp meters are turned on. Ramp meters and associated equipment need to be installed well in advance of when strategies are slated to take effect. This gives parties responsible for ramp meter implementation time after meters are deployed but before meters are turned on to test each meter to confirm they are working properly.
- **Staffing** - New staff may need to be hired, or existing staff may need to be trained, when ramp management and control activities are added to a traffic management program. Staff may be needed to plan, design, operate or maintain strategies. Practitioners must determine the impacts that ramp management activities have on existing staff levels, and must assess how staffing needs will be filled. Practitioners must also assess the effect that changes to staffing have on current funding allocations. This is often overlooked during the planning stage, yet can be costly if training new staff is required or inadequate training is provided. Contractors may be hired on a full-time or part-time basis to satisfy or supplement staffing needs (1).
- **Training** - Systems and devices that support ramp management strategies can only be used to their furthest extent if staff are properly trained on how to operate and maintain them. All operators or maintenance staff responsible, whether existing or newly hired, will need to be trained on the procedures specific to individual systems and devices, operational policies, and testing and calibration methods. This includes typical and disaster specific emergency procedures.

7.3.2 Public Information and Outreach

Public information and outreach is needed to build consensus and understanding of the ramp management program and its associated activities. Public information and outreach is also critical from the stand point of acquiring public input so that strategies adequately address needs. Without a public information and outreach campaign motorists may not understand the ramp management strategies that have been implemented, and may not know how to properly

respond to them. This may result in confusion or even contempt for ramp management strategies.

The size and scope of the public outreach effort should be commensurate with the size and scope of the ramp management strategy being implemented. Information released to the public, local agencies, and the media should be fair and accurate, to reduce the chance that the reliability of released information will be called into question at a later date. Information can be disseminated to the public, neighborhood groups and local agencies through brochures like the one shown in Figure 7-7, public information meetings, handouts, and/or print and electronic media.

- **Local Leaders** - Local leaders can be valuable advocates of or powerful opponents to ramp management strategies. Practitioners responsible for ramp management should determine whether local leaders are predisposed to either advocacy or opposition to the proposed strategies, and to develop an outreach program that targets both the advocates and the opponents.
- **Motorists** - Motorists' initial impressions of ramp management strategies may be negative because negative aspects associated with these strategies are more easily observed than their benefits. For example, motorists may tend to focus on the fact that ramps that were once unrestricted, now have meters installed that delay their trips. Motorists often fail to understand that the negative aspects are usually more than completely offset by the improvements to mainline speed, delay, and safety. Therefore, public information campaigns should emphasize how strategies work, the reasons why strategies are being considered, and the benefits likely to be observed. By doing so, motorists' negative perceptions of ramp management strategies may be mitigated to a greater extent.

7.3.3 Agency Agreements, Policies and Procedures

Intra- and inter-agency agreements, policies and procedures either need to be created or reviewed to determine if the ramp management strategies are supported, and if they are supported to dictate how strategies can then be implemented. An assessment of local, county, state and federal laws, regulations, and policies should be reviewed to determine if additional policies are needed and to assure that the planned strategies fit within the existing legal and policy framework for the local area. Agency agreements, policies and procedures may be needed to capture support for ramp management strategies as well as to define agency expectations for how strategies will be designed, implemented, operated, and maintained. Depending on the importance of issues identified, agreements between agencies can be formal memoranda of understanding, less formal letter agreements, or informal handshake agreements. In any case, it is critical that personnel from different agencies as well as personnel from different departments within the agency responsible for ramp strategy implementation coordinate to thoroughly flesh out the details pertaining to proposed ramp management strategy deployments.

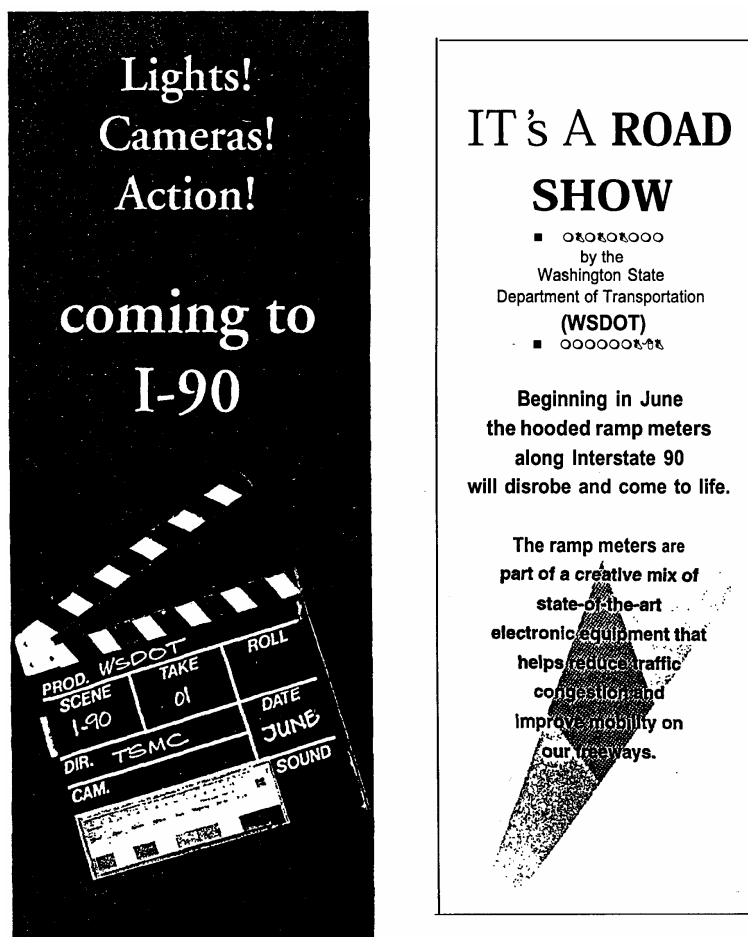


Figure 7-7: Brochure Cover
(Reference 2)

The following sub-sections identify several key policies and procedures necessary to design, implement, operate, maintain, and enforce ramp management strategies. Both intra- and inter-agency policies and procedures are described, as well as the policies and procedures that span the two.

7.3.3.1 Intra-Agency Agreements, Policies and Procedures

Ramp management strategies require approval and support from upper management and other department managers before implementation can be seriously considered. Support is needed from upper management to secure the resources needed for implementation (e.g., personnel, contracts to procure and install communications, field equipment, workstations, and servers as well as any construction needed), operation, and maintenance of strategies. In addition, upper management support is needed to ensure that implemented ramp management strategies will remain an integral aspect of regional transportation directives and that ramp management investments can be expanded to other areas of need, if appropriate. Input from managers of other departments is needed to verify that ramp management strategies fit into current operations and can be seamlessly integrated. Managers of other departments may also identify implementation challenges associated with selected strategies, which can be resolved before strategies are implemented.

7.3.3.2 Inter-Agency Agreements, Policies, and Procedures

Ramp management strategies also require coordination among partner agencies to establish region-wide policies that guide how strategies are implemented and how associated issues are resolved. Coordination needs to continue beyond the planning stages and into the operations stages of ramp management. Several types of agencies with differing agendas will likely be involved with or affected by the operation of ramp management strategies, therefore, policies should be drafted to ensure equity among motorists and agencies across jurisdictional borders. The impacts of ramp management strategies, such as ramp metering, may expand beyond the freeway to local arterials, increasing the traffic demand on the arterial as well as introducing other unwanted impacts (e.g., reduced safety, increased emissions, increased fuel consumption). Without local agency support, continued operation of ramp management strategies may be problematic. It is important to continue the coordination that was established during the planning stages throughout the life cycle of ramp management strategies. Policies and operational procedures should be revisited and modified if needed to make sure that agency needs continue to be met.

7.3.4 Maintenance

Systems, software, and other equipment that support ramp management strategies must be routinely maintained to ensure adequate performance and operational stability. Frequently maintaining systems, software and equipment, helps agencies maximize returns on their investments by offering the best chance for systems to be operated up to and possibly beyond their design life span. This saves the time, effort, and funding needed to purchase new systems before deployed systems reach their designed life span. Failure to maintain ramp management equipment results in disruptions or failure of the strategies or systems that the equipment supports, and makes it difficult to achieve the goals set out for these strategies. Systems that are maintained according to vendor requirements will be useable for longer periods than those that are minimally maintained or not maintained at all.

Maintenance activities associated with ramp management strategies, and most particularly with regard to ramp metering include:

- Replacing defective or broken components.
- Updating software and system inventories.
- Logging repairs.
- Testing equipment.
- Cleaning system components.

When systems or devices fail, staff must be available to fix problems in a timely manner to reduce the impact on and exposure to the public. This is particularly important for systems that support emergency operations, such as automated gates. If ramp management strategies cannot be adequately maintained due to lack of funding or available staff or for other reasons, they should not be implemented. Additionally, if strategies are implemented and they are not routinely maintained, the potential for equipment malfunction will increase. This in turn will result in greater public skepticism of the effectiveness of ramp management strategies, and may in time erode public support for ramp management.

7.3.5 Performance Monitoring, Evaluation and Reporting

Ramp management strategies should be monitored and evaluated to determine if they are achieving their intended objectives, and to make necessary improvements so that optimal system performance can be achieved. Selected strategies should be observed in the field and if

possible confirmed in the TMC. If problems are observed or reported, adjustments to the strategies, maintenance, or another responsive action should be performed.

Evaluating the effectiveness of ramp management strategies should not be considered a one-time activity, but should be part of a periodic review of the effectiveness of the component and of the overall system. Ramp management strategies should be analyzed on a continual basis and more formal evaluations should be conducted several times within the first year of deployment and then annually thereafter. Evaluations at two weeks, six months, and one year after initial operation often meet the needs to report how the system is doing in the first year of operation.

The results of performance monitoring and evaluation should be reported to the public, partner agencies and the media. This helps communicate the effectiveness of ramp management projects to these groups, builds a general understanding of the benefits of the ramp management strategy, and builds support for ramp management activities. Reporting formats should be tailored to the specific needs of the audience in which they will be reported.

7.4 EXAMPLES

This section provides two examples where ramp management strategies have been used and have provided benefits.

7.4.1 Ramp Metering (Twin Cities, Minnesota) (3,12)

The Minnesota Department of Transportation (Mn/DOT) owns and operates an extensive ramp metering system in the Minneapolis/St. Paul metropolitan area (also referred to as the Twin Cities). The ramp metering system has over 430 ramp meters and is one of the most extensive ramp metering applications in the nation. The Twin Cities ramp metering program is used for corridor and regional traffic control and has historically employed some of the most restrictive metering algorithms in the nation. Characteristics of the Twin Cities metering program are captured in Table 7-3.

Table 7-3: Twin Cities, Minnesota Ramp Metering System Summary

Characteristic	
Number of Meters	430
Freeway Miles	210 in Twin Cities metropolitan area.
Types of Metering Control Applied	Mix of pre-timed, traffic responsive, and system wide ramp metering.
Time of Day Operations	Both AM and PM peak periods.
Planned Expansion of the System	350 by 2008
Special/Unique Application or Capabilities	Represents one of the most comprehensive ramp metering systems in the United States. Includes some metering of freeway-to-freeway ramps.

The Twin Cities ramp metering system was subject to an extensive and well publicized evaluation in 2000 when the meters were turned off for a six-week period for evaluation of the impacts of the application. An extensive planning and policy review effort followed to modify the region's metering system to better balance the needs of system operators and regional travelers. Many useful lessons learned resulted from this effort involving the evaluation and performance monitoring of mature metering systems. The lessons learned in this effort illustrate the need for system evaluations, both as a tool for further improving the system and measuring the benefits of the system.

The evaluation of the ramp metering system was mandated by the State legislature. This mandate was prompted by a small, but vocal, group of citizens who were opposed to ramp metering. The legislature directed Mn/DOT to suspend the operation of the metering system for a six-week period and provided funding for a comprehensive independent evaluation of the impacts observed during the shutdown period to identify the overall impacts of the system. Throughout the shutdown experiment, the evaluation was extensively covered in the local media and followed by the public.

System performance data was collected during two six-week periods, both preceding and during the ramp metering shutdown. Data collected prior to the shutdown was used to represent travel conditions "with" the ramp metering system. Data collected during the shutdown period was used to reflect "without" the ramp metering system.

Several performance measures were used to evaluate the ramp metering system. These included traffic volumes and throughput, travel times, reliability of travel time, safety, emissions, fuel consumption, and public perception. The highlights are bulleted below.

- **Throughput:** Traffic volumes on the freeway mainline were observed to decrease by nine percent when the meters were shut down. There was no appreciable change in the volumes on the parallel arterials observed when the meters were shut down.
- **Travel Time:** Freeway speeds were reduced by 14 percent, or 11.9 km/h (7.4 mi/h), when the meters were shut down, resulting in greater travel times that more than offset the elimination of ramp queue delays. There was no appreciable change in the travel times on the parallel arterials observed when the meters were shut down.
- **Travel Time Reliability:** Travel times were nearly twice as unpredictable when the meters were shut down.
- **Safety:** Crashes on freeways and ramp segments increased by 26 percent when the meters were shut down.
- **Benefit/Cost Analysis:** The ramp metering system was estimated to produce approximately \$40 million in benefits to the Twin Cities region. These benefits outweighed the costs of the ramp metering system by a ratio of 15 to 1.
- **Market Research:** Survey and focus group efforts were used to gather perceptions and opinions on the metering system. This research revealed that the majority of Twin Cities' residents supported the use of ramp metering and felt that the system provided them with a benefit. However, many residents also supported modifications to the system to decrease time spent waiting in the ramp queues. The market research findings generally supported the observed impacts of increased safety, improved travel time, and more reliable travel times resulting from ramp meter operation. One noted discrepancy involved the time spent waiting in the ramp queues reported by travelers. Travelers perceived their wait times to generally be twice as great as the observed wait times.

7.4.2 Permanent Ramp Closure (Honolulu, Hawaii) (13)

This case study explores the simulated and real-world results of the H-1 freeway entrance ramp closure. The H-1 freeway (eastbound and westbound) qualifies as a severely congested facility because central portions of the H-1 operate below 50 km/h (31.1 mi/h) for at least one hour during the AM peak period.

Project staff started the simulated H-1 freeway ramp closure by analyzing and selecting the appropriate ramp. Using over 30 simulated alternatives, discussions with HDOT Traffic staff, helicopter surveillance, and driver experience, it was determined that the Lunalilo Street entrance ramp was the source of a major bottleneck. The Hawaii Department of Transportation (HDOT) then conducted a two-week ramp closure experiment on the Lunalilo Street entrance ramp in Fall 1997. Ramp metering was considered for the H-1 corridor. However, since both the mainline and entrance ramp traffic volumes were very high, the metering rate would need to have a long cycle, which effectively means closing the ramp since less than 30 percent of the ramp volume would be allowed access. This helped to show that ramp metering would not have been the appropriate solution. In addition, ramp metering would not have been effective given the close proximity of many of the entrance ramps.

Though this ramp closure experiment was just two weeks long, there were some notable lessons learned. First, it is possible to conduct a ramp closure experiment on a major interstate freeway. Not only is it doable and safe, but it is also an affordable option to a ramp metering solution which would require considerable alignment changes in this case. Second, while experimentation is a wonderful method to determine the actual results, a short-term project is not able to attain simulated results because equilibrium and normal driving conditions can not be realized in two weeks time. Third, detailed simulations can be an effective representation of existing traffic conditions and future traffic conditions. Lastly, this experiment demonstrated a successful and cooperative multi-agency effort. Both HDOT and the City and County of Honolulu worked well together to meet the extraordinary demands of this short-term project.

Specifically, the positive impacts of the ramp closure included:

- Though ramp metering would be a less disruptive alternative, it would have required extensive alignment modifications to meet the storage and acceleration requirements. Therefore, using the entrance ramp closure was a much more economical solution.
- The geometry of the Lunalilo Street entrance ramp was particularly favorable for a ramp closure. This entrance ramp extends to become the right lane of the two-lane Vineyard Boulevard exit ramp. This closure re-routes the traffic to a high-design arterial street (Vineyard Boulevard) which reconnects to the freeway further downstream. And the remaining left lane at the Vineyard Boulevard exit ramp was sufficient to allow mainline motorists off the freeway.

The negative impacts of the ramp closure included:

- Since the experiment was only two weeks in length, the results were not comprehensive enough.
- Ten percent of freeway motorists rated the experiment bad or very bad. This mostly applied to the drivers who exited early and did not experience the experiment site and therefore perceived longer travel times.
- Fifty-two percent of the Lunalilo Street entrance ramp users found the experiment to be bad or very bad.

Motorists who exited at or past the experiment site gave consistently higher ratings than those who exited earlier. It is clear that the motorists who exited early and did not experience the experiment site perceived longer travel times.

A majority of the freeway motorists (51 percent) found the experiment to be good or very good. Of the motorists who use the Lunalilo Street entrance ramp, 25 percent found the experiment to be good or very good, and 23 percent found it neutral.

The two-week ramp closure experiment led to a formal pilot project aimed at easing congestion on the H-1 freeway. The pilot project, which began in August 2004, closed the Lunalilo Street entrance ramp to morning weekday commuters from 6:00 to 9:30 AM. This was an attempt to eliminate a dangerous, traffic-slowing weave on the freeway. The State's preliminary data showed the change was working and has had little effect on area residents. The results were as follows:

- Travel time savings on the H-1 freeway after the project started was 10 minutes.
- The time it took to get from Piikoi Street to the freeway's Queen Emma Overpass via the Lunalilo Street entrance ramp was an average of 9.2 minutes before the demonstration. With the rerouting, the same distance was covered in 4.5 minutes.
- There was no difference in the amount of traffic on the Punahou Street H-1 entrance ramp before and during the ramp closure project.
- There was a small increase of traffic on the School Street entrance ramp, but the increase was not enough to create congestion around the ramp.

In October 2004, the State decided to extend the Lunalilo Street entrance ramp closure project so more data could be collected and community concerns answered.

Surveys handed out to motorists since the change show that 70 percent of the drivers near 'Ainakoa Avenue in Kahala rated the project very good or good. However, 39 percent of the drivers on Vineyard Boulevard, where the Lunalilo Street traffic has been diverted, said the project was bad or very bad.

Closing the Lunalilo Street entrance ramp in the morning rush hour has helped thousands of East Honolulu commuters on H-1 freeway get to work faster, but Makiki residents say they have paid the price for the convenience of others. The State Transportation Director said that the demonstration project closing the entrance ramp has been a success, but that a final look at the Makiki concerns must be done before making the ramp closure change permanent.

In Fall 2004, the Lunalilo Street entrance ramp closure project was made permanent. Since this time HDOT staff have been working with a local engineering firm to implement ways to automate the closure with devices such as a retractable/collapsible curtain of delineators and a zipmobile for relocating New Jersey style barriers (14).

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8. MANAGED LANES

8.1 INTRODUCTION

Managed lanes (Figure 8-1 as an example) involve the *regulation, warning, guidance* and *redistribution* of traffic to meet such overall goals as:

- Improve traffic operations
- Facilitate movement of people and goods
- Improve safety
- Generate revenue



Figure 8-1: Example of Managed Lanes

Managed lanes are certain freeway lanes set aside for a variety of operating strategies that move traffic more efficiently in those lanes. As a result, travelers have *options* in traveling on a congested freeway. High-occupancy vehicle (HOV) lanes (See Chapter 9) are examples of managed lanes. The concept of HOV-only lanes is *evolving* into a new type of facility that offers *more choices* and *more flexibility* for a wider range of freeway users.

The Texas Department of Transportation works to the following definition (1):

"A managed lane facility is one that increases freeway efficiency by packaging various operational and design actions. Lane management operations may be adjusted at any time to better match regional goals."

Managed lanes can improve the safety and efficiency of freeway operations. Managed lanes have typically encompassed such methods as:

- Static signing and striping (Discussed in Chapter 6)
- Changeable message signs. (Discussed in Chapter 13)
- Lane control signals.
- Temporary traffic control devices.
- Law enforcement / legal restrictions.
- Economic incentives / disincentives.

Agencies often combine these methods into an effective subsystem from both a safety and operations perspective. Examples include:

- Appropriate static signing and temporary traffic control devices to temporarily close a travel lane for maintenance or construction activity (2).
- Static signing to notify drivers that large trucks are restricted to certain travel lanes and police enforce those restrictions.
- Upstream dynamic message signs to encourage diversion from the freeway or reinforce warning of a downstream lane closure.
- Reversible lanes (*zipper* lanes in some deployments) to accommodate highly directional demand.
- Tolls that vary by time of day or by demand to mitigate peak period congestion.

8.1.1 Purpose of Chapter

This chapter provides:

- A systematic approach to the development of a managed lane subsystem.
- A summary and description of various managed lane strategies and technologies.
- Insight into issues associated with managed lane subsystems.

The chapter addresses several of the key activities for developing a freeway management program (as discussed in Chapter 3) to determine an effective managed lanes system approach. The chapter proceeds to describe specific strategies and technologies, addresses special issues associated with design and implementation and concludes with some examples of managed lane subsystems.

8.1.2 Relationship to Other Freeway Management Activities

This chapter closely relates to several other chapters in the Handbook. Chapter 3, *Freeway Management Programs and Projects*, (in particular the section on systems engineering), provides the overall framework guiding all freeway management systems, including the managed lane subsystems discussed in this chapter. Since the development of managed lanes often requires roadway improvements, Chapter 5, *Roadway Improvements*, can prove relevant. Managed lanes often include additional static signing and striping which is covered in Chapter 6, *Other Roadway Improvements*. Chapter 7, *Ramp Management and Control*, is related as well since control of ramp traffic is key to maintaining mainline flow. In that chapter, the section on

Freeway-to-Freeway Ramp Metering is particularly pertinent. Chapter 9, *High Occupancy Vehicle Treatments*, relates to this chapter since HOV lanes represent a specific form of lane management. Since managed lanes become particularly important when incidents occur, Chapter 10, *Traffic Incident Management*, also is related. Finally, Chapter 13, *Information Dissemination*, describes technologies frequently used for managed lanes.

8.2 CURRENT PRACTICES, METHODS, STRATEGIES, AND TECHNOLOGIES

8.2.1 Overview

At the most basic level, the problems treated via managed lanes are similar to those specified for other freeway management subsystems. These include excessive peak period directional demands that result in congestion, safety problems, and excessive vehicle emissions that degrade the air quality of a region. The specific types of problems usually treated through managed lanes include:

- One or more lanes must be closed to all traffic for some period of time (due to scheduled work activity or an incident).
- One or more types of vehicles need to be separated from each other in one or more lanes.
- Flow on one or more lanes needs to be reversed to accommodate directional peak demands.
- Speeds or flow rates in certain lanes are judged to be too high for safe and efficient operations.
- Traffic must be safely routed through a work zone

The following strategies can be applied to managed lanes:

- Truck lanes
- HOV lanes
- Use of narrow lanes and shoulders
- Contraflow lanes
- Reversible lanes
- Mainline metering
- Speed advisories and controls
- Work zone controls
- Toll Facilities
- Congestion pricing

8.2.2 Benefits

Examples of objectives that managed lanes can address include:

- Reduce the frequency of collisions caused when motorists encounter congested conditions, work zones, or incidents.
- Improve throughput and / or reduce emissions by achieving more uniform and stable traffic

flow as demand approaches capacity. This uses the freeway more efficiently and retards or prevents the onset of congestion.

- Improve reliability of travel times for certain classes of travelers
- Distribute total delay in a more equitable manner, preserving some capacity for downstream segments.
- Increase the efficiency of operation under reduced capacity conditions caused by incidents or maintenance operations.
- Divert some freeway traffic to alternative routes or encourage alternative departure times to better use corridor capacity. This will reduce peak-period traffic demand on the freeway.
- Provide a travel time incentive to high-occupancy vehicles.
- Extend pavement life (by restricting trucks from particular lanes).

Specific benefits for the various lane management strategies are discussed in subsequent sections.

8.2.3 Key Considerations During Freeway Management Program Development

The basic steps outlined in Chapter 3, and particularly the section on systems engineering, apply to the development of a managed lanes subsystem. As discussed in that section, before developing the concepts of a particular system, some preliminary steps are necessary – specifically, understanding the local institutional environment, and identifying stakeholders.

The institutional environment includes what can realistically be done in the realm of managed lane concepts, receptivity to innovation and new ways of doing business, willingness to invest in managed lane solutions, and local laws and regulations that may impact the operation of managed lanes.

To properly perform a needs analysis and complete a concept of operations, the stakeholders or potential partners in managing this subsystem must be identified. Ultimately a consensus must be reached among them as to how the system will operate. This consensus assumes particular importance, as some lane management strategies require legislation and enforcement to implement. The support of enforcement agencies becomes essential to the success of the strategy.

Stakeholders involved in managed lanes will vary depending on the identified problems and treatments but will likely include:

- State and local DOTs.
- State and local law enforcement agencies.
- Elected officials.
- Citizens committees
- Transit agencies.
- Trucking companies.
- Private contractors.

After identifying the stakeholders affected by managed lane actions, a consensus about the problems and need for solutions must be developed. Early on, it is critical to establish support from elected officials and the general public for managed lane concepts. This is particularly important when not all motorists are affected equally by the actions that may be implemented (via tolls, lane restrictions for certain vehicles, etc.). Support is also needed from upper management at each of the agencies identified.

Concern over the interaction between automobiles and trucks on freeway facilities often becomes a controversial aspect of freeway management. Trucking companies have usually demonstrated a willingness to work with public transportation and enforcement agencies to develop compromises on when and where trucks will travel during peak periods, major freeway construction activities, or special events (3). Consequently, trucking companies can serve as crucial stakeholders in managed lanes.

After identification of the stakeholders, the next step in developing a lane management and control subsystem is preparation of a concept of operations as described in Chapters 3 and 14. The concept of operations begins with a description of the current system or situation. This includes a needs analysis (i.e. a consensus on what are the problems or situations that need to be addressed through this subsystem.) The needs analysis should articulate the identified problems and their degree of severity. This will help shape the program to include the most cost effective strategies.

It is important that the concept of operations broadly defines the proposed managed lanes system. The concept of operations must take into account the political sensitivities and ramifications of the alternative features. Alternatives that adversely impact some motorists to the advantage to other motorists have typically met resistance. Alternatives that involve direct cash outlays, such as toll facilities or congestion pricing schemes, have also met resistance. These alternatives require more public outreach and political interaction among the stakeholders to ensure that they will prove successful if implemented

8.2.4 Relationship to National ITS Architecture

As indicated in Chapter 3, the National ITS Architecture (4) provides a common structure or framework to promote compatibility and interoperability among systems, products, and services. Market packages relevant to managed lanes include:

- Freeway Control
- HOV Lane Management
- Traffic Information Dissemination
- Incident Management System
- Electronic Toll Collection
- Reversible Lane Management
- Speed Monitoring
- In-Vehicle Signing
- Automated Highway System
- Work Zone Management

8.2.5 Strategies

This section describes strategies frequently used to manage freeway lanes.

8.2.5.1 Truck Lanes

The goals of various forms of truck lanes are to improve traffic operations, improve safety and facilitate the flow of goods. (5) Truck lanes fall into the following categories:

- Lane restrictions
- Separated roadways
- Dedicated roadways
- Interchange bypass lanes
- Climbing lanes

Lane restrictions typically prohibit trucks from using the far left lane. At least 3 travel lanes are normally needed to implement lane restrictions. Several States adopted this type of lane restriction because trucks were often observed traveling abreast across several lanes, denying passing opportunities for other vehicles. Also, to provide for uniform pavement wear, trucks are sometimes restricted from the right lanes. Lane restrictions through construction zones are used to move the trucks away from workers and from narrower lanes. Table 8-1 (6) is a summary of experience regarding lane restrictions in various states and in research studies.

A survey of State practice in 1986 by the FHWA (7) identified the most common reasons given for using truck lane restrictions:

- To improve operations (fourteen States).
- To reduce accidents (eight States).
- For pavement structural considerations (seven States).
- Because of restrictions in construction zones (five States).

Truck restrictions can be implemented in a number of other ways as well. Table 8-2 (8) summarizes the constraints and impacts of different types of restrictions.

A recent project in Houston implemented a truck restriction lane on an eight-mile section of the I-10 East Freeway (9). The study reported a 68 percent reduction in crashes over a 36-week period. A truck restriction lane on I-40 near Knoxville resulted in a substantial reduction in the percentage of trucks traveling the left lane even with minimal sign usage and enforcement. (10)

Table 8-1: Truck Lane Restriction Experiences

(Reference 6)

Location / Study	Conditions	Results / Comments
Florida I-95, Broward County	Conducted a 6 month, 7am to 7 pm study in 1988	Public feels safer with lane restrictions for trucks. Overall accidents up 6.3 percent (7 am to 7 pm period); truck accidents down 3.3 percent.
Georgia	Beginning Sept. 1986, trucks were restricted to the right lane(s) except to pass or to make a left-hand exit.	On I-285, trucks were at fault in 72 percent of lane-changing violations. Before the restriction, trucks were observed occupying all lanes thus prohibiting passing.
New Jersey	Turnpike Authority (NJTA) imposed lane restrictions in the 1960's. Restrictions do not allow trucks in the left lane of turnpike roadways that have three or more lanes by direction.	Sources at the NJTA stated that the compliance rate for truck lane restrictions is very high.
Illinois	Began in 1964.	Public feels safer, and better operations.
Maryland Capital Beltway	Believes to have been implemented as a reaction to a major truck accident.	Public feels safer. Effects on safety not well known.
Virginia Capital Beltway	Four studies, one for 24-months, others for 12 months.	Public and political perception: safer highways. Engineering study recommended removal. Accident rate increased 13.8 percent during 2-yr. Study. Second study also showed increase.
Michigan	Statewide restrictions require trucks to use the right two lanes on roadways that have three or more lanes.	Establishment was thought to be politically motivated. No studies available to evaluate the countermeasure.
Garber Study	Simulation based on data from nine sites.	Decreased headways in right lane. Slight increase in right lane accidents.
Hanscom Study(23)	Two 3-lane suburban sites, all <100,000 AADT.	Beneficial traffic operations and reduced congestion.

Table 8-2: Summary of Impacts from Truck Restrictions

(Reference 8)

Action	Constraints / Limitations	Impacts
Lane Restrictions	<ul style="list-style-type: none"> • Lane drops at freeway-freeway interchanges limit applications. • Could be difficult to enforce. • Could accelerate pavement deterioration. • Could reduce visibility of overhead signing (if trucks restricted to outside lanes). 	<ul style="list-style-type: none"> • For freeway segments with lane drops, would concentrate lane changes in short section of freeway. • Would increase merging conflicts.
Time-of-Day Restrictions	<ul style="list-style-type: none"> • Truck traffic peaks do not coincide with typical commuter peaks. • Could be difficult to enforce. • Could be challenged on legal basis. 	<ul style="list-style-type: none"> • Negligible impact on operating speeds. • Could divert trucks to other less congested time periods, or other, lower quality roadways. • Could negatively impact trucks that must travel during restricted periods.
Speed Restrictions	<ul style="list-style-type: none"> • Differential speed limits for trucks and non-trucks could be difficult to enforce. • Could require extensive enforcement program. • May require use of innovative detection, apprehension, and citation strategies. 	<ul style="list-style-type: none"> • Reduction in speed differentials in restricted lane could have positive safety impacts.
Route Restrictions	<ul style="list-style-type: none"> • Efficient routing plan could not exclude freeways. 	<ul style="list-style-type: none"> • Negligible impacts on safety and operations. • Could have positive impacts if applied to transportation of hazardous materials.
Driver Training / Certification	<ul style="list-style-type: none"> • Requires strict application and enforcement of regulations. 	<ul style="list-style-type: none"> • Short-term impacts minimal. • Long-term impacts could be significant.
Increased Enforcement of Existing Regulations	<ul style="list-style-type: none"> • Would require additional enforcement personnel. • Could require incorporation of enforcement requirements in design / redesign of freeways. 	<ul style="list-style-type: none"> • Increased enforcement could lead to increased compliance with traffic laws. However, there is no conclusive proof that increased compliance reduces accidents.

Separated roadways for trucks are less common. A well-known example is the New Jersey Turnpike, which features completely separated roadways, one reserved for passenger cars only, and the other open to both commercial and non-commercial traffic. Figure 8-2 shows a *dual-dual* section of the Turnpike. The data in Figure 8-3 shows that the dual-dual portions of the NJ Turnpike enjoy lower accident rates than the sections where commercial traffic is not separated.



Figure 8-2: Dual-dual Section of New Jersey Turnpike.

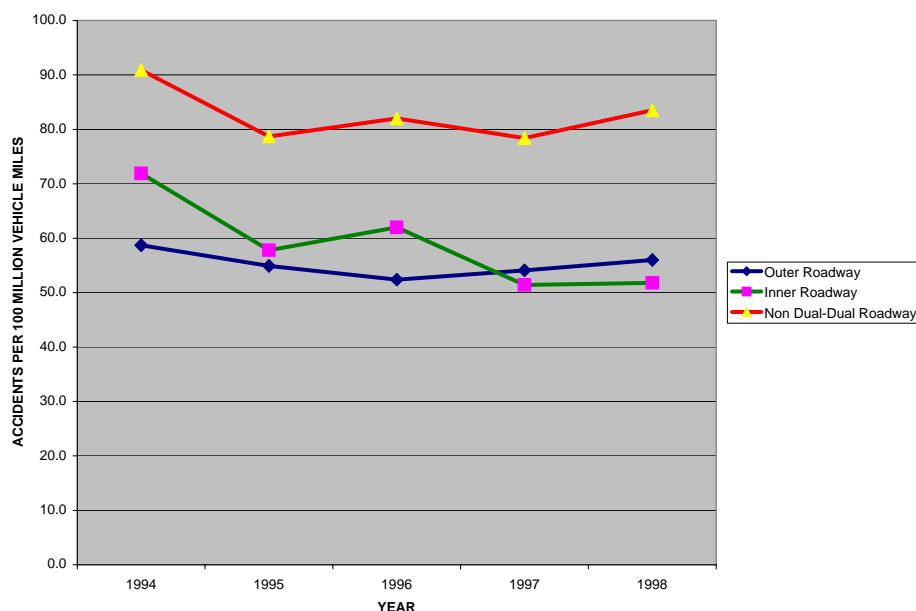


Figure 8-3: Accident Data on New Jersey Turnpike.

Dedicated roadways for trucks are even less common. One example is the South Boston Bypass Road, a two lane undivided roadway with no shoulders. The SBBR is restricted to commercial vehicles only - including taxis, jitneys, limos, and automobiles with commercial plates. The restriction was instituted to mitigate noise and emissions by siphoning truck traffic from I-93 through an industrial edge of South Boston. The roadway reduces demand on a saturated I-93 through the middle of downtown Boston and usually operates with free flowing heavy truck traffic.

Climbing lanes typically are built to improve operations on grades by separating slow moving heavy vehicles from the rest of traffic. These lanes have become a common practice and AASHTO (11) provides established criteria. Additional information is provided in Chapter 5.

Interchange bypass lanes have been implemented in Southern California and Portland, Oregon to route trucks around a major merge, thereby improving traffic operations at the interchange. Figure 8-4 shows such a bypass lane at the I-5 / I-405 interchange in Los Angeles.

8.2.5.2 HOV Lanes

Another form of managed lanes is the dedication of a lane(s) to *high-occupancy vehicles* only. (For discussion of high occupancy vehicle lanes, see Chapter 9 (High Occupancy Vehicle Treatments)).

Entire roadways have been restricted to HOV use on an emergency basis. In the wake of the terrorist attacks of September 11, 2001, New York City required vehicles entering bridges and tunnels south of 63rd Street in Manhattan to have at least 2 occupants (See Figure 8-5). This was to reduce traffic congestion due to heightened security checks of vehicles using these facilities.



Figure 8-4: I-5 Truck Bypass, Los Angeles



Figure 8-5: HOV Restrictions into NYC During Period Following September 11, 2001

8.2.5.3 Use of Narrow Lanes and Shoulders

Research has confirmed that shoulders and narrow lanes can be used effectively to increase capacity in congested metropolitan corridors. This strategy is discussed in Chapter 5 herein and in Reference 12.

8.2.5.4 Contraflow Lanes

A contraflow lane is a freeway lane in the off-peak direction of flow (normally adjacent to the median) that is designated for use by HOVs traveling in the direction of peak flow for at least a portion of the day (See Chapter 9). They may also be used during major evacuations as discussed in Chapter 12. Normally, the contraflow lane is *separated* from the off-peak (or opposite) flow by insertable cones, pylons, or movable concrete barriers.

Application of contraflow lanes has been limited to areas of extreme congestion where directional flow imbalance permits their use. This approach is sometimes used as an interim measure during the definition and development of long-range solutions. Table 8-3 describes two contraflow projects in the New York / New Jersey metropolitan area on severely congested approaches to tunnels.

Table 8-3: Characteristics of Contraflow HOV Lanes on Grade-Separated Facilities in the New York Metropolitan Area.

Lane Characteristics	New Jersey	New York
Route	I-495 approach to Lincoln Tunnel	I-495 approach to Queens Midtown Tunnel
Length in miles	2.5	2
Year started	1971	1972
AM / PM	AM	AM
Remaining off peak traffic lanes	2	2
Buffer lane	No	No
Typical bus volumes	500/peak hour 900/peak period	120/peak hour 200/peak period
Typical passenger volumes	21,000/peak hour 35,000/peak period	6,000/peak hour 10,000/peak period

Disadvantages of freeway contraflow lanes include:

- Labor-intensive daily operations to set out and retrieve traffic cones used as lane delineation markers, and
- Contraflow freeway HOV lanes tend to have low accident rates but high severity indices; capacity reduction in off-peak direction typically increases accident rate in that direction (Reference 13)

8.2.5.5 Reversible Lanes

To best use existing facilities, a number of jurisdictions have instituted reversible-lane flow (also known in Europe as *tidal* flow lanes). Reversible lanes change the directional capacity of a freeway to accommodate peak directional traffic demands. To warrant reversible lanes, peak-period traffic volumes should exhibit or anticipated to exhibit significant directional imbalance (e.g., 70/30 percent, Reference 40). If warranted, reversible lanes can use right-of-way more efficiently and economically. Figure 8-6 illustrates an example of the directional peaks that reversible lanes can mitigate.

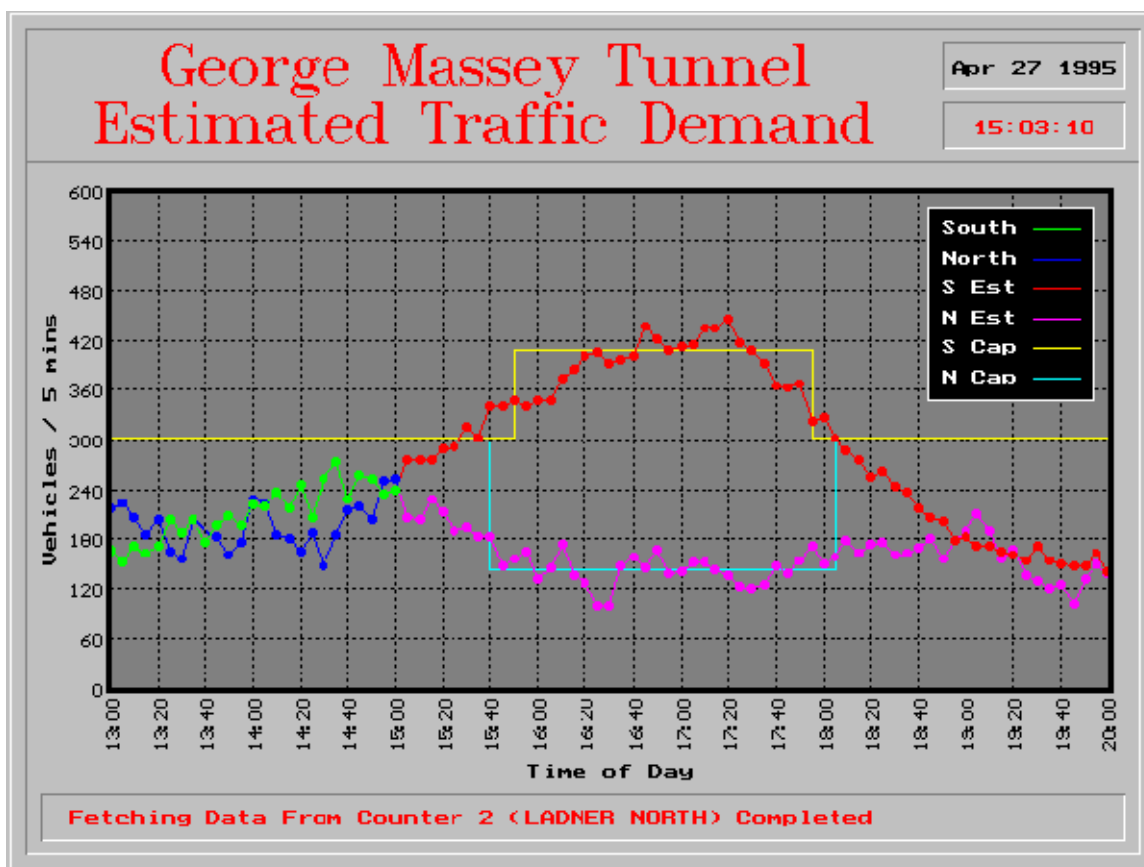


Figure 8-6: Directional Peaks Potentially Mitigated by Reversible Lanes

Reversible lanes on a freeway have usually been implemented on a roadway cross-section that includes a *completely separated* set of lanes in the center of the freeway. These are reversed in accordance with peak demands usually on a time-of-day basis.

An example is the set of reversible express lanes (lanes that do not have access to and from all interchanges) on San Diego's I-15 which have been in operation for 14 years. The reversible 2-lane facility is located between the Ted Williams exit (SR-56) to the north and the SR-163 exit to the south. This facility has three operational barrier gates that are open from 5:45 am to 9:15 am for the morning peak inbound, (southbound), and from 3:00 pm to 7:00 pm for the evening peak outbound, (northbound). The I-15 HOV facility uses both lanes in the same direction for each operational period and is open to the following vehicles:

- 2+ person carpools
- 2+ person vanpools
- Buses
- Motorcycles

On weekends, the I-15 HOV facility is normally not open / used except in extenuating circumstances. As a result of a managed lanes initiative, the lanes are now open to single occupant vehicles (SOVs) as part of the Congestion Pricing / HOT Lane initiative. (See section 8.2.5.10 and Chapter 9).

In addition to the three barrier gates, the equipment that operates the facility includes pop-up lane delimiters for lane control, video cameras, vehicle detection, lighting, and 12 CMS signs. The configuration is shown in Figure 8-7.

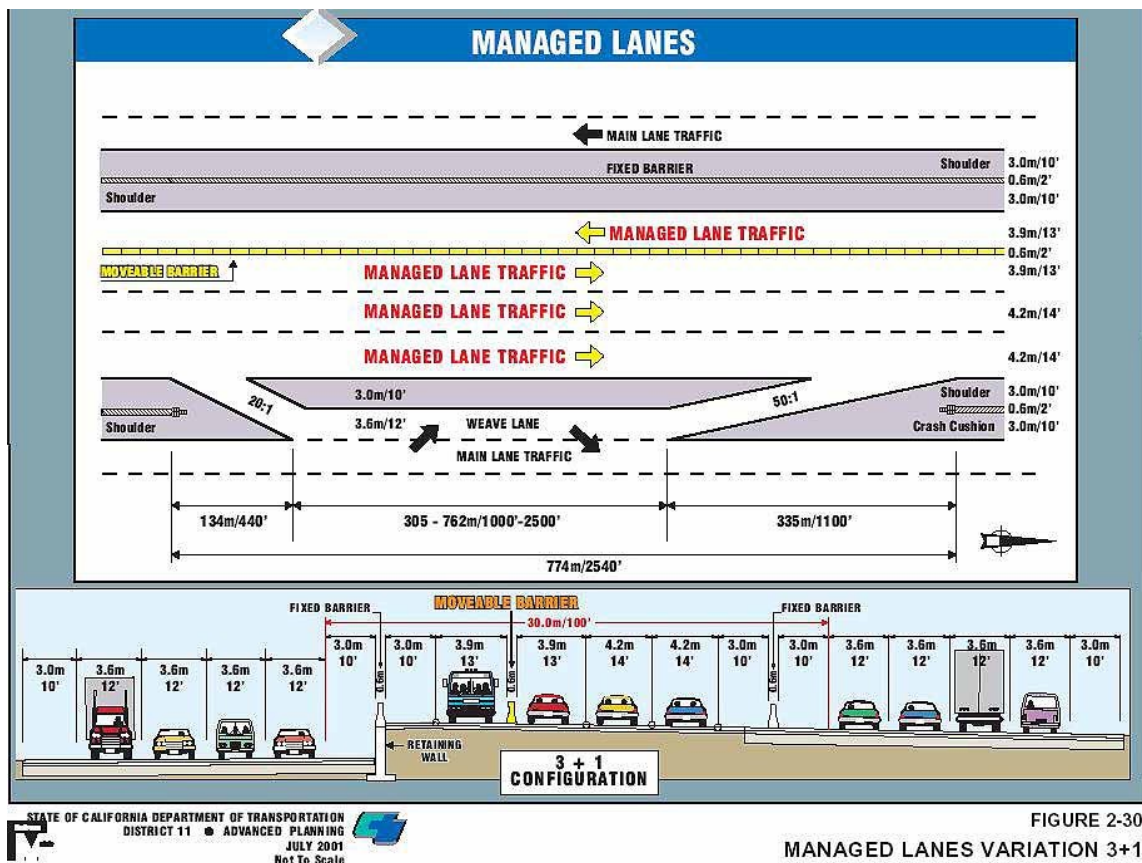


Figure 8-7: Schematic of I-15 Reversible Lanes

Separated reversible lanes have also been designed and implemented on the Kennedy Expressway in Chicago, Interstates 5 and 90 in Seattle, and the Shirley Highway in Northern Virginia (See Figure 8-8).



Figure 8-8: Shirley Highway (I-395 Northern Virginia) Median Reversible Lanes

The Kennedy Expressway has a 7-mile, two-lane reversible roadway in the median strip. The reversible lanes serve as express lanes and have only one access between their terminals for outbound-only flow. The outer roadways have three to four lanes and operate in only one direction.

Interstate 5 on the northern approach to Seattle has a 7.5-mile reversible-lane section in the median. However, the reversible lanes are not express and have several interchange points. The major features of this system include:

- The only transfer points between the reversible-lane section and the outer roadways are at the two ends of the section. The other seven interchanges are direct transfers between the reversible lanes and the arterial street system.
- The ramp connections to the reversible roadway are controlled by devices that include:
 - Swing gates,
 - Changeable message signs to inform the motorist of the current operating direction.

These devices are activated locally at each ramp site. To help motorists become familiar with the system, lane reversal is usually performed at the same time each weekday (with weekend hours varying slightly from the weekday).

Reversible lanes not using a completely separated set of lanes are often used in tunnel and bridge operations for:

- Assigning roadway lanes to prevailing directional traffic flow requirements,
- Balancing traffic flow during maintenance operations, and
- An element in incident response plans.

The center lane of the San Diego Coronado Bridge is reversible along its 1.6-mile length. The configuration is changed twice a day to accommodate peak hours (3 lanes in the peak direction and 2 in the off-peak direction). It uses a moveable barrier, is deployed Monday through Friday and has been in operation for 10 years.

New York's Tappan Zee Bridge reverses a lane twice a day, changing the center lane from northbound to southbound and back again. This application also uses *Moveable Barrier Technology*. (See section 8.2.6.6).

Reference 15 identifies the following considerations that need to be addressed when considering a Moveable Barrier technology (MBT) application (which are also applicable to any reversible lane / contraflow lane scenario):

- If reversing a traffic lane is considered, the basic requirement is that off-peak traffic can be accommodated in the remaining lanes. If the traffic volume is too high to be accommodated in the remaining lanes and if severe traffic congestion exists in the peak direction, the feasibility of reversing the direction of a lane should still be investigated in conjunction with other measures, such as ramp metering, to reduce traffic in the off-peak direction. Even if some congestion occurs in the off-peak direction as a result of implementing the contraflow lane, it can still be justified if there is a net benefit in the implementation of such a lane. In other words, the benefits derived from the additional lane in the peak direction exceed the disbenefits resulting from one fewer lane in the off-peak direction.
- If a shoulder is converted to a traffic lane in the peak period by using positive separation technologies, enough right-of-way must exist for the safe operation of such a lane.

8.2.5.6 Mainline Metering

Mainline metering controls the mainline traffic entering a freeway section or a limited access bridge or tunnel. While the technique can create congestion on the mainline upstream of the controlled section, it can help maintain uncongested flow on the mainline downstream. While limited applications of mainline metering on controlled access facilities such as bridges and tunnels roads have been found effective, the concept has not yet found application to a typical metropolitan freeway system.

Mainline metering can accomplish the following objectives:

- Deter traffic from using the freeway, particularly in bottleneck areas.
- Smooth traffic flow through a bottleneck.
- Provide more equitable distribution of delay penalties with respect to motorists entering at metered ramps. (16)
- Minimize congestion-induced emissions in environmentally sensitive areas (such as tunnels).

Mainline metering can cause queues on the mainline, which may be met by significant community opposition.

Toll facilities often function as mainline meters. The principal example of mainline metering in the U.S. is westbound I-80 at the San Francisco-Oakland Bay Bridge (16). Shown in Figure 8-9, this installation places the mainline meters just downstream of a 22-bay toll plaza. Westbound traffic approaching the San Francisco-Oakland Bay Bridge passes through the toll plaza and is then metered to narrow the 22 lanes of traffic into four lanes as efficiently as possible. HOV lanes allow HOVs to bypass the traffic queues.

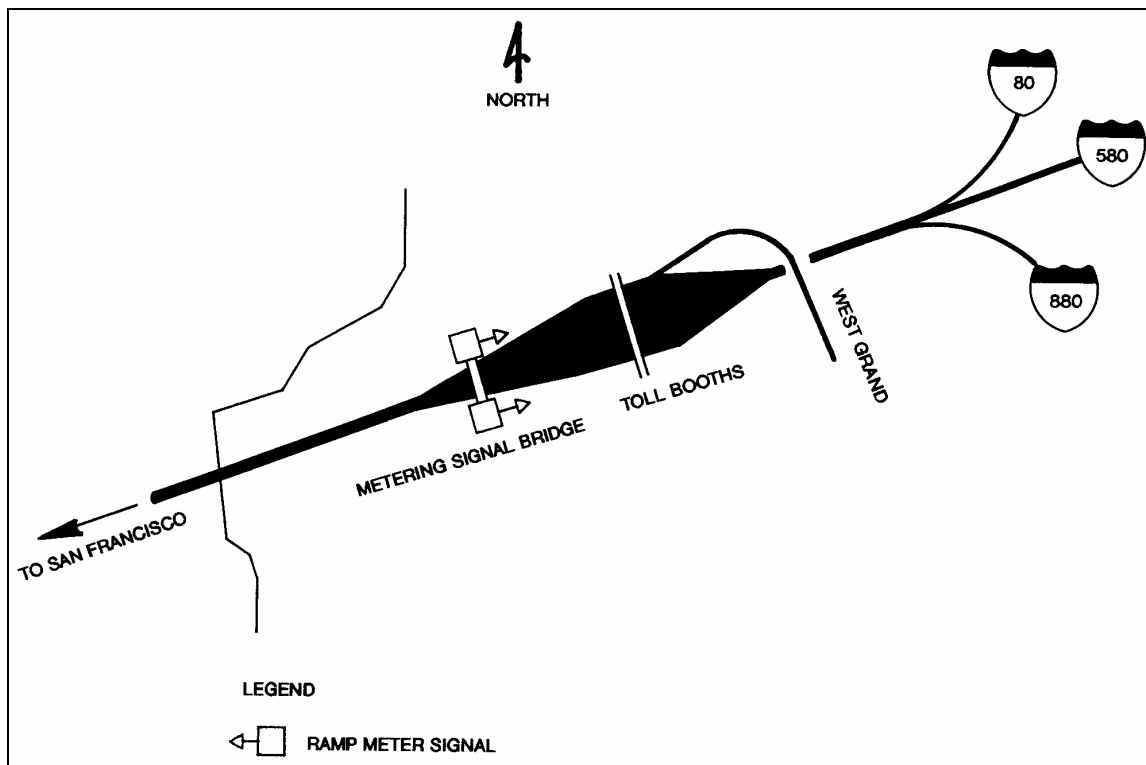


Figure 8-9: Mainline Meter On I-80, Oakland, CA (Westbound Direction).

Meters have smoothed traffic flow at the merge and helped heavy vehicles attain normal speed before reaching the uphill bridge approach. Prior to metering, downstream throughput on the bridge averaged 8200 to 8300 v/hr. Throughput after metering averaged 9500 v/hr. Public acceptance of the long queue delays has been good (16).

Mainline metering has also been used on one lane at the westbound entrance to the Holland Tunnel in New York City (17). A before and after study concluded that metering improved traffic volume throughput by approximately 7%.

Another potentially effective use of mainline metering that has not yet been applied is in a construction zone where traffic demand greatly exceeds the capacity available, and some reserve capacity for vehicles entering at downstream ramps needs to be provided (18).

8.2.5.7 Speed Advisories and Control

Variable speed limits (VSL) are intended to allow reasonable and realistic speeds based on time of day, traffic conditions, weather conditions, construction or maintenance activities, and other factors. With the exception of school zones, use of variable speed limits in the United States has been limited, although many transportation agencies have expressed interest in them. Use has probably not been more widespread due to concerns over their legal basis, the level and type of enforcement required, and the lack of information on proven benefits.

Some static speed limits in dynamic environments have low levels of compliance, and speed limits that are responsive to the situation should be more credible and may result in improved compliance. In other situations, the speed limit may be too high for the conditions, and a variable speed limit could provide additional information that may be beneficial to the driver.

Variable speed limits use traffic speed and volume detection, weather information and road surface condition technology to determine appropriate speeds at which drivers should be traveling, given current roadway and traffic conditions (19). These advisory or regulatory speeds are usually displayed on overhead or portable changeable message signs (CMS) (See Figure 8 -10). In the U.S., VSL are deployed in Colorado, Minnesota, Nevada, New Jersey, Massachusetts and Washington State. Often they are part of larger incident management, congestion management, weather advisory, or motorist warning systems.



Figure 8-10: Variable Speed Limit Sign.

An example deployment is on the New Jersey Turnpike where enforceable variable speed limit signs have been in use since the late 1960s to provide early warning to motorists of slow traffic or hazardous road conditions. Approximately 120 signs are installed over 148 miles of roadway. The posted speed limits are based on average travel speed and are displayed automatically (manual override used for lane closures and construction zones). The posted speed limit can be reduced from the normal speed limit (depending on the milepost location 65 mph, 55 mph, and 50 mph) in five-mph decrements, to 30 mph. The posted speed limit can be reduced for six reasons: accidents; congestion; construction; ice; snow; and fog. The speed warning signs display, "Reduce Speed Ahead" and the reason for the speed reduction. When appropriate, the distance between the warning sign and the beginning of the congestion is displayed on the warning sign. The New Jersey Turnpike Authority feels that the signs are effective, and provide motorists with information on unusual roadway conditions that dictate the need for speed reduction. State Police enforce the reduced speed limits by issuing summonses to those motorists found to be in violation.

VSL systems have been in use for the last 30 years and currently are successfully being deployed and / or tested in Australia and Europe. An example is the Netherlands' Motorway Control System. It provides lane control and speed limit signs generally every 500 meters and is used to slow traffic either in advance of a slowdown / shock wave or work zone. The system has proven effective in reducing collisions by about 16% (20) and has increased throughput 3 – 5 percent. It also reduces the cost of work zone traffic control.

Tests are being conducted in Maryland, Michigan and Virginia to determine the effectiveness of Variable Speed Limits in work zones. VSL systems will rely on input of vehicle speeds and other information to post an appropriate speed limit, allowing motorists to maintain the most efficient and safe speeds, without endangering themselves, other drivers, or workers. Each of the selected states will implement VSL systems in a work zone, monitor operations, and evaluate system effectiveness.

8.2.5.8 Work Zone Controls

A *work zone* is an area of a highway with construction, maintenance, or utility work activities; it extends from the first warning sign or rotating / strobe lights on a vehicle to the END ROAD WORK sign or the last temporary traffic control device. Within a work zone, safe traffic flow is maintained by providing temporary signage, channelizing devices, barriers, pavement markings, and / or work vehicles. Traffic management in work zones is important to the safety of both workers and motorists. Time is required to properly develop and implement the traffic control when lanes must be closed to complete the work. No one sequence of traffic control devices can be designed for all situations. In addition, a work zone cannot always maintain the same number of lanes and the path through a work zone will be influenced by the traffic control devices present. Where possible the traffic control plan should be designed to provide the same number of lanes of traffic during construction as before. Ideally, the traffic control plan should be designed for the same free-flow traffic speed that existed before freeway construction.

The MUTCD (2) extensively discusses *temporary* traffic control plans that include temporary traffic control measures for facilitating travel through a work zone. These plans play a vital role in providing continuity of safe and efficient road user flow through a work zone. Temporary traffic control plans can be very detailed or simply reference typical drawings contained in:

- The MUTCD,
- Standard approved highway agency drawings and manuals, or
- Specific drawings contained in the contract documents.

The degree of detail in the temporary traffic control plan depends entirely on the complexity of the situation. The selected traffic control plan should have the approval of the responsible highway agency prior to implementation.

In addition to the MUTCD, several other resources exist for planning and evaluating work zone strategies. These include:

- FHWA Office of Operations *Work Zone Mobility and Safety* web site at <http://ops.fhwa.dot.gov/wz/index.asp>
- The *Work Zone Operations Best Practices Guidebook* (available from the web site)
- The FHWA *Work Zone Mobility and Safety Self Assessment Guide* (available from the web site)

The *Work Zone Operations Best Practices Guidebook* (21) is a resource designed to give state and local transportation agencies, construction contractors, transportation planners, trainers, and others with interest in work zone operations access to information and points of contact about current best practices for achieving work zone mobility and safety. This guide leverages the collection of work zone operations best practices by providing an easily accessible compilation of the best practices in a variety of cross-references, thereby enabling users to find best practices in several different ways, including by:

- State
- Participating organizations (e.g., Federal, State, County, City, Contractor)
- Life cycle (e.g., planning, design, construction)
- Nature of Work (e.g., utility, resurfacing, marking / signage, maintenance, interchange upgrade, bridge repair, bridge maintenance, construction, night work)
- Traffic conditions (e.g., enforcement activities, heavy / normal / light traffic, high posted speeds, large trucks present)
- Setting (e.g., urban, rural)
- Roadway characteristics (e.g., expressways, divided facilities, freeways, freeway ramps, toll roads, arterials)
- Categories:
 - Policy and procedures
 - Public relations, education, and outreach
 - Prediction modeling and impact analysis
 - Planning and programming
 - Project development and design
 - Contracting and bidding procedures
 - Specifications and construction materials, methods, and practices
 - Traveler and traffic information (project related)
 - Enforcement
 - ITS and innovation technology
 - Education and feedback

The best practices are *descriptive* not *prescriptive*. That is, they describe approaches used by transportation agencies, along with contact information. Each organization must determine which of these practices are best suited for its particular situation, considering all factors that affect work zone operations.

The *Work Zone Mobility and Safety Self-Assessment Guide* (22) is grouped into functional categories that deal with the project development processes, such as *Leadership & Policy, Planning & Programming, Design, Construction & Operations, Communications & Training, and Evaluation*. The performance-rating scheme is based on the classic process improvement approach. It includes 5 stages - *Initiation, Development, Execution, Assessment, and Integration*. Within each stage there is a High, Medium, and Low performance level to choose from. The results of this self-assessment can provide an indication of how well transportation agencies are doing in mitigating the impact of work zones on congestion and crashes.

Finally, it is emphasized that the concept of *work zone management* is more than lane management strategies and the set up / configuration of the work zones themselves (i.e., cost-effective mitigation measures to directly handle the traffic impacts encountered during the construction and maintenance operation). The exposure of the motorist and the highway worker can be reduced – thereby also reducing motorist delays and crash rates – through other proactive means, including:

- Reducing the volume of traffic going through the work zone – The volume of traffic going through the work zone can be reduced by diverting traffic to other routes, detours or modes of transportation, changing driver behavior and trip times during the life of the project, and / or closing the facility during construction.
- Reducing the length of time work zones are in place – The length of time work zones are in place can be reduced by time-based bidding, providing incentives for early completion, putting disincentives in the contract for restricting traffic (*lane rental*), forcing the contractor to concentrate on shorter sections within the overall project length, partnering, constructability reviews, and / or receiving contractor input on the sequencing of the construction project during the early phases of project design.
- Reducing the frequency that work zones are established to perform construction and maintenance operations – The frequency that work zones are established can be reduced by extending the life of the facility, using the corridor approach, designing for success, and / or an effective preventive maintenance program.
- Providing real-time traveler information to advise motorists of work zone status (current number of lanes closed) and traffic conditions in advance and through the work zone.
- Improving transit service to further reduce traffic volume through the work zone.

8.2.5.9 Toll Facilities

Toll facilities are fully controlled access roadways designed to the same high standards of design as freeways. However, because of both the economic influence they exert on traffic demand for the facility and the traffic metering effect that occurs at the toll collection plazas, toll facilities can also be considered another form of managed lanes. Toll facilities form the most direct user charge for providing revenues based on the costs of travel. Often, they can be

implemented more quickly, because the capital funding is available up front and because toll roads often do not have to comply with federal regulations. Also, toll facilities provide a revenue stream for ongoing operations and maintenance.

Legislation has been enacted to facilitate the development of toll facilities through innovative financing. For example, the Federal Highway Act of 1987 provided for eight demonstration projects across the nation, allowing a mixture of toll revenues with state and federal funds on new projects. California enacted legislation that allows the development of joint-power authorities to collect developer fees for transportation projects, and awarded four franchises to private entities, allowing private designing, financing, construction, and operation of toll facilities for 35 years.

Toll road facilities are a means of financing roadway improvements. The intent is to finance roadway construction only if there is sufficient demand willing to pay a premium for services rendered by the facility. Furthermore, the user population must be willing to pay for the opportunity to save time in the system because toll road facilities are generally less congested. The concept of toll roads has proved a realistic procedure to finance the construction of needed facilities. There are several advantages and disadvantages involved in the implementation of toll roads as opposed to free roads. Table 8-4 lists some of the advantages and disadvantages of financing a road via user tolls.

Table 8-4: Advantages and Disadvantages of Toll Road Financing.

Advantages	Disadvantages
<ul style="list-style-type: none"> • Timely construction, no delays. • Reduced construction costs. • Earlier realization of benefits, such as lower fuel costs, greater safety, comfort and convenience. • Regular inspections and maintenance required by lenders. • Inclusion of operating costs in financing and incoming plans; costs include police, emergency services, and snow and ice control. • Ability to free tax funds for “free” roads. 	<ul style="list-style-type: none"> • Higher maintenance and operations costs, in most cases. • Infrequent access. • Possible adverse effect on other roads in corridor. • Delays at toll booths. • Added costs of borrowing, since financing is through issue of bonds, not from general tax revenues (state and federal) • Added costs of collecting tolls. • Opposition in areas without existing toll facilities

8.2.5.10 Congestion Pricing

Congestion Pricing (also known as Value Pricing) is a lane management strategy whose use has increased significantly due to the public acceptance and use of Electronic Toll Collection (ETC) technologies (See section 8.2.6). Congestion pricing charges a premium to road users who want to drive during peak periods such as rush hour or holiday weekends.

Travel during congestion costs society more (in terms of increased infrastructure needs, increased emissions and fuel consumption); therefore users during those times should pay more. The most straightforward way to implement congestion pricing is on existing toll facilities if they are congested during certain times of day, much like transit or airline fares are often higher during peak travel times.

Key features of congestion pricing for freeway lane management include:

- Facility users carrying ETC transponders
- Tolls varying by time of day based on expected congestion in the corridor
- Discount pricing as an incentive to high occupancy vehicles
- Photo-enforcement of toll violations

Benefits of congestion pricing are:

- Enhanced mobility management of congested facilities
- Short term travel mobility improvement
- Expanded acceptance of ETC for managing transportation facilities
- Increased utilization of HOV or special purpose lanes
- Possible improved public perception of HOV lane use
- Provision of a new management option for the tool kit
- Bridge to long term improvements

Key issues to address when considering congestion pricing include:

- Technology compatibility – among toll collection systems in the region and across the country and across travel modes.
- Enforcement – concerns about legislative changes needed to allow vehicle owners to be ticketed, rather than drivers. Also, verification of occupancy requirements (if implemented) needs to be accommodated without unduly affecting the overall operation of the facility.
- Privacy – concerns about the potential tracking of individuals through the ETC technology. One alternative proposed is the use of *Smart* cards that maintain their own internal data about the individual's account.
- Price determination – questions have to be resolved as to whether charges should be based on short-term marginal road user costs of an additional vehicle added to the traffic stream, or on long-term costs of providing an equivalent amount of extra capacity to the facility.

There are logistical, institutional, and attitudinal barriers that must be addressed when implementing a congestion pricing system. A feasibility study must therefore be undertaken prior to implementation. The following tasks should be conducted:

- Review of appropriate state-of-the-art technology.
- Attitudinal surveys of the system users.
- Organization of participating agencies and private sector partners.
- Conceptual design for select U.S. cities.
- Preliminary capital and operational and maintenance cost estimates.
- Development of a conceptual implementation plan (i.e., time frame, lead agency, potential funding sources, institutional requirements).

Congestion (roadway) pricing has seen limited use in the United States, though already proven successful in efforts to reduce congestion in Singapore, London, and several Norwegian cities. Implementation of roadway pricing has been discouraged in the U.S. due to technical and political problems. The use of ETC technology overcomes some of the technical barriers such as congestion at toll booths. To overcome political barriers, demonstration projects can be performed to introduce the concept. Congestion pricing should not be introduced on a facility that traditionally has no charge. Two recommended facilities that should be used to introduce this concept are:

- Existing toll facilities, where off-peak discounts and peak-hour surcharges can be introduced to increase ride-sharing incentives and reduce congestion.
- Completely new facilities.

A pricing schedule should be designed so that initial costs are fairly low. These costs should be maintained for a period of 6 to 12 months to permit behavior patterns to stabilize, after which the cost should increase. This process should continue until the cost is at the desired level. The use of congestion pricing is expected to improve the traffic flow, ridesharing, and emission-reduction experienced on the roadway. These improvements should be quantified in the demonstration project to prove these benefits.

Table 8-5 presents barriers to the implementation of congestion pricing using ETC technology, and recommended strategies. Three arguments that justify the use of congestion pricing are:

- Economic argument – automobile users should pay the full cost of the congestion their use of the road imposes on the public.
- Congestion is reduced.
- Environmental improvement - less congestion means less air pollution due to slow moving traffic flows.

One rationale for congestion pricing is that it generates revenue. The facility sells to motorists, on a time-of-day or congestion-level basis, the excess capacity available from operation of HOV or other special purpose freeway lanes or exclusive roadway toll facilities. This concept of High Occupancy Toll (HOT) lanes is discussed in Chapter 9 and Reference 39.

Congestion pricing has gained institutional acceptance as a management tool with the success of toll road and express lane facilities in Southern California. These facilities include:

- In San Diego, California, the *FasTrak Facility* provides two reversible express lanes in the median of Interstate Highway I-15. This two-lane 8-mile section of separated lanes was restricted to HOV with 2 or more people. This restriction resulted in severely underutilized express lanes while the adjacent unrestricted lanes were typically heavily congested with 30 minutes of delay. By implementing ETC for all vehicles, the SOV could use the excess capacity of the express lanes for a toll. The SOV toll dynamically varies from \$0.50 to \$4.00 depending on the level of congestion in the express and general purpose lanes. High occupancy vehicles continue to enjoy free use of the express lanes.
- Expanding on the toll road concept in Orange County, California, three toll roads (San Joaquin Hills – SR73, Foothill – SR241, Eastern – SR241/261/133) were built through the issue of bonds backed by future tolls and fees.

Table 8-5: Barriers to Congestion Pricing Implementation.

Barrier	Description	Recommended Strategies
Technical		
Logistical Problems	<ul style="list-style-type: none"> • Numerous structures at checkpoints needed. • Equipping vehicles with proper equipment. • Geography of the city. 	<ul style="list-style-type: none"> • Provide financial incentive for equipment installation on vehicles. • Many problems solved with time.
Uniformity	<ul style="list-style-type: none"> • Different ETC technologies used by each agency. 	<ul style="list-style-type: none"> • Develop standards for ETC systems. • Will require legislation but should not be a problem.
Social and Political		
Congestion and Pricing as an Additional Tax	<ul style="list-style-type: none"> • Public perceives it as another form of taxation instead of a price to use the road. 	<ul style="list-style-type: none"> • Stress that this is a user fee to support roads, not a tax. • Stress that revenues from the system will be linked to further expenditures on the system. • Describe lower rates at non-peak periods as a reward for traveling at that time.
Privacy	<ul style="list-style-type: none"> • Public does not want their vehicular movements monitored. 	<ul style="list-style-type: none"> • Stress that a congestion pricing payment is no different than an itemized telephone bill. • Information not used for enforcement. • Pictures only taken of license plates. • Not looking at individuals, just tags.
Equity	<ul style="list-style-type: none"> • Forces poorer drivers off the road -- politically undesirable. 	<ul style="list-style-type: none"> • Show that it would not be any more equitable or inequitable than present system.
Business Interests	<ul style="list-style-type: none"> • May create decreased interest in downtown shopping areas. 	<ul style="list-style-type: none"> • Effects not certain -- need demonstration project.

- SR-91 Express Lanes (Figure 8-11) is a four lane 10 mile toll road built in the median of California's Riverside Freeway between the Orange / Riverside County line and the Costa Mesa Freeway. The state of the art facility features a fully-automated toll facility, and the first application of value pricing in the U.S. The use of ETC technology eliminated the need to stop and pay tolls at traditional toll booths, thus ensuring the free flow of traffic on the SR-91 express lanes.



Figure 8-11: SR-91 Express Lanes

8.2.6 Technologies

The following technologies can be applied to managed lanes:

- Static signing and striping.
- Dynamic message signs
- Variable speed limit signs
- Speed warning systems
- Lane-use control signals
- Moveable barriers
- Channelizing devices.
- Electronic toll collection

The generic relationship between these technologies and lane use management strategies is shown in Table 8-6.

Table 8-6: Relationship of Technologies to Strategies

TECHNOLOGIES STRATEGIES	Static Signing and Striping	Dynamic Message Signs	Variable Speed Limit Signs	Speed Warning Systems	Lane-use Control Signals	Moveable Barriers	Channelizing Devices	Electronic Toll Collection
Truck Lanes	√							
HOV Lanes	√	√						
Narrow lanes and Shoulders	√			√				
Contraflow Lanes	√				√	√		
Reversible Lanes	√	√			√	√		
Mainline Metering	√							
Speed Advisories / Controls	√	√	√	√				
Work Zone Controls	√	√			√	√	√	
Toll Facilities		√						√
Congestion pricing	√	√						√

Decision makers must assess the candidate technologies to determine which are most appropriate to achieve the desired strategies. The assessment should consider both the *spatial* and *temporal* operational characteristics of the freeway. For example, spatial considerations address technology adequacy from the aspect of roadway design and construction and may require the decision maker to answer such questions as:

- Is the pavement on the shoulder adequate to support heavy-vehicle travel?
- How will restricting large trucks to a specific lane or lanes affect vehicle merging or diverging maneuvers at entrance and exit ramp locations?

Temporal considerations also prove important in assessing technologies. For example, before considering truck lane restrictions on a freeway, a decision maker may consider whether truck-automobile conflicts and crashes are a problem at all times of the day or only during certain periods. Likewise, decisions regarding when and how many lanes will be closed to accomplish a given work activity are a major part of the work zone planning process. For instance, it may be possible to close more travel lanes at night to do the work, but this requires channelizing devices and other traffic control devices that provide higher levels of retro-reflectivity (increasing planning and traffic control costs). Other considerations include cost, time to implement, political feasibility, and estimates of benefits.

To aid in this assessment the remainder of this section describes each of the identified technologies and provides examples of deployment.

8.2.6.1 Static Signing and Striping

As discussed in Chapter 6, static signing and striping provide the required guidance and warning to ensure the safe and orderly movement of traffic. Signs can implement managed lanes by restricting certain vehicles from using a particular lane. Examples include:

- Restricting trucks to the right most lane(s) or from using a facility at specific times of day.
- Establishing lane(s) for high-occupancy vehicle use only.

Static signing and striping are also used for warning purposes in advance of construction and maintenance work zones to inform motorists that one or more travel lanes are closed downstream. These generally supplement the channelizing devices placed at the point of closure that require drivers to vacate the lane at that point (channelizing devices are discussed later in this section).

Standards on static signing and striping are covered in the *Manual on Uniform Traffic Control Devices* (2). Some states also publish their own manuals that should be followed when specifying lane management signing.

8.2.6.2 Changeable Message Signs

Changeable message signs can advise motorists of freeway conditions so that they can take appropriate action to improve the efficiency and safety of travel. Chapter 13 (Information Dissemination) provides a detailed discussion of dynamic message sign technologies. For managed lane applications, the more limited capability variable speed limit signs, speed warning systems and lane control signals (LCS) can also convey lane use and lane status information to drivers.

8.2.6.3 Variable Speed Limit Signs

Using variable speed limits as a strategy is discussed in section 8.2.5.7. The technologies that apply to VSL signs span those that are generally used for dynamic message signs. They can range from limited message signs capable of displaying numerals only to infinitely variable message signs with full message capability but used for displaying variable speed limits. See Chapter 13 for a description of changeable message sign capabilities.

8.2.6.4 Speed Warning Systems

Speed warning systems sense the speed of a passing vehicle and activate a dynamic message sign informing the driver of his or her current speed. These systems find application at the approaches to work zones, at high accident locations where speed is a contributing factor, and at other locations experiencing excessive speeds for prevailing conditions. Typically, a radar senses a vehicle's speed and activates a DMS with a message such as:

"YOU ARE SPEEDING AT [xx] M.P.H. 45 M.P.H. CURVE AHEAD."

In a deployment in Colorado (See Figure 8-12), the maximum design speed for a curve was 43 mi/h due to limited sight distance. The 85th percentile of truck speed was 66 mi/h before installation and 48 mi/h after. However, studies conducted under the *Midwest States Smart Work Zone Deployment* initiative indicate that no significant difference was observed in the number of vehicles observing the speed limit (24). Other studies have indicated that dynamic

speed displays can be effectively combined with a static speed limit sign posted above the display for comparison.



Figure 8-12: Speed Warning Sign

8.2.6.5 Lane-Use Control Signals

Lane-use Control Signals (LCS) are fixed-grid CMS (refer to Chapter 13) that use both color and symbols to convey information. The *Manual on Uniform Traffic Control Devices (MUTCD)* defines LCS as special overhead signals that permit or prohibit the use of specific lanes of a street or highway or that indicate the impending prohibition of their use. LCSs are most commonly used for reversible-lane control, but are also used in non-reversible freeway lane applications. Examples include (25,26,27):

- Toll booths,
- HOV lanes,
- Reversible transitways on freeways,
- Arena traffic, and
- Parking control.

Other applications include:

- Restricting traffic from certain lanes at certain hours to facilitate merging traffic from a ramp or other freeway,
- Controlling lane use for tunnels and bridges,
- On a freeway, near its terminus, to indicate a lane that ends, and
- On a freeway or long bridge, to indicate that a lane may be temporarily blocked by a crash, breakdown, construction or maintenance activities.

In addition, at least one operating agency uses LCS to indicate to motorists that a shoulder can be used as a travel lane during peak travel periods. Interstate 66 in Virginia uses the left most lane as an HOV lane during the peak periods; therefore, the shoulder lane is used during this period to allow the same number of lanes for use by non-HOV traffic. Lane-use control signals are used to indicate when the shoulder lane can be used. Figure 8-13 shows a European freeway LCS.



Figure 8-13 LCS (Germany)

The MUTCD (2) provides information on the design, location and operation of lane-use control signals. The MUTCD describes the signal displays and defines the meaning of the displays.

The most common types of LCS are fixed-grid fiberoptic, and fixed-grid LED light emitting. Regardless of the technology used, LCSs cannot force vehicles to vacate a lane or use a shoulder as a travel lane. They do provide guidance about lane status, and are intended to promote safer operations by warning motorists upstream of an actual lane blockage.

A panel of eight TxDOT managers and engineers with expertise in Lane Control Signal (LCS) design and operation for freeways discussed problems and potential solutions regarding LCS. Their recommendations included the following:

- Visibility
 - Drivethroughs should be performed to determine if the red X is display has sufficient legibility distance.
 - If choosing double-stroked symbols for LCS displays, a maximum pixel spacing and/or effective stroke-width-to-letter-height should also be specified.
 - A regular cleaning and bulk replacement schedule should be implemented.
 - Back plates or back panels should be considered for placement behind LCS on overhead sign structures.
- Spacing and Mounting Locations
 - LCS should be placed every 0.8 to 1.6 km (0.5 to 1.0 mi), but special geometric characteristics and driver decision points should also be considered during this placement.
 - Mounting LCS on a cross-street bridge structure rather than on an overhead sign structure is desired.
 - Positive guidance principles should be employed when determining the placement of the LCS.

8.2.6.6 Moveable Barriers

Moveable Barrier Technology (MBT) provides the opportunity to change the direction of a freeway lane while providing continuous positive protection between opposing flows of traffic. The technology can also provide continuous protection between a work zone that changes in width and length and adjacent traffic lanes. MBT can accomplish these changes quickly, making it possible to respond to changes in traffic volumes that occur within a day. Therefore, MBT provides a strategy to change the capacity of a freeway in the peak direction quickly and easily, with a resulting reduction in congestion (15)

A moveable barrier (Figure 8-14) is comprised of a series of interconnected sections of barrier elements (*zipper*) hinged together to form a continuous chain. The cross section is similar to other portable barriers, but with a "T"-shaped top. Each section is about 1 meter in length and weighs approximately 3300 kg. Sections of barrier can easily be locked together or unlocked by inserting or withdrawing a steel pin through the hinge components attached to either end of the barrier.

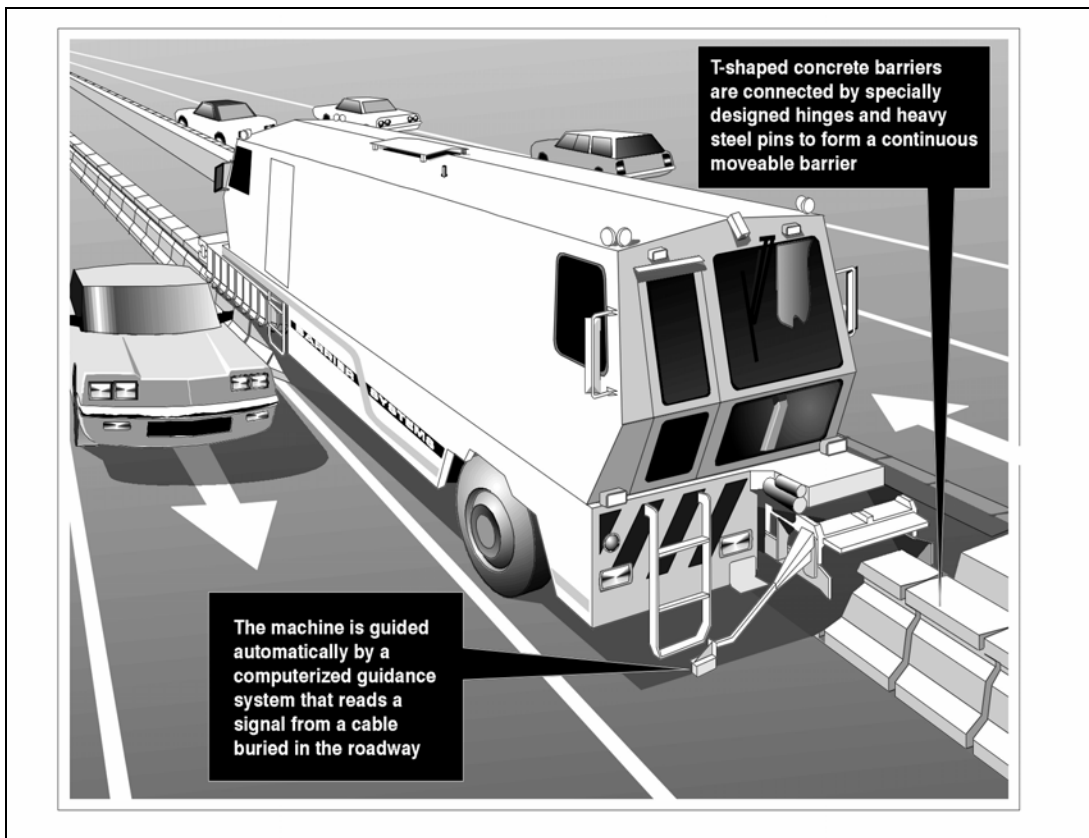


Figure 8-14: Moveable Barrier Technology

A specially designed conveyor system on a self-propelled barrier transfer machine (BTM) is used to shift the barrier laterally across the roadway. The distance of the shift can be varied from 4 to 24 feet. Conveyor wheels on the BTM engage the T-shaped top of the barrier. The

barrier can then be lifted several inches off the ground, moved sidwinder fashion through an elongated "S" curve, and accurately repositioned to form a new lane line. Barriers can be moved at a speed of more than five miles per hour.

Many reversible lane applications employ moveable barriers over the distance of one to several miles to control traffic and minimize head-on collisions. Moveable barriers also tend to keep the reversible lane speeds at free flow conditions, thus providing lane users with time savings. Figure 8-15 shows the repositioning of a typical moveable barrier.



Figure 8-15: Moveable Barrier Being Repositioned

8.2.6.7 Channelizing Devices for Work Zones

Static signs are used for directing traffic in advance of and within a work zone. CMSs (See Chapter 13) and arrow panels supplement *channelizing* devices and provide additional target value and suitable messages that attract motorists' attention as they approach a work zone. Highway Advisory Radio (HAR) (See Chapter 13) can provide additional information, including route detours. Newspaper articles, traffic broadcasts, fax, e-mail and the Internet can alert motorists to general construction and maintenance work zone locations, but provide limited detailed information about specific lane closures and traffic delays.

Within the work zone itself, traffic must be channeled from the lane(s) being closed to the designated pathway. A number of different types of channelizing devices can be used, depending on the duration of the closure and traffic speeds. These devices include:

- Cones.
- Tubular markers.
- Vertical panels.
- Drums.
- Barricades.

Regardless of the device used, it is critical that proper spacing and length of taper be employed to safely transition motorists from the closed lane(s) to open lane(s).

Portable barriers may be used to separate traffic from the work area and to protect construction workers. Special signing and temporary delineation and / or route detours may be needed when these barriers are moved and traffic is shifted.

There is a wide variety of channelizing devices currently available for use in highway work zones. The MUTCD (2) presents basic design standards for these devices and general guidelines for their use; however, it is the highway agency's choice where and when to use particular devices or sets of devices. Typically, work zone channelizing devices are chosen on the basis of one of the following practices:

- Select the device with the lowest initial cost.
- Select the device normally used by the agency.
- Select a device already in stock.
- Select the "very best" device just in case.

Each of these approaches has drawbacks, and collectively they have resulted in inflated job costs, unnecessarily large inventories, lack of uniformity, and in some cases improper device use. As an alternative to the typical methods used for selecting channelizing devices for work zones, the value engineering approach can be used. The approach involves 7 steps:

- Determine the intended purpose of the devices.
- Identify available alternative devices.
- Select appropriate measures of device performance.
- Determine the performance of the alternative devices on the basis of selected performance measures.
- Estimate the total cost of each acceptable alternative.
- Calculate the relative value of each acceptable alternative, where value equals performance divided by cost.
- Select the alternative with the greatest value.

The following recommendations should be followed when using this approach:

- Base value engineering study on comprehensive and accurate information.
- Use a team approach – team members are well-trained and diverse in experience and technical background.
- Consider value engineering approach most appropriate for central office use – through pooling central office staff and data-gathering resources.

The responsible highway agency will make the final choice of the channelizing devices used in the work zone. However, using the approach suggested the agency should be able to balance the needs of the work zone with the agency budget.

8.2.6.8 Electronic Toll Collection

Electronic Toll Collection (ETC) adds a new control element to the set of lane management strategies that are useful for moving traffic through toll facilities. At major toll facilities where ETC has been introduced, motorists usually benefit from a significant reduction in vehicle travel

time and shorter queues. In Reference 28, a dedicated cash lane had an average transaction time of 10.5 seconds for a passenger car and 29.5 seconds for a commercial vehicle. A dedicated ETC lane processed 1000 vph, with an average transaction time of 3.6 seconds per vehicle. The typical savings is 6.9 seconds per passenger car. The greater time savings, however, is realized with the elimination of queues due to the reduction of transaction time. In the study, queues of over 20 vehicles, which took up to three minutes to process had been observed at some toll plazas prior to ETC. With the introduction of ETC, there are virtually no queues at interchanges and barriers where there once was often heavy congestion.

The basic components that make the system work are (See Figure 8-16):

- Transponders on the vehicles.
- Tag reader antennas at each plaza toll lane.
- Lane controllers that control the lane equipment and track vehicles passing through.
- Host computer system - all of the toll plaza controllers are connected to a central database.

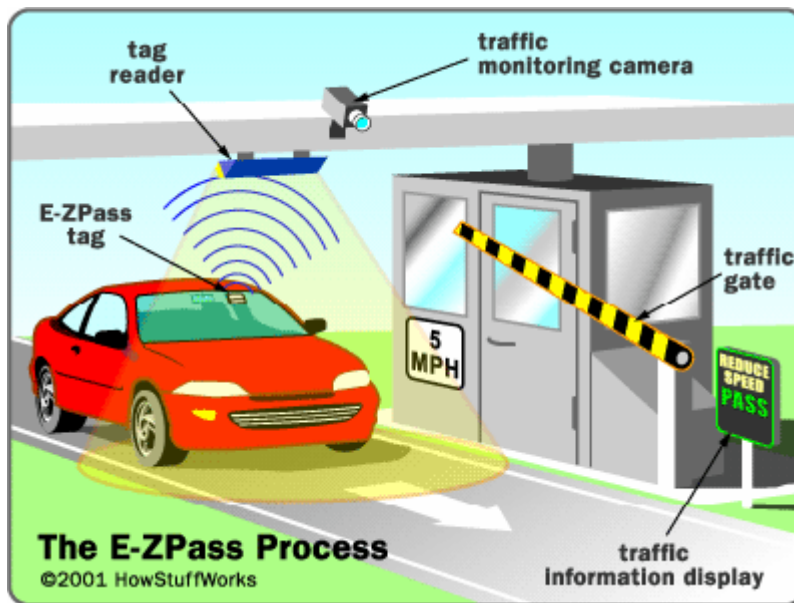


Figure 8-16: The E-ZPass Process at a Toll Booth

Drivers usually pay a deposit to obtain a transponder, which is about the size of a deck of cards. This device is placed on the inside of the car's windshield behind the rearview mirror. A transponder is a battery-operated radio frequency identification (RFID) unit that transmits radio signals. The transponder is a two-way radio with a microprocessor, operating in the 900-MHz band. Stored in this RFID transponder is some basic account information, such as an identification number.

Antennas, or electronic readers, are positioned above each toll lane. These antennas emit radio frequencies that communicate with the transponder. The detection zone of an antenna is

typically 6 to 10 feet (2 to 3 m) wide and about 10 feet long. These two devices, the transponder and the antenna, interact to complete the toll transaction.

Some electronic toll-collection systems may also include a light curtain and treadles. A light curtain is just a beam of light that is directed across the lane. When that beam of light is broken, the system knows a car has entered. Treadles are sensor strips embedded in the road that detect the number of axles a vehicle has. A three-axle vehicle is charged a higher toll than a two-axle vehicle. These two devices are safeguards to ensure that all vehicles are counted correctly.

The system works as follows:

- As a car approaches a toll plaza, the radio-frequency (RF) field emitted from the antenna activates the transponder.
- The transponder broadcasts a signal back to the lane antenna with some basic information.
- That information is transferred from the lane antenna to the central database.
- If the account is in good standing, a toll is deducted from the driver's prepaid account.
- If the toll lane has a gate, the gate opens.
- A green light indicates that the driver can proceed. Some lanes have text messages that inform drivers of the toll just paid and their account balance.

The entire process takes a matter of seconds to complete. The electronic system records each toll transaction, including the time, date, plaza and toll charge of each vehicle. Typically, motorists maintain prepaid accounts. A yellow light or some other signal will flash to indicate if an account is low or depleted.

At the toll plaza, ETC introduces three types of toll lanes. These are *Cash Only*, *ETC Only* and *Mixed Cash / ETC*. Two key questions for plaza operations must be addressed by all ETC equipped toll facilities. The first is: how many of each type of toll lane be provided as a function of arriving traffic volume and percentage of vehicles equipped with tags? The second issue is: how should each type of toll lane be distributed across the toll plaza?

The rules regarding how fast a motorist can pass through the toll plazas vary from system to system. Agencies with traditional lane based toll plazas impose speed restrictions that slow vehicles to 5 mph (8 kph) as they pass through the toll lane. These lanes are monitored using video cameras. If a vehicle goes through the plaza without a transponder, a camera takes a snapshot of the license plate, records it and sends a violation notice to the owner. Some toll agencies are adopting a high-speed approach that utilizes an "open" toll plaza without lane restrictions, booths, or barriers, thereby allowing motorists to pass through the system at highway speeds.

8.2.7 Design and Related Considerations

The preliminary design process for a managed lane subsystem includes matching objectives with lane management strategies. The relationship of typical objectives to lane management strategies is shown in Table 8-7. Each of the cells identified by a check can be a candidate strategy to fulfill that objective. Note that objectives will most likely differ between areas.

The next step is to eliminate those strategies that do not achieve, in whole or in part, the *specific* project objectives. For example, if the sole objective of the project is to improve vehicle

throughput, the cells containing strategies that are not candidates for this objective are shown crossed out in Table 8-8. The surviving strategies are shown in bold type on that table.

Table 8-7: Relationship of Strategies to Typical Objectives

OBJECTIVES STRATEGIES	Improve Vehicle Throughput	Reduce Collisions	Improve Equity	Improve Operations Under Restricted Conditions	Divert to Alternate Routes or Change Departure Time	Improve HOV Flow	Improve Pavement Wear
Truck Lanes	√	√					√
HOV Lanes						√	
Narrow lanes and Shoulders	√						
Contraflow Lanes						√	
Reversible Lanes	√			√			
Mainline Metering	√		√			√	
Speed Advisories and Controls		√					
Work Zone Controls		√		√	√		
Toll Facilities					√		
Congestion pricing					√		

Table 8-8: Elimination of Strategies that Do Not Meet Project Objectives

OBJECTIVES STRATEGIES	Improve Vehicle Throughput	Reduce Collisions	Improve Equity	Improve Operations Under Restricted Conditions	Divert to Alternate Routes or Change Departure Time	Improve HOV Flow	Improve Pavement Wear
Truck Lanes	√	✗					✗
HOV Lanes						✗	
Narrow lanes and Shoulders	√						
Contraflow Lanes						✗	
Reversible Lanes	√			✗			
Mainline Metering	√		✗			✗	
Speed Advisories and Controls		✗					
Work Zone Controls		✗		✗	✗		
Toll Facilities					✗		
Congestion pricing					✗		

The functional requirements of a managed lane component define specific strategies needed to achieve one or more of the stated objectives for that component. In theory, the strategies should be defined independent of the technology used to implement them. However, some managed lane objectives may be so narrowly defined and governed by standards or policies (e.g. temporary freeway lane closures for maintenance) that this step, in and of itself, defines the technology to be used (6). For other objectives, though, the technology required may not be so obvious, and so a definition of functional requirements would be warranted. Possible functional requirements of a managed lanes subsystem to increase peak period freeway capacity include:

- Automatically determine when freeway lane volumes reach 90 percent of estimated capacity.
- Ensure that no stalled vehicles are located on the shoulder in the affected section of freeway.
- Notify motorists at the beginning of the affected section that freeway shoulder can be used as a travel lane.
- Notify motorists at the end of the affected section that they should return to the normal freeway travel lanes.
- Terminate motorist notification of permissible freeway shoulder usage at the end of the peak period.

The functional relationships, data requirements, and information flows show how the managed lane functions will be integrated with each other and with the other freeway management system components (such as surveillance or motorist information dissemination). When defining the functional relationships, data requirements, and information flows as they impact dynamic signs and surveillance, the *National Transportation Communications Interface Protocol (NTCIP)* and the *National ITS Architecture* should be followed (4). This approach provides the following advantages:

- It allows components from different vendors to be used interchangeably, increasing competition and reducing costs.
- It eases future upgrades or expansions of the components. The necessary interfaces to other components of the freeway management system (i.e., surveillance) have already been established.

For other managed lane functions, informal functional relationships, data requirements, and information flows may be acceptable, but should be prepared nonetheless. For example, the functional relationships, data requirements, and information flows for managing a temporary total freeway closure over the weekend might include how real-time data concerning traffic conditions, project status, and / or the effects of weather are transferred among the transportation agencies (such as the traffic, maintenance, and public information divisions), enforcement agencies, the media, and the private contractor.

Enforcement should be a key element of all managed lanes plans. Plans should address both the management and coordination requirements among the various partners, relative to enforcement. Operational issues such as staff requirements and citation locations also need to be addressed during plan development.

8.2.8 Emerging Trends

The broad concept of managed lanes is, in many respects, an emerging trend. Specific applications in this regard are summarized below.

8.2.8.1 Separated lanes / roadways / guideways

It is anticipated that the separation of commercial and non-commercial traffic will become increasingly important (e.g. approximately 120 miles of truck bypass lanes are being planned in Southern California). On a much more distant horizon, the Netherlands has advanced a *Combi-Road Driverless Truck Guideway* concept in which unmanned trucks carrying sea containers drive on dedicated tracks with active longitudinal guidance from seaports to inland terminals (29). Figure 8-17 illustrates a prototype of this system.



Figure 8-17: Combi-Road Driverless Truck Guideway

8.2.8.2 Automated Speed Enforcement

Automated speed enforcement (ASE) has been used as a speed control and enforcement tool by over 40 countries around the world, with some systems having been in place for up to 30 years (30). Studies (31) indicate that the technology is effective in reducing speeds and accidents. In 1998, it was used in four states: Arizona, California, Colorado, and Oregon.

A 1992 study on the Capital Beltway in the Washington D.C. area (32), demonstrated that it is operationally feasible to use photo-radar technology to detect and photograph speed violators on high-speed, high-volume roads. Photo-radar technology can produce clear photographs that can be used to prosecute speeding drivers in court. The equipment proved capable of detecting and properly photographing a much higher percentage of speed violators than can the average police officer in a patrol car. The study also concluded that it is feasible to propose legislation for the use of photo-radar

technology that could safeguard individual rights, meet constitutional requirements, and enforce speed limits.

Although automated speed enforcement is currently not well accepted by the U.S. public, the technology would seem particularly relevant to work zone traffic control (21) and high accident locations where excessive speed is determined to be a contributing factor.

8.2.8.3 Smart Work Zones

Smart Work Zones refer to the application of intelligent transportation systems within work zones to improve safety and reduce congestion at work zone locations. These systems can be used to warn drivers of downstream congestion, alert drivers of slower speeds ahead, and suggest alternate routes based on prevailing conditions (24,33,34,38).

The Smart Work Zone usually integrates changeable message signs, speed sensors, video cameras, and highway advisory radio (HAR) through a computerized control system that automatically determines appropriate responses to current traffic conditions. These systems can be deployed to provide traveler information in work zones where permanent traffic management systems do not exist. Some systems can operate with little or no day-to-day human intervention (33).

There are four principal components of the Smart Work Zone:

- Speed detectors and / or surveillance equipment
- Central control system
- Information dissemination devices
- Communications systems

Speed sensors and / or surveillance equipment are located within the work zone to determine the traffic conditions within the work zone. Traffic data is transmitted to a portable, central control system located at the work site or a traffic management center where the incoming data is processed. The traffic data is analyzed to determine if a speed advisory, delay advisory, or route diversion message should be displayed. If the data indicates that some type of message should be displayed, the central control system transmits a signal to CMSs, HAR, and / or other device in order to alert drivers to conditions in the work zone (33). The traffic data gathered can also be displayed graphically on the Internet or transmitted via an automated fax or e-mail.

In addition to the mobility, safety, and cost savings benefits experienced by the deployment of a Smart Work Zone, research has indicated that agencies deploying Smart Work Zones have developed improved relationships with the public and other agencies (34). At some sites, the improved relationship with the public was documented through numerous positive letters and e-mails, and through survey responses.

8.2.8.4 Vehicle-Highway Automation

The implementation of *vehicle-highway automation* in the 21st century will provide an enhanced level of surface transportation accessibility and mobility (35). A first-generation of vehicle-highway automation is coming into focus, in which automated vehicles operate on today's roads with no extensive infrastructure modifications required. Early co-pilot systems would evolve to auto-pilots gradually. These vehicles would operate at spacing a bit tighter than commuter flows

of today, with traffic flow benefits achieved through vehicle-cooperative systems as well as vehicle-infrastructure cooperation.

The vehicles may cluster in designated lanes, which are also open to normal vehicles, or may be allowed on high-occupancy vehicle (HOV) lanes to increase their proximity to one another and therefore get the benefits of cooperative operations (access to HOV lanes also creates a powerful incentive for consumers to invest in these systems). Stabilization of traffic flow and modest increases in capacity are seen as the key outcomes.

Once this level of functionality is proven and in broad use, a second generation scenario comes into play, which expands, to dedicated lanes, presumably desired by a user population with a high percentage of automation-capable vehicles. With growing use, networks of automated vehicle lanes would develop, offering the high levels of per-lane capacity achievable through close-headway operations.

An important force in the development of vehicle-highway automation is a federal pooled-fund program, *Cooperative Vehicle-Highway Automation Systems (CVHAS)*. The program uses pooled resources from public and private sector partners to research, develop, evaluate and deploy CVHAS solutions to improve transportation mobility, safety, air quality, and energy reduction. CVHAS seeks to facilitate the sharing of technological and institutional experiences gained from its projects and the projects of its individual members.

CVHAS defines vehicle-highway automation systems as systems that provide driving control assistance or fully automated driving, based on information about the vehicle's driving environment that can be received by communication from other vehicles or from the infrastructure, as well as from its own on-board sensors. These systems could have implementations for special classes of vehicles (transit buses or heavy trucks, for example) prior to the broader implementation for the general population of light-duty passenger vehicles.

8.2.8.5 Congestion Pricing

In its 1995 two-volume report, *Curbing Gridlock: Peak-Period Fees to Relieve Traffic Congestion*, (36) the National Academy of Sciences praises congestion pricing as a potentially powerful tool to persuade people to carpool, use transit, telecommute, vary the times they travel, alter their routes, choose other destinations, or avoid or combine some trips. Experience in other countries, such as England, France, and Singapore, demonstrates that congestion pricing does significantly reduce gridlock during peak traffic periods.

In a separate California study funded by the Federal Highway Administration, (37) researchers found that congestion pricing and other market-based transportation pricing measures offer great potential for reducing congestion, improving air quality, cutting energy consumption, and increasing the efficiency of the state's transportation system. It is highly likely that the future will see the increasing use of congestion pricing. The factors that lead to this conclusion are the:

- need for more aggressive strategies to combat congestion
- increasing number of deployed electronic toll collection systems
- unending search for additional revenue sources
- increasing number of successes achieved with congestion pricing

8.3 IMPLEMENTATION AND OPERATIONAL CONSIDERATIONS

8.3.1 Funding Source Identification

Many managed lane strategies are supported as part of an operating agency's normal activities, or are addressed during development of other components of the freeway management system (e.g., information dissemination subsystems). Consequently, the primary concern for these strategies is the extent to which introducing the new strategy affects the existing budget for operations and maintenance, and whether this impact can be accommodated through a reallocation of agency funds.

Two of the major managed lane options, implementation of tolls and / or congestion pricing strategies, result in revenues that are used to offset the cost of constructing and operating these strategies. Traditionally, toll facilities were converted to "free" roadways once the bonds used to construct the roadway had been paid. Recent changes in legislation, however, now allow agencies to continue toll operations after bond payment, and to use the revenues to fund other traffic management activities.

8.3.2 Incremental Implementation

Experience from past freeway management projects indicate that it is best to implement strategies and techniques incrementally where possible to develop operational experience with the strategies, and to demonstrate the advantages of the techniques to elected officials and to the public. This may be true for some of the more "innovative" or controversial managed lane strategies as well. For these situations, consideration should be given to initiating small, demonstration-type projects at a location or over a section of freeway where the benefits are expected to be the greatest. In this way, the partners can illustrate the benefits of the strategy and generate the support necessary to proceed with more extensive implementation if desired.

8.3.3 Evaluation

The final stop in the decision process for managed lanes is to establish the mechanism for evaluation of the strategies once they have been implemented. It is important to monitor the impacts and benefits of new strategies and techniques as they are implemented to determine if they meet the intended objectives and functions for which they were designed. Also, it is important that these data be collected so that they can be collated and disseminated in an ongoing manner to elected officials and the general public. In this way, continued funding for these strategies can be obtained more readily, and expansion of activities to further improve facility operations will be more readily accepted.

8.4 EXAMPLES

This section describes some example applications of the managed lane concept.

8.4.1 Variable Speed Limit Signs In Work Zones

The use of variable speed limit signs in work zones has been demonstrated by the Minnesota Department of Transportation (Mn/DOT) (38). The objective of the system was to make work zone speed limits on a high-volume urban freeway easier to sign and enforce. The system incorporated two modular message blocks on each speed limit sign placed in a work zone. The signs are easily moved because they are mounted on U-channel supports. While construction

workers are not present, the speed limit continues to be 65 mph. When construction workers arrive, a designated worker changes the speed limit to 45 mph. The displayed speeds are enforceable. In 2000, Mn/DOT deployed one sign for the demonstration. This demonstration has led Mn/DOT to conduct an evaluation to include as many as eight variable speed limit signs (22).

8.4.2 Variable Speed Warning System

A *Dynamic Downhill Truck Speed Warning System* was installed at the Eisenhower Tunnel on I-70 west of Denver in mid-1995. The objectives were to:

- Identify vehicle-specific safe operating speeds for long downgrades.
- Reduce runaway truck accidents through real-time driver information.
- Modify driver behavior.



The system consists of:



- Weigh in motion sensor
- Changeable message sign
- Inductive loop detectors
- Computer hardware and software

The algorithm within the computer system computes a safe speed based on the truck weight, speed, and axle configuration. The recommended speed is displayed on a variable message sign. Each truck receives a vehicle-specific recommended safe speed message. It is an advisory system. Since system deployment, truck-related accidents have declined on the steep downhill grade sections while the volume of truck traffic has increased by an average of 5 percent per year.

8.4.3 San Antonio Transguide

Transguide is designed to locate incidents within two minutes and then warn motorists within 15 seconds. Upon detection of an incident, the type, lanes obstructed, and traffic data are entered into the server which then searches through a database of over 150,000 scenarios and selects the appropriate response. Among other actions, this response recommends what changes should be made to LCSs, and other equipment. These changes are presented to the operator for review and, upon approval, the system executes all the changes within 15 seconds. LCSs display one of the following symbols to guide motorists into the appropriate lanes:

	This lane or ramp is open to traffic
	There is a hazard on a shoulder adjacent to this lane or this ramp has a hazard or congestion ahead; this symbol may soon be used to warn of congestion ahead on freeway mainlanes

	<p>This lane is closed ahead and traffic should merge in the direction indicated</p>
	<p>This lane or ramp is closed</p>

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9. HIGH OCCUPANCY VEHICLE TREATMENTS

9.1 INTRODUCTION

The term “High-Occupancy Vehicle (HOV)” is defined as a motor vehicle with at least two or more persons, including carpools, vanpools, and buses. A “High Occupancy Vehicle (HOV) Facility” is any type of treatment that gives priority to HOVs, including freeway lanes, park & ride lots, and other elements. Individual HOV facilities may require different vehicle occupancy levels, which are expressed as either two or more (2+), three or more (3+), or four or more (4+).

Priority treatments for HOVs have proven to be one of the most flexible, cost effective alternatives for increasing the person-moving capacity of congested metropolitan transportation systems. This “lane management” concept emphasizes *person movement* rather than traditional *vehicle movement*. It offers multi-person vehicles the opportunity to travel in reserved lanes that preserve higher operating speeds and more reliable travel times.

A related strategy – and a relatively recent lane management concept – is that of High Occupancy Toll (HOT) lanes. HOT lanes combine HOV and pricing strategies by allowing vehicles that don’t meet passenger occupancy requirements to gain access to HOV lanes by paying a toll.

9.1.1 Chapter Scope & Objectives

The breadth of the HOV topic is too great to be handled in any detail in this Handbook. Accordingly, the reader’s attention is directed to the following extensive references for additional information:

- The “HOV Systems Manual”, NCHRP Report 414 (Reference 1), is perhaps the most exhaustive single reference on the topic. This manual provides a comprehensive guide to developing policies, planning, designing, implementing, marketing, operating, enforcing, and evaluating HOV facilities.
- The Federal Highway Administration (FHWA) maintains an HOV website at www.ops.fhwa.dot.gov/travel/traffic/hov/index.htm. It includes an inventory of HOV facilities, a list of training resources, and links to several technical references and reports.
- Another valuable website is the HOV Pooled Fund Study (<http://hovpfs.ops.fhwa.dot.gov>). The goal of the PFS is to assemble regional, state, and local agencies and FHWA to identify issues, select projects to address these issues, and disseminate the results of these projects (using the website).
- The Transportation Research Board’s HOV Systems Committee also maintains a website of links and reference information at www.HOVworld.com.
- High Occupancy Toll (HOT) lanes are addressed in the “A Guide for HOT Lane Development” (Reference 5). The guide presents a wide range of information on HOT lanes. It addresses a wide range of policy and technical issues that are associated with HOT lanes, focusing on how these activities are likely to differ from those associated with more traditional highway improvements.

9.1.2 Relation to Other Freeway Management Activities

HOV facilities represent just one potential element for managing the surface transportation network; and as such, must be viewed from various perspectives (e.g., users, decision makers, providers) and operational / planning “tiers” (as discussed in Chapter 2). Moreover, as with other freeway management strategies, the performance of HOV facilities must be continuously monitored and evaluated. (Refer to chapter 4).

There are many freeway management activities, as discussed in other Chapters, that relate directly to HOV treatments; and to understand the role of HOV facilities within the freeway management spectrum, it is important to understand the relationships between these activities and the HOV facility. The following table itemizes those related activities and their relationship.

Table 9-1: Freeway Management and Operations Activities and Their Relationship to HOV Treatments

Ramp Management and Control (Chapter 7)	As an incentive for HOVs, bypass lanes are provided for HOVs at ramp meter locations that allow the HOV to proceed in a dedicated lane without being required to stop at the meter signal, or with a shorter queue if required to stop.
Managed Lanes (Chapter 8)	HOV and HOT facilities represent a special case of lane management.
Traffic Incident Management (Chapter 10)	Incident management is an important element of HOV operations (i.e., maintaining the full capacity of the priority lanes / facility)
Planned Special Event Management and Control (Chapter 11) Emergency & Evacuation Management (Chapter 12)	For some special events, HOV is implemented to encourage people to utilize fewer vehicles, thereby reducing congestion. During major emergencies / evacuation, when additional capacity is needed, occupancy restrictions on HOV lanes may be removed.
Information Dissemination (Chapter 13)	Changeable Message Signs are used to convey the current restriction status of HOVs in some systems. CMS are also used to identify current pricing for HOT operation.

9.2 CURRENT PRACTICES, METHODS, STRATEGIES & TECHNOLOGIES

9.2.1 Overview

The primary concept behind priority facilities is to provide HOVs with both travel time savings and more predictable travel times. These two benefits serve as incentives for individuals to choose a higher-occupancy vehicle mode over driving alone. The person-movement capacity of the roadway is increased by carrying more people in fewer vehicles. In some areas, additional incentives, such as reduced parking charges or preferential parking for carpools and vanpools, have been used to further encourage individuals to change their driving habits (1).

The intent of HOV facilities is not to force individuals to make changes against their will. Rather, the objective is to provide a cost-effective travel alternative that a significant volume of

commuters will find attractive enough to change from driving alone to use a high-occupancy mode. Many HOV projects have focused on meeting one or more of the following three common objectives:

- Increase the average number of persons per vehicle
- Preserve the person-movement capacity of the roadway
- Enhance bus transit operations (1).

9.2.2 Benefits

As an example of HOV system benefits, Reference 2 describes the results of an extensive monitoring effort of HOV lane use and performance in the Puget Sound area in 2000. Available data showed the following for most HOV facilities:

- Substantial travel time savings exist in comparison to general purpose lane travel.
- HOV lanes are operating much more reliably than general purpose lanes.
- HOV lanes are successfully moving large numbers of travelers, particularly in the peak periods when general purpose lane congestion is highest.
- HOV person and vehicle volumes are increasing substantially in the peak period.
- An increasing percentage of peak period travelers are taking advantage of ride sharing (transit and carpool) travel modes.
- While not all HOV facilities are equally successful, taken as a whole the HOV lane system is successfully meeting the general policy goals of providing mobility within the limited right-of-way available.
- Some regional HOV lanes are so successful at attracting users that they are starting to show signs of stress from high use. The most obvious sign of stress is recurring congestion at specific locations. At these locations, consideration of geometric improvements and/or changes in operating conditions may be required.

Another example of the benefits and overall success of HOV systems is the growth of this strategy. The report "HOV Facility Development: A Review of National Trends" (Reference 3) states: "Based on current roadway improvement program plans identified by various regions and agencies, the number of HOV lane-miles in existence in 2001 will climb almost 50 percent by the end of this decade. A majority of the planned future HOV lanes will be implemented as extensions to current lanes."

9.2.3 Key Considerations During Freeway Management Program Development

HOV systems can be an important part of a freeway management and operations program. HOV facilities have most commonly been used in roadway corridors that are either at, or near, capacity, and where the physical and/or financial feasibility of expanding the roadway is limited. When properly planned and implemented, HOV facilities can offer a number of advantages. However, HOV facilities are not appropriate for all situations, nor does their implementation eliminate the need to pursue other complimentary strategies. The potential use of HOV facilities should be examined thoroughly before any such improvements are made, including demand estimation tools and approaches for assessing the potential environmental impacts (1).

A comprehensive approach in planning, designing, implementing and operating HOV facilities can help ensure successful projects. The NCHRP HOV Systems Manual (Reference 1) provides a comprehensive overview of the steps involved in planning, designing, and implementing HOV facilities on freeways (as well as in separate rights-of-way and arterial streets). Some of these

key elements are summarized in Section 9.3. It is noted that they parallel the activities identified in the “funnel diagram” from Chapter 3 (e.g., institutional environment and stakeholders, goals and objectives, concept of operations, performance monitoring). Moreover, Reference 1 emphasizes the need to coordinate this process with other roadway and transit improvements to ensure an integrated multimodal transportation system.

9.2.4 Relationship to National ITS Architecture

The National ITS Architecture includes an “HOV Lane Management” market package. This market package “manages HOV lanes by coordinating freeway ramp meters and connector signals with HOV lane usage signals. Preferential treatment is given to HOV lanes using special bypasses, reserved lanes, and exclusive rights-of-way that may vary by time of day. Vehicle occupancy detectors may be installed to verify HOV compliance and to notify enforcement agencies of violations.”

9.2.5 Technologies and Strategies

This section summarizes the types of HOV facilities typically found on freeways. Ancillary facilities (e.g., park-and-ride lots, bypass lanes at metered ramps) are also noted, as well as a discussion of HOT lanes. Information on the planning, design, implementation, and operation of HOVs is provided in section 9.3.

9.2.5.1 HOV Lanes on Freeways

Three types of HOV lanes are commonly found on freeways, and a variety of different operations and approaches. These are exclusive HOV lanes, concurrent flow HOV lanes and contraflow HOV lanes. In addition, exclusive HOV lanes can be operated either bi-directionally or reversible. The following describes the characteristics of the various HOV treatments (1).

- **Exclusive HOV Facility** – Facilities or lanes built within the freeway right-of-way that are physically separated from the general purpose freeway lanes, and are used exclusively by HOVs for all or a portion of the day. Most of these facilities are physically separated from the general purpose lanes through the use of concrete barriers; although a few facilities are separated by a wide painted buffer, with and without traffic channelizer separation. These may be two-directional, or reversible (Figure 9-1). The latter type usually operates inbound toward the central business district and other major activity centers in the morning, and outbound (i.e., the reverse direction) in the afternoon. Some type of daily set up (for reversing directions) is required with reversible facilities.
- **Contraflow Lane** – A freeway lane in the off-peak direction of flow (typically the innermost lane) that is designated for exclusive use by HOVs traveling in the peak direction. Normally, the contraflow lane is “separated” from the off-peak (or opposite) flow by insertable cones, pylons (Figure 9-2), or movable concrete barriers. Contraflow lanes are usually operated during the peak periods only.
- **Concurrent Flow Lane** – A freeway lane in the same direction of travel (normally the inside lane or shoulder) that is not physically separated from the other freeway lanes, but is designated for exclusive use by HOVs for all or a portion of the day. Paint striping is a common means used to delineate these lanes. (Figure 9-3).



Figure 9-1: Examples of Exclusive / Barrier-separated HOV Facility (Reversible)



Figure 9-2: Examples of Contraflow Lanes



Figure 9-3: Example of Concurrent Flow Lane
(Courtesy Virginia Department of Transportation)

9.2.5.2 Ingress and Egress Alternatives

Ensuring that buses, vanpools, and carpools can easily and safely merge into and out of the HOV lane is critical to the success of the facility. A variety of treatments can be used as summarized below (1):

- **Direct Merge** – Used on concurrent flow HOV lanes, this approach allows HOVs to merge directly into HOV lanes from adjacent general-purpose lanes. Merging can be continuous along the entire length or at specific designated points. Where designated, the access openings are usually regulated with signs and pavement markings in accordance with guidelines in the MUTCD.
- **Slip Ramps** - The at-grade slip ramps are easy and inexpensive to build. An opening large enough for normal merge/diverge maneuvers is placed in the barrier. This type of ramp is usually from a park-and-ride lot to the frontage road, the freeway, or the HOV lane.
- **Direct Access Ramps** – Grade separated or direct access ramps provide exclusive ingress and egress for HOVs. Further, direct ramps may provide access from adjacent roadways, park-and-ride lots, and transit stations.
- **Direct Freeway HOV-to-Freeway HOV Connection** – These facilities provide direct connections from an HOV on one freeway to an HOV lane on another freeway.

In addition to the physical alternatives for ingress, there are operational strategies, including:

- **HOV Bypass Lanes at Ramp Meters** – This operational strategy is used to provide priority treatment to HOVs at metered ramps. Typically, a separate lane is provided adjacent to the general purpose lane(s) for HOVs so that they do not have to stop at the ramp meter signal, but rather move around the ramp queue and directly enter the freeway. In some systems, the HOV ramp lanes is also metered, but at a relaxed rate relative to the general purpose ramp lanes, still providing time savings.
- **Priority Pricing** – A variation of congestion pricing that allows non-HOVs to use High-Occupancy Toll (HOT) lanes for a charge. HOT lanes are discussed in Section 9.2.6.

9.2.5.3 Park-and-Ride Facilities

Park-and-ride facilities are an integral part of a multimodal transportation system. The purpose of these facilities is to provide a location for individuals to transfer from a low-occupancy mode of travel to a high occupancy mode of travel. Park-and-ride facilities are typically provided in conjunction with scheduled transit services.

Many of the HOV facilities in operation around the country are connected either directly or indirectly to park-and-ride lots. For HOV lanes, transfers at park-and-ride lots are usually made from an automobile to a bus; however, transfers may also occur from other originating modes or from single-occupancy vehicles to carpools or vanpools. There are many benefits associated with the proper use of park-and-ride facilities, including the following (4):

- Encouragement of use of high occupancy travel to maximize the efficiency of the transportation system.
- Improvement in efficiency of transit system by providing high-density areas for transfers and by increasing ridership.
- Assistance with congestion management, through a reduction in the number of single-occupancy vehicles on the freeway.
- Reduction in energy consumption and air pollution over what otherwise would occur by not providing these facilities.

9.2.5.4 Transit Centers

Transit Centers may also be associated with HOV facilities. These centers provide an interface between transit modes such as between buses offering different services. These facilities may co-exist with park-and-ride lots. The two types of centers are *on-line*, which are located on the HOV lane and *off-line* stations, which are located adjacent to or near the HOV lane.

9.2.5.5 Enforcement Areas

Enforcement of HOV facilities is discussed in Section 9.3. It is important that the HOV design includes adequate and safe enforcement areas. To be effective, an officer must have a safe and convenient place to issue citations or warnings. The enforcement activity should be in view of HOV users so that they can see when the lane restrictions are being enforced; however, it should not interfere with traffic on the HOV and mixed-flow lanes.

9.2.6 High Occupancy Toll (HOT) Lanes

One of the most recent management concepts – High Occupancy Toll (HOT) lanes - combines HOV and pricing strategies by allowing vehicles that don't meet passenger occupancy requirements to gain access to HOV lanes by paying a toll. The lanes are “managed” – that is, by using price and occupancy restrictions to manage the number of vehicles traveling on them, HOT lanes maintain volumes consistent with uncongested levels of service even during peak travel periods. The appeal of this concept is tri-fold:

- It expands mobility options in congested urban areas by providing an opportunity for reliable travel times to users prepared to pay a significant premium for this service;
- It generates a new source of revenue which can be used to pay for transportation improvements, including enhanced transit service; and
- It improves the efficiency of HOV facilities, which is especially important given the recent decline in HOV mode share in 36 of the 40 largest metro areas (5).

Figure 9-4 illustrates how the concept of excess capacity for HOV lanes can be used to manage overall roadway congestion. The key to effective use of this strategy is to actively manage, using dynamic toll collection, how many vehicles can use the excess capacity. This keeps a congestion free incentive for carpool and transit vehicles (HOV), while at the same time fully utilizing the facility. Managing the excess capacity of a facility is accomplished by charging a dynamic toll for access, with tolls set by level of congestion as well as vehicle class. The motorist has the option of paying for a congestion free restricted freeway lane or traveling free on a congested general purpose freeway lane.

Per Reference 5, approximately 70 percent of the nation's HOV lane miles operate with peak hour volumes of between 900 and 1500 vehicles/hour. Ten to 15 percent are operating with over 1500 peak hour vehicles, and the remaining 10 to 15 percent below 900 vehicles in peak hours. This suggests that several HOV facilities have some available capacity to allow other user groups on the facility. However, residual capacity is quite limited and additional traffic levels would need to be managed closely. The combined ability of HOT operations to introduce additional traffic to existing HOV facilities, while using price and other techniques to better manage and control the number of additional motorists and maintain high service levels, renders the HOT lane concept a promising means of utilizing this available capacity.

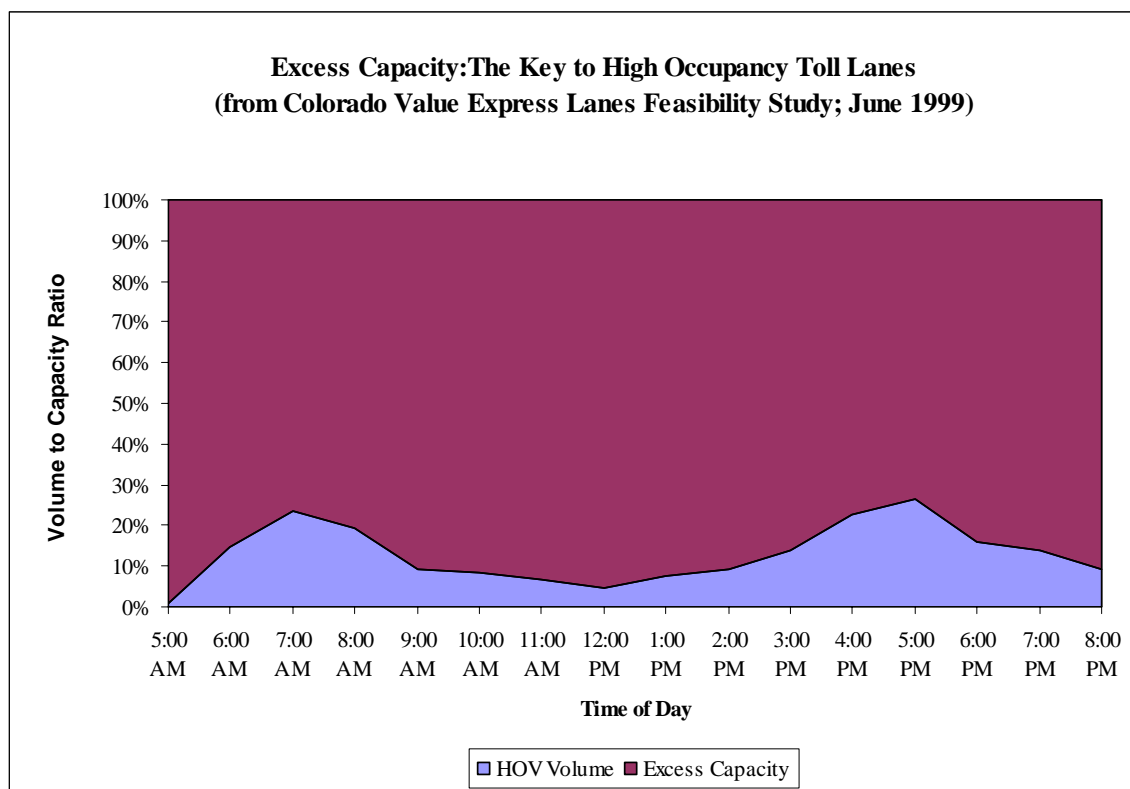


Figure 9-4: Concept of Excess Capacity

Most HOT lanes are created within existing general-purpose highway facilities and offer potential users the choice of using general-purpose lanes or paying for premium conditions on the HOT lanes. HOT lanes utilize electronic toll collection and traffic information systems that also make variable, real-time toll pricing of non-HOV vehicles possible. Information on price levels and travel conditions is normally communicated to motorists via changeable message signs, providing potential users with the facts they need in order to decide whether or not to utilize the HOT lanes or the parallel general-purpose lanes that may be congested during peak periods. HOT lanes may be created through new capacity construction or conversion of existing lanes. Conversion of existing HOV lanes to HOT operation is the most common approach.

Some of the unique attributes of HOT lanes (relative to HOV) include:

- **Pricing Systems:** In order to maintain superior traffic service conditions, toll levels are set to limit the number of users by willingness to pay. The fee structure may be fixed, varying by time of day, or dynamic, varying in response to real-time traffic conditions. In either case, higher tolls are charged during peak demand periods. Information on toll levels is conveyed to motorists through variable message signs located near entry points.
- **Toll Collection Procedures:** In order to avoid the delays associated with manual toll collection, HOT lanes rely on electronic payment systems or paid monthly passes during test pilot periods. Therefore, only those vehicles equipped with a transponder tag or valid permit may use the lanes.

- **Vehicle Type:** A range of management policies may be implemented related to vehicle type. Depending on local transportation goals, low-emission vehicles, motorcycles, emergency vehicles, transit vehicles, taxis, and/or trucks may be allowed to use a HOT lane, either at no cost or for a reduced fee.

In addition to the benefits normally associated with HOV (travel time savings, trip time reliability) HOT lanes can provide additional benefits (5):

- **Revenue Generation:** HOT lanes can provide an additional source of revenue to support transportation improvements such as the construction and operation of the lanes themselves, or to address corridor transit needs or other local demand management strategies. In areas with funding constraints, certain improvements might not be possible without the additional revenue provided by HOT lanes.
- **Utilization of Excess Capacity:** HOT lanes may provide an opportunity to improve the efficiency of existing or newly built HOV lanes by filling “excess capacity” which would not otherwise be used.
- **Remedy for Under-Performing HOV Lanes:** In some areas there has been increasing pressure to convert under performing HOV lanes to general purpose use. HOT lane applications have the potential to increase the number of vehicles traveling on underutilized facilities and possibly reduce pressure to convert them to general-purpose use.

Given that the HOT lane concept is relatively new and has not yet been widely deployed, it is important to recognize the contexts into which HOT lanes can be most effectively introduced. These include (5):

- High density corridors typical of larger metropolitan area with limited travel options and a lack of parallel highway routes where a new HOT facility can appeal to several travel markets;
- Newly created HOV facilities where HOT operations can maximize use of the expanded lane capacity;
- Congested HOV facilities where a transition from HOV 2 to HOV 3 eligibility provides available capacity for HOT users; and
- Underutilized HOV facilities where paying SOV users can utilize the excess capacity with level of service maintained by pricing.

While it is possible to allow limited scale HOT lane use on single-lane HOV facilities, it is preferable to implement HOT operations on facilities providing more than one travel lane per direction.

9.2.7 Emerging Trends

The report “HOV Facility Development: A Review of National Trends” (Reference 3) presents several trends in the future HOV lane development, including:

- Augmenting the use of occupancy restriction with pricing, where vehicles are allowed to travel in the HOV lane for a fee, if they do not satisfy the minimum occupancy requirement established for a particular time period for an HOV lane (i.e., HOT lanes, as discussed in the previous section)

- The concept of managed lanes is just now emerging as a topic in a number of major metropolitan areas where significant roadway improvements are being planned within major freeway corridors. The role of the HOV concept is broadening. Occupancy is one of a number of operational strategies that could be applied in a managed lane application and it will continue to be explored in more freeway corridors and metropolitan areas around the country. Some agencies are now considering operational strategies that serve express traffic, trucks, inherent low emission vehicles, and pricing (i.e., HOT lanes) as a means of managing demand.
- The viability and operational benefits of HOV lanes will continue to come under greater and greater scrutiny from various advocacy groups, general public and elected officials as the severity of congestion grows in metropolitan areas. While public perceptions from recent unpublished surveys in Seattle and Los Angeles (2001) still strongly support a commitment to HOV lanes, these same surveys also report that individuals feel that HOV lanes are not adequately used. This finding suggests that operating agencies will need to expend greater effort in attempting to both promote awareness and continuously improve the operation of each HOV lane and its related system.
- Monitoring, evaluating, and reporting of HOV lane performance will play a greater importance in the operation, planning, decision making, provision of travel condition, and benefit information to the general public. If greater emphasis is not placed on performance monitoring, reporting, and the proactive management and operation of HOV lanes to make adjustments in the operating policies in some locales, the viability of the concept of HOV lanes as a whole could continue to be eroded.
- Proactive management and operation will be important. This could involve adjusting the hours of operation, combining operational strategies with occupancy (e.g., pricing, vehicle type), or some combination. Other changes that may be appropriate could involve significantly altering or terminating the operation of some poorly performing HOV lanes. In locations where the demand to use HOV lanes exceeds the capacity, it may be necessary to provide additional lanes, raise the occupancy requirement, or pursue the use of other additional operational strategies.

Finally, while no means of automating the occupancy enforcement of HOV lane occupancy requirements has yet emerged, work continues, Reference 6 identifies the basic functions of such a system:

- Collect and transmit video images of vehicle license plates and vehicle compartments for all HOV lane users to a remote computer workstation.
- Perform automatic license plate character recognition on the license plate video image.
- Synchronize captured video images of vehicle occupants with license plate numbers.
- Search a license plate database containing vehicle occupancy histories and, based upon failure to meet set criteria, display the vehicle license plate number and vehicle compartment images on a computer monitor for review and enforcement purposes.

Until such an automated system is perfected and accepted, enforcement presence will continue to require a continued commitment of the necessary staff and resources.

9.3 IMPLEMENTATION & OPERATIONAL CONSIDERATIONS

The numerous issues associated with policy development, planning, designing, implementing, marketing, operating, enforcing, and evaluating HOV facilities are addressed (in a comprehensive manner) in the NCHRP “HOV Systems Manual” (Reference 1) and other references noted herein. This section only provides a brief overview of some of these issues, many of which are identified in Reference 1 as “the key elements to achieving the desired project goals and objectives.”

9.3.1 Planning

In order for HOV systems and facilities to be properly integrated within the freeway system, system-planning needs to occur at various levels, including strategic planning, long-range system planning, short-range planning, and service or operations planning. At the strategic planning level, freeway and transit agencies need to determine their roles, missions, and types of HOV services they want to provide in a metropolitan area. Through the long-range planning process, agencies can ensure that HOV facilities and services are incorporated into the future design of freeway systems and that funding for capital-intensive facilities are programmed into area transportation improvement plans.

9.3.2 Interagency Coordination / Stakeholders

HOV facilities require that staff from agencies responsible for the freeway and roadway system, transit services, rideshare programs, and other programs work together. Interagency cooperation and coordination is critical to the success of an HOV project. That said, experience indicates that one agency or group needs to have overall responsibility. Experience has also indicated that one individual or a small group of individuals (i.e., “champions”) has been instrumental in the development, promotion, and support of most HOV projects (1).

Table 9-2 is from the *HOV Systems Manual*, and presents the roles of each of these partners in developing, operating and enforcing an HOV facility on a Freeway. In addition to these stakeholders, the HOV process needs to also consider the following:

- **Policy Makers:** Elected and appointed officials should be kept informed on the use of HOV facilities. Since elected officials, especially members of the state legislature are often the driving force behind HOV operational changes, it is important to keep these individuals informed on bus, carpool, and vanpool use of HOV facilities. Briefings, newsletters, E-mails, and other techniques may be used to provide ongoing updates on vehicle volumes and passenger levels, as well as any potential issues associated with HOV lanes.
- **Media:** The broadcast and print media represent an important constituency group for HOV facilities. The media has a significant influence on public perceptions and opinions, and represents an important method of getting information out to commuters, the public, and policy makers. Providing representatives from the media with accurate and timely information on HOV strategies – particularly operational changes – will help ensure that commuters and the public are aware of the changes, understand the reasons why changes are made, and comply with new requirements.

Table 9-2: Agencies and Groups Involved in Developing an HOV Operation and Enforcement Plan

(Reference 1)

Agency or Group	Potential Roles and Responsibility
State Department of Transportation	<ul style="list-style-type: none"> • Overall project management • Developing operations and enforcement plan • Designing Facility • Operating Facility • Staffing Multi-agency team or committee
Transit Agency	<ul style="list-style-type: none"> • Overall project management or supporting role • Developing or assisting with operations and enforcement plan • Bus operations • Enforcement or assisting with enforcement
State Police	<ul style="list-style-type: none"> • Assist with development of operations and enforcement plan • Usually responsible for enforcement of freeway HOV facilities • Coordination with judicial personnel
Local Police	<ul style="list-style-type: none"> • Assist with development of operations and enforcement plan • May assist with enforcement • Coordination with judicial personnel
Local Municipalities	<ul style="list-style-type: none"> • May have overall project management with arterial street and traffic signal applications • Support role with other HOV facilities • Developing or assisting with the operations and enforcement plan • Designing facility • Operating facility • Staffing multi-agency team or participating on team
Rideshare Agency	<ul style="list-style-type: none"> • Assist with development of operations and enforcement plan • Participate on multi-agency team
Metropolitan Planning Organization (MPO)	<ul style="list-style-type: none"> • Assist in facilitating meetings and multi-agency coordination • Ensure that projects are included in necessary planning and programming documents • May have policies relating to HOV facilities
Federal Agencies – FHWA and FTA	<ul style="list-style-type: none"> • Funding support • Overall approval of various steps
Other Groups	<ul style="list-style-type: none"> • Judicial system – state and local courts • EMS, fire, and other emergency personnel • Tow truck operators

- **Commuters and General Public:** Commuters, especially HOV users, and the general public represent the constituents of HOV projects. Obtaining input from these groups through surveys, focus groups, and other market research techniques may be appropriate in assessing different HOV operational strategies. Communicating new requirements to these groups is also critical.

9.3.3 Operations Planning / HOV Policies

The development of an operations plan is foremost in the success of the HOV facility. It should be noted that the development of an operations plan cannot be done in isolation, but needs close integration with the facility's enforcement plan (1). The plan should also address the various policy issues associated with HOVs, including those discussed below:

9.3.3.1 Operational Alternatives for the HOV

This addresses the type of HOV facility, and it has a direct and significant impact on other elements of the plan such as the ingress and egress and enforcement. The operation of separated HOV roadways may be reversible or two-way. The facility can be restricted to HOVs during peak periods only or throughout the day. Limiting access to a reversible HOV facility is crucial if the facility is to be operated in a safe and efficient manner. A system of gates must be considered at each end (and at any intermediate access points) to prevent wrong-way traffic from entering the facility, if located on a freeway. In addition to these features, this type of facility should also have a system of changeable message signs (CMS) that inform commuters as to the operational status of the facility (open or closed).

9.3.3.2 Vehicle Eligibility Requirements

The HOV facility provides operators and managers the flexibility to match the vehicle eligibility (and the vehicle occupancy requirements) to the lanes. Further, each can be changed to maintain the proper balance if necessary. Vehicle eligibility (i.e., what types of vehicles can use the facility) is one of the first issues that must be determined to develop the Operations Plan. Various types of vehicles can be considered for the use on the HOV facility including:

- Buses
- Vanpools
- Carpools
- Taxis
- Emergency vehicles
- Low – emission vehicles
- Commercial vehicles
- Airport Shuttles and other services
- Motorcycles
- Tolloed vehicles (HOT)

9.3.3.3 Vehicle Occupancy

Vehicle occupancy (e.g., 2+ or 3+) should be examined against the demand for the facility to estimate the impact the occupancy requirements may have on traffic flow. The goal is to implement HOV facilities in such a way that balances the flexibility of HOV growth and the public perception as to the use of a facility. An initial minimum vehicle occupancy requirement must be selected to optimize the efficiency of the facility. The selection must allow for growth in traffic volumes as more commuters choose to switch to carpooling arrangements and take advantage

of the travel time and fuel savings. Title 23 United States Code 102(A) allows State departments of transportation to establish the minimum occupancy requirements for vehicles operating on HOV lanes; except that no fewer than two occupants per vehicle may be required and that motorcycles and bicycles shall not be considered single occupant vehicles. Retaining the potential to carry more people over time offers important operational flexibility. At the same time, though, public perception of the adequacy of HOV lane usage must also be addressed. Peak hour HOV traffic volumes need to be high enough to help mitigate public concerns over underutilization of HOV facilities. The positive aspect of 2+ eligibility is that a staged resource of commitment to ridesharing is being established. Less work is involved in forming a 2+ carpool versus a 3+ carpool, and the base volume to draw from is considerably greater. There may be less eventual resistance to adding a third passenger than to forming an initial 3+ carpool.

Subsequent changes in occupancy requirements need to be weighed with projected future demand. Implementing an operational change from 2+ to 3+ occupancy could reduce vehicular demand by as much as 75 to 85 percent. This could be severe if only a 10 to 20 percent reduction in demand is necessary for the near future. A new HOV 3+ lane typically may carry only a few hundred peak-hour vehicles, while an adjacent freeway lane is carrying 1500 to 2000 peak-hour vehicles. Even though the HOV lane may be carrying more peak-hour person trips than an adjacent general purpose lane, the traveling public may perceive the lane to be underutilized. Additionally, there is the potential political difficulty in making a change from 2+ to 3+, as evidenced by the fact that very few such attempts have been successful. Varying occupancy requirements by time-of-day is another possibility.

Another consideration is regional consistency. It is the exception to have different occupancy (or eligibility) requirements on different facilities or in different corridors within the same metropolitan region.

9.3.3.4 Hours of Operation

Hours of operations for an HOV facility may be characterized as:

- 24 –hour continuous use
- Extended morning and afternoon hours – in this scenario, the lanes are used for much of the morning and afternoon.
- Peak Period only
- Dynamic – only when warranted (metered ramps with bypass)

A number of factors, including geometric design, volumes of HOV and mixed-flow traffic, hours of congestion, and regional consistency will influence HOV operating hours. Twenty-four hour HOV use of priority facilities is sometimes preferred, because violations tend to be lower and there is less motorist confusion. Also, 24-hour use may provide a greater overall incentive for the formation of new carpools. Some HOV facilities, such as reversible lanes, may not be conducive to 24-hour operation. The hours of operation for reversible facilities must allow time for a variety of necessary functions, such as clearing the lane, moving gates, and changing signing.

Part-time operation provides benefits only during the peak hours of defined need, allowing all traffic to use the lanes during other periods. This approach can reduce enforcement requirements and minimize public criticism during periods when the HOV lane appears empty. Part-time use of a shoulder as an HOV facility should be implemented only after careful

consideration of operational and safety problems. The right shoulder HOV facility differs from a part-time HOV lane that reverts to mixed-flow use during off-peak periods, in that the shoulder serves as a refuge for emergency breakdowns. Its use needs to be limited to a small number of vehicles because of the inherent conflicts at right side entrance and exit ramps. The shoulder facility requires special delineation and signing, and involves separate enforcement problems for both peak and off-peak periods. Motorists may tend to use the shoulder as a freeway lane during off-peak hours when it should be used as a shoulder.

9.3.4 Public Awareness and Marketing

Marketing and promoting the HOV facility is paramount to its successful implementation. More than one facility has either failed or had significant setbacks as a result of not informing or involving the public. The process of successful marketing of HOV facility includes (1):

- **Public Involvement:** An HOV facility must have public support to be successful. Ensuring that the public is involved early and throughout the planning, design, and implementation stages can help ensure this support. A variety of methods can be used to encourage the participation of commuters, travelers, neighborhood groups, and other organizations. These include meetings, workshops, surveys, focus groups, charettes, and hearings.
- **Education:** Building on the early involvement of the public, ongoing public education (and marketing activities) can also enhance the chance of a successful HOV project. Experience indicates that ongoing outreach efforts with the public and policy makers are needed even with effective HOV facilities. Given the turnover in elected and appointed officials, the numerous demands on these individuals, and the multitude of projects and programs vying for the attention of officials and the public, regular updates on the use, effectiveness, and benefits of HOV facilities are needed. The ongoing reinforcement of travel options is also important for new residents as well as long-term commuters.
- **Marketing:** Building from the two other elements, promoting the facility's or project's information to a wider audience provides a means to target specific audiences with specific information. The "HOV Marketing Manual" (Reference 7) provides detailed information on HOV marketing, as summarized in Table 9-3.

Table 9-3: Summary of HOV Marketing Manual

- Market Research (focus groups, telephone surveys, mail-back surveys, traffic measurements)
- Constituency Building (educational workshops, interagency coordination, political / enforcement / judicial liaison, identifying media partners, keeping the media's attention, environmental group concerns, community relations)
- Campaign Strategies (identifying key issues, identifying target audiences, hiring professionals, selecting media channels)
- Marketing Materials (brochures, newsletters, flyers, print ads, newspaper advertisements, radio and television spots, outdoor advertising)
- Media Relations (press kits, press releases, personnel training)
- Community Relations (public meetings, ridesharing agencies, business liaison, private industry support, telephone hotline)
- Evaluation Plan
- Monitoring the Project and Campaign (data collection, measuring exposure, presenting findings)

9.3.5 Enforcement

Enforcement of vehicle-occupancy requirements and other policies are critical to the successful operation of HOV facilities. HOV enforcement programs help ensure that operating requirements, including vehicle-occupancy levels, are maintained to protect HOV travel time savings, to discourage unauthorized vehicles, and to maintain a safe operating environment. Visible and effective enforcement promotes fairness and maintains the integrity of the HOV facility to help gain acceptance of the project among users and non-users (8).

Public acceptance of an HOV project is closely linked to the perception that the facility is well used and that the vehicle occupancy requirements are enforced. Support for an HOV facility will be lessened if commuters traveling in the adjacent freeway lanes feel the privilege of using the HOV lanes is being abused. Ensuring that the project design includes adequate and safe enforcement areas, and that visible ongoing enforcement is provided are important to the success of an HOV project (1).

Detection and apprehension of violators, and effective prosecution of violators, are essential. Therefore, law enforcement personnel with full capability to issue citations must be employed on HOV facilities. Moreover, police officers help ensure the safe and efficient operation of the facility. Depending on the type of facility and priority users, the potential safety and operational problems caused by vehicle breakdowns, wrong way movements and/or other vehicles' encroachments into the HOV facility may have an adverse impact on operations and must be a concern of the enforcement authority.

Effective enforcement usually includes a number of components. The following general elements should be considered in developing and conducting an enforcement program (8):

- Legal authority to enforce a facility,
- Nature of citations for violations and the level of fines,
- General enforcement strategies,
- Specific enforcement techniques,
- Funding,
- Communicating the program elements to users, non-users, and the public.

Enforcement strategies for HOV facilities can generally be categorized into four basic approaches – routine enforcement, special enforcement, selective enforcement and self-enforcement. All of these strategies may be appropriate for consideration with the various types of HOV projects.

A variety of enforcement techniques can also be used to monitor HOV facilities. These techniques focus on providing surveillance of the lanes, detecting and apprehending violators, and issuing citations or warnings to violators. Examples of approaches include stationary patrols, roving patrols, team patrols, multipurpose patrols, electronic monitoring, citations or warning by mail. Most areas use a combination of enforcement techniques.

A 1988 Texas Transportation Institute study (reference 9) of the enforcement procedures for HOV lanes determined the following key concepts related to effective HOV enforcement:

- The level of enforcement needed is dependent upon facility type. In general, concurrent flow facilities require more enforcement than do separated roadway and contraflow facilities.
- To be effective, an officer must have a safe and convenient place to issue citations or warnings. The enforcement activity should be in view of HOV users so that they can see when the lane restrictions are being enforced; however, it should not interfere with traffic on the HOV and mixed-flow lanes.
- To preclude high violation rates, a highly visible enforcement presence has to be maintained at a level where potential violators and legitimate users believe that violators have little chance to use the lane without getting caught.
- On limited access facilities, diverting potential violators before they can traverse some part of an HOV lane can be safer and more efficient than apprehending them after the fact. Whenever possible, enforcement areas should incorporate this concept.

Where enforcement is difficult to accomplish, or perceived as being unsafe, police may avoid apprehending violators, resulting in increasing numbers of illegal vehicles using the lane. Where enforcement has been a problem, 60 percent or more of the vehicles that used the lanes were violators. Experience suggests that steady doses of routine enforcement, combined with moderate application of special enforcement, can generally keep violation rates on exclusive HOV facilities in the 5 to 10 percent range. Heavy, consistent doses of special enforcement would be necessary to have violation rates below 5 percent. There are locations where no amount of enforcement can bring violation rates to an acceptable level (10).

In some metropolitan areas, programs have been initiated where motorists can call in to report HOV facility violators. Appropriate literature is sent to frequent violators, and enforcement personnel can make a point of watching for these vehicles in the HOV lane. These “so called” HERO programs can be helpful in reducing violation rates. Also, a system of video cameras combined with officer observation may be considered for non-occupancy infractions such as speeding or toll evasion (where pricing is applied), where state laws permit such technology. Currently, no state allows video for occupancy infractions because the system cannot be supported as fool-proof in the courts. Another factor that will have a positive impact on the violation rate is the cost of the fine for a violation. Fines exceeding \$250 for first offenders have been used, significantly lowering the violation rate.

9.3.6 Performance Monitoring

As discussed in Chapter 4, evaluating the effectiveness of HOV treatments (or any freeway management strategy for that matter) should not be considered a one-time activity, but should be part of a periodic review of the effectiveness of the component and of the overall system. In addition to providing information to the sponsoring agencies on the effectiveness of the treatment(s), the information would be helpful in communicating the effectiveness of the project to the public and enhancing a general understanding of the role that the HOV project has performed.

For each objective associated with the HOV program, the appropriate measure(s) of effectiveness should be identified, along with the desired threshold level of change that will be used to determine if the facility has met the objective. Commonly used objectives (i.e., for new HOV projects that add a lane to the freeway) and measures of effectiveness are identified in Table 9-4.

9.3.7 Other Considerations

Other issues that may be of concern with the development and implementation of an HOV treatment include the following:

- **Logical HOV Segments:** Ensuring that logical segments of an HOV project are opened for operations enhances the chance of a successful facility. For example, projects that allow HOVs to bypass congested freeway segments and provide good access may be better received than projects located where there is no congestion or those which funnel HOVs back into sections of heavy traffic (1).
- **Supporting Facilities and Service:** Successful HOV projects encompass more than just the HOV facility. Elements such as park – and – ride lots, new or expanded bus services, ramp meter bypass lanes, and other supporting components all contribute to the success of an HOV project (1).
- **Supporting Programs and Policies:** The existence of other supporting programs and policies also enhances the likelihood of a successful project. Ridesharing programs, guaranteed ride home programs, parking management and pricing policies, employer effort, land use policies and zoning ordinances may encourage HOV use (1).

Table 9-4: Suggested Objectives and Measures of Effectiveness for HOV Facilities

(Reference 1)

Objective	Measures of Effectiveness
<ul style="list-style-type: none"> HOV facility should improve the capability of a congested freeway corridor to move more people by increasing the number of persons per vehicle 	<ul style="list-style-type: none"> Actual and percent increase in the person movement efficiency Actual and percent increase in average vehicle occupancy rate Actual and percent increase in carpools and vanpools Actual and percent increase in bus riders
<ul style="list-style-type: none"> HOV facility should increase the operating efficiency of bus service in the freeway corridor 	<ul style="list-style-type: none"> Improvement in vehicle productivity (e.g., operating cost per vehicle / passenger) Improved bus schedule adherence (on-time performance) Improved bus safety (accident rates)
<ul style="list-style-type: none"> HOV facility should provide travel time savings and a more reliable trip time to HOVs utilizing the facility 	<ul style="list-style-type: none"> Peak – period, peak – direction travel times less than adjacent general purpose freeway lanes Increase in travel time reliability
<ul style="list-style-type: none"> HOV facility should have favorable impacts on air quality and energy consumption 	<ul style="list-style-type: none"> Reduction in emissions Reduction in total fuel consumption Reduction in vehicle-hours of travel
<ul style="list-style-type: none"> HOV facility should increase the per-lane efficiency of the freeway corridor 	<ul style="list-style-type: none"> Improvement in the peak-hour per-lane efficiency of the total facility
<ul style="list-style-type: none"> HOV facility should not unduly impact the operation of the freeway general-purpose lanes 	<ul style="list-style-type: none"> Level of service in the freeway general-purpose lanes should not decline
<ul style="list-style-type: none"> HOV facility should be safe, and not unduly impact the safety of the freeway general-purpose lanes 	<ul style="list-style-type: none"> Number and severity of accidents for HOV and general – purpose lanes Accident rate
<ul style="list-style-type: none"> HOV facility should have public support 	<ul style="list-style-type: none"> Support for the facility among users, non-users, general public, and policy makers Violation rates
<ul style="list-style-type: none"> HOV facility should be a cost-effective transportation improvement 	<ul style="list-style-type: none"> Benefit – cost ratios

- Scheduling.** If the HOV project is a retrofit, implementation scheduling can be complicated by a variety of unknowns, generally related to the policies and procedures of the various agencies involved. If the project requires daily monitoring (e.g., contraflow or reversible-flow operations), an additional period following construction completion should be included for pre-operation testing. This period allows police to refine enforcement strategies and the operations team to make minor adjustments in the facility design prior to operation. The advance period will vary by project and type of facility to acquaint bus operators, deployment

staff, police, and others with how to handle daily operation, maintenance, and emergencies (11).

- **HOV Operation During Construction.** One of the most effective methods of cultivating an early market for an HOV project is to start offering preferential treatment during the construction phase. Additionally, this approach can be a cornerstone of the traffic management plan aimed at preserving corridor flow during construction activities. These benefits often outweigh the complications this approach creates for contractors and throughout the construction period.

9.3.8 HOT Issues

HOT lanes have many of the same issues as noted above. Additionally, there are a number of unique concerns. For one, HOT lanes may involve the introduction of tolls for the first time. This may require DOTs to establish new legal and institutional structures and operational capabilities before HOT lane projects can actually be implemented. They may also introduce unfamiliar project financing and operational approaches. Most importantly, they introduce public relations challenges that have the potential to bring HOT lane initiatives to an abrupt halt at nearly any stage of their development (5).

Several other important choices face transportation officials and policy makers as HOT lane projects become more clearly defined. These decisions can have repercussions on design, as well as equity issues and are likely to include (5):

- Eligibility of vehicles. What size and type of vehicles should be eligible to use the HOT lane? If demand exceeds supply, how should users be selected?
- Toll collection. How should the toll collection program be administered?
- Government agency (if so, which one?) or a private contractor under government contract?
- Toll collection technology. Should the project use electronic toll collection or a permit decal system?
- Intermediate access. What frequency of access for buy-in vehicles should be permitted?

9.4 EXAMPLES

Information on the numerous freeway HOV implementations across the nation can be found at the Federal Highway Administration's High Occupancy Vehicle website, www.ops.fhwa.dot.gov/travel/traffic/hov/index.htm. Two case studies - involving a change in occupancy requirements and HOT lanes - are described below.

9.4.1 El Monte Busway

Opening in 1973, the El Monte Busway on the San Bernardino (I-10) Freeway is the oldest high-occupancy vehicle (HOV) facility in the Los Angeles area. In 1999, the California Legislature approved Senate Bill 63 (SB 63), lowering the vehicle-occupancy requirement on the El Monte Busway from three persons per vehicle (3+) to two persons per vehicle (2+) full time. The legislation directed the California Department of Transportation (Caltrans) to make this change on January 1, 2000 as part of a temporary demonstration project, which was to extend until June 30, 2001. The legislation also required Caltrans to monitor and analyze the effect of this change on the operation of the freeway and the Busway. Based on the operational effects of the change, as documented in the Caltrans operational study (as summarized below), new

legislation was passed increasing the vehicle-occupancy requirement back to 3+ during the morning and afternoon peak periods and maintaining the 2+ requirement at all other times, effective July 24, 2000.

The Caltrans monitoring program tracked travel speeds, vehicle volumes, and person movement on both the Busway and the general-purpose freeway lanes. Conditions prior to implementation of SB 63, during the 2+ demonstration, and after the change to the 3+ peak/2+ off-peak requirements were monitored by Caltrans. The Caltrans assessment focused on the morning and afternoon peak periods, when demands on the freeway system are greatest and traffic volumes are highest. Further, the analysis focused on the peak direction of travel during these time periods. The results are addressed in Reference 8 and summarized below.

Overall, lowering the vehicle-occupancy requirement from 3+ to 2+ full time had a detrimental affect on the Busway. At the same time, significant improvements were not realized in the general-purpose freeway lanes. The major negative effects on the Busway and the neutral effects on the general-purpose lanes are highlighted below.

9.4.1.1 Travel Speeds

Peak hour travel speeds in the Busway were negatively effected during the 2+ demonstration. Travel speeds in the Busway declined from freeflow conditions at 65 mph to approximately 20 mph in the morning westbound direction. In the afternoon eastbound direction, travel speeds on the Busway decreased from 65 mph to 27 mph during the first month of the demonstration and then increased to 40 mph for the duration of the test.

A significant corresponding increase in travel speeds did not occur in the general-purpose lanes. Travel speeds in the morning westbound direction increased from 25 to 37 mph on the freeway lanes during the first month of the 2+ demonstration, but decreased to 23 mph for the remainder of the operation. In the afternoon, eastbound peak hour freeway travel speeds increased from 32 to 40 mph during the demonstration.

Travel speeds on both the Busway and the freeway lanes returned to close to pre-demonstration levels with the implementation of emergency legislation, AB 769, and the return to the 3+ occupancy requirement during weekday peak-periods. Travel speeds on the Busway increased to 45 mph in the morning and 55 mph in the afternoon peak hours. Although lower than the pre-demonstration 65 mph, both of these speeds represent generally freeflow conditions. Travel speeds in the general-purpose lanes were slightly lower than the pre-demonstration speeds at 20 mph and 28 mph for the morning and afternoon peak hours, respectively.

9.4.1.2 Vehicle Volume and Persons per Hour per Lane

Examining these two measures together is important, as vehicle volumes may increase as the result of a change in the vehicle-occupancy requirement, but the total number of people being carried may decline or may increase at a much lower rate.

- The number of vehicles on the Busway in the morning peak hour increased from 1,100 to 1,600 during the 2+ demonstration, but the number of persons carried declined from 5,900 to 5,200. Thus, more vehicles carrying fewer people were on the Busway. Trends in the afternoon peak-period were different with hourly vehicle volumes increasing from 990 to 1,500 and person volumes increasing from 5,100 to 5,600.

- Vehicle volumes in the general-purpose lanes increased slightly or remained relatively constant over the three time periods, as did the number of persons per hour per lane. Thus, lowering the vehicle-occupancy rate on the Busway, and the subsequent increase in 2+ carpools on the Busway, did not have a corresponding affect of lowering vehicle volumes in the freeway lanes. The increase in vehicles may have resulted from latent demand in the corridor, with commuters diverting from other routes.

9.4.1.3 Public Transit Connections

Buses have always been a key element of the El Monte Busway. Lowering the vehicle-occupancy requirement to 2+ had a significant effect on bus operations. The increase in the number of two-person carpools, which caused congestion on the Busway, resulted in lower bus operating speeds, longer bus travel times and reduced on-time performance, increased service overtime and operating costs, and increases in customer complaints. For example:

- The slower operating speeds resulted in longer bus travel times and reduced on-time performance. Schedule adherence and on-time performance dropped from an average of 88 percent in the fall of 1999 to 48 percent in May 2000. The consistent 20-minute travel time savings provided to bus passengers over vehicles in the general-purpose lanes was lost during the 2+ demonstration.
- The slower bus operating speeds, longer travel times, and reduced on-time performance also caused declines in service productivity. Bus operators finishing their runs late were frequently not able to return for a second trip in the corridor. To fill these voids and to maintain schedules, extra buses and operators had to be dispatched when available. At some points during the demonstration, as many as 10 extra buses and operators were staged in the downtown area to help ensure that trips were not missed and schedules were maintained.
- The affected transit agency estimated that the personnel and fuel costs associated with providing these extra buses were approximately \$1,250 per weekday. If the 2+ requirement had been continued, the annual cost of providing the additional buses would have been approximately \$325,000.

9.4.1.4 Enforcement and Vehicle – Occupancy Violations

The changes in vehicle-occupancy levels significantly affected the violation rates on the Busway as shown below.

Time Period	Busway	
	AM Peak-Period	PM Peak-Period
Before January 2000	7%	2%
January 1 - July 24, 2000	1%	1%
Immediately after July 24, 2000	41%	56%
December 2001	4%	9%

The violation rates declined during the 2+ demonstration, as 2+ person carpools which would previously have been cited became authorized users. The violation rates increased significantly during the early phase of the 3+/2+ operations. Extra enforcement and more visible enforcement were not provided during the initial 3+/2+ operation. As a result, it appears that many 2+ carpools continued to use the lane during the 3+ peak-period. In response to concerns over these high violation rates, CHP undertook an aggressive enforcement program in January 2001. Elements of the program including briefings for all CHP shifts, press releases and radio broadcasts highlighting the correct occupancy requirements, announcing increased enforcement of the rules, and four weeks of enforcement saturation with extra offices assigned to the Busway. These efforts resulted in the violation rates returning to levels similar to those before the 2+ demonstration.

9.4.2 San Diego I-15 Corridor

The I-15 FasTrak involved the conversion of an underutilized preexisting eight-mile 2-lane HOV facility to a peak-period reversible HOT. The project is sponsored by the San Diego Association of Governments (SANDAG), the local metropolitan planning organization (MPO), which has earmarked a significant portion of the revenues derived from the HOT lane to fund transit improvements in the I-15 corridor. Key operational attributes include (5):

- The lanes operate only during peak hours in the direction of the commute. From 5:30 AM to 11 AM, all vehicles in the HOT lanes travel southbound; from 11:30 AM to 7:30 PM, all vehicles travel northbound.
- On normal commute days, the toll ranges between \$0.50 and \$4.00, depending on current traffic conditions; although tolls may be raised up to \$8.00 in the event of severe traffic congestion. To maintain free-flow on the FasTrak lanes at all times, toll rates are adjusted every 6 minutes in response to real-time traffic volumes. The actual toll at any given time is posted on roadside CMS signs (shown below) to inform drivers of the current price for using the lanes.



- Customers must have a FasTrak account and transponder to use the HOT lanes. Motorists enter the HOT lanes at normal highway speeds. Toll collection occurs when the motorist travels through the tolling zone at the entrance.

- To preserve the carpooling incentives that existed with the original HOV lanes, carpools and other vehicles with two or more occupants may always use the FasTrak lanes for free.

The I-15 HOT lane initiative also included early and aggressive efforts to assess public opinion and potential usage of the lanes before the facility was launched. Additionally, the implementing agency SANDAG also has paid close attention to marketing issues throughout project implementation and operational phases. The SANDAG I-15 FasTrak Online website (<http://argo.sandag.org/fastrak/library.html>) provides full documentation of the supporting studies that were used to formulate tolling schedules, marketing plans and promotional materials.

Reference 5 provides additional details on the lessons learned from the I-15 HOT lanes, including:

- Team effort among key stakeholders is important for ensuring consensus and maintaining momentum from project planning to implementation.
- A local, influential political champion may explain why the I-15 project was implemented while other value pricing proposals have not been realized.
- Strong community outreach efforts to citizens, community groups, and elected officials must continue throughout project planning, implementation and operation to communicate information regarding project goals, plans, progress and benefits.
- Detailed project agreements may be needed to specify the roles and responsibilities of participating agencies and other parties. These should be arranged as early in the project process as possible, leaving some flexibility for unexpected issues.
- Dynamic tolling involves significant technical and administrative complexities. The project schedule should budget time to plan and implement new technologies, institutional arrangements and administrative procedures.
- Reciprocity with other toll agencies is important. Data compatibility and revenue transfer are key issues to work out.

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10. TRAFFIC INCIDENT MANAGEMENT

10.1 INTRODUCTION

A *traffic incident* is a non-recurring event that causes a reduction of roadway capacity or an abnormal increase in demand. In most metropolitan areas, traffic incident-related delay (not including other non-recurring delay caused by weather, work zones, etc.) is estimated to account for between 25 and 30 percent of total congestion delay. In smaller urban areas, it can account for an even larger proportion (Reference 1). Although the problems most often associated with traffic incidents are congestion and associated traveler delay, increased fuel consumption, and reduced air quality, the most serious problem is the occurrence of secondary crashes. Another related issue is the danger posed by traffic incidents to response personnel serving the public at the scene.

Although traffic incidents constitute only a portion of all public safety and emergency management incidents, the general principles for effective management of all types of incidents are comparable. Effective traffic incident management (TIM) programs, like other incident management programs, feature ongoing, actively administered, organizationally structured, interjurisdictional, multi-disciplinary and fully documented procedures. More than merely an assemblage of technologies and activities, successful TIM programs must be fully integrated into the culture of the stakeholder institutions.

For example, the Washington state program features high level institutional coordination documented in the Joint Operations Policy Statement (JOPS). This was signed on February 13, 2002, by the Washington State Patrol and the Washington State DOT, and makes a matter of policy the extensive coordination between the two agencies on a number of matters, including traffic incident response. One of the stated goals is the clearance of all incidents within 90 minutes.

Traffic incident management is the systematic, planned, and coordinated use of human, institutional, mechanical, and technical resources to reduce the duration and impact of traffic incidents, and improve the safety of motorists, crash victims, and traffic incident responders. Effectively using these resources can also increase the operating efficiency, safety, and mobility of the highway. This results from reducing the time to detect and verify a traffic incident occurrence; implementing the appropriate response; safely clearing the incident; and managing the affected flow until full capacity is restored (Reference 1).

A traffic incident management program is a logical, structured, and integrated set of traffic incident management activities tailored to a specific geographic area. It includes policies, strategies, and technologies integrated into a multi-agency, multi-jurisdictional environment aimed at reducing the occurrence and impact of traffic incidents. To be successful, a TIM program must be on-going and actively managed. The TIM program should be developed and managed in conjunction with the area's freeway management and operations program. The organization of the TIM program and the operational responsibilities of its participants should fit into the organization structure of the region, recognizing the existing assignment of traffic incident management activities and addressing gaps and overlaps in those assignments.

10.1.1 Purpose of Chapter

The *Traffic Incident Management Handbook* (Reference 1) treats traffic incident management in depth and is considered the primary reference on the subject. This chapter summarizes that reference, highlighting the essential elements of an effective traffic incident management program. References 2, 3, 4 and 11 should also be consulted.

10.1.2 Relationship to Other Freeway Management Activities

Traffic incident management is often a major element – if not the cornerstone – of a freeway management and operations program. The ultimate success of a traffic incident management program depends on the on-going collaboration and coordination (as discussed in Chapter 2) among the various entities involved. Several ITS components can support and enhance a traffic incident management program, including surveillance (Chapter 15) to detect and verify incidents, disseminating information to travelers regarding the resulting congestion and alternatives (Chapter 13), improving response via the coordination afforded by a Traffic Operations Center (Chapter 14), as well as the real-time sharing of information (Chapter 16) among the affected agencies. Additionally, the various activities and coordination needs for traffic incident management parallel those associated with special event management (Chapter 11) and emergency / evacuation management (Chapter 12).

Traffic incident management is a critically important piece of a freeway management program, and should be considered in all stages of developing and implementing a freeway management and operations program (Chapter 3). Moreover, like all programs and activities that are intended to improve the operation of the transportation network, the performance of a traffic incident management program should be regularly monitored and assessed (Chapter 4), potentially resulting in changes and refinements.

10.2 CURRENT PRACTICES, METHODS, STRATEGIES, AND TECHNOLOGIES

10.2.1 Overview

A traffic incident is a non-recurring event on or near the roadway that causes a reduction of roadway capacity or an abnormal increase in demand. Such events include traffic crashes, disabled vehicles, spilled cargo, and highway maintenance and reconstruction projects. Non-emergency events (e.g. ball games, concerts, festivals) are considered planned special events and are discussed in Chapter 11 (Planned Special Event Management) and Reference 6. Emergencies such as natural disasters and terrorist attacks are also unplanned; and they can cause a reduction of capacity or an abnormal increase in demand. But their impacts and management requirements extend well beyond the roadway as discussed in Chapter 12, *Freeway Management During Emergencies and Evacuations*.

Traffic incidents, such as crashes, spills, and vehicle disablements, vary widely in scope and severity. To mitigate these nonrecurring events in the safest, quickest, and most cost-effective manner requires:

- A traffic incident management toolbox of integrated policies, strategies, and technologies (Reference 1), thereby reducing the time to detect and verify a traffic incident occurrence;
- Implementing the appropriate response;
- Safely clearing the incident; and
- Managing the affected flow until full capacity is restored.

Quick clearance policies and freeway service patrols target minor traffic incident occurrences (Reference 5) but more recently have been applied to aggressive removal of heavily damaged vehicles and cargo (shoving, dragging, scooping, bulldozing), prohibitions against in-lane off-loading of cargoes, towing and recovery practices, and crash investigations. Major incidents like a severe crash or spill (especially hazmat) require a more intensive traffic incident management effort usually involving a cooperative, multi-agency approach. In essence, the unpredictable and dynamic nature of traffic incidents mandates the planning and coordination of a wide range of traffic incident management tools.

The goal of the *Traffic Incident Management Handbook* (Reference 1) is to assist agencies responsible for traffic incident management activities on public roadways to improve their programs and operations. Agencies typically responding to highway incidents include:

- Law Enforcement
- Fire and rescue
- Towing and recovery
- Emergency medical services (EMS)
- Environmental Protection (for HAZMAT incidents)
- Transportation agencies

The intended audience for this chapter and the *Traffic Incident Management Handbook* is primarily managers who are responsible for traffic incident management program development; and field practitioners who are responsible for providing program services on a day-to-day basis. As such, the Traffic Incident Management Handbook provides guidance from two perspectives – first, as a process to follow in establishing a new traffic incident management program or in improving an existing one; and second, through the identification of tools and strategies that can enhance field operations.

10.2.2 Benefits

Reduced traffic incident duration has proven the greatest contributor to the benefits of a traffic incident management program. Reductions in duration can be achieved by:

- Reduced detection and verification time
- Timely and appropriate response
- Rapid clearance
- Managed recovery (advising upstream motorists of an upcoming problem or directing entering motorists to remain on a parallel route)

Benefits of an effective program are both *quantitative* and *qualitative*. The quantitative benefits include:

- Increased survival rate of crash victims
- Reduced delay
- Improved response time
- Improved air quality
- Reduced occurrence of secondary incidents
- Improved safety of responders, crash victims and other motorists
- Reduced recovery time

Qualitative benefits include: enhanced traveler information services, increased driver warning capabilities, improved coordination and cooperation of response agencies, improved public perception of agency operations, and reduced driver frustration.

10.2.3 Key Considerations During Freeway Management Program Development

The *Traffic Incident Management Handbook* (Reference 1) defines an 8-step process for implementing a successful traffic incident management program. This process, summarized below, contains many of the key elements for establishing a freeway management program as discussed in Chapter 3.

A Traffic Incident Management program needs to be facilitated (but not owned) by a lead agency that can provide staff and resources to do so. The program itself must be multi-agency and multi-disciplinary and must continuously, actively and professionally engage all public and private sector program partners.

Regardless of what process is used for developing a traffic incident management program, it is essential that traffic incident management be coordinated with all other elements of the broader freeway management program, and that overall performance of the transportation network be considered.

- **Identify Stakeholders.** Critical to the success of a traffic incident management program is the development of a cooperative spirit and consensus among the various stakeholders. Therefore the first step is to identify the relevant stakeholders, such as state, city, and county departments of transportation, Metropolitan Planning Organizations (MPOs), emergency preparedness organizations, emergency medical services, fire departments, state and local law enforcement, transit operators, commercial transportation firms, environmental protection, maintenance, towing operators, major employers, user groups, media, elected officials, policy makers and others specific to the region. Once these stakeholders commit to establishing a traffic incident management program, they can sponsor a traffic incident management Task Force that meets periodically to guide and enhance the program. It has often been said that traffic incident management primarily consists of assembling the involved stakeholders together in an open and non-confrontational atmosphere; the stakeholders will then collectively design their own unique and effective program.
- **Define the Problem:** Before identifying, much less selecting a solution, a clear understanding of the severity, impacts, and locations of incident-related problems is required. Problem definition can be accomplished through a combination of data collection, data compilation, brainstorming, and constructive critiques of existing practices. In addition to considering responder activities, responsibilities, and roles in assessing the current practices, it is also important that the Traffic Incident Management Task Force consider the legal and policy environment in which incident management is carried out.
- **Set Goals and Objectives:** The Traffic Incident Management Task Force should next establish guiding principles for program development. These “guiding principles” most often take the form of a mission statement, backed up by goals and objectives and based on the

identified problems. Simply stated, goals and objectives describe what the program is designed to accomplish. Goals and objectives need to be multi-agency in scope; not merely the goals and objectives of individual agencies. Goals reflect long-term aspirations, and may include: reduce secondary incidents, increase safety for responders, increase and improve use of alternate routes, reduce liability for responding agencies. Objectives typically define the specific, often measurable, level of performance that would be required to progress toward a given goal. Objectives could include: decrease detection times, improve response times, increase motorist information, improve clearance procedures, decrease number of lanes closed, and decrease road and lane closure times.

- **Develop Alternatives:** Traffic incident management programs consist of many individual practices, tools and infrastructure elements. Based on the goals and objectives, the group can develop alternatives to combine available traffic incident management tools and techniques into program packages for evaluation. These packages can include those defined in the ITS National Architecture, along with those in Reference 1. In addition to ensuring that the techniques developed are appropriate in terms of covering each of the functional areas of incident management, it is also important that they be suited to the level of interagency coordination that has been established, or that is feasible.
- **Evaluate and Select Alternatives:** The developed alternatives can be evaluated using high-level estimates of costs, expected benefits of each alternative, and prioritization. Successful programs have often used a building-block approach, first initiating low-cost components to demonstrate the benefits of traffic incident management activities. Greater support may then become available for more capital-intensive alternatives. Both short- and long-term strategies can be formulated. Alternatives can then be assigned priorities based on Task Force consensus, or more rigorous cost-benefit studies can be used.
- **Implement Alternatives:** It is at the point of implementation that mechanisms for resolving many of the issues of incident management must be developed. These issues may include: funding sources, jurisdictional boundaries, operational responsibilities, joint training, field communications, on-site command and approval of alternate routes. One mechanism for formalizing understandings among agencies and jurisdictions is an interagency or inter-jurisdictional agreement. The number, formality, and content of these agreements needed are a function of the specific needs and operating environment of a given area
- **Reevaluate Alternatives:** Traffic incident management is an ongoing process, one that must take into account changes in the local operational, technological, political, and funding environment. Effective program evaluation and the subsequent reevaluation of alternatives to refocus or refine an existing system require the routine collection of appropriate data (e.g., detection time, response time, clearance time, delay and costs). Regular data collection allows program managers to assess the effectiveness of their efforts, to identify areas for improvement, to demonstrate the benefits provided by the program, and to support requests for additional resources. Regular debriefings have also proved effective in continuously reevaluating traffic incident management alternatives.
- **Refine the System:** To continuously improve and adapt a traffic incident management program, effective feedback is needed both from upper management and field-level personnel. Genuine communication and coordination on both levels will continue to improve

the traffic incident management process, adapt to the area's changing needs and meet the needs of the participating agencies, affected jurisdictions and the motoring public.

In addition to securing broad stakeholder participation from the relevant agencies and jurisdictions, it is also important to ensure that an adequate amount and the appropriate type of public outreach are pursued. Public outreach serves two primary functions: to make the public aware of the value of incident management, leading to generalized public support; and to help the public better understand how their actions, such as moving drivable vehicles out of traffic, and providing good information in reporting incidents, can support effective incident management (1).

10.2.3.1 Traffic Incident Management Program Framework

Reference 3 presents a framework for developing traffic incident management programs as summarized in Figure 10 - 1. This process includes the previously defined steps but adds additional focus on stakeholder involvement.

10.2.3.2 Traffic Incident Management Self - Assessment

With respect to the next-to-last step identified in Reference 1 (i.e. "reevaluate alternatives"), FHWA has developed a self-assessment tool to assist in this reevaluation process. The Traffic Incident Management (TIM) Self-Assessment tool (Reference 8) is designed to:

- Allow local stakeholders to assess how well they manage traffic incidents and identify areas for improvement.
- Allow FHWA to assess, at a national level, the needs identified by practitioners and develop program initiatives to address those needs
- Give FHWA a national program metric to gauge overall progress in traffic incident management.

The TIM Self-Assessment is a tool to be used by state and regional program managers to assess their achievement of a successful multi-agency program to manage traffic incidents effectively and safely. The tool also provides a method to assess gaps and needs in existing multi-agency regional and statewide efforts to mitigate congestion caused by traffic incidents. The TIM self-assessment is not intended as a one-time exercise, but should be conducted on an annual or biennial basis. This will provide a consistent measure of program improvements and allow for continual refocusing of resources to those areas needing them most.

The TIM Self-Assessment consists of a series of questions (summarized in Table 10-1) designed to allow those with traffic incident management responsibilities to rate their performance in specific organizational and procedural categories – specifically, Program and Institutional Issues, On-Scene Operations Issues, and Communications and Technology Issues. The questions in each of these areas address the essence of good traffic incident management programs based upon more than ten years of knowledge and experience gained nationwide. Each question is scored from 0 (no progress in this area) to 4 (outstanding efforts).

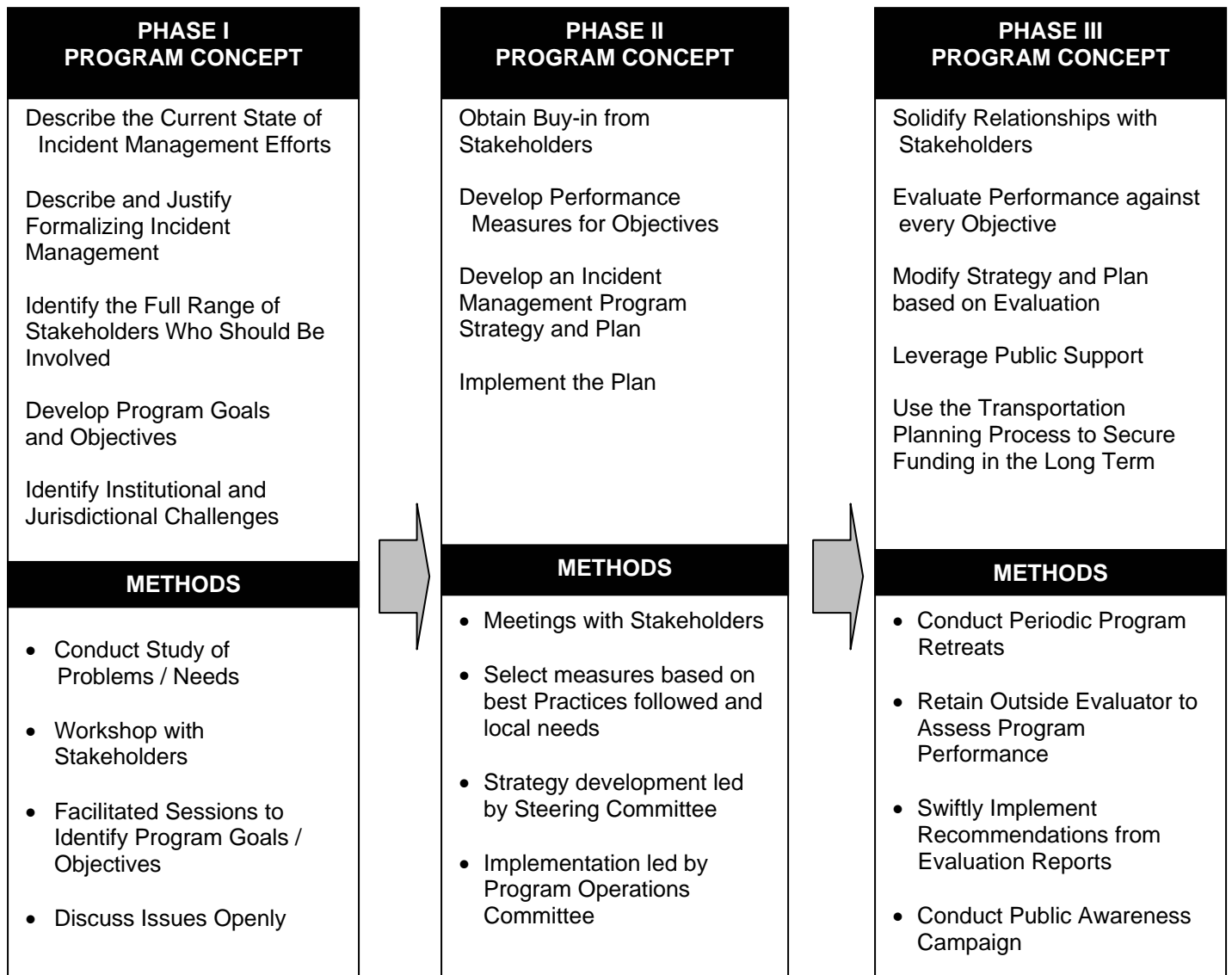


Figure 10-1: A Framework for Organizing and Sustaining Incident Management Programs (Reference 3)

Table 10-1: Traffic Incident Management Self – Assessment Questions

(Reference 8)

1 – Program and Institutional Issues

Does your TIM program:

- Have multi-agency, multi-year strategic plans detailing specific programmatic activities to be accomplished with appropriate budget and personnel needs identified?
- Have formal interagency agreements on operational and administrative procedures and policies?
- Have field-level input into the plans ensuring that the plans will be workable by those responsible for their implementation?
- Have formalized TIM multi-agency administrative teams to meet and discuss administrative policy issues?
- Hold regular meetings of the TIM administrative team?
- Conduct training through simulation or “in-field” exercises?
- Conduct post-incident debriefings?
- Conduct planning for “special events” – (a) construction and maintenance; (b) sporting events / concerts / conventions / etc.; (c) weather-related events; (d) catastrophic events?
- Have multi-agency agreements on what measures will be tracked and used to measure program performance?
- Have agreed upon methods to collect and analyze / track performance measures?
- Have established targets for performance in: a) response and b) clearance?
- Conduct periodic review of whether or not progress is being made to achieve targets?

2 – Operational Issues

Does your TIM program:

- Have established criteria for what is a “major traffic incident” – traffic incident levels or codes?
- Identify high-ranking agency members available on 24/7 basis to respond to a major incident?
- Have a pre-identified (approved) contact list of resources (including special equipment) for traffic clearance and hazardous materials response?
- Have the response equipment pre-staged for timely response?
- Train all responders in traffic control procedures?
- Utilize on-scene traffic control procedures for various levels of incidents in compliance with MUTCD?
- Utilize traffic control procedures for the end of the traffic incident queue?
- Have mutually understood equipment staging and emergency lighting procedures on-site to maximize flow past a traffic incident while providing responder safety?
- Utilize the Incident Command System?
- Have specific policies and procedures for fatal accident investigation?
- Have specific policies and procedures for hazardous materials response?
- Have quick clearance policies?
- Have a pre-qualified list of available and contracted towing and recovery operators (to

include operators' capabilities)?

- Use motorist assist service patrols?

3 – Communication and Technology Issues

Does your TIM program:

- Have a two-way interagency voice communications system allowing for direct on-site communications between incident responders?
- Provide data and video information transfer between agencies and applications (TMC-CAD integration)?
- Use Traffic Management Center(s) to coordinate incident notification and response?
- Have a developed technical infrastructure for surveillance and rapid detection of traffic incidents?
- Have specific policies and procedures for traffic management during incident response (i.e. signal timing changes, opening/closing of HOV lanes/ramp metering)?
- Have the ability to merge/integrate and interpret information from multiple sources?
- Have a real-time motorist information system providing incident-specific information?
- Provide motorists with travel time estimates for route segments?

10.2.4 Relationship to National ITS Architecture

The traffic incident management market package, as defined in the National ITS Architecture (Reference 7), treats both unexpected incidents and planned events so that the impact to the transportation network and traveler safety is minimized. The market package includes traffic incident detection capabilities through roadside surveillance devices (e.g. CCTV) and through regional coordination with other traffic management, maintenance and construction management and public safety and emergency management centers as well as weather service entities and event promoters. Information from these diverse sources are collected and correlated by this market package to detect and verify incidents and implement an appropriate response.

This market package also supports traffic operations personnel in developing an appropriate response in coordination with public safety and emergency management, maintenance and construction management, and other incident response personnel to confirmed traffic incidents. Incident response also includes presentation of information to affected travelers using the *Traffic Information Dissemination* market package and dissemination of traffic incident information to travelers through the *Broadcast Traveler Information* or *Interactive Traveler Information* market packages. The roadside equipment used to detect and verify incidents also allows the operator to monitor traffic incident status as the response unfolds. The coordination with public safety and emergency management agencies might be through data sharing and integration of public safety CAD and transportation management data and communication systems or through other communication with emergency field personnel.

10.2.5 Technologies and Strategies

Traffic incident management consists of the following major stages as illustrated in Figure 10 - 2:

- Detection
- Verification
- Motorist Information
- Response
- Site Management
- Traffic Management
- Clearance
- Recovery

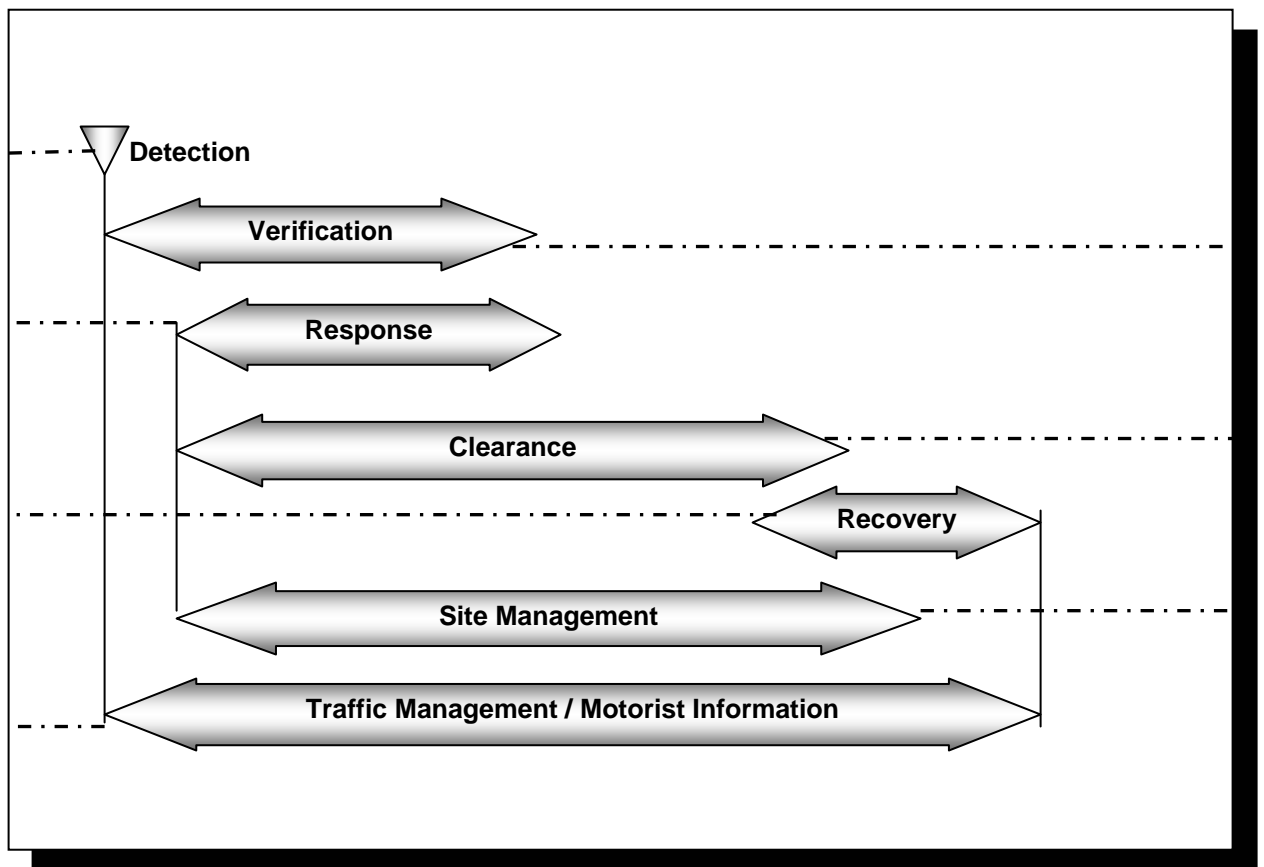


Figure 10 - 2: Timeline of Stages in the Traffic Incident Management Process

A wide variety of techniques and approaches can be applied to each of these stages. These are summarized below with further detail found in Reference 1.

Detection is determining that a traffic incident has occurred. Rapid detection is necessary to minimize the period of time during which roadway capacity is reduced. Methods commonly used to detect incidents include:

- Cell phone calls from motorists
- CCTV images viewed by operators
- Traffic stream probes such as toll tags with software to estimate travel time between readers
- Electronic detection (video processing, radar, induction loops) with traffic incident detection algorithms
- Traffic reporting services
- Service patrols
- Police patrols
- Calls from public works crews
- Helicopter reporters
- Fleet vehicles
- Motorist aid telephones / call boxes

Verification is determining the precise location and nature of an incident, as well as the display, recording, and communication of this information to the appropriate agencies. Proper verification is required to reduce the time required to deploy an appropriate response to the scene of an incident. Operations center personnel may verify incidents and communicate with incident responders on scene, or provide details to emergency agency dispatchers. Verification methods include:

- Field units (e.g. police) at the incident site
- Closed circuit TV images
- Communication with helicopters operated by police, media or information service providers
- Combining or *fusing* information from multiple cellular calls
- Airborne platforms or satellites

Motorist information is the activation of a variety of communications media to relay traffic incident conditions to travelers. Dissemination of motorist information is one of the primary services provided by many TMCs, as discussed in Chapters 13 and 14 herein. Techniques include:

- Commercial radio and television
- Changeable message signs (CMS)
- Highway advisory radio (HAR)
- Telephone information systems
- In-vehicle or personal data assistant information
- Internet/on-line services
- Information service providers (ISP)

Response is the activation, coordination, and management of the appropriate personnel, equipment, and communication links and motorist information media as soon as it is reasonably certain that a traffic incident has occurred. Timely and effective response reduces the incident's duration, and therefore, the time of roadway operation at reduced capacity. Techniques include:

- Interagency response planning and mutual-aid agreements
- Intra- and inter-agency communications. This includes voice radio interoperability, data and video links between public safety communication centers (CAD systems), TMCs and highway operations centers. (See Reference 10 and [http: www.ctc.org/NTFI](http://www.ctc.org/NTFI)).
- Personnel and logistics support

- Equipment storage sites
- Advanced response vehicles that include a mobile communications platform, GPS and other features to facilitate efficient response

Site management consists of:

- Accurately assessing incidents
- Properly establishing priorities
- Notifying and coordinating with appropriate agencies and organizations
- Maintaining clear communications among responders

Effective site management increases safety for crash victims, motorists and responders; coordinates responder activities; and decreases the impacts of incidents on the transportation system. Techniques include:

- Institution of an Incident Command System (ICS)
- Use of Unified Command Structure of ICS for major incidents (Refer to Chapter 12 herein for more information regarding ICS).
- Identification and implementation of equipment requirements
- Coordination of multi-agency response
- Proper placement and staging of response vehicles at traffic incident scenes

Traffic management is the application of traffic control measures at the incident site and on facilities affected by the traffic incident. Effective traffic management minimizes traffic disruption while maintaining a safe workplace for responders and reducing the likelihood of secondary crashes. Techniques include:

- Preparation
 - Alternate route planning
 - Availability of cones, flares, warning signs, arrow boards, portable CMS and other traffic control resources
 - Availability of traffic control devices such as CMS, HAR, ramp meters, traffic signals
- Flow management at scene
 - Establish point traffic control at scene
 - Manage roadway space
- Queue management to actively monitor the end of queue and warn approaching motorists.
- Flow management on alternate routes
 - Establish and operate alternate routes
 - Actively manage traffic control devices
- Reduce long-term traffic incident duration

Clearance is the removal of vehicles, wreckage, debris, spilled material and other items from the roadway and the immediate area to restore roadway capacity. Improving traffic incident clearance procedures can:

- Restore the roadway to its pre-incident capacity quickly and safely
- Minimize motorist delay

- Make effective use of all resources
- Enhance the safety of responders and travelers
- Protect the roadway and private property from unnecessary damage during the removal process
- Improve the public image of the response agencies

Refer to Reference 5 for a synthesis of traffic incident clearance policies and strategies.

Techniques include:

- On-site clearance planning
- Tow trucks and heavy-duty wreckers with sufficient up-righting, lifting and recovery capability
- Service patrols to remove minor incidents
- Police patrols with push bumpers, jumper cables, water and other supplies to expedite clearance
- Innovative recovery vehicles, debris recovery systems
- Effective tow and wrecker service contracts, policies or procedures.
- Efficient accident investigation procedures and technology including photogrammetry and total station surveying systems
- Streamlined spill cleanup procedures
- Accident investigation sites
- Quick clearance policies
- Policies for cleanup of minor engine fluid spills
- Inventory of resources, their locations, and what organizations are responsible for each and contacts for each organization.

Recovery consists of restoring traffic flow at the site of the traffic incident; preventing more traffic from flowing into the area and getting trapped in the upstream queue; and preventing congestion from spilling across the roadway network. Thus it encompasses the activities of site management, traffic management and clearance. First responders normally are focused on the immediate vicinity of the traffic incident and likely do not have the resources or information to handle the “big picture.” (The end of the queue can range from 1000 feet to 20 miles back from the site.) Resources including traffic operations centers and their operating staff can facilitate recovery by managing the network-wide effects of traffic incidents and thus hastening recovery.

10.2.6 Emerging Trends

The “Freeway Management State-of-the-Practice White Paper” (Reference 9) identifies the following areas as the “state-of-the-art”¹⁷:

- Traffic incident management systems are focusing more on coordination among multiple agencies than ever before. State of the art systems incorporate data sharing techniques between transportation and public safety agencies. An emerging capability is to integrate CAD information into a freeway management system. CAD-TMC integration is being developed and field-tested and is expected to be deployed extensively in the near future.
- Automation of key traffic incident management activities to reduce labor-intensive operations such as CCTV monitoring being performed by TMC operators. Algorithms using probe travel time measurements appear to provide promise in automating traffic incident detection functions, with more research required in this area.

- Integration of public safety Computer Aided Dispatch (CAD) and TMC data systems. Incidents *detected* via cell phone calls will then be known to the TMC, which can then take appropriate actions. Also, transportation and safety agencies will be able to more quickly identify the problem and coordinate their actions.

Reference 11 identifies seven top issues as a roadmap to the future to improve traffic incident management program planning, field operations, and inter-agency communications as follows:

- Professionalize incident management (Institutional)
- National program models and guidelines (Institutional)
- Creation of standards and guidelines for performance data (Institutional)
- Recognize regional focus in developing, operating, funding TIM technologies (Technical)
- Develop regional / cross-agency systems architectures (based on standards) (Technical)
- Establish a clearinghouse for incident management data (Operational)
- Integrate TIM needs into highway planning and design (Institutional)

10.3 IMPLEMENTATION AND OPERATIONAL CONSIDERATIONS

While the specific form and nature of the above techniques and strategies vary from region to region, elements of successful programs have much in common. These implementation and operational elements fall into three major categories – people, practices, and infrastructure as summarized below.

People

- *Traffic Incident Management Administrative Teams* represent public and private stakeholders and meet regularly to discuss program, policy and procedural issues. A TIM Administrative Team is the working body (mid-level managers) that coordinates activities of the stakeholders and makes program and budget recommendations to the multi-agency TIM *Program Steering Committee* (upper level and CEO).
- *Incident Response Teams (IRT)* are interdisciplinary teams specially trained to handle a range of roadway emergencies.
- *Multi-agency training* proves fundamental in maintaining and improving traffic incident management, safety and program quality.
- *Field guides* (paper or electronic) supplement training and are tailored to the nature, scope and resources of each region's program.

Practices

- *Service patrols* are roving vehicles that patrol to provide motorist assistance and handle minor incidents. They can effectively reduce detection time and the duration of the incident. Outstanding examples are found in Chicago, Minneapolis, the San Francisco / Oakland Bay area and Northern Virginia / Washington, D.C.
- *Post-incident debriefings* can identify areas for improvement and confirm the value of effective practices.
- Inter-agency agreements
- Policies and relationships with private towing companies
- Wrecker service contracting and updating towing minimum requirements
- Contracts for special equipment such as heavy-duty cranes and rotators
- Policies regarding the removal of truck cargo following an incident

- Enhanced accident investigations by enforcement agencies using technology to support more rapid and efficient completion
- Ordinances relating to traffic incident removal
- *Documentation and evaluation* can quantify and articulate the program's value relative to cost. This can prove important in convincing policy makers to provide funding and support for the program. Commonly used statistics to evaluate traffic incident management programs include:
 - Number of service patrol assists
 - Average elapsed time from traffic incident occurrence to detection
 - Average IRT response time
 - Average elapsed time to restoration of capacity

Infrastructure

Intelligent Transportation Systems (ITS) – the application of advanced sensor, computer, electronics and communication technologies - complement traffic incident management programs to maximize the efficiency and safety of the transportation infrastructure. ITS can assist in many of the stages of traffic incident management, particularly:

- Detection via electronic sensors and traffic incident detection software
- Verification via closed circuit television
- Motorist information via dynamic message signs, in-vehicle devices, kiosks, Internet
- Response via the coordination afforded by a Traffic Operations Center (TOC), as well as computer aided dispatch (CAD), and center – to – center communications.

10.4 EXAMPLES

Examples are provided in Reference 1, with two summarized here.

10.4.1 Chicago, Illinois Service Patrol

Chicago's service patrol program, which was kicked off by the Illinois Department of Transportation (IDOT) in 1960, is one of the country's oldest and most successful. The Emergency Traffic Patrol (ETP) initially consisted of several pickup trucks operating during peak periods only. Today, the program, known as *Minuteman*, has a much broader scope than other service patrols. Whereas most programs focus on removing minor incidents, Minuteman is part of the entire incident response program for IDOT and can clear large truck and cargo spill incidents as well as minor incidents. The program operates around the clock and includes 35 emergency patrol vehicles (the size of a medium-duty tow truck), 11 light utility 4 x 4's, a sand truck, a step van, a tractor / retriever, two 50-ton and two 60-ton heavy-duty recovery units. Every vehicle in the fleet is equipped with heavy-duty push bumpers. One of the country's larger programs, ETP's staff includes 76 positions:

- Fifty-five patrol drivers, who are known as *Minutemen*
- Three shift supervisors
- Eight foremen
- Two mechanics
- A storekeeper
- An equipment technician
- Five building and office staff, and
- A patrol manager

IDOT Minutemen receive comprehensive initial training and frequent ongoing and re-certification training. The patrol operation encompasses 12 beats, which are organized along overlapping shifts and routes to provide extra coverage on high-incident sections. All beats are patrolled 24 hours a day, 365 days a year.

In all, the ETP logs an estimated 1.8 million miles per year. Minutemen typically spend up to 15 to 20 minutes with a motorist at a disabled vehicle. If the disability cannot be corrected, the Minutemen call a motor club or the State Police to order a tow. The Minutemen can transport motorists off the freeway if they so request. Although disabled vehicles are relocated to a shoulder, accident investigation site, or nearby exit, the service patrol does not tow vehicles beyond these points.

A 1990 program evaluation found a benefit-cost ratio of 17:1. Public support for the program is high, as demonstrated by the 900 thank you letters received each year.

10.4.2 Washington State Department of Transportation (WSDOT) Documentation and Evaluation

The Washington State Department of Transportation's (WSDOT) incident response program developed a relational database to organize and store incident records. WSDOT Incident Response Team (IRT) members collect a wide and comprehensive range of data for each incident to which they respond. Data are entered into a portable computer in the field. The data comprising the WSDOT incident response database are identified in Table 10 - 2.

In 1997, using this database, an independent team of faculty and research engineers evaluated WSDOT's incident management program. The evaluation was based on three measures of effectiveness: (1) congestion mitigation, (2) benefit to cost ratio, and (3) positive public perception. The evaluation revealed substantial benefits associated with the program, including a 12 percent drop in the time required to clear an incident over a two-year period. Another positive finding was a benefit-to-cost estimate in the range of 4:1 to 13:1. The evaluation also pointed out areas for improvement.

Table 10-2: WSDOT Incident Response Database Elements

CATEGORY	INFORMATION
Location (City and County)	<ul style="list-style-type: none"> • Nearest city • County in which the incident occurred, by code
General Information	<ul style="list-style-type: none"> • Name of person preparing the report • Date of the report • Date of the incident • Time of the incident • Time the IRT received the call to respond to the incident • Time the first IRT member arrived at the scene • Date and time incident ended • Time last IRT member left the scene • Repair notes
WSDOT Personnel	<ul style="list-style-type: none"> • Number of WSDOT employees involved • Number of hours each was at the incident site
Location (WSDOT Region and Maintenance Area)	<ul style="list-style-type: none"> • WSDOT Region and Maintenance Area in which the incident occurred • Regional Maintenance Area number
Highway / Route Information	<ul style="list-style-type: none"> • State route number and nearest milepost number • Description of the intersection if state route and milepost number not available • Travel direction of affected lanes • Lanes closed (i.e. ramp, single lane, multiple lanes, all lanes in one direction, or all lanes in both directions) • Roadway surface • Reason for road closure (i.e., single-vehicle accidents, multiple-vehicle accidents, fatal accidents, hazardous and non-hazardous material spills)
Travel Conditions	<ul style="list-style-type: none"> • Weather conditions (i.e., rain, snow, fog, wind, calm and clear) • Road conditions (i.e., dry, wet, ice-covered, snow-covered) • Light conditions (i.e., day, dawn, dusk or night - night with street lights on, night with street lights off, or night with no street lights at all)
Agency Participation	<ul style="list-style-type: none"> • Agencies present at the incident site (WSDOT, Washington State Patrol, Department of Ecology, County Emergency Services, Fire Department, County Police, City Police, or other)
Equipment	<ul style="list-style-type: none"> • WSDOT equipment used • Incident Response Team equipment used • Non-WSDOT equipment used
Materials and Maintenance	<ul style="list-style-type: none"> • IRT vehicle materials used

	<ul style="list-style-type: none"> • Follow-up maintenance
Clean-up	<ul style="list-style-type: none"> • Delayed cleanup until off-peak time • Conditions at the incident scene (i.e., presence of hazardous materials, non-hazardous materials, fuel spillage, fire, flammable liquid, corrosive material, explosive material, radioactive material, or toxic materials) • Agency responsible for cleanup
Traffic Control	<ul style="list-style-type: none"> • Lane where the incident originated • Detour route, if applicable • Occurrence of incident in construction zone • When lanes opened
Investigation	<ul style="list-style-type: none"> • Method of Washington State Patrol investigation (i.e., tape, total station equipment) • WSP accident and case number (if applicable) • Lead investigating agency (WSP, county, city) • Number of vehicles involved in the incident • Number of injuries • Number of fatalities
Number of Vehicles	<ul style="list-style-type: none"> • Number of vehicles by type (e.g., one bus, two passenger cars, and a taxi)
Causing Party's Vehicle Type	<ul style="list-style-type: none"> • Type of vehicle the causing party was driving
Driver and Vehicle Identification	<ul style="list-style-type: none"> • Driver's last name, first name and middle initial • Driver's license number • State or province in which the licenses were issued • Vehicle license number of the party at fault • Vehicle year, make, model, and vehicle identification number • State or province that issued the vehicle license of the party at fault • Insurance of the party at fault • Insurance company
Comments	<ul style="list-style-type: none"> • Description of cargo that was cleared from incident, how it was disposed of, of whether it was stored, etc. • Other information / comments

10.5 REFERENCES

- 1) Federal Highway Administration, *Traffic Incident Management Handbook*, November 2000, http://www.itsdocs.fhwa.dot.gov//JPODOCS/REPT_MIS/@9201!.PDF
- 2) Federal Highway Administration, *Incident Management Successful Practices: A Cross-Cutting Study*, April 2000. Reports traffic incident management program benefits and lessons learned in addition to summarizing keys to effective traffic incident management training, leadership, and interagency coordination.
- 3) Federal Highway Administration, *Regional Traffic Incident Management Program: An Implementation Guide*, May 2001. Documents a framework for establishing and sustaining a traffic incident management program.
- 4) Transportation Research Board, *Special Report 260: Strategic Highway Research: Saving Lives, Reducing Congestion, and Improving Quality of Life*, November 2001. Presents the goals and objectives of a research program, funded by and commencing with the next federal-aid highway program authorization, aimed at preventing and reducing the impact of nonrecurring incidents.
- 5) Transportation Research Board, NCHRP Synthesis Topic 33-05, *Safe and Quick Clearance of Traffic Incidents*, 2003. This TRB study assesses the state-of-the-practice and identifies successful policies and strategies to effect quick clearance of traffic incidents.
- 6) Federal Highway Administration, *Managing Travel for Planned Special Events*, 2003
- 7) U.S. Department of Transportation, *Version 4.0 of the National ITS Architecture*, <http://itsarch.iteris.com/itsarch/>
- 8) Federal Highway Administration, *Traffic Incident Management (TIM) Self-Assessment Guide*
- 9) Federal Highway Administration, "Freeway Management and Operations: State – of – the – Practice White Paper, January, 2003
- 10) National Task Force on Interoperability, *Why Can't We Talk? Working Together to Bridge the Communications Gap to Save Lives, A Guide for Public Officials*, January 2003.
- 11) National Conference on Traffic Incident Management, March 11-13, 2002, Irvine, CA.

11. PLANNED SPECIAL EVENT MANAGEMENT

11.1 INTRODUCTION

A *planned special event* is a public attended activity or series of activities, with a scheduled time and location that may increase or disrupt the normal flow of traffic on affected streets or highways.

Planned special events include sporting events, concerts, festivals, and conventions occurring at permanent multi-use venues (e.g., arenas, stadiums, race tracks, fair grounds, amphitheaters, convention centers, etc.). They also include less frequent public events such as parades, fireworks displays, bicycle races, sporting games, motorcycle rallies, seasonal festivals, and milestone celebrations at temporary venues. The term *planned* special event is used to describe these activities because of their known locations, scheduled times of occurrence, and associated operating characteristics. Emergencies, such as a severe weather event or other major catastrophe, represent special events that can induce extreme traffic demand under an evacuation condition. However, these events occur at random and with little or no advance warning, thus differing from “planned” special events. (Freeway management during such emergencies and evacuations is discussed in the next chapter).

A planned special event represents a trip generator; thus the impact an event has on transportation system operations as a whole must be examined. This includes freeway operations, arterial and other surface street operations, transit operations, and pedestrian flow. Unlike roadway construction activities or traffic incidents that impact travel within a single corridor, a planned special event impacts all corridors serving the event venue location.

11.1.1 Purpose of Chapter

The FHWA technical reference *Managing Travel for Planned Special Events* (Reference 1) presents and recommends various planning initiatives, operations strategies, and technology applications that satisfy the special customer requirements and stakeholder performance requirements driving planned special event travel management. This chapter summarizes that reference, highlighting the essential elements involved in managing traffic during planned special events.

Reference 1 guides users through all phases of managing travel for planned special events, from the earliest planning stage through post-event activities, via the provision of recommended procedures, flowcharts, tables, and checklists. The technical reference bridges the gap between the state-of-the-practice and state-of-the-art in managing travel for planned special events by providing:

- A framework for establishing a stakeholder coordinated and integrated planned special event management practice and
- Innovative techniques for enhancing the efficiency and applicability of current agency event-specific plans.

Reference 1 is aimed at assisting responsible agencies in managing the ever-increasing number of planned special events impacting transportation system operations in rural, urban, and metropolitan areas. It communicates to a wide audience that includes the novice planned special event practitioner, the experienced planned special event practitioner, the local, single-

jurisdiction event planner and operations manager, and the regional, multi-jurisdiction event planner and operations manager.

Reference 2 (NCHRP Synthesis 309: *Transportation Planning and Management for Special Events*) reports on the state-of-the-practice of transportation-related activities associated with the planning and management of special events.

11.1.2 Relationship to Other Freeway Management Activities

Freeways are often the primary corridor flow routes that serve event patrons and participants destined to / from a planned special event and various areas of a region and beyond. These corridor flow routes connect to local, street-level flow routes that, in turn, serve event venue parking areas. A freeway interchange marks a point of connection between corridor flow routes and local flow routes.

The main objective of freeway management during planned special events is to minimize freeway mainline congestion. Freeway management and operations strategies implemented in response to local traffic flow or ramp operation degradation preserve freeway mainline operations. Freeway management for planned special events involves interchange operations and metering (Chapter 7), traveler information dissemination (Chapter 13), transportation management centers (Chapter 14), and traffic surveillance (Chapter 15). Other keys to success include achieving regional operations collaboration and cooperation (Chapter 16), deploying managed lanes (Chapter 8) to improve freeway safety and operations efficiency, and implementing traffic incident management (Chapter 10) techniques and strategies. Moreover, like all programs and activities that are intended to improve the operation of the transportation network, the performance of a traffic incident management program should be regularly monitored and assessed (Chapter 4), potentially resulting in changes and refinements.

11.2 CURRENT PRACTICES, METHODS, STRATEGIES, AND TECHNOLOGIES

11.2.1 Overview

Planned special events pose a unique and diverse set of challenges to stakeholders charged with maintaining transportation system safety, mobility, and reliability. These challenges include:

- Managing intense travel demand,
- Mitigating potential capacity constraints,
- Influencing the utility associated with various travel choices, and
- Accommodating heavy pedestrian flow.

Managing travel for planned special events encompasses both a local and regional level. The local level involves managing travel for one planned special event. The regional perspective concerns proactively improving travel management for all planned special events occurring in a region where, in most major U.S. metropolitan areas, hundreds of planned special events occur annually.

The goals of managing travel for planned special events involve achieving predictability, ensuring safety, and maximizing efficiency. The characteristics of a planned special event that define the level of event-generated trips, coupled with the event venue location and scope of available transportation system capacity, collectively may yield unpredictable impacts on travel without proper planning and analysis. Operations, with safety an overarching criteria, during the event can improve transportation system efficiency of operation. With the foreknowledge of a

planned special event and the early initiation of planning efforts, practitioners can achieve efficient transportation system operations even with the additional traffic generated at and adjacent to the event venue.

The successful implementation of a transportation management plan for planned special events results in lessened traffic congestion and improved safety for event patrons and other transportation system users. Successful transportation management also maintains satisfactory mobility levels for residents and businesses in the vicinity of the event venue and preserves the overall reliability of the local and regional transportation system. Achieving this success requires the involvement of both transportation system operators and other stakeholders, representing various interests and disciplines, to meet the needs of the community and region.

11.2.1.1 Planned Special Event Classification

A planned special event impacts the transportation system by generating an increase in travel demand in addition to possibly causing a reduction in roadway capacity because of event staging. The first step toward achieving an accurate prediction of event-generated travel demand and potential transportation system capacity constraints involves gaining an understanding of the event characteristics and how they affect transportation operations. In turn, practitioners can classify the planned special event in order to draw comparisons between the subject event and similar historical events to shape travel forecasts and gauge transportation impacts. Figure 11-1 shows typical operational characteristics of a planned special event. Each characteristic represents a variable that greatly influences the scope of event operation and its potential impact on the transportation system.

Five categories of planned special events, and their general characteristics, are listed in Table 11-1. The table also indicates major event examples that require significant advance planning and stakeholder coordination to efficiently manage transportation system operations.

11.2.2 Benefits

Communities and regions have promoted and supported planned special events to boost tourism and fuel local and state economies. Public agencies can enhance the image of their area by adopting a planned, coordinated, and integrated approach toward managing travel for planned special events that minimizes traffic congestion, maintains transportation system reliability, and exceeds the customer service expectations of all road users. Benefits to transportation stakeholders and transportation system operators include:

- Deployment of new technologies for traffic control and monitoring.
- Incorporation of new procedures and tactics into everyday traffic management tasks.
- Upgrade of transportation system infrastructure.
- Improvement in stakeholder productivity.
- Promotion of interagency sharing of personnel and equipment resources.
- Leverage of public support for newly deployed traffic management and transit initiatives.
- Attraction of new regular transit users and carpoolers.
- Development of new interagency relationships crossing jurisdictional boundaries.
- Improvement in communication and trust between stakeholders.
- Coordination of and participation in regional coalitions to influence policy and improve activities for all planned special events.
- Dissemination of lessons learned and solutions to technical problems that other jurisdictions may encounter in the future.
- Promotion of stakeholder efforts in the media.

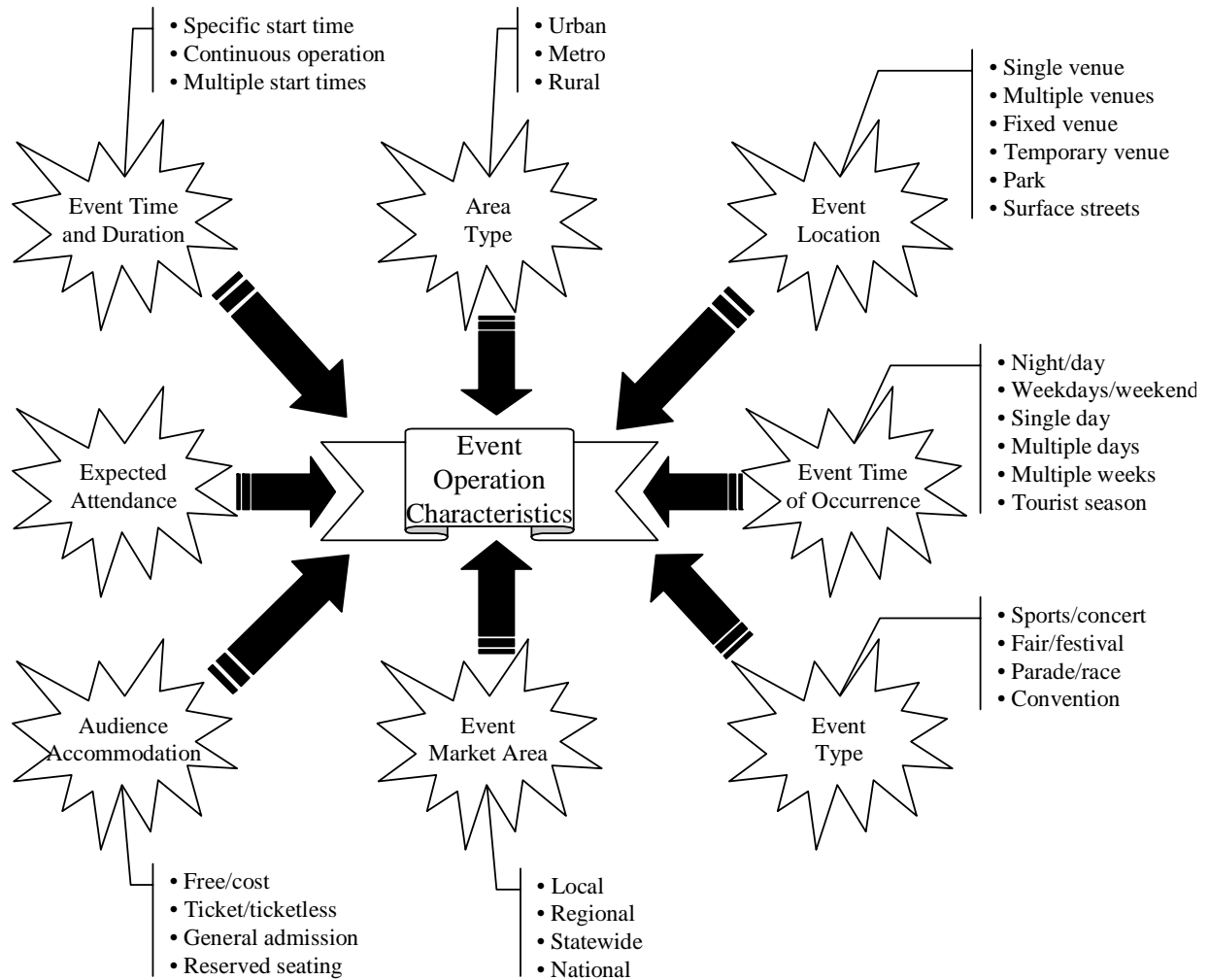


Figure 11-1: Special Event Operations Characteristics

Table 11-1: Planned Special Event Categories and Characteristics

(Reference 1)

SPECIAL EVENT CATEGORY	EVENT OPERATIONS CHARACTERISTIC	MAJOR EVENT EXAMPLE
Discrete/recurring event at permanent venue	<ul style="list-style-type: none"> • Time specific duration. • Specific starting and predictable ending times. • High peak arrival rates. • Weekday event occurrences. • Known venue capacity. • Advance ticket sales. 	<ul style="list-style-type: none"> • Capacity attendance events, such as football games and auto races, at large stadium venues. • Events occurring during periods of high background traffic demand. • Events occurring at venues under reconstruction where a significant portion of venue parking cannot be utilized. • Sports championship or other events having a national scope.
Continuous event	<ul style="list-style-type: none"> • Occurs over single or multiple days. • Event patrons arrive and depart through the event day. • Does not exhibit sharp peak arrival and peak departure rates. • Capacity of venue not always known. • Occurs at temporary venues, parks, or fixed venues. 	<ul style="list-style-type: none"> • High attendance events in downtown areas. • Events occurring at temporary venues that have limited access to adjacent high-capacity arterial roadways and freeways. • Events generating trips encompassing a regional, multi-county area.
Street use event	<ul style="list-style-type: none"> • Occurs on a street requiring temporary closure. • Affects background traffic flow. • Capacity of spectator viewing area not known. • Spectators not charged or ticketed. 	<ul style="list-style-type: none"> • High attendance events relative to area type. • Race events featuring a street course of significant distance. • Events having a scheduled long duration and necessitating extended street closures.
Regional/multi-venue event	<ul style="list-style-type: none"> • Events happen at multiple venues. • Events have a time specific duration, a continuous duration, or both. • Regional market area. 	<ul style="list-style-type: none"> • Events occurring at adjacent venues at the same time. • Events including a subset of free events or events occurring at temporary venues. • Major fireworks displays.
Rural event	<ul style="list-style-type: none"> • Rural or rural/tourist area. • High attendance events attracting event patrons from a regional area. • Limited roadway capacity serving an event venue. • Lack of regular transit service. 	<ul style="list-style-type: none"> • High attendance festivals. • Capacity attendance events at amphitheater or racetrack venues. • High attendance events occurring at the peak of tourist season.

11.2.3 Key Considerations During Freeway Management Program Development

The task of managing travel for planned special events incorporates advance planning, management, and evaluation activities encompassing five distinct, chronological phases summarized below.

- **Program planning** – encompasses advance planning activities completed months prior to a single, target event or activities related to a series of future planned special events.
- **Event operations planning** – involves advance planning and resource coordination activities conducted for a specific planned special event.
- **Training and implementation** – represents a transition phase between event operations planning and day-of-event activities. Stakeholders work to strategize traffic management plan deployment in addition to conducting necessary testing and training activities.
- **Day-of-event activities** – refers to the daily implementation of the traffic management plan in addition to traffic monitoring. Rapid deployment of traffic management plan strategies and tactics, including contingency plans, requires a well-organized traffic management team and communications infrastructure.
- **Post-event activities** – covers the evaluation of local and regional transportation operations based on stakeholder debriefings and an analysis of traffic data collected during the day-of-event.

Integration of these five phases creates a seamless process allowing for continuous improvement of transportation system performance from one planned special event to the next. Therefore, phased integration meets the challenge of managing travel for planned special events on a regional level. Moreover, the planning, implementation, and traffic management activities for planned special events should also be coordinated with other transportation process, including regional / statewide transportation planning, developing a regional ITS architecture, and developing a freeway management and operations program as discussed in Chapter 3.

A regional planned special events program is an ongoing process designed to address a region's needs for managing special events. The program involves those agencies that have a role in managing planned special events as well as that may have an oversight or funding role. The program will put into place a framework for handling all planned special events in a region. This would include a template for groups created to deal with specific special events, identification of funding to support such planning, and identification of infrastructure improvement needs in the region to better manage special events.

A comprehensive freeway management program should include a committee on planned special events, comprised of stakeholders that have achieved interagency coordination through past, cooperative travel management efforts. Stakeholder representatives personally know one another, and agencies have knowledge of the resources and capabilities of each committee participant. Stakeholders commonly include traffic operations agencies, law enforcement, transit agencies, event organizers or venue operators, and the media. Committees in metropolitan areas may create task forces for specific planned special event venues or recurring large-scale events. The committee or task force generally meets and performs event operations

planning tasks on an as-needed basis. The group may also convene regularly (e.g., weekly, monthly, or quarterly) to review program planning efforts or future planned special events.

The institutional and political environment surrounding special events is an important consideration, and should not be underestimated. Quite frankly, special events are often very politically charged. The organizers may not have the budget required to implement the types of mitigation activities needed to keep traffic flowing, or they may not want to spend much money on traffic mitigation. Moreover, it is not unknown for organizers to use their political influence at any suggestion of a “process slowdown” or comprehensive traffic mitigation requirements. The traffic manager is caught in the middle – if there is a slowdown, he /she gets criticized; and if there is not enough traffic control/mitigation, he/she gets criticized from the public and often the event organizer who didn't want to hear about traffic impacts during event planning. Even a good permitting process often doesn't resolve this issue. It is therefore critical that the practitioner be aware of this situation, and plan for it in the freeway management and operations program whenever possible. In other words, work with event organizers on traffic mitigation; but also have some contingency resources available in able to do what is needed.

11.2.3.1 Evaluation and Assessment

The FHWA Traffic Incident Management (TIM) Self-Assessment tool (Reference 3, and also discussed in Chapter 10 herein) contains a TIM administrative team assessment question on planned special events – specifically question 4.1.2.5. This question asks: “does the assessed TIM program conduct planning for “special events” including sporting events / concerts / conventions, etc.?” The tool includes several assessment questions potentially applicable to measuring a program's progress regarding the advance planning and management of travel for planned special events. Table 11-2 lists pertinent assessment questions categorized by the five defined phases of managing planned special events.

11.2.4 Relationship to National ITS Architecture

Management of planned special events is not specifically identified in the National ITS Architecture, other than the traffic incident management market package, which treats both unexpected incidents and planned events. In many respects, the activities associated with managing planned special events overlay much, if not all, of the “links and sausage” diagram (previous Figure 3-4). Moreover, many of the market packages support special events, including the various traveler information packages, network surveillance, freeway control, surface street control, regional traffic control, reversible lane management, regional parking management, transit operations, just to name a few.

11.2.5 Technologies and Strategies

The mitigation of congestion and potential safety impacts identified through a planned special event feasibility study requires development of a traffic management plan and complementing travel demand management strategies. Table 11-3 lists numerous tools for mitigating planned special event impacts on local roadway and regional transportation system operations. In meeting the overall travel management goal of *achieving efficiency*, these tools target using the excess capacity of the roadway system, parking facilities, and transit. Through travel demand management, event planning team stakeholders develop attractive incentives and use innovative communication mechanisms to influence event patron decision-making and, ultimately, traffic demand.

Table 11-2: Traffic Incident Management Program Assessment Questions Relative to Managing Planned Special Events

(Reference 3)

PHASE	ASSESSMENT QUESTION
Program Planning	<p>Does your program:</p> <ul style="list-style-type: none"> • Have formal interagency agreements on operational and administrative procedures and policies? • Have multi-agency, multi-year strategic plans detailing specific programmatic activities to be accomplished with appropriate budget and personnel needs identified? • Have field-level input into the strategic plans ensuring that the plans will be workable by those responsible for their implementation? • Have formalized multi-agency teams to meet and discuss administrative policy issues? • Hold regular meetings of the administrative team? • Have multi-agency agreements on what measures will be tracked and used to measure program performance? • Have established criteria for what is a “major event” – event levels or codes?
Event Operations Planning	<p>Does your program:</p> <ul style="list-style-type: none"> • Have agreed upon methods to collect and analyze/track performance measures? • Have established targets for performance? • Have a pre-identified (approved) contact list of resources? • Have response equipment pre-staged for timely response? • Utilize traffic control procedures in compliance with the MUTCD? • Have mutually understood equipment staging procedures? • Have quick clearance policies? • Have a pre-qualified list of available and contracted towing and recovery operators? • Use motorist assistance patrols? • Have specific policies and procedures for traffic management during the event?
Training and Implementation	<p>Does your program:</p> <ul style="list-style-type: none"> • Conduct training through simulation or “in-field” exercises? • Train all responders in traffic control procedures?
Day-of-Event Activities	<p>Does your program:</p> <ul style="list-style-type: none"> • Utilize traffic control procedures for the end of the traffic queue? • Utilize the Incident Command System? • Have a two-way interagency voice communications system allowing for direct communications between responders? • Use Traffic Management Center(s)? • Have the ability to merge/integrate and interpret information from multiple sources? • Have a real-time motorist information system providing event-specific information?
Post-Event Activities	<p>Does your program:</p> <ul style="list-style-type: none"> • Conduct post-incident debriefings? • Conduct periodic review of whether or not progress is being made to achieve performance targets?

Table 11-3: Tools for Mitigating Planned Special Event Impacts on Transportation System Operations

CATEGORY	EXAMPLE TOOLS
<i>Traffic Control and Capacity Improvements</i>	
Freeway traffic control	<ul style="list-style-type: none"> • Ramp closures • Elimination of weaving areas • Alternate routes • Ramp metering
Street traffic control	<ul style="list-style-type: none"> • Lane control • Alternative lane operations • On-street parking restrictions • Trailblazer signing • Parking management systems
Intersection traffic control	<ul style="list-style-type: none"> • Access restriction • Lane balance • Advance signing • Traffic signal timing and coordination
Traffic incident management	<ul style="list-style-type: none"> • Service patrols • Tow truck staging • Quick clearance of traffic incidents • Advance warning signs • Portable lighting
<i>Freeway Management</i>	
Traffic surveillance	<ul style="list-style-type: none"> • Closed circuit television systems • Field observation • Aerial observation • Media reports • Portable traffic management systems
En-route traveler information	<ul style="list-style-type: none"> • Changeable message signs • Highway advisory radio • Media
<i>Travel Demand Management</i>	
Transit incentives	<ul style="list-style-type: none"> • Public transit service expansion • Express buses from park and ride lots • Charter bus service
High occupancy vehicle incentives	<ul style="list-style-type: none"> • Preferred parking • Reduced parking cost
Event patron incentives	<ul style="list-style-type: none"> • Pre-event and post-event activities
Bicyclist accommodation	<ul style="list-style-type: none"> • Bicycle routes and available parking/lock-up
Local travel demand management	<ul style="list-style-type: none"> • Background traffic diversion • Truck diversion
Pre-trip traveler information	<ul style="list-style-type: none"> • Internet • Telephone information systems • Public information campaign • Event and venue transportation guide • Kiosks • Television • Roadside traveler information devices

11.2.6 Emerging Trends

The “Freeway Management State – of – the – Practice White Paper” (Reference 4) addresses the “state – of – the – art”¹⁸ in special events management as follows: “In addition to using the state of the art features available from other related system functions, focuses on utilizing mobile devices to help manage traffic during special events. The use of portable dynamic message signs for special events is relatively common practice. However, expanding that concept to other devices is more state-of-the-art than state-of-the-practice. Portable devices that have been used for special events management include portable CCTV cameras and detection devices to monitor conditions surrounding special event venues.”

11.3 IMPLEMENTATION AND OPERATIONAL CONSIDERATIONS

Figure 11-2 summarizes the phases of managing travel for planned special events and the common products generated by coordinated stakeholder groups under each phase.

11.3.1 Program Planning

Program planning involves the participation and coordination of stakeholders having an oversight role in addition to agencies directly responsible for event operations planning. Products of program planning include establishing new institutional frameworks, policies, and regulations to plan, monitor, and evaluate future planned special events. A stakeholder task force on special events may identify future infrastructure needs, in addition to funding mechanisms, to better manage travel for recurring events.

Program planning for all planned special events in a region requires an institutional framework for generating and managing programs and initiatives that, in turn, improve planning and day-of-event operations for future events. A key consideration involves integrating a planned special event program with other ongoing freeway and transportation management programs.

Program planning for local planned special events typically incorporates a government agency permitting and regulation framework. Through a carefully constructed permitting process, stakeholders can achieve a better sense of what resources are needed to handle the event. Figure 11-3 presents a flowchart summarizing key event organizer and public agency actions throughout a special event permit process, from submitting a permit application to conducting the proposed event.

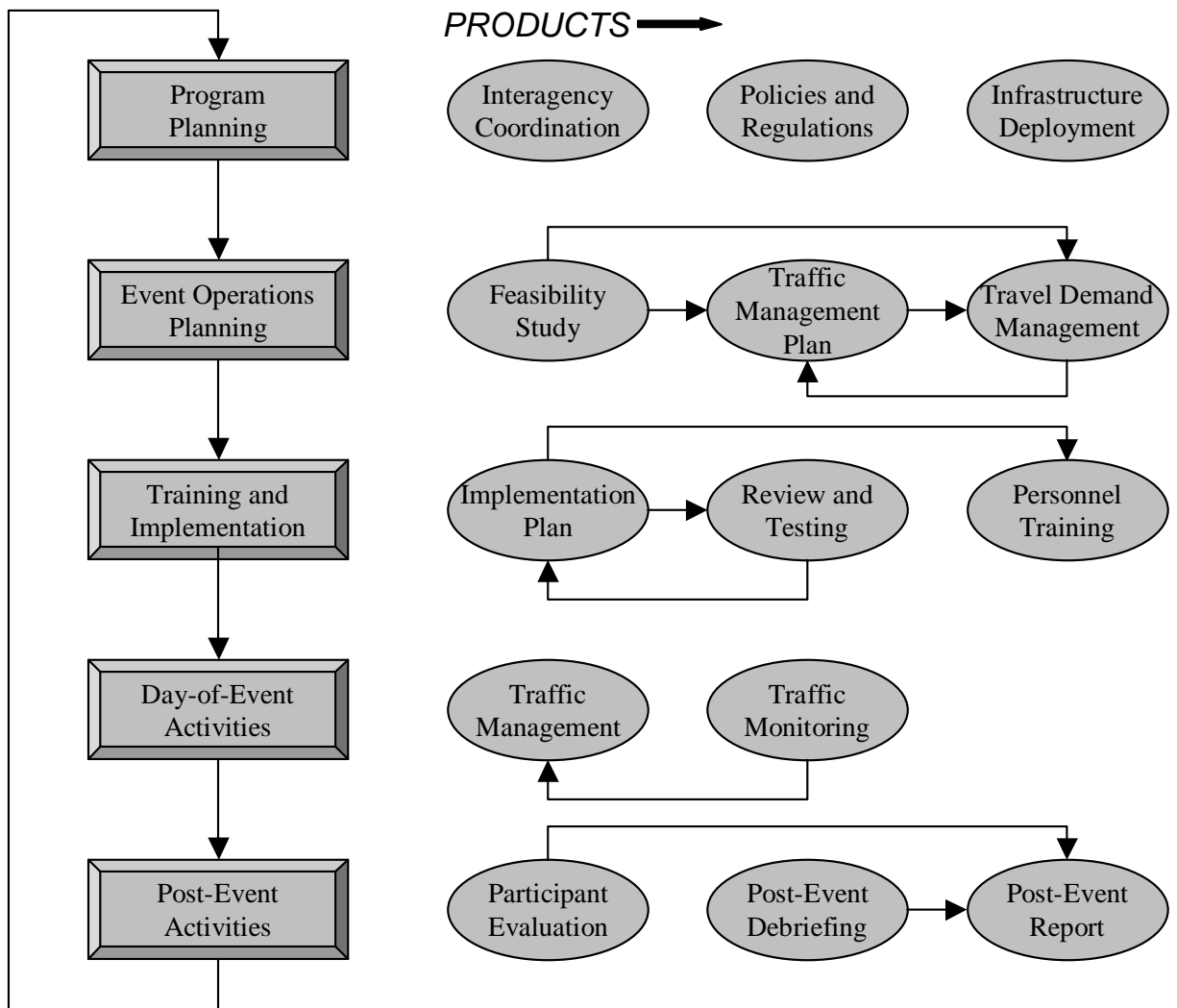


Figure 11-2: Integration of Planned Special Event Management Phases

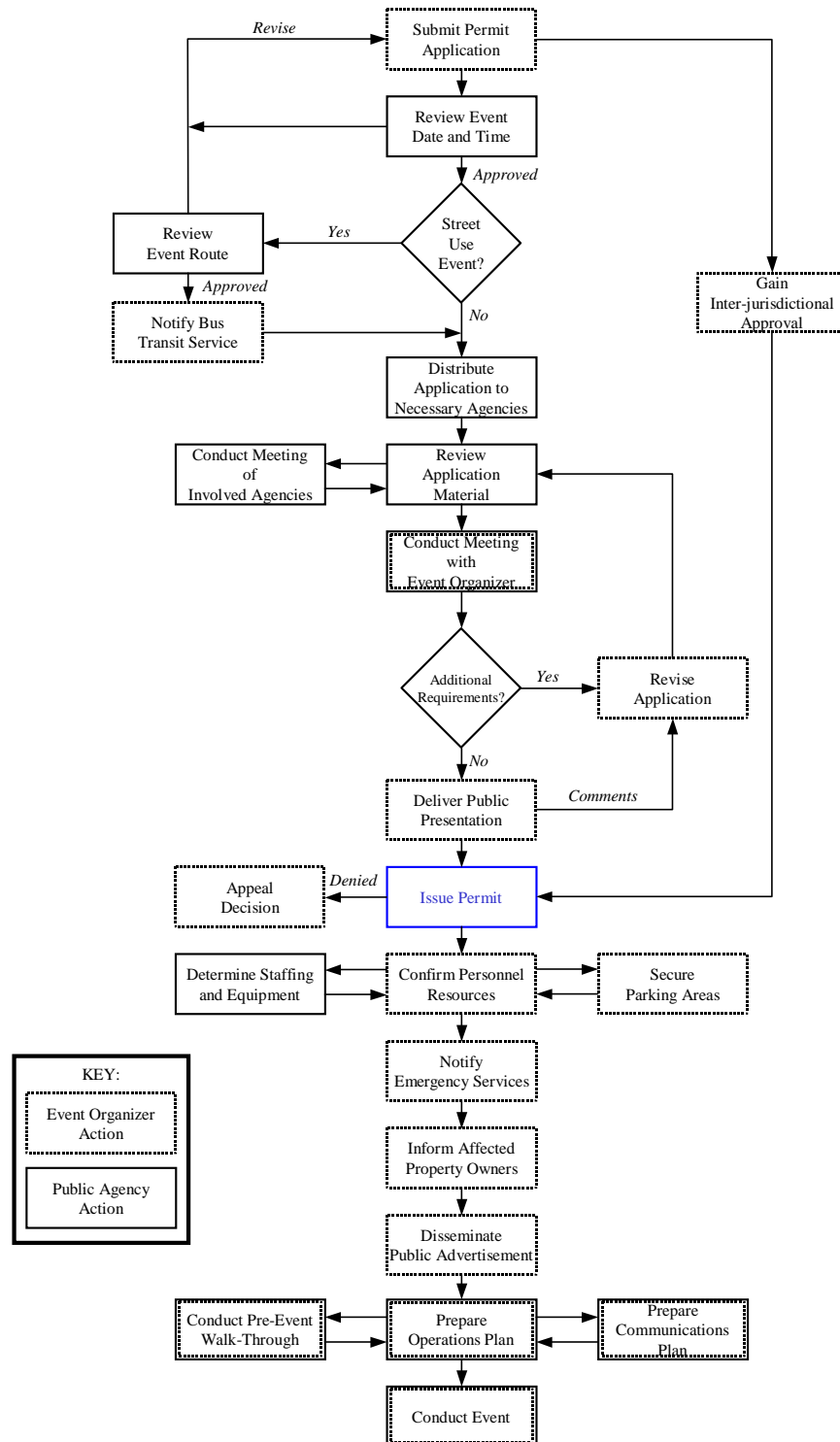


Figure 11-3: Planned Special Event Permit Process

11.3.2 Event Operations Planning

The event operations planning phase encompasses three stages of advance planning for a specific planned special event:

- **Preparation of a feasibility study to predict the anticipated impacts of the event.** The structure and approach of a planned special event feasibility study resembles a Traffic Impact Study required for planned developments, as illustrated in Figure 11-4. The figure shows the sequential steps in preparing a feasibility study for a planned special event. The feasibility study gauges the impact that a proposed event has on traffic and parking operations at and in the vicinity of the venue initially without roadway capacity improvements or initiatives to reduce travel demand. The feasibility study results define the scope of traffic management plan, including a freeway traffic control plan, required to successfully manage travel for a planned special event.
- **Development of a traffic management plan to safely and efficiently service predicted traffic demand.** A traffic management plan includes operations strategies for managing event-generated and background traffic within the local and regional area (e.g., freeway corridors serving the event venue) impacted. The plan also specifies techniques to facilitate site access, parking, and pedestrian access. Table 11-5 indicates the components of a traffic management plan for planned special events. Not all components represent a distinct formal plan but warrant consideration, either individually or in concert with another component.
- **Identification of travel demand management strategies to optimize transportation system operating efficiency.** Travel demand management (TDM) represents a key product of the overall advance planning process when forecasted traffic demand levels approach or exceed available roadway system capacity. TDM strategies do not represent infrastructure improvements to increase capacity, but rather are methods that cause traffic demand reduction by exposing other travel choices, particularly for event patrons, using alternate forms of transportation. The goal is to optimize transport of event patrons and non-attendee transportation system users through incentives aimed at consolidating person trips and alternating user travel patterns at no additional penalty to the user. Table 11-6 lists TDM initiatives for planned special events.

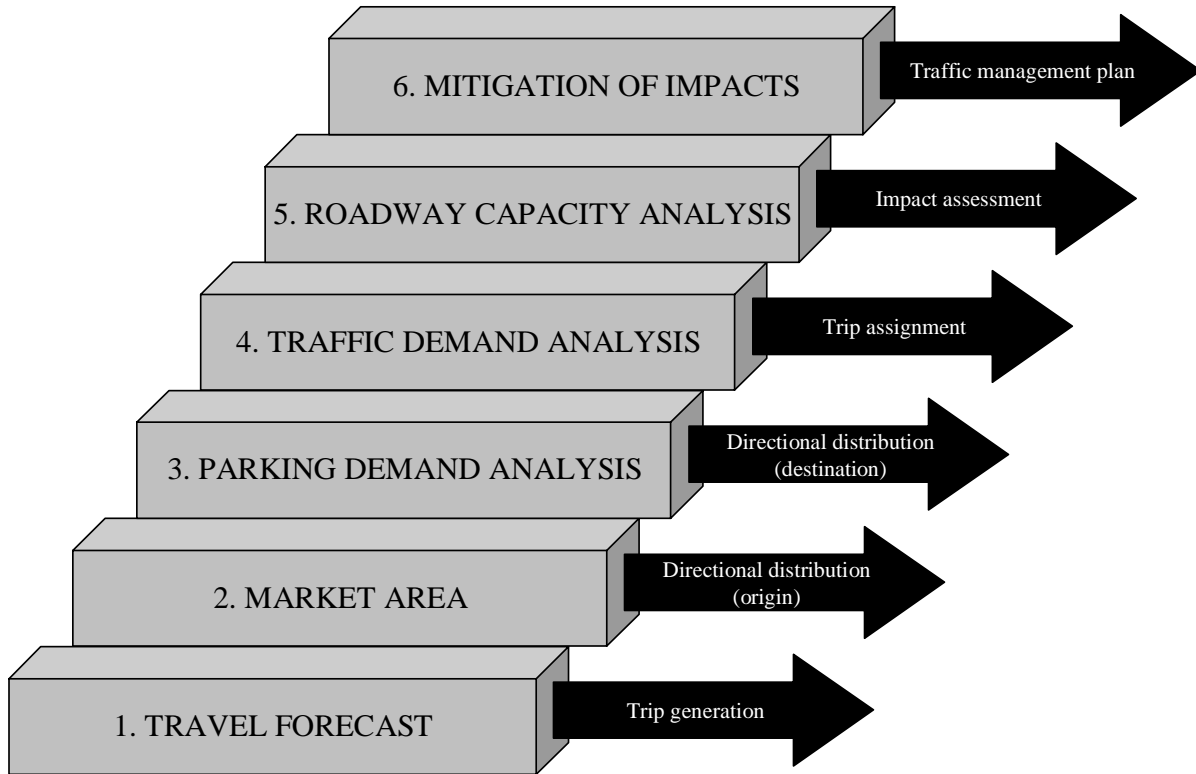


Figure 11-4: Feasibility Study Analysis Steps

Table 11-4: Traffic Management Plan Components

COMPONENT
<ul style="list-style-type: none"> • Site access and parking plan • Pedestrian access plan • Traffic flow plan • Traffic control plan • En-route traveler information plan • Traffic surveillance plan • Traffic incident management and safety plan

Table 11-5: Travel Demand Management Initiatives

INITIATIVE
<ul style="list-style-type: none"> • Mass transit incentives, including expanded public transit service and charter bus service. • High occupancy vehicle incentives. • Bicyclist accommodation. • Event patron incentives.

11.3.3 Training and Implementation

Training and implementation activities include implementation plan development, stakeholder review and testing, and personnel resource management. The objectives of these activities are to improve the efficiency of traffic management plan deployment, and to increase traffic management team preparedness. In turn, this creates a more responsive traffic management team and fluid team operation, thus translating to better transportation system performance on the day-of-event.

- An implementation plan communicates traffic management plan specifics using a quick reference format. Individual stakeholders may develop a plan for the freeway/arterial corridor(s) or street networks under their jurisdiction. The plan is intended for use by traffic management team personnel at the command post and in the field. It describes location-specific traffic control and parking operations, thus integrating the specifications of various traffic management plan components. On a management-level, an implementation plan specifies an action plan for activating, changing, and deactivating traffic management plan provisions.
- Stakeholder review and testing allows the traffic management team to identify potential limitations of the traffic management plan prior to the day-of-event. It promotes traffic management team coordination and increases stakeholder familiarity of the duties, responsibilities, and capabilities of other stakeholders. Activities range from table-top exercises that examine how different agencies react to various scenarios to “hands-on” applications that can involve performing a full-scale simulation or deploying a traffic management plan for smaller planned special events as a test.
- Personnel resource management typically includes the design of critical transportation control and management strategies around staff and contractors available on the day-of-event. However, the recruitment of temporary staff and volunteers expands traffic management team capabilities and elevates its operations efficiency. Practitioners can capitalize on the benefits of having additional personnel resources by recognizing volunteer limitations and applying proven training methods.

11.3.4 Day-of-Event Activities

Day-of-event activities involve the actual implementation and operation of the traffic management plan during the day-of-event. Not only do the requirements of the traffic management team have to be considered, but it is also very essential to monitor what can be a very fluid situation to see how the plan is working and then determine what needs to be adjusted based on real-time traffic conditions.

The traffic management team must adopt a formal management process to ensure successful traffic management plan deployment and minimal impact to transportation system users. The Incident Command System (ICS) can be used to handle traffic management during planned special events. Unified Command represents an ICS management process that functions to coordinate inter-jurisdictional and multi-disciplinary stakeholders comprising the traffic management team without sacrificing agency authority, responsibility, or accountability. An advantage of using the ICS during a planned special event is that it clarifies how decisions are

made if the traffic management plan requires adjustment. ICS is discussed in more detail in Chapter 12.

Since multiple stakeholders are involved, it is critical that they be able to communicate with one another on the day-of-event. Operating on a common channel with clear language greatly improves interagency communication. To minimize confusion and extraneous information being shared among agencies, the question of who will use which frequencies should be decided during the planning process. Stakeholders should understand how they can reach other traffic management team members during the event, which channels they will be found on, and what information should be shared.

Traffic monitoring represents an important day-of-event activity, serving to provide traffic and incident management support in addition to performance evaluation data. Timely deployment of contingency plans developed during the event operations planning phase depends on the accurate collection and communication of real-time traffic data between traffic management team members.

11.3.5 Post-Event Activities

Post-event activities range from informal debriefings between agencies comprising the traffic management team to development of a detailed evaluation report. Evaluation results represent valuable input data for use in planning for future planned special events.

- At the conclusion of the planned special event, a debriefing session should be held. The stakeholder debriefing is an opportunity to bring together those involved and impacted by the planned special event. In it, these individuals, and the groups they represent, can compare what the plan called for and what actually took place. They can also examine areas the plan may not have addressed but turned out to be issues in hindsight. The purpose of the post-event debriefing is not to just identify what could have been done better but to note what was successful. As has been the case from the start of the event operations planning process through the event itself, multiple viewpoints are helpful as stakeholders identify key successes and lessons learned.
- A report that reviews the planned special event is necessary to document what was learned. By clearly outlining the material in the report, it becomes easier to identify the key successes and lessons learned. It also makes it easier to go back to the report and look at particular aspects of the traffic management plan implemented when planning the next planned special event. Post-event report components include an operational cost analysis, qualitative evaluation results, and quantitative evaluation results. The qualitative evaluation is based on a number of factors, including the survey of the public and event patrons. Also important is the qualitative evaluation provided by those stakeholders who managed the event. The quantitative evaluation provides a numerical picture of the event. The quantitative evaluation is very useful when conducting a cost/benefit analysis of activities for the planned special event. Knowing where the most benefit was realized for the costs incurred can help in the planning process to see if resources should be reallocated for the next event.

11.4 EXAMPLES

Reference 1 profiles numerous successful practices, highlighting proven policies, regulations, strategies, and tactics used in the advance planning, management, and monitoring of travel for planned special events. In turn, operators will gain an understanding of the keys to successful planned special event transportation management, as summarized below:

- Achieve early, constant input and participation of involved agencies.
- Predict event-generated travel impacts on both a local and corridor/regional level.
- Develop an integrated transportation management plan that can accommodate a range of traffic demands and other contingencies.
- Ensure successful traffic management plan implementation.
- Deploy a well-organized traffic management team equipped with the ability to communicate seamlessly between agencies.
- Conduct continuous traffic monitoring on the day-of-event and maintain protocol for modifying the traffic management plan to accommodate real-time traffic
- Transfer event management successes into daily applications, and translate lessons learned into future event planning and operations needs

11.5 REFERENCES

- 1) Federal Highway Administration, *Managing Travel for Planned Special Events*, September 2003.
- 2) Carson, J.L. and R.G. Bylsma, *Transportation Planning and Management for Special Events*, NCHRP Synthesis 309, Transportation Research Board, National Research Council, Washington D.C., 2003, 71 pp.
- 3) "Traffic Incident Management Self Assessment Guide," Federal Highway Administration, Washington, D.C., 2002 [Online]. Available: <http://ops.fhwa.dot.gov/Travel/IncidentMgmt/timsa.htm>. [2003, July 8]
- 4) Federal Highway Administration, "Freeway Management and Operations: State – of – the – Practice White Paper, January, 2003

12. FREEWAY MANAGEMENT DURING EMERGENCIES AND EVACUATIONS

12.1 INTRODUCTION

Disaster planning, prevention, preparedness, response, and recovery fall into the category of emergency management. FEMA defines an emergency as any unplanned event that can cause deaths or significant injuries to employees, customers or the public; or that can shut down businesses, disrupt operations, cause potential environmental damage, or threaten a facility's financial standing. Emergency management is the process of preparing for, mitigating, responding to, and recovering from an emergency (1, 2).

Natural disasters and terrorist attacks are generally sudden and unexpected. Even those emergencies that can be anticipated and predicted (e.g., hurricanes, snow / ice storms) have relatively short advance - response times amounting to, at best, a few days; and even then, great uncertainty can exist as to the exact location, timing, and storm strength until just before the emergency occurs. The most effective strategy is to plan in advance, to prevent and mitigate wherever possible, and to respond when necessary with flexibility, coordination, and speed. This type of strategy requires management coordination, compatible communication systems, and real time information feedback to decision-makers that permits immediate changes in strategy when required. This approach also requires mechanisms for disseminating information to the general public that provide the most up-to-date guidance on the best transportation options for avoiding bottlenecks in the transportation system.

The transportation network – particularly freeways – plays a major role during emergency management, including expediting evacuations from the affected area, and the return following the emergency. In some cases, emergency management also involves the restoration of transportation services. Freeway practitioners must be fully cognizant of the role they can, and must play, and the concomitant responsibilities during emergencies, such as:

- **Hurricanes:** A hurricane is a tropical weather system with winds that have reached a sustained speed of 74 mph or more. Recent trends have increased the vulnerability of the US to hurricanes. The combination of growing population and development in coastal zones, rising ocean levels, coastal erosion, and changing climatic trends have increased the potential for loss of life and property in coastal regions of the country. While more stringent building codes have been enacted to reduce damage from winds and flooding, not all coastal populations can be protected in their homes or shelters. To counter this threat, states in the Atlantic and Gulf coast regions of the US have plans to evacuate people from vulnerable areas in advance of threatening storms. The two most recent large-scale evacuations – Hurricanes Georges in 1998 and Floyd in 1999 – resulted in some of the largest traffic jams ever recorded, revealing the fact that emergency response agencies may not have been as prepared for such scenarios as previously assumed. In the aftermath of these events, transportation agencies at the federal, state, and local levels have begun to take a more active role in the planning, management, and operation of hurricane evacuations.

- **Floods:** Most communities in the United States can experience some kind of flooding after spring rains, heavy thunderstorms, or winter snow thaws. Floods can be slow, or fast rising, but generally develop over a period of days; the exceptions being “flash floods” (which result from intense storms dropping large amounts of rain within a brief period, and can occur with little or no warning), and dam failures (which can suddenly let loose a gigantic quantity of water). Inland flooding has been the cause of more than half the deaths arising from hurricanes in the last three decades. In fact, nearly 9 of every 10 presidential disaster declarations result from natural phenomena in which flooding is a major component (2). People who are at risk of being flooded out of their homes need to be evacuated. Flooding can also disrupt the roadway network (e.g., cars can be easily swept away in just 2 feet of moving water), requiring region-wide diversions and dissemination of traveler information.
- **Earthquakes:** An earthquake is a sudden, rapid shaking of the earth caused by the breaking and shifting of rock beneath the earth’s surface. This shaking can cause buildings and bridges / elevated roadways to collapse, and sometimes trigger landslides and avalanches, all impacting the transportation network. As an example, on January 17, 1994, at 4:30 a.m., an earthquake of a magnitude of 6.8 shook Los Angeles, California. While the actual earthquake (and its subsequent aftershocks) lasted only about 1 minute, it damaged 114,000 residential and commercial structures spread over 2,100 square miles, took 72 lives, and severely crippled four critical Southern California freeways (I-5, SR-14, I-10, and SR-118), significantly impairing the Los Angeles regional transportation system. This single event necessitated year’s worth of highway work to rebuild the damaged freeways. Additionally, numerous transportation management and operational strategies and technologies implemented / expanded (e.g. service patrols, HOV, surveillance, CMS, transit service) to retain traveler mobility and keep traffic flowing as smoothly as possible during the rebuilding efforts.
- **Winter Storms:** A winter storm can last several days and be accompanied by high winds, freezing rain or sleet, heavy snowfall, and extremely cold temperatures. Such adverse weather conditions dramatically affect the nation’s surface transportation system. During adverse weather, reduced visibility, or slick pavement conditions, nearly 6,500 fatal crashes occur, over 450,000 injury crashes occur, and an estimated 544 million hours of time are lost annually ¹⁹. In fact, the leading cause of death during winter storms is from automobile or other transportation accidents (2). It is therefore not surprising that a significant portion of state and local DOT maintenance budgets – particularly in northern climates – are geared towards treating roadways (e.g., plowing snow, anti-icing, applying abrasives, fog dispersal).
- **Wildland Fires:** As residential areas expand into relatively untouched wildlands, people living in these communities are increasingly threatened by forest fires. Unpredictable wildfires can wipe out huge sections of landscape and endanger the lives of residents, necessitating evacuations from the threatened locations. Additionally, the smoke from these fires can significantly reduce visibility over a wide area, resulting in reduced speed limits, roadway closures, and diversions. As an example, the “Rodeo - Chediski” fire in the White Mountains of Arizona in 2002 resulted in the burning of 360,000 acres, the destruction of over 400 homes, and the evacuation of 32,000 people. It also required an army of 4,177 firefighters who needed to be transported to and around the area. Another example – a wildfire in the Bitterroot Valley of Montana in 2000 required the closure of highways and

diversions. Moreover, when the roads were open, traffic had to be escorted by pilot cars due to low visibility.

- **Homeland Security:** The terrorist attacks of September 11, 2001 exacted a terrible toll on the United States and fundamentally changed the way of life in America. Surface transportation was also changed, and continues to change in response to the attack. Agencies that own and operate surface transportation systems must understand the relevant lessons from the 9/11 experience and respond accordingly so that we as a nation are well prepared should we be attacked again. The transportation infrastructure itself may be the target of terrorist attacks²⁰. The ability of the surface transportation network to cope with such contingencies requires additional information and operational capabilities – for example, to identify potential dangers (and then respond) before anything can happen, to detect any such catastrophic incidents, to facilitate first responder access and military deployments, and to effectively route evacuations from major metropolitan areas; all while maintaining the appropriate balance between these transportation security needs and the efficiency of the transportation network. Practitioners must ensure the operation and integrity of America's surface transportation system as part of the overall "Homeland Security" effort, even when the incident involves weapons of mass destruction (WMD).

The full capability of the transportation system must be harnessed and optimized – including freeway management and operations, and supporting ITS-based systems – to effectively move people and goods during a major emergency and / or national security event.

12.1.1 Purpose of Chapter

This chapter provides a high-level overview of procedures, institutional arrangements, and supporting documentation that are applicable to emergency management; many of which may be unfamiliar to the freeway practitioner, but nevertheless can have a major impact on the operation and management of the freeway during emergency situations. The applications of freeway management strategies and technologies in support of emergency and evacuation management are also discussed. It also addresses some of the issues that the freeway practitioner should consider with respect to protecting the freeway infrastructure itself and the supporting ITS-based systems.

Several references that provide more detailed information on emergency management practices are identified. Key websites for obtaining additional information regarding emergency management include the emergency management website maintained by the Federal Highway Administration (FHWA) at <http://www.ops.fhwa.dot.gov/OpsSecurity>; the website of the Federal Emergency Management Agency (FEMA) at www.fema.gov; and the website of AASHTO's security task force at <http://security.transportation.org>.

12.1.2 Relationship to Other Freeway Management Activities

Operating and managing the freeway network during emergencies and evacuations is just one aspect of a very large and complex issue, which can also entail the life safety of thousands of individuals, national security considerations, etc. That said, these freeway management activities use many of the same principles and strategies identified in Chapters 10 (Traffic Incident Management) and 11 (Planned Special Event Management), recognizing that the seriousness of the impacts and the number of involved / interested stakeholders is much greater. Most of the technologies and strategies identified in other chapters are also applicable

to emergency and evacuation management, including lane management and contraflow operations (Chapter 8), information dissemination (Chapter 13), using the TMC as an emergency management center (Chapter 14), surveillance of evacuation and diversion routes and road weather monitoring (Chapter 15), and regional integration and sharing of information between centers (Chapter 16) including law enforcement, fire and rescue, EMS, and other emergency management officials.

12.2 CURRENT PRACTICES, METHODS, STRATEGIES, AND TECHNOLOGIES

12.2.1 Overview

Transportation emergencies occur when an extraordinary event affects the transportation system and causes congestion, delay, confusion, and/or general disruption of one or more modes of transportation. The associated impacts are typically not part of day-to-day transportation operations. Moreover, these traffic impacts are usually quite severe, possibly of long duration, and / or require special motorist reactions.

The surface transportation network in general, and freeway management and operations in particular (from the perspective of this Handbook) must be an integral part of the emergency management process. As discussed in References 1 and 2, this process includes the following activities:

- **Planning** – Having a solid, tested plan in place can help any organization cope and respond in the event that an emergency occurs. Planning activities include establishing a planning team, analyzing the current capabilities and potential hazards, developing an emergency plan (e.g., response procedures, resource lists) and then implementing the plan (including training and exercises).
- **Prevention** – On-going activities to reduce the risk of life, property, and the environment from hazards; in essence, identifying and minimizing risks to protect the agency from disaster.
- **Preparedness** – This includes the activities and systems developed prior to an emergency, which are used to support and enhance prevention, response, and recovery.
- **Response** – Once an emergency occurs, the ability to respond efficiently and effectively is extremely important. These response activities address the immediate and short – term effect of the emergency.
- **Recovery** – Once the dangers of the emergency have passed, the focus will shift to rebuilding and recovery, resuming “normal” operations as quickly as possible.

Freeway operations and management must be duly considered during all of these steps. Moreover, the freeway practitioner must play an active role, such as determining evacuation routes, identifying vulnerable transportation facilities, developing strategies and implementing systems to expedite both the evacuation from and access to the emergency area, and participating in the response and recovery activities. The essence of freeway operations during emergency situations is to:

- Find out what the emergency is, and how this emergency has affected the freeway network (both the supply and demand side). For many emergency situations, it may be necessary to

alter the network (e.g., one-way contra flow operations) to support evacuations from the impacted areas, as well as to divert other traffic around the affected areas / roadways. In some instances (e.g. earthquake emergency, terrorist attack), it may also be necessary to dispatch resources to assess structural damage to the roadway infrastructure itself.

- Route increased traffic on the network, which itself may be altered or damaged. This may involve demand prediction, multi-modal coordination, and regional coordination. It will also involve providing timely information to large numbers of motorists, as well as to emergency management agencies and first responders, all of who will be using the network. It is emphasized that freeway management and operations during emergency and situations must take into consideration two specific and often simultaneous functions – the movement of people from the emergency area; and the movement of emergency and rescue personnel and equipment into the emergency zone as needed.

The handling of these issues is dependent upon several variables – whether the occurrence of the disaster can be predicted in an adequate amount of time (applicable specifically to hurricanes, floods, and wildfires, where there may be time to enact evacuation or emergency responses); whether there is infrastructure damage or destruction of the transportation infrastructure as a result of the man-made or natural disaster; and whether there are continuing security / terror threats that may impact the implementation of emergency or evacuation responses.

Another consideration is that of national security and the movement of military personnel and equipment. Because the nation's highways link U.S. military bases with rail, seaports, and airports, the National Highway System (NHS) serves as a key component in national defense mobility. In particular, the highways comprising the Strategic Highway Network (STRAHNET) support the mobilization needs of the U. S. Armed Forces. Approximately 15,000 miles of the NHS are part of the STRAHNET, linking military bases with railheads, seaports, and airports. It is an important element of defense mobilization; and freeway management activities and coordination with between DOT's and the military are important for prompt and efficient military movements.

12.2.2 Benefits

Freeway management during emergencies must be oriented, first and foremost, toward saving and preserving lives. The ability to evacuate individuals from the area directly impacted by the emergency overrules any other activity on the freeway facility; except perhaps for quick access to the affected area by emergency and rescue vehicles so that additional lives can be saved.

12.2.3 Key Considerations During Freeway Management Program Development

Freeway management and operations is just one aspect of emergency management. Accordingly, the broader context of emergency management should be duly considered when developing a freeway management program. For example (referring to the “funnel” diagram in Figure 3-1 in Chapter 3):

- **Institutional Environment / Planning Processes:** One of the key themes of this Handbook is that freeway management and operations should be an integral part of the established processes within transportation agencies. Moreover, the freeway management practitioner must be cognizant of and, to the greatest extent possible (commensurate with his/her responsibilities), participate in these processes ensuring that freeway management and

operations receives appropriate consideration. This is particularly true for emergency management. It is imperative that freeway managers and practitioners (and managers for other transportation modes) become involved in emergency planning and operations (e.g., serve on statewide task forces addressing emergency and terrorist incident responses; be involved in the development of state and regional emergency management and evacuation plans; review these plans, including transportation and terrorism annexes, to ensure that they are written so as to provide adequate guidance for highway responses; communicate with / provide information to emergency management agencies). Moreover, freeway practitioners must be aware of and understand the institutional structures (e.g., Incident Command System) and policies (e.g., area of a terrorist attack treated as a crime scene) that come into play during emergency situations.

- **Stakeholders:** The number of stakeholders that are involved in emergency management is quite large. These many of the same stakeholders that are involved during normal operating conditions and minor incidents (e.g., other transportation agencies, police, fire, emergency service providers, news media), as well as organizations with which the freeway practitioner may not typically interact, including:
 - Federal Emergency Management Agency (FEMA), which is responsible for the consequence management aspect of any major incident
 - NOAA's National Weather Service (NWS) which is the lead agency for tracking severe weather
 - Federal Bureau of Investigation (FBI) as the lead agency in crisis management to prevent and/or respond to a potential or actual terrorist incident
 - Other law enforcement agencies (e.g., setting up and enforcing new traffic management configurations (contra flow) and restrictions)
 - State and local emergency preparedness and coastal management organizations
 - Military commands and bases during defense mobilization
 - US Army Corps of Engineers
 - National Forest Service
 - American Red Cross
 - Visitors Bureaus (e.g., availability of hotel rooms for evacuees)
 - Public transit and rail agencies for evacuation planning (e.g., alternatives to the roadway network)
 - Public Health agencies
- **Needs and Services:** This assessment should include an analysis of the potential vulnerability of the transportation infrastructure (bridges, TMC facilities) and ITS – based systems (software, traveler information dissemination methods) during emergencies, including the possibility that these facilities and systems may be a target for terrorism. (Additional information on this consideration is provided in Section 12.3.8.
- **Concept of Operations:** The Concept of Operations is crucial to provide guidance and structure for both the planning and implementation of emergency responses and regional evacuations. For example, the Regional Evacuation Con Ops for the State of Florida (3) includes the following sections: Overview, Authority, Planning Assumptions, Operations, Activities Necessary to Support the Concept of Operations, Pre – Positioning of Necessary Resources, Information Exchange, Managing Adjustment to the Regional Evacuation, Host Response Operations (e.g., traffic management, shelter operations, public information),

Completion of Regional Evacuation, Re-entry into Evacuated Areas, Responsibilities, Maintenance of the Procedure. Reference 5 also identifies several items that should be included in the Concept of Operations (Table 12 - 2).

12.2.4 Relationship to National ITS Architectures

As indicated in Chapter 3, the National ITS Architecture provides a common structure or framework to promote compatibility and interoperability among systems, products, and services. The “Emergency Management Subsystem”, (refer to the “links and sausage diagram in Chapter 3) represents public safety and other allied agency systems that support coordinated incident management and emergency response. The subsystem includes dispatch centers operated by police, fire, and emergency medical services; centers associated with HAZMAT response and search and rescue special detachments; and security / surveillance services that improve traveler security. The Emergency Management subsystem creates, stores, and utilizes emergency response plans to facilitate coordinated response. Real-time traffic information received from the other center subsystems is used to further aid the emergency dispatcher in selecting the emergency vehicle(s) and routes that will provide the most timely response.

The National ITS Architecture defines various ITS elements and strategies in terms of market packages. For emergency management and transportation security, this includes the following:²¹

- **Emergency Routing** – Supports automated vehicle location and dynamic routing of emergency vehicles, as well as coordination with the Traffic Management Subsystem (e.g., surveillance information on road network conditions)
- **Roadway Closure Management** – Closes roadways to vehicular traffic when driving conditions are unsafe and other scenarios where access to the roadway must be prohibited. It includes automatic or remotely controlled gates or barriers to control access.
- **Transportation Infrastructure Protection** – Includes the monitoring of transportation infrastructure (e.g., bridges, tunnels and management centers) for potential threats using sensors and surveillance equipment and barrier and safeguard systems to preclude an incident, control access, or mitigate the impact of an incident.
- **Wide-Area Alert** – Uses ITS traveler information systems to alert the public in emergency situations such as child abductions, severe weather threats, civil emergencies, and other situations that pose a threat to life and property.
- **Early Warning System** – Monitors and detects potential, looming, and actual disasters including natural disasters (hurricanes, earthquakes, floods, winter storms, etc.) and technological and man-made disasters (hazardous materials), and acts of terrorism.
- **Disaster Response and Recovery** – Enhances the ability of the surface transportation network to respond to and recover from disasters. It supports coordination of emergency response plans, provides enhanced access to the scene for response personnel and resources, and provides better information about the transportation system in the vicinity of the disaster.

- **Evacuation and Reentry Management** – Supports evacuation of the general public from a disaster area and manages subsequent reentry to the area. It addresses evacuations for all types of disasters, including those that are well – planned and orderly (e.g., in advance of a hurricane), as well as those (e.g., terrorist attacks) that occur without warning and allow little or no time for preparation or public warning.
- **Disaster Traveler Information** – Uses ITS to provide disaster-related traveler information to the general public, including evacuations and reentry information.

Other market packages that support emergency and evacuation management include the various traveler information packages, network surveillance, freeway control, regional traffic control, incident management system, reversible lane management, HAZMAT management, roadside HAZMAT security detection, road weather data collection, weather information processing / distribution, and roadway automated treatment.

12.2.5 Technologies and Strategies

Most technologies and strategies that are utilized in support of emergency and evacuation management are discussed in other chapters of the Handbook. For example:

- Variable speed limits for reduced visibility operations, contra flow lanes for evacuations / reentry, and other lane management strategies (Chapter 8)
- Traffic flow surveillance (Chapter 15)
- Road Weather Information Systems (RWIS), Environmental Sensor Stations (ESS), and forecasts / predictions of areas needing treatment such as deicing and plowing (Chapter 15)
- Traveler Information via Dynamic Message Signs and other dissemination methods (Chapter 13)
- General incident management (Chapter 10)

Some of the unique attributes and operational issues associated with emergency and evacuation management are discussed in the next section.

One important consideration is that a significant portion of pre-planned evacuation routes (for hurricanes, fires, etc.), military deployment routes, and regional diversion routes (as a result of damaged roadway infrastructure) may go through rural areas, which are typically not instrumented with ITS technologies. Access to timely and accurate information during evacuations is critical to the evacuation process. Information about traffic flow rates and speeds, along with lane closures, weather conditions, incidents, and the availability of alternative routes is needed to effectively guide evacuees. If DOT and enforcement officials are working blind, with little quantitative knowledge of which evacuation routes are flowing well and which are in gridlock, they will be unable to redirect traffic from routes that are over capacity to nearby roads that are carrying little traffic. Consideration should therefore be given to the installation of such ITS devices – permanently or temporarily – along evacuation routes; even though normal traffic operations may not warrant their implementation. As discussed in other chapters, portable trailer mounted devices – including dynamic message signs, CCTV cameras and pan/tilt/zoom controls (including an extendible mast), and surveillance stations – are available that incorporate battery power with a solar charging system and wireless communications. These may be used for such routes. Another consideration is that these rural routes involve very sparsely populated areas with little access to power and communications.

12.2.5.1 Static Signs

The main static sign used for hurricane evacuations is the evacuation route marker, which is included in the *Manual on Uniform Traffic Control Devices* (MUTCD – Reference 6). The circular sign measures 18 inches in diameter and reads “EVACUATION ROUTE” in white legend on a blue background. The legend also includes a white reflectorized arrow, which varies in direction. The MUTCD suggests the placement of evacuation route markers 150 to 300 feet in advance of and at any turn in an approved evacuation route and as straight-ahead confirmation where needed.

12.2.5.2 Barriers

During emergency management, it may be necessary to close roadways and / or their access points (e.g., on ramps for the direction opposite of contraflow operations). These barriers and gates may be temporary and installed manually (similar to that for maintenance activities); or they may be permanent gates – similar to railroad crossing arms – that are controlled remotely. Such barriers and gates are also addressed in the MUTCD.

12.2.6 **Emerging Trends**

Freeway management and operations in support of evacuations, and particularly Homeland security, is an evolving program area. The ITS America supplement to the National ITS Program Plan (4), focusing on Homeland security, identifies a wide range of recommended research actions, including:

- Development and deployment of ITS-based transportation security technologies, such as sensors and analysis capabilities to automatically and immediately detect potential threats along the roadways and transportation centers.
- Security – enhancing commercial vehicle technology for sensing and identifying hazardous materials, tracking potentially hazardous cargo, to assure that a commercial vehicle is being driven by an authorized person along an authorized route, and to safely halt vehicles which deviate from these guidelines.
- Hardening transportation-related facilities, and providing back ups and alternatives under a range of attack / disaster scenarios. For example, TOC design will likely include considerations such as perimeter barriers, detection for intruders and weapons / explosives, chemical and biological weapon detection technologies, mylar sheeting on windows to protect against flying glass in the event of an explosion, etc. This also includes protecting the software – based information processing systems that may be vulnerable to hacking and other technology-driven interference, thereby protecting the availability, integrity, and confidentiality of data.
- Creating a national ID card for transportation workers that would support rapid and reliable electronic identity and credentials verification.

The Program Plan also recommends that these security measures be developed and implemented in such a way that overall mobility, efficiency, and personal freedoms are not adversely affected.

12.3 IMPLEMENTATION AND OPERATIONAL CONSIDERATIONS

From the perspective of freeway management and operations, emergencies are very similar to planned special events (as discussed in the previous chapter) in that the impacts are wide ranging, significant planning and stakeholder coordination are necessary to mitigate these impacts, and similar strategies and technologies are often utilized. That said, there are also notable differences, such as:

- Perhaps most significant is that, unlike planned special events, the location and time of an emergency is generally unknown until just before or after the emergency situation actually occurs. Hurricanes and winter storms are tracked, and projected landfalls / affected areas are known; but the reliable lead-time is, at best, a matter of a day or two. Earthquakes and terrorist attacks occur essentially without warning.
- An emergency will often have a greater area of impact than a planned special event.
- The focus for planned special events is the management of a significant uni-directional traffic flow (e.g., access to, and then from, the special event venue for participants and spectators. This is also an important consideration during emergencies (e.g., the orderly movement of residents and workers from the affected emergency area). Moreover, with emergency situations there is often a critical, simultaneous need for immediate access to the affected area by “first responders” (e.g., police, fire, security, medical) traveling in the opposite direction of the primary flow. Additionally, there is the reentry of evacuated persons following the emergency.

Nevertheless, the Special Event Handbook (summarized in the previous chapter) identifies several implementation and operational activities that are applicable to emergency and evacuation management, as discussed below.

12.3.1 Institutional Framework / Planning / Policies

The key to surviving any disaster is to be prepared and to be informed; and planning is an important part of this preparation. FEMA has developed an “Emergency Management Guide for Business & Industry” (Reference 7), which is available from the FEMA web site (Reference 2), and summarized in a presentation on the FHWA emergency management web site (Reference 1). The guide provides a step –by –step approach on how to create and maintain a comprehensive emergency management programs. The planning process is summarized in Table 12-1.

Table 12-1: Planning Process for Emergency Management

(Reference 7)

Step 1 – Establish A Planning Team

- | | |
|---|---|
| <ul style="list-style-type: none"> • Form the team, obtaining input form all functional areas. | <ul style="list-style-type: none"> • Establish authority • Issue a Mission Statement • Establish a schedule and budget |
|---|---|

Step 2 – Analyze Capabilities and Hazards

- Review internal plans and policies
- Meet with outside groups (i.e., other stakeholders)
- Identify applicable laws and regulations
- Identify critical products, services and operations
- Identify internal resources and capabilities
- Identify external resources
- Do an insurance review
- Conduct a vulnerability analysis
 - Potential emergencies
 - Probability
 - Potential human impact
 - Potential property impact
 - Potential business impact
 - Resources / ability to respond

Step 3 – Develop the Plan

- Identify challenges and prioritize activities
- Write the plan
 - Executive Summary
 - Emergency Management Elements
 - Emergency Response Procedures
 - Supporting Documents (resource, emergency call lists)
- Establish a training schedule
- Coordinate with outside organizations
- Review, conduct training and revise
- Seek final approval
- Distribute the plan

Step 4 – Implement the Plan

- Integrate the plan into agency operations
- Conduct training, drills and exercises
- Regularly audit, evaluate and modify the plan

One of the activities identified in the Table is to develop a mission statement. This can include a list of high – level policies. For example, Caltrans has established a set of emergency response policies (Reference 8), which include:

- Minimize the loss of life and property
- Protect State-operated facilities and the State highway system
- Maintain and protect up-to-date damage and operations information to public, media, local jurisdictions, the Governor, State legislators, as necessary
- Open damaged state transportation system components as soon as possible
- Cooperate with other key agencies at the local, State, and federal levels
- Support the State emergency-response efforts by the California Governor’s Office of Emergency Services, California Highway Patrol, and local jurisdictions
- Conduct periodic drills and exercises in cooperation and other public agencies

12.3.1.1 Emergency Operations Plans

The federal government, through FEMA, requires all states to have a comprehensive Emergency Operations Plan. These plans guide emergency operations for all types of hazards, from natural to manmade and technological. Within this “all-hazards framework” (e.g., earthquake, HAZMAT, hurricane, snow / ice, terrorism emergencies, mass gathering event) state DOTs have been designated with certain transportation-oriented responsibilities. The functions are typically set forth in the state emergency management plans and often detailed in DOT emergency operations plans. These functions can be summarized in terms of a set of transportation roles identified in Table 12-2.

Table 12-2: DOT Emergency Management Functions

(Reference 5)

First Response

- Assist with evacuation of persons from immediate peril.
- Transport materials, personnel, and supplies in support of emergency activities. Assistance may include transporting resources from state agencies, from local governments from other parts of the state, or from private commercial companies.
- Assist in the design and implementation of alternate transportation services, such as mass transit systems, to temporarily replace transport capacity lost to disaster damage.
- Assess the condition of highways, bridges, tunnels and other components of the state's transportation infrastructure and:
 - Close those determined to be unsafe;
 - Post signing and barricades;
 - Notify law enforcement and emergency management personnel;
 - Protect, maintain and restore critical transportation routes and facilities;
 - Develop detour routings as appropriate.
- Assess and report impacts to airports, ports, and marine facilities in the disaster area.
- Conduct aerial reconnaissance and photographic missions, provided resources are available.
- Provide hazardous materials containment response and damage assessment.
- Coordinate roadway clearance activities and prioritize and perform emergency repairs in the disaster area. Assist local governments in related repair activities.
- Remove and/or assist in debris removal and disposal, as appropriate, to provide emergency access to disaster areas or to assist in eliminating health and safety problems associated with debris.
- Coordinate state agency efforts in support of utility restoration.
- Issue permits required to repair/restore utility lines or pipes that are immediately adjacent to, or run over or under state highways.

- Provide needed equipment and/or technical assistance in support of the restoration of critical public works.

Concept of Operations²²

- Implement DOT emergency functions for the prioritization and/or allocation of state resources necessary to maintain and restore the state's transportation infrastructure.
- Provide all available and obtainable transportation resource support including:
 - Transportation equipment, e.g., passenger and utility vans, trucks and/or trailers; aircraft, aircrews, and ground and operations personnel and communications for transportation of emergency officials;
 - Transportation facilities, e.g., vehicle repair facilities, equipment, and personnel; fleet parking and storage areas to be used for staging, parking, and storage of emergency vehicles; motor pool and vehicle service facilities and personnel for refueling and servicing emergency vehicles;
 - Vehicular traffic management and control signs and devices e.g., barriers, cones, of various types;
 - Vehicular traffic flow data and information from permanent and temporary monitoring sites.
- Assign personnel to emergency operations center(s) to coordinate with and assist law enforcement agencies and other agencies involved in evacuation efforts.

System Surveillance and Management

- Monitor and control transportation systems and infrastructure, and coordinate transportation activities with other agencies (local, state, and Federal).
- Provide traffic control assistance.
- Assist state and local government entities in determining the most viable available transportation networks to, from, and within the disaster area and regulate the use of those networks for the movement of people, equipment, supplies, records, etc.
- Identify specific traffic management actions to maintain a smooth flow for evacuation routes and transport of emergency resources, including traffic control points, barricade plans, and potential one-way/reverse lane operations.
- Provide any highway clearances and waivers required to expedite the transportation of high-priority materials and the evacuation of personnel during periods of declared emergencies.
- Coordinate the closure of high-risk roadways such as bridges, tunnels, or flood prone sections of roadway.

Agency Communications

- Provide communications resources in support of statewide operations

Public Information

- Provide information on road closures, infrastructure damage, debris removal, and restoration activities related to highway systems and facilities.
 - Provide real-time traffic counter data and traffic reports for roads within the affected area or on roads leading into the area.
 - Assign appropriate personnel at key disaster sites to oversee operations and to provide consistent, verified public information to emergency management agencies, public information officers, and the media. When evacuation plans have been implemented, inform motorists which routes and intersections will lead to host shelters.
-

12.3.1.2 Evacuations

While they may not be directly involved in evacuation decisions, per se; freeway practitioners should be aware of the factors and considerations that go into evacuation decision-making. The purpose of evacuation is to move threatened populations from areas where the emergency

presents a risk to life and property – such as those areas that susceptible to storm surge, flooding, and wind damage during a hurricane, or burning in the event of a wildland fire. Evacuation decisions for hurricanes are based on information from computerized tracking and analysis models and discussions with the National Weather Service. Key factors include:

- Providing enough time for people in storm surge zones and mobile homes to move before the arrival of tropical storm force winds (39 MPH).
- Selecting an evacuation time to provide significant movement during day light hours
- Making the decision before a peak news time when the media can warn the greatest number of people

Similar factors are applicable to other evacuations where there is advance warning.

The ultimate decision to evacuate an area is usually left to the elected officials in charge of that jurisdictional unit, who are advised by the local Director of Emergency Management. Once an evacuation is deemed necessary, the extent and type of evacuation must be determined. The type and urgency are dependent on the characteristics of the emergency (e.g., strength / project landfall of a storm, strength and spread of a fire) and clearance times.

Hurricane evacuations are typically classified as one of three types (8):

- **Voluntary:** Voluntary evacuations are targeted toward people most vulnerable to hurricane storm surge and extreme winds, including offshore workers, persons on coastal islands, and other special populations having particularly long lead-time requirements. No special traffic control or transportation measures are usually taken during voluntary evacuations and people may remain if they so choose.
- **Recommended:** Recommended evacuations are issued when a storm has a high probability of causing a threat to people living in at-risk areas. Again, decisions of whether or not to leave are left to individuals and few special transportation arrangements are made.
- **Mandatory:** During a mandatory evacuation, authorities put maximum emphasis on encouraging evacuation and limiting ingress to coastal areas. One of the problems of mandatory evacuations is that they are difficult to enforce. Many people resist being ordered to leave their homes and property by government officials. Moreover, some states do not allow enforcement of mandatory evacuations.

In the case of winter storms, there may not be an evacuation; but non-essential services, both public and private, may be closed prior to the arrival of the storm to minimize the amount of traffic on the roadways. (Note – The reduction in traffic not only reduces the likelihood of weather-related crashes; but also simplifies the weather maintenance activities such as plowing snow, anti-icing, applying abrasives, etc.)

The critical issue in any pre-emergency evacuation / closure is timing. The earlier the evacuation / closure order is issued, the more time residents and tourists will have to evacuate. Unfortunately, the earlier it is issued the greater the possibility the hurricane could change course before landfall or a winter storm could change its track / lose strength, rendering the evacuation / closure unnecessary or leading evacuees to more dangerous locations. Evacuations and closures that turn out to be unnecessary can also lead to a “Cry Wolf” syndrome in which some people are less likely to evacuate during future threats.

12.3.2 Stakeholder Roles & Coordination

The expanded number of emergency stakeholders is noted in section 12.2.3. Coordination with these stakeholders is essential to ensure consistency of evacuation routes and zones; traffic management, sheltering procedures, public information, etc. Formal coordination structures have been developed for emergency management as summarized below.

12.3.2.1 Terminology

In coordinating with other stakeholders during the preparation for and response to an emergency, it is important to understand terminology specific to various types of emergencies. For example:

- Hurricanes are classified into five categories according to wind velocity. Category 1 is the mildest, with winds from 74 – 95 mph. Category 5 is the strongest, with winds above 155 mph.
- The Richter scale is a logarithmic measurement of energy released by an earthquake. Earthquakes with a magnitude of at least 4.5 are strong enough to be recorded by sensitive seismographs all over the world. The effects of earthquakes are measured by the Modified Mercalli Intensity scale, in which the intensity of a quake is evaluated according to the observed severity at specific locations. The Mercalli scale rates the intensity on a Roman numeral scale that ranges from I to XII. The Loma Prieta (northern California) earthquake in October 1989 registered 7.1 on the Richter scale and as high as XI on the Mercalli scale.
- The Department of Homeland Security has developed a five-level threat notification Homeland Security Advisory System (HSAS) The following Threat Conditions (from Reference 9) each represent an increasing risk of terrorist attacks.
 - 1 - Low Condition (Green). This condition is declared when there is a low risk of terrorist attacks.
 - 2 - Guarded Condition (Blue). This condition is declared when there is a general risk of terrorist attacks.
 - 3 - Elevated Condition (Yellow). An Elevated Condition is declared when there is a significant risk of terrorist attacks. Associated activities include increasing surveillance of critical locations; coordinating emergency plans as appropriate with nearby jurisdictions; and implementing, as appropriate, contingency and emergency response plans.
 - 4 - High Condition (Orange). A High Condition is declared when there is a high risk of terrorist attacks. Associated activities include taking additional precautions at public events and possibly considering alternative venues or even cancellation; preparing to execute contingency procedures, such as moving to an alternate site or dispersing their workforce; and restricting threatened facility access to essential personnel only.
 - 5 - Severe Condition (Red). A Severe Condition reflects a severe risk of terrorist attacks. Protective measures include Increasing or redirecting personnel to address critical emergency needs; assigning emergency response personnel and pre-positioning and mobilizing specially trained teams or resources; monitoring, redirecting, or constraining transportation systems; and closing public and government facilities. Under most circumstances, the protective measures for a Severe Condition are not intended to be sustained for substantial periods of time.
- One important measure of fire danger that the National Weather Service uses is the Lower Atmosphere Severity index, better known as the “Haines Index”. Six is the highest rating’

and was the reading for east-central Arizona the night before the aforementioned Rodeo fire.

12.3.2.2 Federal Response Plan

Most disasters and emergencies are handled by State and local responders. The Federal Government is called on to provide supplemental assistance when the consequences of a disaster exceed State and local capabilities. If needed, the Federal Government can mobilize an array of resources to support State and local efforts. Various emergency teams, support personnel, specialized equipment, operating facilities, assistance programs, and access to private-sector resources constitute the overall Federal disaster operations system.

The Federal Response Plan (FRP) outlines how the Federal Government assists State and local governments when a major disaster or emergency overwhelms their ability to respond effectively to save lives; protect public health, safety, and property; and restore their communities. The FRP describes the policies, planning assumptions, concept of operations, response and recovery actions, and responsibilities of 25 Federal departments and agencies and the American Red Cross, that guide Federal operations following a Presidential declaration of a major disaster or emergency.

The FRP has proven to be an effective framework for coordinating delivery of Federal disaster assistance to State and local governments. Since it was issued in 1992, Federal agencies have demonstrated that they can work together to achieve the common goal of efficient, timely and consistent disaster response and recovery. An interim edition of the FRP (Reference 10, and available from the FEMA web site) reflects the passage of the Homeland Security Act of 2002 and the establishment of the Department of Homeland Security (DHS). The FRP:

- Sets forth fundamental policies, planning assumptions, a concept of operations, response and recovery actions, and Federal agency responsibilities;
- Describes the array of Federal response, recovery, and mitigation resources available to augment State and local efforts to save lives; protect public health, safety, and property; and aid affected individuals and communities in rebuilding after a disaster;
- Organizes the types of Federal response assistance that a State is most likely to need under 12 Emergency Support Functions (ESFs), each of which has a designated primary agency. ESFs include Transportation, Communications, Public Works and Engineering, Firefighting, Information and Planning, Mass Care, Resource Support, Health and Medical Services, Urban Search and Rescue, Hazardous Materials, Food, and Energy.
- Describes the process and methodology for implementing and managing Federal recovery and mitigation programs and support/technical services;
- Addresses linkages to other Federal emergency operations plans developed for specific incidents;
- Provides a focus for interagency and intergovernmental emergency preparedness, planning, training, exercising, coordination, and information exchange; and

- Serves as the foundation for the development of detailed supplemental plans and procedures to implement Federal response and recovery activities rapidly and efficiently.

12.3.2.3 Incident Command System

Most incidents require the assistance of several different agencies, including fire, law enforcement, public works, emergency management agencies, etc. across one or more jurisdictions. This is particularly true for major emergencies. The efforts of these entities must be coordinated in order to achieve an efficient and effective response.

The Incident Command System (ICS) concept has been developed to govern the communications that must occur among these multiple entities. The cornerstone of ICS is a formalized management structure and procedures for controlling personnel, facilities, equipment, and communications. Initially developed as a result of wild fires in southern California in 1970, the ICS concept has been widely adopted and endorsed by numerous organizations (e.g., American Public Works Association, International Association of Chiefs of Police, National Fire Academy) as the standard to use for responding to all types of incidents and emergencies. Moreover, ICS is required by law to be used for response to HAZMAT incidents.

The ICS is made up of the following eight components, all working together to provide the basis for the ICS concept of operations:

- Common terminology
- Modular organization
- Integrated communications
- Unified command structure
- Consolidated action plan
- Manageable span – of – control
- Pre-designated incident facilities
- Comprehensive resource management

The formalized management structure on which the ICS is based is divided into five basic functions – command, planning, operations, logistics, and finance / administration – all of which are overseen by the Incident Commander, who is responsible for on-scene management and command authority.

The ICS includes a vast amount of protocols and procedures – details that are beyond the scope of this Handbook. What is important is that freeway practitioners recognize that such an ICS structure exists, and will likely be implemented during emergencies. It is also noted that the FRP uses the principles of the Incident Command System (ICS). Moreover, the Federal government is currently working on a single National Incident Management System (NIMS) that will describe a singular version of the ICS – one that is most likely different from the current version as described above.

12.3.2.4 Evacuation Liaison Team

The Evacuation Liaison Team (ELT) has been established to support regional hurricane response efforts by compiling, analyzing, and disseminating traffic related information that can be used to facilitate the rapid, efficient, and safe evacuation of threatened populations. It is

comprised of FEMA and US DOT (located at the FEMA Regional Operations Center), communicating with counterparts at the state level to ensure transportation – related information is shared among the affected States and the Federal government. Roles and responsibilities of the ELT include:

- Provide federal and state emergency management officials with timely and accurate traffic / evacuation related information during multistate hurricane threats
- Provide an overall liaison function, clearinghouse and centralized communication link between the states, regions, FEMA and others agencies and the media as appropriate
- Receive, compile, and analyze vital information such as status of evacuations, traffic flows (volumes, speeds, travel times), problem areas, availability of shelters, emergency messages and instructions
- Disseminate the appropriate information via website, video conferencing, teleconferences, email, facsimile
- Assist in providing the necessary data, analysis, intelligence, etc. to facilitate evacuation, propositioning, staging, and re-entry planning, decision-making and problem solving.

The ELT may be activated under a variety of criteria, such as when a storm has the potential to become intense (category 3 –5), poses a threat to multi-state areas, evacuation may be possible within 24 – 36 hours, or state(s) request activation. The freeway practitioner should become involved in these activities – including establishing and maintaining contact with ELT, developing and analyzing traffic projections (including traffic simulations), disseminating information, and implementing evacuation strategies.

12.3.3 Public Outreach

Positive public response to evacuation warnings is essential for the successful, safe, and efficient evacuation of an area. Prior to hurricane season, public awareness campaigns remind the public to prepare for hurricanes. As a hurricane approaches, the appropriate notification procedures and messages must be used to convince the public that evacuation is in their best interest. Several effective methods to promote public awareness include: (11)

- Educational campaigns;
- Public service announcements;
- Brochures illustrating designated evacuation routes;
- Internet

With respect to the Internet, several states publish their Hurricane Evacuation Routes on their DOT and other agency web sites (Figure 12-1), along with additional disaster – related information and links (e.g., evacuation decision-making criteria, preparedness information and checklists, real-time weather and traffic conditions, shelter sites and hotels, home and business protection)

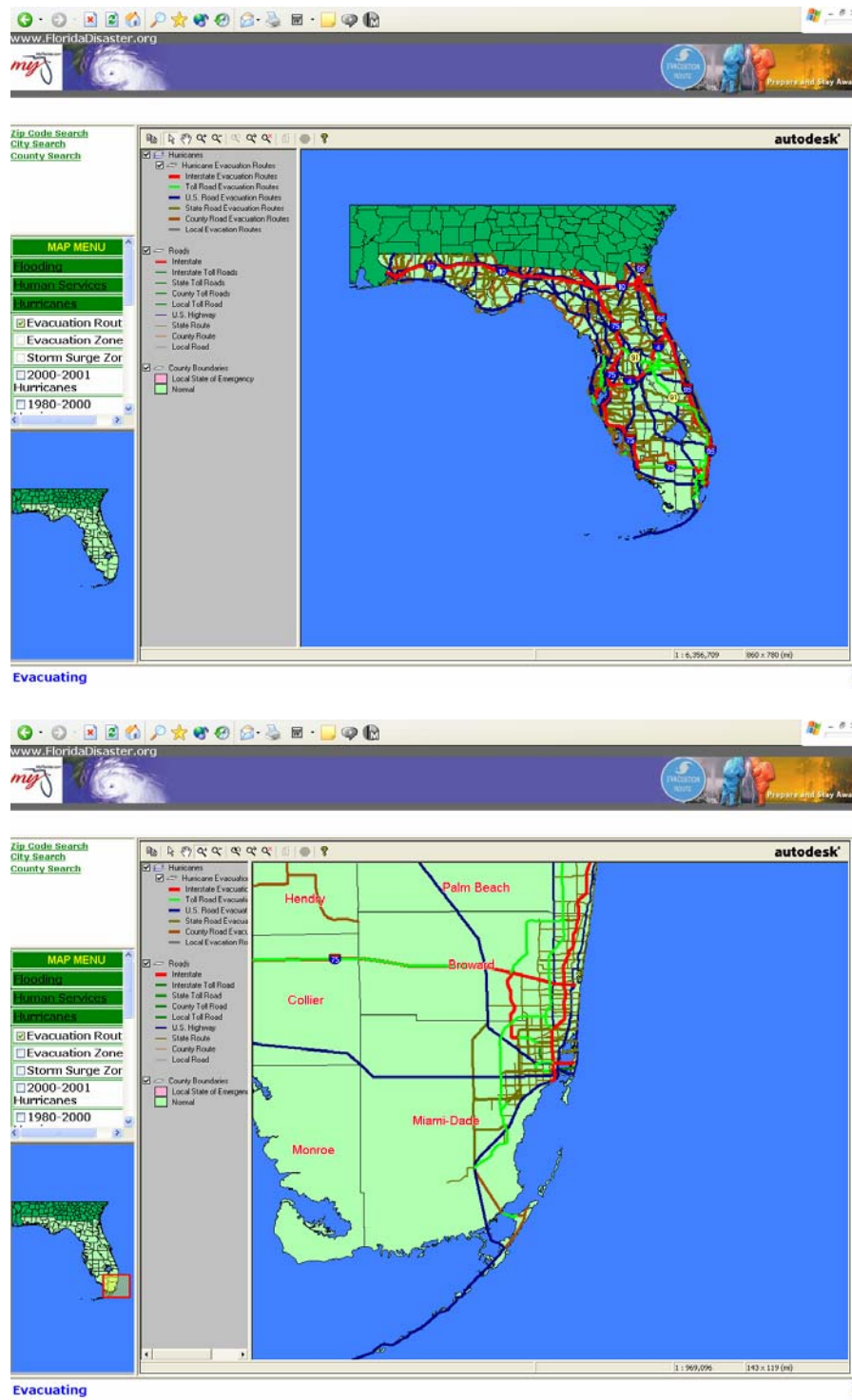


Figure 12-1: Website Showing Evacuation Routes
(Source: www.floridadisaster.org)

12.3.4 Area of Impact / Analyses

Hurricane evacuation studies (HES) were initiated in the 1980's by the Federal Emergency Management Agency (FEMA) to integrate key aspects of hurricane evacuation planning and to assist in disaster preparedness. A HES typically consists of the analyses noted below (13); and though it is focused on hurricanes, the general principles are applicable to all emergency evacuations:

- **Hazards Analysis:** The primary objective of the hazards analysis is to determine the probable worst-case effects from the various intensities of hurricanes that could strike the region. The study identifies "worst-case effects" (i.e., the peak storm surges, high wind speeds, inland flooding, and wave effects) that can be expected at all locations within the study area, regardless of the point of hurricane landfall.
- **Vulnerability Analysis:** The purpose of the vulnerability analysis is to identify the areas, populations, and facilities that are potentially vulnerable to flooding and extraordinary wind damage under a variety of hurricane threats. The vulnerable population is comprised of all persons residing within the area subject to storm surge and the residents of mobile homes located above expected flood levels.
- **Behavioral Analysis:** In preparing hurricane evacuation plans, assumptions must be made regarding the manner in which the population in and around the vulnerable area will react to the threat, including the percentage that will evacuate, the probable destinations, the number of vehicles that will be used (including the number that may be motor homes or towing boats / campers), the evacuation response of tourists, and the percentage of evacuees who would require public assistance for emergency transportation. These assumptions are necessary for shelter planning, transportation modeling, and guidance in evacuation decision-making and public awareness efforts.
- **Shelter Analysis:** The purposes of the shelter analysis are to estimate the number of evacuees that will seek public shelter and the number of shelter spaces available, and to provide information for use in determining evacuation clearance times in the transportation analysis.
- **Transportation Analysis:** The primary purpose of the transportation analysis is to calculate the clearance times needed to conduct a safe and timely evacuation for a range of hurricane threats. Other purposes are to define the evacuation roadway network and to evaluate traffic control measures/highway improvements for improved traffic flow. Some of the considerations and issues are noted below:
 - In choosing roadways for the hurricane evacuation network, care should be taken to designate only those roads that are not expected to flood from rainfall or storm surge while the evacuation is in progress. Other desirable characteristics are little or no adjacent tree coverage, substantial shoulder width and surface, and current designation as an evacuation route in an existing evacuation plan.
 - Clearance times – which vary depending upon storm scenario, behavioral response, and (if appropriate) tourist occupancy level – are an important product of the analysis. Clearance time is normally estimated for each county. It begins when the first evacuating vehicle enters the roadway network, prior to an evacuation order or advisory, ends when the last vehicle reaches an assumed point of safety, and includes the time

spent traveling along the roadway network and waiting due to traffic congestion (queuing delay time).

- The movement of evacuating vehicles during a hurricane evacuation requires extensive traffic control efforts to make maximum use of roadway capacity and to expedite safe escape from hurricane hazards. The transportation analysis should reveal critical roadway segments and intersections and recommend specific traffic control measures and/or roadway modifications to help alleviate the anticipated problems in these areas.

12.3.4.1 Transportation Modeling Methodology.

One of the means of planning and preparing for evacuations involves the use of computer modeling. The traffic models noted in Chapter 4 (e.g., CORSIM, INTEGRATION, PARAMICS, VISSIM, TRANSIMS, DYNASMART) can be used for a variety of emergency / evacuation / reentry scenarios by changing the appropriate network and traffic flow parameters. Additionally, specialty models for emergency management have been developed as summarized below: (8)

- The most widely applied flooding model for evacuation analysis is the Sea, Lake and Overland Surges from Hurricanes (SLOSH) model. Developed by the National Weather Service to predict hurricane storm surge for a given set of conditions, it is also used to plan evacuation routes and locate emergency shelters based on estimates of which geographic could be flooded in certain storm scenarios. SLOSH is used by weather experts at NOAA.
- Hurricane and Evacuation (HURREVAC) program. HURREVAC is a decision support system for emergency management officials. It uses geographic information system (GIS) information to correlate demographic data with shelter locations and their proximity to evacuation routes to estimate the effect of strategic-level evacuation decisions.²³
- The Oak Ridge Evacuation Modeling System (OREMS) – developed by the Center for Transportation Analysis at the Oak Ridge National Laboratory (ORNL) using the CORridor SIMulation (CORSIM) platform – OREMS was developed to simulate traffic flow during various defense-oriented emergency evacuations. The model can be used to estimate clearance times, identify operational traffic characteristics, and other information such as evacuation routes and times necessary to develop evacuation plans. It also allows users to experiment with alternate routes, destinations, traffic control and management strategies, and evacuees' response rates.
- The Evacuation Traffic Information System (ETIS) is a secure, web-based, Geographic Information Systems tool developed to assist the Evacuation Liaison Team, state emergency managers, and state traffic engineers. It enables them to share information with each other, and to provide information on the anticipated traffic levels and patterns. (At this time, it is only available to officials within the hurricane community.) The main page of the ETIS displays a map of the U.S. from Texas to Maryland, and shows information on counties that have called an evacuation, the evacuation participation rate and type (i.e., voluntary or mandatory evacuation), expected congestion levels on primary evacuation routes, and road closures. Tables accessible through the system give the anticipated state-to-state traffic volumes and likely destinations of the evacuees.

12.3.5 Traffic Management Plans

12.3.5.1 Contraflow Lanes

Contraflow, or reverse laning as it is also commonly known, involves the reversal of traffic flow in one or more of the inbound lanes (or shoulders) for use in the outbound direction with the goal of increasing capacity. Four different variants of contraflow may be used as shown schematically in Figure 12-2. Because it offers the largest increase in capacity, the most common contraflow strategy is to reverse all inbound lanes to the outbound direction.

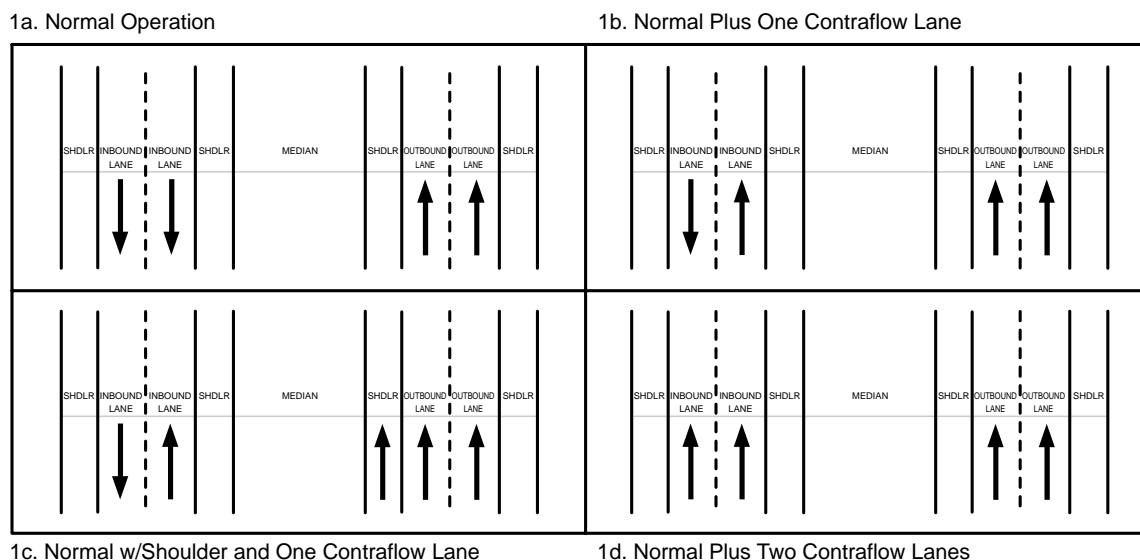


Figure 12-2: Contraflow Operational Scenarios

(Reference 8)

Though not as widely used, single-lane contraflow strategies are also possible, such as one lane reversed and one lane with inbound flow for emergency/service vehicle entry only; and one lane reversed and one lane with normal flow for inbound traffic entry. The main advantage of this strategy is its ability to maintain a lane for inbound law enforcement personnel and emergency service vehicles, critical for clearing incidents. It can also permit access for people that want to move against the evacuation traffic. One of the major drawbacks of single-lane reversals is that it raises the potential for head-on accidents.

Another strategy to improve capacity is to use the outbound left shoulder as an additional outbound lane. The capacity increase depends on the width and condition of the shoulder. Two additional concerns associated with the use of shoulders are pavement suitability and bridge widths. Shoulders are typically designed with a thinner pavement cross-section and greater cross-slope. They may not be able to withstand prolonged traffic loading and thus provide an inadequate riding surface. Cross-section width can be a problem on bridges. Many freeway bridges, particularly older ones, have been constructed with narrow shoulders. If shoulders were

used as outbound lanes, these locations would create bottlenecks causing additional congestion as vehicles merge back into the through lanes.

Contraflow sections typically start with a median crossover or traffic control configuration that redirects or splits a portion of the outbound traffic stream into the inbound lanes. The specific location of these crossover points is usually a function of roadway geometry, the approximate beginning of congestion during evacuations, and the proximity of the location to other evacuation routes.

Contraflow section termini designs also vary by location. One of the controlling criteria for the location of a termination point is the prevention of merging congestion. This can be accomplished in several different ways:

- The method that is most common, particularly for shorter segments, is to permanently split the traffic flows. In this type of design one of the streams of traffic is diverted onto a separate roadway, while the other continues travel on the original route.
- The other common type of contraflow termini design is the attrition-merge. In this design, traffic in the normal and reverse flow lanes is reduced by allowing vehicles to exit to secondary routes at points along the contraflow segment. Through a process of exit attrition, it is assumed that traffic would be reduced to a level at the end of the segment that would allow a merging of the traffic streams without causing bottleneck congestion.

Cross-over designs should also address the placement and location of traffic control devices in the vicinity of the crossover, the use of highway advisory radio (HAR) and dynamic message signs (DMS) to guide evacuees, and the specific numbers and locations of police vehicles at the beginning and termination points and along the ramps of the segment. Another possibility is the installation of drop-gate barricades at the upstream end of on-ramps to assist in the control and diversion of in-bound traffic flow

Other management and operational issues associated with contraflow lanes for evacuations include:

- Use of contraflow for reentry of evacuated individuals following the emergency
- Time and labor required to set up, initiate, and enforce contraflow operations (e.g., traffic control devices and barricades must be erected and weighted down, inbound lanes must be cleared of vehicles over their length, and law enforcement and DOT field personnel must be positioned at their assigned locations). Set up time depends on the length of the segment, the number of interchanges involved, and the number ramps and merge points that may require control.
- Criteria affecting decisions as to if and when to initiate contraflow operations (e.g., storm characteristics (size, intensity, track) and potential risks; traffic volume; set up time; and time of day)
- Factors for determining when to shutdown the evacuation (e.g., the arrival of tropical storm force winds, and the need to evacuate DOT and enforcement personnel; decrease in evacuation traffic volumes; time –of – day /nightfall).

- Who has the authority to start and end contraflow operations (refer to discussions in Chapter 2). In most states, this authority resides with the Governor, although that responsibility falls on enforcement and/or transportation officials in a few states.

As an example of the effectiveness and benefits of contraflow operations, Reference 14 “Best Practices for Road Weather Management, Version 2.0” provides the following excerpt. From a cases study entitled “South Carolina Hurricane Evacuation Operations”. “On Tuesday, September 14th the Governor issued a voluntary evacuation order at 7:00 AM followed by a mandatory evacuation order at noon. In response, over 350,000 people evacuated on Tuesday, and roughly 160,000 departed on Wednesday. The timing of evacuation orders, the public’s response to the orders, the lack of lane reversal operations, and unmanned traffic signals in small towns contributed to severe congestion on Interstate 26 between Charleston and Columbia. Travel time, which is normally 2½ hours, ranged from 14 to 18 hours during the evacuation. The maximum per lane volume on the interstate was 1,445 vehicles per hour. The Governor ordered contraflow operations to minimize travel times during reentry. Traffic and emergency managers quickly developed a contraflow plan to accommodate reentry traffic in reversed westbound lanes. DMS and HAR were deployed to notify travelers of closures and alternate routes. As a result of contraflow, the maximum volume during reentry was 2,082 vehicles per hour per lane—a 44 percent increase over evacuation volumes. Contraflow operations and dissemination of traveler information significantly improved mobility by increasing roadway capacity and traffic volumes.”

12.3.5.2 High Occupancy Vehicle Lane Usage

During an evacuation, officials may opt to allow high occupancy vehicle (HOV) lanes to be opened to all traffic regardless of occupancy restrictions (11, 15). Several issues need to be examined when considering this option. Bottlenecks may form at the terminus of the HOV lane – particularly if the lane merges into the general purpose lane (forcing a merge) as compared to removing the restriction from the lane – which may reduce capacity and offset any potential benefits. Confusion may result because not all motorists may be familiar with HOV facilities. Public awareness prior to evacuation is needed to ease confusion. Furthermore, dropping occupancy limitations sets precedents for similar actions in the future and this may not be desired.

An alternative to lifting occupancy requirements on HOV lanes would be to encourage normal HOV lane usage during evacuations. This might encourage people to travel in groups. Furthermore, “evacuation buses” could be provided to get people to leave their personal vehicles behind, reducing demand on the evacuation route. The ability of such buses to use the HOV lanes to bypass evacuation congestion might provide strong incentives for their usage.

12.3.5.3 Work Zones

Since the need for maintenance and construction during the hurricane season is unavoidable, some DOTs have made attempts to avoid conflicts by adding special provisions in construction contracts to accommodate evacuation traffic through work zones. The most common way to do this has been to add clauses that require a contractor to cease all construction activities once an evacuation is declared, clear all equipment, and open all lanes of traffic including those under construction. Other options to maintain capacity through work zones on evacuation routes have

included limiting the construction season, distance, performance time, and/or phase sequencing of projects. These types of contraction provisions can potentially increase the cost and/or duration of projects, since they may require a contractor to work in shorter segments or use non-standard construction practices. (8)

12.3.5.4 Traveler Information

During emergency situations (e.g., major evacuations, response and recovery operations, national security emergencies), traffic and traveler information requirements reach a critical point. In addition to providing information on the locations of evacuation routes, roadway configurations (e.g., use of shoulders, contra-flow, available exits and entrances), traffic flow conditions / congestion on available routes, etc.; the traveler information should also include real time information on locations and availability of lodging and shelter, and services such as gas stations, rest area locations, and restaurants and food stores.

12.3.5.5 Contingencies for Continued Operations

Another element of any traffic management plan is contingencies for the continued operation of freeway management systems and regional information sharing networks; such as redundant / emergency communications (e.g., satellite telephones); power, continuity of operations and essential functions in the event that the TMC becomes inoperable. Of course, the most desirable scenario is to locate and design the TMC such that it can continue to operate during severe weather conditions and other emergencies (e.g., back up power, overnight accommodations for staff, located outside a flood plain, seismically isolated). As this may not always be the case, it is important to develop a "Continuity of Operations Plan" (COOP)

Presidential Decision Directive 67 requires that all Federal Departments and agencies have a viable Continuity of Operations Plan (COOP) capability, which details how their essential functions will be performed during an emergency or any situation that may disrupt normal operations and leave office facilities damaged or inaccessible. Objectives of a COOP include: (1)

- Ensuring the continuous performance of an agency's essential functions / operations during an emergency
- Protecting essential facilities, equipment, records, and other assets
- Reducing or mitigating disruptions to operations
- Reducing the loss of life, minimizing damage and losses
- Achieving a timely and orderly recovery from an emergency and resumption of full service to customers

Elements of a viable COOP include:

- Plans and Procedures, such as procedures for employee advisories, alerts, and COOP activations
- Identification of Essential Functions. This includes determining which functions must be continued under all circumstances, prioritizing those functions, and identifying the associated staffing and resource requirements (including mission critical data and systems)

- Delegations of Authority. Identify authorities for making policy determinations and decisions during emergencies – both within the various levels of the agency, and as participants of interagency emergency response teams, identify the circumstances under which these delegated authorities are exercised (become effective and terminate), identify the authority of designated successors
- Orders of Succession for key positions and titles within the agency, including the conditions under which succession will take place and method of notification. It is recommended that successors be geographically dispersed, and that they receive appropriate orientation.
- Alternate Facilities – Identify alternate operating facilities, and prepare personnel for the possibility of sudden relocation of essential functions and / or contingency staff to these facilities. Such alternate facilities should be capable of supporting critical operations in a threat – free environment.
- Interoperable Communications – In order for agency operations to be successful at an alternative facility, critical communication systems must be available with a degree of redundancy. These communications systems must support connectivity to internal organizations and systems, and to other organizations and the public.
- Vital Records and Databases – Plans must also provide for the identification, protections, and ready availability of electronic and hardcopy documents, references, record, and information systems needed to support essential functions under any type of emergency.
- Tests, Training and Exercises

12.3.6 Training / Exercises

A regional emergency / evacuation exercise sufficient in scope to test all major elements of the emergency and evacuation plans should be conducted periodically. The participants should include state, regional, and local agencies that have emergency preparedness responsibilities. The scope could range from only tabletop communications to full activation of field personnel and emergency operations centers. Regardless of the scale, the goal of the exercise should be to test the effectiveness of each emergency management plan, including safe, efficient, and effective evacuations.

The exercise should test the ability of emergency management officials to identify the appropriate emergency scenario as it develops, including those of neighboring communities. Official's responses should be tested in the areas of emergency decision making, communications, public warnings, manpower/equipment deployment, resource allocation, timing of evacuation order or advisory, shelter activation, emergency transportation, damage assessment and traffic control. Communications and emergency power systems should be fully tested, long-term if possible. Monitors should be stationed at each emergency operations center and, if appropriate, in the field to evaluate response activity.

A post-exercise review should be conducted to evaluate the effectiveness of each plan. Officials who participated in the exercise should also contribute to the review. Monitors should be asked to critique the activity to which they were assigned. A critique report should be published that documents the exercise methodology, identifies problem areas, and recommends

improvements. Areas where future preparedness training would be beneficial should also be identified.

12.3.7 Military Deployment Coordination

Military deployment strategy has transformed from the Cold War forward – deployed force to a capabilities – based power projection force located largely in the United States. Strategic and mobility readiness are the keys to the military's ability to project power. Smaller forces may be deployed by air, while larger forces would typically be deployed by sea. Movements by sea require that a large number of vehicles and equipment be moved from military installations to the point of embarkation by either railroad or by convoys on public roads. These convoys need to arrive at a particular location at a specified time. The mission, threat, number of troops, terrain, highway network, and time available set the specific planning factors and influence how the convoy will be operated and managed.

During the past several years, FHWA has been working closely with the Military Traffic Management Command Transportation Engineering Agency (MTMCTEA) in an initiative to support military mobilization. The principal objective of this initiative is to ensure that states have adequate coordination procedures to support military deployments while, at the same time, managing civilian traffic during national emergencies – in essence, to meet military deployment needs such that these movements do not become a major impediment.

During a national security emergency involving a military deployment, state DOT's must coordinate with both the FHWA and military transportation organizations. Supporting roles might include:

- Issuing the correct permits (e.g., overweight, oversize vehicles) for convoy vehicles using the State roadway system. (Note – DOD policy states that no vehicle movement that exceeds legal limitations or regulations, or that subjects highway users to unusual hazards, will be made without permission from the State, local, and / or toll authority.)
- Providing operational information to the military about work zone restrictions / closures, incidents, conditions at public rest areas / refueling locations, etc., that may impact convoy timeliness.
- Assessing and monitoring traffic flow conditions and operations on the designated routes.

State and local deployment planning require an understanding of coordination and communication protocols. It is important to know who will be calling from the military, and whom the state agency would contact within the military establishment to coordinate a response. A guide is being developed, with a final version expected in 2004.

12.3.8 Terrorism and Homeland Security

As discussed in previous sections, freeway management strategies and supporting ITS technologies are clearly applicable to emergencies and evacuation. The events of September 11, 2001 raised the consciousness of the transportation community along with the consciousness of others, about the need for better critical infrastructure protection and crisis management, disaster planning and prevention, as well as effective detection and response, particularly in the case of deliberate terrorist attacks. Freeway management operations and the supporting ITS technologies have an important role to play in advancing the surface transportation aspects of Homeland Security. As an example of this new concern, ITS America

in their supplement to their 10-Year Vision (4) added a “Security” goal, joining the goals of safety, efficiency / economy, mobility / access, and energy / environment.

Weapons of mass destruction in the hands of terrorists introduce new considerations to “emergency management” and disaster planning such as the following:

- People are the intended target.
- Advance warnings are unlikely.
- Multiple simultaneous attacks are possible.
- Emergency responders may be targets.
- The weapons may introduce serious and long-lasting hazards.
- The weapons may introduce large-scale damage or contamination to critical equipment and facilities.
- Public reaction is unpredictable.

The introduction of WMD also signals the need for some modifications to the existing set of agency roles and responsibilities (5):

- Law enforcement and national security agencies will play a larger role in a terrorist incident. State DOT personnel will need to understand the different relationships inherent during and after a terrorist WMD incident.
- If an incident occurs on or near a highway, state DOT personnel may be first or early responders. Therefore, basic training may be needed in identifying possible signs and consequences of terrorist incidents for appropriate actions including the consideration of their own safety.
- Specific traffic control regimes may be needed to evacuate people or to establish emergency access. Preplanning strategies, signage and equipment may be appropriate together with capitalizing on Intelligent Transportation Systems (ITS) and traveler information resources.
- Some resources may become unavailable for use if contaminated. Having procedures and equipment in place for decontamination becomes more important. Medical treatment and facilities could be overwhelmed quickly.
- Response resources may be required far beyond those originally anticipated; especially where a WMD is used that initially leaves few distinguishing marks. State DOT response resources need to be available but may also need to be protected as the consequences spread.
- Addressing public concerns is critical. Panic and uncontrolled flight are possible, and controls may need to be quickly put into effect. A comprehensive public information strategy is necessary. Where highways are concerned, state DOT personnel will be expected to provide information, (e.g., through variable message signs) to motorists evacuating an area.

ITS provides tools and enhanced opportunities to help safeguard the transportation system against a variety of threats, both natural and human caused, help the transportation system and its operators react swiftly and responsively in case of disruptions, and materially help agencies with primary responsibility to respond – for example (from the perspective of an FMS), providing

surveillance of transportation facilities, including bridges and tunnels, and operations / management centers; and safeguarding ITS systems and data against inadvertent or deliberate interference or misuse. The goal is a “transportation system that is prepared for and well-protected against attacks, that responds rapidly and effectively to natural and human – caused threats and disasters, that supports appropriate transportation, emergency management, and public safety agencies, that ensures the ability to move people and goods even in times of crisis, and that can be quickly and efficiently restored to full capability (4).

Information and communication systems are potentially vulnerable to hacking, deliberate overloading, denial of service, and other technology-driven interference, in addition to physical attack. The potential for this kind of interference increases as transportation systems come to depend more on information processing and dissemination, software, and communications. This growing dependence on technology to manage and operate the freeway network creates a critical need for:

- Protecting the availability, integrity, and confidentiality of data
- Reducing the vulnerability of systems and services and ensuring the continuity of operations
- Guarding against the effects of cascading and escalating failures in multiple interconnected systems.

Two guides have been recently developed in the aftermath of 9-11. They can be downloaded from the website of AASHTO’s security task force at <http://security.transportation.org>. Each is briefly discussed below.

12.3.8.1 Guide to Updating Highway Emergency Response Plans for Terrorist Incidents

This Guide (Reference 5) focuses the need for updating emergency response plans in light of emerging terrorist threats using weapons of mass destruction (WMD). It offers specific process guidance, in a checklist format, as to how state DOTs can update their emergency response plans. It also describes generic highway emergency response strategies typically used by state DOTs that may be utilized for emergency response to terrorist incidents.

The guide provides checklists designed to help state DOTs focus on where modifications and updates may be required in their plans and procedures. The checklists are divided into two broad topic areas:

- **Internal arrangements:** These checklists focus on the DOT’s internal organization and preparedness for a response to a terrorist incident. This topic area focuses on modifications to the DOT’s organization, responsibilities, procedures, communications, equipment, training and other critical areas.
- **External relationships:** These checklists focus on the state DOT’s role within the larger emergency management framework of a state. This topic area focuses on issues that the state DOT may wish to take up with the other major players in the state emergency planning process.

The Internal Arrangements and External Relationships categories are then broken down further into relevant topics:

- Planning, training and exercising
- Roles and responsibilities

- First response
- Concept of operations
- System surveillance and management
- Agency communications
- Public information.

The checklist covers numerous pages, and even a summary is beyond the scope of this Handbook. Nevertheless, there are a few program modification considerations and process suggestions worth noting from the relatively narrow perspective of freeway management and operations, as summarized in Table 12-3.

12.3.8.2 Guide to Highway Vulnerability Assessment for Critical Asset Identification and Protection

This Guide (16) was developed as a tool for State Departments of Transportation (DOTs) to:

- Assess the vulnerabilities of their physical assets such as bridges, tunnels, roadways, and inspection and traffic operation facilities, among others;
- Develop possible countermeasures to deter, detect, and delay the consequences of terrorist threats to such assets;
- Estimate the capital and operating costs of such countermeasures; and
- Improve security operational planning for better protection against future acts of terrorism.

The Guide provides six steps for conducting a vulnerability assessment of highway transportation assets. These six steps provide a straightforward method for examining critical assets and identifying cost-effective countermeasures to guard against terrorism. For each step, the objective is clearly stated, the practice of that step by other state and federal agencies is referenced, a detailed approach is described, and illustrative examples are provided.

Table 12-4 summarizes the six steps for conducting a vulnerability assessment of highway transportation assets. These six steps represent an integrated and iterative approach to vulnerability assessment. This approach depends upon the formation of a dedicated, multidisciplinary team with ready access to a range of resources – from databases to personnel – as well as a commitment from senior State DOT officials to examine critical assets carefully and identify cost-effective countermeasures to provide better protection against the threats of terrorism involving the use of weapons of mass destruction (WMD).

Table 12-3: Emergency Management Considerations for Freeway Management
(Adopted from Reference 5)

- Understand the Incident Command System
- Terrorist incident scenes (including those on the highway) are subject to crime scene management requirements
- A thorough analysis of potential highway and related transportation facility vulnerabilities and risks relating to terrorist incidents, identification of high risk or vulnerable terrorist targets within the DOT, and developing appropriate plans to protect those potential targets.
- As appropriate, build planned responses for the different levels and types of threat.
- Properly equipping and credentialing (e.g., proper ID cards) DOT personnel to perform their roles
- Know where the assets are (e.g., heavy equipment to move debris), and determine how those assets can be deployed quickly
- Ensure surveillance can quickly be applied to high-profile/high-risk structures, such as bridges, tunnels, highways, and overpasses, using existing monitoring equipment, e.g., CCTV, where possible.
- Ensure that plans include procedures for limiting access to security and other government agencies, e.g., close access ramps, install concrete barriers at security installations and facilities that house command centers.
- Develop evacuation route plans showing the freeways and arterials to be used in the evacuation of traffic and people out of emergency areas. Ensure that evacuation plans address termination of work zone closures.
- Consider the feasibility of invoking reverse-laning to evacuate emergency areas and review factors such as decision-making criteria used to invoke the reverse-laning, modeling traffic impacts, staffing and resource requirements, and the implementation timelines for reverse-laning in each of the identified routes.
- Coordinate concurrent work zone activities so they do not all occur at the same time for parallel routes in case of a terrorist incident.
- Assuming there is more than one DOT operations center, determine the relationship of the centers in terms of response, including the ability to shift control depending on the locale of an incident. If there is only one DOT operations center, identify ways to provide redundant or backup services in the event a terrorist incident affects the primary operations center
- Procedures for securing DOT centers
- Procuring additional portable ITS assets (DMS, HAR) to facilitate management of critical facilities where permanent infrastructure does not exist.
- Explore opportunities to bolster TMCs in preparation for emergency response situations. (e.g., cover larger geographic areas; supplement data with aerial camera links to the TMC; implement robust communication links that are fail-safe; establish additional backups and redundancies, perhaps at secondary locations, in case a primary location is affected by damage, power outages, or other issues
- Add additional simulation capabilities so that traffic outcomes of a terrorist incident can be modeled
- Determine how advanced traveler information systems might be utilized to convey information to the public during and following a terrorist incident.

Table 12-4: Steps for Conducting a Vulnerability Assessment of Highway Transportation Assets (Reference 16)

Step 1 – Critical Assets Identification

- Create an all – inclusive list of critical assets (i.e., those that enable the agency to achieve its mission, including infrastructure, facilities, equipment, and personnel)
- Establish and assign values to the critical asset factors (e.g., vulnerability to attack, consequences of loss / damage, consequences to public services and emergency response functions, consequences to general public / economic impact)
- Prioritize the all – inclusive list of critical assets

Step 2 – Vulnerability Assessment: Identify and evaluate critical assets in terms of their susceptibility to and the consequences of terrorist attacks

- Characterize the threat
- Assign vulnerability factors to the critical assets (e.g., level of recognition / visibility, number of users / attendance, proximity to vehicle traffic / parking access, level of protected / controlled security access, site specific hazards)
- Score the vulnerability factor for each asset

Step 3 – Consequence Assessment: Identify assets which, if attacked, produce the greatest risks for undesirable outcomes given a specific set of circumstances and conditions

- Plot critical asset criticality vs. vulnerability
- Consider consequences for those assets that have both high criticality and high vulnerability.

Step 4 – Countermeasures

- Identify potential countermeasures with respect to deterrence, detection, and defense (Refer to Table 12-5)
- Map countermeasures to high-priority critical assets
- Assess countermeasure effectiveness (i.e., a subjective measurement as to how well the application reduces either the potential for or the consequences of attacks)

Step 5 – Cost Estimation

- Create countermeasure “packages” (i.e., combinations of countermeasures that make sense operationally and from a vulnerability reduction perspective).
- Determine acquisition and operations / maintenance costs
- Apply costs to assets

Step 6 – Security Operational Planning

- Clarify security planning scope and objectives
- Develop plan
- Initiate training and exercise activities (e.g., awareness, training, standards)

Table 12-5: Potential Countermeasures

POTENTIAL COUNTERMEASURES (Reference 16)
Increase inspection efforts aimed at identifying potential explosive devices as well as increased or suspicious potential criminal activity.
Institute full-time surveillance at the most critical assets where alternate routes are limited or have not been identified.
Eliminate parking under any of the most critical type bridges. Elimination of the parking can be accomplished through the use of concrete barriers.
Place barriers in such a way as to eliminate ease of access where a vehicle could be driven right up to the asset.
Install security systems with video capability at all DOT facilities.
Protect ventilation intakes with barriers.
Install and protect ventilation emergency shut off systems.
Install Mylar sheeting on inside of windows to protect employees from flying glass in the case of an explosion.
Place a full-time security officer in a guard shack to control access.
Lock all access gates and install remote controlled gates where necessary.
Develop and implement a department-wide security policy.
Limit access to all buildings through the issuance of a security badge with specific accesses identified and controlled through the card.
Train all DOT personnel to be more observant of their surroundings and potentially dangerous packages, boxes, people, etc.
Improve lighting
Increase surveillance at tunnels by installing cameras linked to the Traffic Operations Center (TOC).
Add motion sensors to fences.

12.4 EXAMPLES

12.4.1 Northridge, CA Earthquake

On Monday, January 17, 1994, at 4:30 a.m., an earthquake of a magnitude of 6.8 shook Los Angeles, California. While the actual earthquake (and its subsequent aftershocks) lasted only about 1 minute, it damaged 114,000 residential and commercial structures spread over 2,100 square miles, took 72 lives, and significantly impaired the Los Angeles regional transportation system, generating a year's worth of highway work in a single event. The Federal Emergency Management Agency (FEMA) reported the Northridge earthquake as one of the largest and most costly federal disasters with initial cost estimates of total damages at \$25 billion.

Among the agencies cooperating in response to the Northridge destruction was Caltrans. Caltrans led the successful reconstruction effort and made two key decisions quickly after the earthquake: to rebuild the damaged freeways, and to retain traveler mobility and keep traffic flowing as smoothly as possible during the rebuilding efforts. Reference17 is a case study of

how this costly disaster became a model of incident management. Some of the key points are summarized below.

12.4.1.1 Restoring Regional Mobility

During the first week following the Northridge earthquake, many businesses and schools were closed, which significantly decreased the demand on the freeway network. Many people also stayed at home that week to repair their own earthquake damage. The first week after the earthquake, people began to return to their jobs and traffic volumes were steadily increasing. Early rough estimates indicated that repairs would take from 6 months to a year. While contract incentives made it likely that the freeway repair might be expedited, Caltrans knew that mitigation measures had to be implemented quickly to balance capacity and demand. Two primary measures were implemented to reduce strain on the highway network – alternate route and detours, and freeway demand reduction measures. For example:

- The use of local streets proved to be the most effective way to handle freeway detours. The damaged freeway segments were far enough apart that detour routes could be designed for each site exclusively without overlapping detour routes and related congestion at other damage locations. For the initial detour routes, Caltrans and the LADOT re-timed traffic signal at 300 intersections and installed 1,000 directional signs and 7,500 parking signs.
- In some corridors, separate detours were implemented for high occupancy vehicles (HOVs - 2 or more persons per vehicle) and single occupancy vehicles (SOVs).
- Caltrans developed a transportation management plan (TMP) to handle traffic until the damaged freeway sections were reopened. They also implemented an Emergency Detour Management Center with emergency communications equipment, helicopter surveillance, and traffic performance acquisition data as well as enhanced tow service, construction zone speeding enforcements, and park and ride lots.
- The Freeway Service Patrol was extended with 13 additional roving tow trucks in the earthquake-affected areas. Following the Northridge earthquake (January 17 – May 1994), 90 percent, or about 15,000, of all assists made by the FSP were on beats covering the damaged freeway areas.
- Following the earthquake, a \$12.6 million design/build contract was put into place to install new traffic monitoring and commuter information equipment to areas that were affected by freeway damage but were not covered by the existing traffic operations equipment. This included additional DMS, HAR, CCTV, and detector stations.
- The media played a large role in disseminating detour information in the days and weeks following the Northridge earthquake. Daily press conferences were held by members of Caltrans and FHWA to discuss the progress of the rebuilding efforts, the status of detours in the area and how advice for commuters to avoid earthquake damage. Newspaper inserts and brochures were also used to inform travelers of other options.

In order to completely restore regional mobility, transportation agencies understood that highway detours would not be enough. The Los Angeles region would have to begin to utilize alternate transportation modes (like transit, HOV, and telecommuting), which would be difficult

in the auto-dependent region. Transit agencies reacted quickly to the potential demand increases, extending service and decreasing service headways in an effort to provide mobility options to commuters. In some cases, fares were reduced. Three new park-and-ride lots also were created at strategic locations to encourage carpools and transit use.

12.4.1.2 Rebuilding

Rebuilding the Los Angeles regional freeway network required a sustained effort by Caltrans and unprecedented cooperation between local, state, and Federal Government agencies. Through demolition, construction bidding, and reconstruction, the agencies involved exercised innovative solutions to existing “red tape” problems to restore the highway network.

Caltrans used emergency contracting procedures to immediately begin debris removal and demolition activities. Caltrans was able to mobilize a demolition contractor and crew at each of the four major damage locations. The demolition of damaged highway infrastructure started on January 17, 1994, and operated around the clock until completion, using non-competitive bid contractors in all but one case.

In the first days following the earthquake, Caltrans and FHWA discussed bidding, and eventually signed a memorandum of understanding (MOU) on January 26, 1994, which outlined the following three bidding procedures:

- A+B Bidding is a “cost-plus-time” bidding procedure that selects the lowest bidder based on a combination of the contract bid items (A) and the amount time (B) needed to complete the project or a critical portion of the project. A+B Bidding is used to motivate the contractor to minimize the overall time on high priority and high usage projects. This encourages contractors to finish early by offering bonuses (incentives) for early completion and assessing fines (disincentives) for late completion.
- Invitational bidding was another procedure used to expedite contract administration by FHWA and Caltrans. This concept was used for those projects that had high user delay costs and an urgent need for early completion. These projects were expected to have short time frames for Caltrans to prepare the bid packages, greatly expedited advertising periods for the contractors to submit bids, and one-day bid openings and awards. Limiting the number of bidders on these critical projects allowed Caltrans to provide packages to the contractors quickly and answer questions.
- Design-build construction is another contracting mechanism that allows initial construction to begin before final drawings for design are approved. Following the Northridge earthquake, Caltrans had 70 design engineers in place and ready to begin work on plans for the damaged freeway sections. Contractors submitted technical proposals for construction work, and those proposals that met the minimum technical guidelines were allowed to participate in the price proposal section of the bidding.

In a report published after a review of transportation decisions made in response to the earthquake, the Transportation Research Circular (published by the Transportation Research Board and the National Research Council) reported several mobility findings:

- Providing immediate transportation solutions took precedence over the opportunity to change motorist behavior.

- Stabilization of traffic conditions took several weeks to several months.
- Where sufficient alternate routes existed, motorists continued driving; where convenient detours were not available, transit options became much more attractive.
- Availability of accurate traffic data was critical in developing emergency detours.
- Areas with well-developed traffic management centers were able to accommodate sudden traffic changes more easily.

12.4.2 September 11, 2001

The Terrorist attacks of September 11, 2001 exacted a terrible toll on the United States and fundamentally changed the way of life in America. Surface transportation has changed and continues to change in response to the attack. Agencies that own and operate surface transportation systems must understand the relevant lessons from the 9/11 experience and respond accordingly so that we as a nation are well prepared should we be attacked again.

Case studies have been developed documenting the actions taken by transportation agencies in response to the September 11 attacks on New York City and Washington D.C. An article in the September 2002 issue of ITE Journal (19) synthesized the findings from both studies. The highlights are summarized below

12.4.2.1 Advance Preparations and Planning

A coordination structure: The coordination of local, state and federal agencies responding to an emergency is an essential part of a pre-existing disaster plan. The Incident Command System (ICS) is a management tool used to handle emergencies and can be adapted to the specific needs of a community region.

Emergency response plans: Public agencies (in both New York and surrounding states) have detailed emergency response plans that are practiced routinely. These plans coordinate decision making both internally and externally in conjunction with the New York City Office of Emergency Management (OEM) (a multi-jurisdictional agency created in 1993).

Jointly staffed facilities: Agencies placed personnel at OEM to receive and pass-on commands to their agency's emergency response center. At agency emergency response centers, key players gathered to make decisions and relay them back to OEM and TRANSCOM. To aid in transportation operations decision-making during emergencies, TRANSCOM disseminated (both internally and externally) the decision of its 16 transportation and public safety agencies so that they could make informed decisions.

Working relationships: Key decision makers had experience in working with OEM, other transportation agencies and the public. These relationships helped support OEM on September 11, and, in general, gave the agencies and the public a level of confidence.

Individual initiative: Human creativity and teamwork become critical when the unpredictable happens. Every emergency, different in its complexity, requires personnel to make quick decisions that may have dramatic consequences on the safety of people in the area. The quality of the agency's staff, their ability to work together and their preparedness at all levels of the organization to handle difficult, changing situations is vital to a successful response.

Practice in a realistic environment: Practice in an emergency command center environment is a key element in smooth response to a disaster. An official at New Jersey Transit noted the importance of practicing for emergencies, and the recognized need to train not just the first string, but also the second and third string of employees, because disasters do not always occur during business hours. On September 11, a number of key transportation staff members were either lost or injured and the responsibility for decision-making fell to others. One field staff noted that “there was no one to talk to at headquarters; it was gone”.

12.4.2.2 Institutional Coordination

Established interagency relationships: The existence of well-established interagency relationships among the many transportation and emergency personnel in New York was an important factor in managing the situation. Through coordination entities such as TRANSCOM and the OEM, agencies built effective working relationships that proved to be a major sustaining factor during and after the crisis.

Internal command centers: Each agency, in addition to its participation in the multi-agency task forces, had set up an internal emergency command center. At the emergency command center, decision-makers were able to communicate with key individuals, both internal and external to the organization.

Coordination across agencies and jurisdictions: Coordination between transportation agencies and their counterparts in public safety and law enforcement was generally good, with just a few exceptions (e.g., the failure to coordinate the release of 260,000 federal employees and lack of notification regarding the intent to release employees caused an unexpected rush of commuters just as the region’s transportation network was winding down from the morning peak period service pattern.)

12.4.2.3 Communication

Multiple communication technologies: Immediate communication with agency field staff in NYC was difficult because landlines were damaged and cellular communication systems were overloaded. Two-way radios helped field personnel communicate during the evacuation; however, field personnel without radio communication were out of touch.

Voice and data communication: New technologies provided communication alternatives that proved successful in the emergency. Internal e-mail, for example helped agencies communicate decisions with their staff. Blackberry Pagers (interactive pagers with e-mail capabilities) that rely on data communication technology were a successful form of communication according to several transportation agencies.

Mobile communication assets: Agency communication centers were also successful in supporting both internal agency decision-making and external communication. Both NYC Transit and New Jersey Transit had mobile communication centers (transit buses equipped with satellite and computer technology), which were used as command posts for communication and decision-making.

12.4.2.4 The Role of Advanced Technologies and Operations

ITS technologies and the associated operations have a major impact. The following highlights a few specific examples of ITS technologies and operations that aided both agencies and travelers on September 11:

- Dynamic message signs and HAR were used to communicate real-time traveler information, along with Web sites advising travelers of road closings and transit disruptions. Both customers and facility operators benefited in having traffic diverted before it reached the bridges or tunnels. After TRANSCOM alerted I-95 Corridor Coalition member agencies of problems in the New York City region, these agencies used HAR and variable message signs (VMS) on I-95 as far south as Delaware and as far north as New Haven to alert travelers to avoid New York City.
- CCTV surveillance was found to be very valuable for assessing the progress and effect of traffic management operations.
- Signal system timing was reset for heavy evening rush. For example, in Washington and in neighboring Montgomery County, computerized traffic signal systems enabled these jurisdictions to handle the “early rush hour” as District workers self-evacuated. Additionally, signals were adjusted to facilitate emergency responders en-route to the Pentagon
- Ramp meters were also reset for heavy evening rush (but became a non-issue as they are only located on routes that were quickly closed to non-emergency vehicles);
- High occupancy vehicle (HOV) lanes were immediately opened to all traffic;
- Construction work zone lane closures were suspended;
- Transportation management centers served as focal points, and proved successful in communicating and disseminating agency decisions both internally and with the public.
- Traffic along key sections of the roadway system including bridges leading to Manhattan was measured, and the information was used to help determine changes in the hours of the lower Manhattan crossings SOV ban.

12.4.2.5 Redundancy and Resiliency

Redundancy in multiple critical systems: Redundancy, the ability to invoke backup for critical systems that fail, either partially or entirely, is imperative to consider in emergency response. The backup systems invoked for use in an emergency are determined by the nature and scope of the emergency itself.

Redundancy in the transportation network: The redundancy of the transportation system in New York helped evacuate Lower Manhattan on September 11 and restore mobility. The automobile is only one of many transportation options. On September 11, when the tunnels, bridges roadways and subways were temporarily closed, local MTA buses continued running above Canal Street, water ferries were pressed into expanded service and people walked. The

MTA was able to restore subway service by early afternoon on September 11 because of the redundancy in its subway tunnels.

Staff redundancy: The need for redundancy in staffing was highlighted when several key transportation decision makers were lost or temporarily missing in the attack. Critical decisions were made by personnel in the field who, at times were cut off from communication with headquarters.

Communication redundancy: The communication system was severely disrupted on September 11. NYC Transit was able to use its separate system to provide landline telephone service to local, state and federal emergency agencies when Verizon's network was disabled. Having the option to use various technologies including two-way radio, Internet, pagers, e-mail, voice and cell phone technologies allowed agencies to adapt to the constantly changing landscape.

Redundant utilities: Redundant mobile generators allowed for restoration of power to emergency control centers and allowed agencies to begin flood prevention efforts to preserve communications and subway tunnels from extensive water damage.

Redundant control centers: Redundant control centers helped enormously. Even though the NYC Mayor's OEM Command Center was destroyed when Seven World Trade Center collapsed, nearly every other major agency in NYC had an emergency control center that swung into action immediately. Moreover, a temporary OEM had to be re-located three times on September 11.

12.4.3 Closing

In closing, Reference 19 identifies the following five lessons learned that should be considered in future planning for emergencies and management thereof:

- 1. Pre-existing relationships among agencies and personnel are key to emergency management success.** Such relationships help transcend the different response approaches used by transportation, military, and law enforcement agencies.
- 2. Preparedness planning is another crucial element,** and must include the development of an emergency response plan and training for all shifts of workers. Planning helps establish relationships and define roles and responsibilities. Training field personnel as well as managers is vital, for they often must make critical decisions with little or no input from senior staff.
- 3. Redundancy must be built into institutions and physical systems,** including personnel, communications, utilities, and control centers. A new approach to redundancy is needed – a backup is not adequate if it is also exposed to failure in an emergency. The transportation infrastructure facilitates emergency response and evacuation, so an alternative network is critical, as are remote backup operations and emergency management facilities.
- 4. Multiple technical communication methods help ensure proper institutional communication.** Redundancy and resiliency in communications is critical. Systems that

depend on cell phones or landlines can be unreliable; an emergency response system should include both alternative technologies and redundant network connectivity.

5. Advanced technologies play an important role in communications and decision making. Traffic management centers, closed-circuit TV, sensor systems, dynamic message signs, advanced traffic control systems, Web sites, and geographic information systems were all identified as useful in aiding internal and external communication. Timely decision-making requires effective communication of accurate information. In the aftermath of disaster, ITS enabled facility managers to: make informed decisions, improve regional transportation management, and enhance communication with the public.

12.5 REFERENCES

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13. INFORMATION DISSEMINATION

13.1 INTRODUCTION

The effective dissemination of traveler information services supports many types of information requests and categories of travelers, and combines multi-modal information in an effective and timely manner. Information may be provided in a number of ways, including static information and real-time information. Static information comes from such sources as transit schedules, planned work zones, and known road closures. Real-time information comes from a variety of sources including roadway-based sensors, surveillance equipment, and drivers. The information assists travelers in selecting their mode of travel, route, and departure times – both pre-trip and enroute. Figure 13-1 illustrates the possibilities of range of data sources, processing and uses of traveler information. The figure depicts the various sources of data (left-hand side, and including freeway conditions) which are collected and centrally processed (central part of figure) to yield integrated information about the current and future travel conditions; and which are broadcast or disseminated to travelers, allowing them to make informed choices about when, where and how to travel (1).

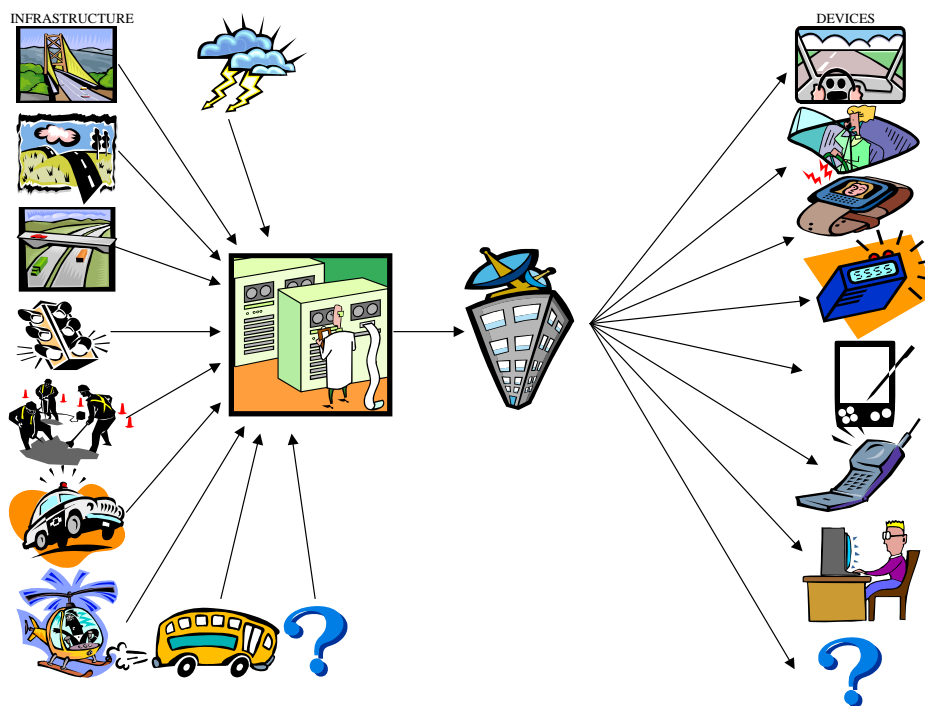


Figure 13-1: Sources and Uses of Traveler Information

(Reference 1)

As shown in the Figure – and like much that is discussed in this Handbook – the traveler information process extends well beyond the freeway, both in terms of where the information is

obtained and how it is distributed. Information on freeway conditions and the dissemination of that information to freeway users should therefore be viewed as part of a broader, region-wide, advanced traveler information system (ATIS).

13.1.1 Purpose of Chapter

This Chapter is a tool for freeway practitioners of all levels involved with the dissemination of traveler information. It provides overview of the wide breadth of information dissemination treatments from planning to operations, including:

- The elements of an information dissemination system,
- Its role in freeway management (and the operation of the surface transportation network),
- Issues involved in planning and commissioning for information dissemination,
- Potential technologies for disseminating the information, and
- Operational considerations

Some topics within this chapter are covered in greater detail than others – the greatest emphasis being placed on those technologies and strategies that are directly related to the operation and management of the freeway itself. For example, significantly more emphasis is provided for Changeable Message Signs (CMS) as compared to dissemination of traveler information via Information Service Providers (ISP's). CMS are located on the freeway right-of-way and communicate directly with the driver, even though the latter method may have a greater impact in the context of the overall surface transportation network. Regardless, many of the issues and principles noted herein are applicable to all forms of traveler information.

Another consideration is the availability of more detailed references. In these cases, the references are noted and summarized. The Federal Highway Administration (FHWA) also maintains a website with up-to-date information on the dissemination of traveler information in the country. Its address is http://www.ops.fhwa.dot.gov/Travel/traveler_info.htm. Another FHWA website dedicated to the 511 traveler information program can be found at <http://www.its.dot.gov/511/511.htm>.

13.1.2 Relationship to Other Freeway Management Activities

The Chapter is but one of many in the Freeway Management and Operations Handbook, and has been developed to “stand alone” within its topic area to a great extent. Not lost on this, though, is the relationship of other elements of the freeway and surface transportation network (i.e., chapters within this Handbook) as well as numerous other references to the topic of information dissemination. These other chapters and references, in cooperation with this Chapter, provide the practitioner with an essentially complete reference of information, guidelines and practices to successfully plan, commission, operate and maintain a traveler information system.

There are many freeway management activities that are related to or dependent upon traveler information dissemination; and to understand the role of information dissemination within the freeway management spectrum, it is important to understand the relationships with these activities. In other words, traveler information dissemination cannot be addressed in a singular fashion. As shown in previous Figure 13-1, before the information can be disseminated it must first be collected from a variety of sources, the collected information must be combined (i.e., data fusion), and the affects of the disseminated information on traveler behavior must be

continuously monitored and assessed. The following table itemizes those related activities and their relationship.

Table 13-1: Freeway Management and Operations Activities and Their Relationship to Information Dissemination

Activity	Relationship
Ramp Management and Control (Chapter 7) Lane Management and Control (Chapter 8)	For both ramp and lane management control, including construction and maintenance activities, it is important to convey the ramp or lane control conditions to the motorists. Devices typically attributed to traveler information, namely the changeable message sign (e.g., overhead lane control sign for lane management, portable CMS for construction), are used.
Traffic Incident Management (Chapter 10) Planned Special Event Management and Control (Chapter 11) Emergency & Evacuation Management (Chapter 12)	Critical to the success of these management strategies in conveying real-time conditions to the pre-trip and en-route travelers. In the case of Planned Special Event Management, conveying future conditions, both known and predicted, such as a lane or road closures, is vital.
Traffic Management Centers (Chapter 14)	Most Traffic Management Centers house the central systems that process information, and control and manage the dissemination.
Surveillance and Detection (Chapter 15)	The surveillance subsystem provides much of the information that is disseminated to travelers.
Regional Integration (Chapter 16)	Information is shared across jurisdictional boundaries and information conveyed to the traveler can be "regional" in nature, (i.e., the effected area may not be in the local control area of the system, but may still effect local travelers.)

13.2 CURRENT PRACTICES, METHODS, STRATEGIES, AND TECHNOLOGIES

13.2.1 Overview

The key to successful driving task performance is efficient information gathering and processing (2). Likewise, properly communicating with motorists is critical to successful freeway traffic management and operations. Motorists rely on a wide variety of information to properly accomplish the control, guidance, and navigational aspects of the driving task. The roadway alignment and general terrain itself provides a great deal of this information through visual "cues;" sources such as pavement markings and regulatory, warning, and guide signs also contribute greatly to the overall information system. However, in an effective freeway

management system, dynamic methods of conveying information to motorists or travelers are often needed to better operate and control the system.

Information dissemination is also managed in order to improve travel conditions in the corridor by influencing traveler behavior (by recommending diversion routes around an incident, for example). This information can be disseminated from a variety of sources (State departments of transportation, transit agencies, private-sector information service providers, etc.) using a variety of methods (changeable message signs, commercial radio traffic reports, traffic information kiosks, internet, etc.).

Traveler information can be categorized as either pre-trip or en-route.

- **Pre-Trip Traveler Information.** Pre-trip traveler information can provide the traveler with current roadway and/or transit information prior to deciding upon the time, mode, and route of travel. Whether provided to travelers at home, the workplace, park-n-ride facilities, transit stations, or multi-modal locations, this capability can help relieve congestion by giving the traveler the information to reroute, delay start of the trip, shift modes, or avoid travel altogether. Often, this information can support itinerary planning, which can provide information on a whole trip from one point to another, even if it involves multiple modes. Reliable pre-trip traveler information may also tend to spread the travel over space and time, making it more balanced. Convenience is essential to successfully implementing pre-trip traveler information systems. Touch-tone telephones, personal computers (Internet), pagers, personal data assistant (PDAs), kiosks, and automated data retrieval systems which augment existing human-operator interfaces have the potential to substantially improve the accessibility of desired traveler information, thus impacting travel behavior.
- **En-Route Traveler Information.** En-route traveler information can provide the traveler with current roadway and transit information while traveling en-route. Information is typically provided via devices deployed along the side of the roadway, or from devices mounted on the dashboard of the vehicle. Along the roadway, Changeable message signs and highway advisory radio messages typically provide information regarding traffic congestion, incident and construction locations, weather advisories, special events which may impact travel on a particular section of roadway, and alternative routes. In-vehicle and personal mobile devices can provide a variety of en-route traveler information to both the traveler as well as transportation providers. Mayday calling systems can alert emergency response and transportation system providers of a stranded or disabled vehicle's location. Sophisticated route guidance systems can assist motorists in route planning as well as providing timely directions via a computer synthesized voice.

Traveler information, pre-trip and en-route, can be categorized as either static or dynamic in nature. Static information can be defined as known or planned events, while real-time information can be defined as the most current available information at a given point in time. Real-time information differs from static information in that it continually changes based upon a wide variety of events.

- **Static Information:** Static traveler information required by travelers can include:
 - Construction and maintenance activities that reduce the number of travel lanes along a section of roadway.

- Special events that generate significant increases in traffic that can impact travel along specific roadways, and sections of roadways.
- Hours of operation of HOV lanes and carpool definition.
- Vehicle restrictions (height, weight, etc.)
- **Real-time Information.** Real-time information can be disseminated both pre-trip and en-route. As an example, incident information is just as critical to the traveler who routinely checks the real-time travel conditions along his or her normal commuting route as it is to motorists currently traveling along the route where the incident has taken place. Real-time traveler information required by travelers can include:
 - Roadway travel conditions associated with travel delay, such as congestion, locations of queues, and incident locations
 - Potential alternative routes which can facilitate travel, particularly in the event of a temporary roadway closure
 - Weather advisories detailing snow, ice, and fog which can impact travel
 - Park-n-ride lot status

Regardless of how it is provided, to be effective traveler information must be timely, complete, accurate, credible, available on demand, and perceived by the individual traveler as being relevant to their needs and providing a value when followed; otherwise, the information will be ignored. In general, for each inaccurate piece of information promulgated by the traveler interface elements, it will take numerous occurrences of accurate information to recapture the traveler's faith in the system.

13.2.2 Benefits

The dissemination of traveler information allows travelers to effectively plan their trip prior to departure; and when en-route, to avoid congestion and problems. Motorists and transit riders want to know their choices and know what to expect – such knowledge being a key attribute of “mobility”. Having accurate and real time information about the performance of the surface transportation network significantly improves the perception of a trip because this information allows travelers to make decisions that give them the sense of having more control over their life. Such knowledge not only gives the traveler better options; it removes a significant stress point, the unknown.

An ATIS case study and survey in Washington D.C. (3) indicates that that the vast majority of current ATIS users are satisfied consumers who feel they save time by utilizing these services on a regular basis. The research suggests that ATIS users do realize significant benefits in terms of time management – better on-time reliability, reduced early and late schedule delay, as well as more predictable travel. They do this, however, without significantly reducing the amount of in-vehicle travel time accumulated over a month or year of regular trip making. Overall, ATIS use proved advantageous in efficiently managing the traveler's time. Specific quantitative examples selected from the Washington DC case study include:

- Peak-period commuters who do not use ATIS were three to six times more likely to arrive late compared to counterparts who use ATIS;
- Cases where ATIS clearly benefits the user (e.g., ATIS user on-time, non-user late) outweighed cases where ATIS clearly disadvantages the user by five to one;

- ATIS users in peak periods are more frequently on-time than conservative non-users, yet they experience only two-thirds as much early schedule delay as non-users. Late shock, the surprise of arriving late, is reduced by 81% through ATIS use.

13.2.3 Key Considerations During Freeway Management Program Development

The dissemination of traveler information for a freeway management system (or a regional Integrated Traffic Management System (ITMS) that incorporates the freeway network) is an integral part of operating and managing the freeway. As such, it must be a key consideration in every aspect of developing the freeway management program, including the activities noted below (referring to Figure 3-1 from Chapter 3).

13.2.3.1 Stakeholders

The information needs of travelers extend well beyond an agency's freeway infrastructure, and include other jurisdictions' freeways, the arterial network, transit facilities, airports, etc. The traveler information stakeholders must include all of these concerns. Moreover, as discussed in Section 13.3 herein, the private sector will also be an active partner in the traveler information process, and must be included as a stakeholder.

13.2.3.2 Concept of Operations

Because information dissemination must be coordinated among the various partners, a portion of the plan should be devoted to a discussion of the management structure and the agreements that will be utilized to achieve this coordination. Items to be included in this portion of the plan include:

- Names of contact person(s) for each partner.
- Protocols and methods to be utilized to coordinate.
- Definition of each partner's responsibilities regarding information exchange.
- Overview of each partner's contribution to the effort (cash, in-kind exchange of equipment or services, etc.).
- Letters or memoranda of agreement regarding the desire to coordinate among partners.

Additional details may need to be included in the letter of agreement if some of the partners will jointly operate some of the information dissemination technologies to be implemented. For example, a transportation agency may wish to allow law enforcement personnel to access and utilize their changeable message signs or highway advisory radio equipment for managing major incidents during late-night hours when the transportation agency does not have someone on duty.

13.2.3.3 Performance Measures

In order to assess the extent to which information dissemination efforts within a freeway management system are meeting goals and objectives, a set of performance criteria and measures-of-effectiveness pertaining to these efforts must be identified. With respect to information dissemination, performance criteria have several different, yet interrelated, dimensions that are of interest, including:

- **Information credibility** – Information must be credible to travelers if it is to be utilized and have an impact upon traffic operations. The following criteria define how credibility is established (4): the information must be accurate; the information must be timely; and the

information must be relevant to its intended audience. This can be measured by a customer satisfaction metric.

- **Market penetration** – Market penetration refers to the percentage of the potential audience reached by the information dissemination efforts. Performance criteria regarding market penetration may be appropriate for evaluating certain system goals and technologies, particularly those emerging as part of Advanced Traveler Information Systems (ATIS). It is expected that some technologies, such as in-vehicle dynamic route guidance, will require only limited market penetration in order to achieve operational benefits. Other technologies, such as information kiosks in major traffic generators, may require agencies to strive for as great a market penetration as possible in order to distribute the information to a wider audience and possibly attract private sector advertising and sponsorship.
- **Traveler response** – Ultimately, the purpose of providing information to travelers is to effect some change in traveler behavior that will cause an improvement in safety or operations. Thus, performance measures are also needed to determine the extent to which information dissemination accomplishes this purpose. Changes in traveler mode, departure time, and route (if appropriate) are appropriate for evaluating the effectiveness of real-time travel-related information. However, it may be very difficult and expensive to obtain actual data for these measures. Traveler opinions about the effectiveness of the information being provided can be another important evaluation measure.

It is important to recognize that because of the complex travel patterns of travelers at any point in the roadway, it may not be possible to adequately measure the overall effects of many types of information or dissemination modes upon traffic volumes, speeds, or delays. The day-to-day variances in travel patterns themselves may mask the effects of any information disseminated during a specific event such as an incident, particularly if the information is intended for a very specific audience (such as vehicles within a freeway traffic stream destined for a specific downstream exit).

13.2.3.4 Evaluation

Care should be taken not to overestimate the benefits achieved by the implementation of information dissemination components in a freeway management program. Specifically, it is important to recognize that travel patterns in a freeway corridor are quite dynamic, and that some drivers will divert naturally when they encounter freeway congestion regardless of whether or not they receive information beforehand about that congestion.

It is also important to utilize the appropriate evaluation methodology. As noted in the aforementioned Washington D.C ATIS study (3), “if ATIS deployments are evaluated purely on time-savings, the benefits of ATIS will likely be grossly underestimated. ATIS users value improved travel reliability. The value of improved on-time reliability is not easily nor directly translated to purely monetary terms, but it is clear that many types of travelers can benefit from ATIS. Trucks delivering auto parts in a just-in-time manufacturing process may highly value any improvement in on-time reliability or reduction in early schedule delay. Commuters face an on-time requirement not only on the home-to-work leg of their daily trip making, but increasingly on the work-to-home return trip in order to meet daycare pickup requirements and other commitments. Improved reliability and predictability of travel are also likely good surrogates for reduced commuter stress. From this common sense perspective, it is clear that the benefit of

improved travel reliability and predictability from ATIS will outweigh whatever small return is generated from the monetary equivalents of aggregate travel time reductions”.

13.2.4 Relationship to National ITS Architecture

As indicated in Chapter 3, the National ITS Architecture provides a common structure or framework to promote compatibility and interoperability among systems, products, and services. The architecture defines the functions that must be performed to implement a given service, the physical entities or subsystems where these functions reside (e.g., the roadside or the vehicle), the interfaces / information flows among the physical subsystems, and the communication requirements for the information flows.

The National ITS Architecture can serve as the basic building block of the functional requirements definition process for detection and surveillance. The functions described in the National Architecture must then be detailed to match the needs and desires of the local agencies. The National ITS Architecture defines various ITS elements and strategies in terms of market packages. This concept recognizes that various ITS components must work together to achieve system goals. They are “tailored to fit separately or in combination-real world transportation problems.” The National ITS Architecture defines a number of Market Packages associated with traveler information. Those most relevant to freeway operations and management include:

- **Traffic Information Dissemination:** This market package allows traffic information to be disseminated to drivers and vehicles using roadway equipment such as Changeable message signs or highway advisory radio.
- **Broadcast Traveler Information:** This market package collects traffic conditions, advisories, general public transportation, toll and parking information, incident information, air quality and weather information, and broadly disseminates this information through existing infrastructures and low cost user equipment (e.g., FM subcarrier, cellular data broadcast). The information may be provided directly to travelers or provided to merchants and other traveler service providers so that they can better inform their customers of travel conditions.

Other traveler information market packages include “Interactive Traveler Information”, “Autonomous Route Guidance”, “Dynamic Route Guidance”, and ISP – Based Route Guidance, as defined in Reference 19. It is also noted that the draft Version 5 of the National ITS Architecture includes new market packages relevant to traveler information during emergencies – Wide Area Alert (which includes “Amber Alerts”) and Disaster Traveler Information.

13.2.5 Technologies and Strategies

Information dissemination components of a freeway management system can range from a single device owned and operated by one agency, to an integrated collection of devices and mechanisms under the control of several agencies and several private sector entities. In this Handbook, a basic distinction is made between kinds of information dissemination technologies depending on which of three main locations it comes from:

- Those located on the roadway where the information transfer to the traveler occurs at a specific point or within a very small segment of roadway (e.g., Changeable message signs or highway advisory radios.)

- Those located within the vehicle where the information transfer is not constrained to a point or a small segment of roadway (e.g., commercial radio, cellular telephone, personal computing devices, or in-vehicle navigation devices).
- Those located off of or away from the roadway altogether, typically at the origin of the trip (e.g., television, internet, personal communication devices, telephones, or kiosks in major traffic generators).

Specific technologies are discussed below.

13.2.6 Changeable Message Signs

One of the most fundamental technologies available for disseminating traffic-related information from the roadside is that of changeable message signs (CMS). CMSs are sometimes (and interchangeably) referred to as dynamic message signs (DMS) or variable message signs (VMS). The term "DMS" is generally used within the context of the National ITS Architecture (19) and the associated standards. "CMS" is the term used in the MUTCD (Reference 21); and is also the terminology most widely used in this Handbook.

CMSs are programmable traffic control devices that can usually display any combination of characters to present messages to motorists. These signs are either permanently installed above or on the side of the roadway, or portable devices attached to a trailer or mounted directly on a truck and driven to a desired location. Portable CMSs are much smaller than permanent CMSs and are oftentimes used in highway work zones, when major crashes or natural disasters occur, or for special events (e.g., sport events) and emergency situations.

When installed, CMSs become a part of the total motorist information system. Thus the information presented on CMSs and the placement of the signs must be consistent and compatible with static signs used on the freeway. Highway signs – both static and changeable – must project a message so that the driver can:

Detect the sign,

Read and understand the sign,

Make appropriate decisions based on the information gained from the sign.

And if necessary:

Initiate a control response, and

Complete the required maneuver. (5)

Section 2A.07 of the Manual on Uniform Traffic Control Devices (MUTCD – Reference 21) defines CMS as "traffic control devices", and requires that a CMS shall conform to the principles established in the MUTCD related to the use of signs within the right-of-way of all classes of public highways, and to the extent practical, the design and applications prescribed in Sections 6F.02 and 6F.52. Section 2E.21 of the MUTCD specifies that "Changeable message signs shall display pertinent traffic operational and guidance information only, not advertising."²⁴

CMSs perform a critical role on freeways. Such signs can furnish motorists with real-time information that advises them of a problem and in some cases, a suggested course of action. CMSs are also used to improve motorist safety and reduce traffic congestion and delay. CMSs can be used to manage traffic by displaying the following types of messages: (5)

- **Early warning** messages give motorists advance notice of slow traffic and queuing ahead and are effective in reducing secondary crashes. When used in freeway work zones, early warning messages also give notice of new detours, changes in detour route, changes in lane patterns, special speed control measures, etc.
- **Advisory** messages provide motorists with useful information about a specific problem along their route. This information allows motorists to change their speed or path in advance of the problem area, or may encourage them to voluntarily take an alternative route to their destination.
- **Alternative route** messages influence motorists to travel to their chosen destination by using different routes than originally intended. The alternative route is one designated by the transportation agency. In cases when the freeway is physically closed as a result of construction, crash, or natural disaster, the motorists are notified that an alternative route must be used.

Table 13-2 lists the applications for which CMSs can be used. (6)

Table 13-2: Applications of CMSs

Category	Applications
Traffic management and diversion	<ul style="list-style-type: none"> • Freeway traffic advisory and incident • Freeway-to-freeway diversion • Special events • Adverse road and weather conditions • Speed advisory
Warning of adverse conditions	<ul style="list-style-type: none"> • Adverse weather and environmental conditions (fog, smog, snow, rain, dust, wind, etc.) • Adverse road conditions (ice, snow, slippery pavement, high water, etc.) • Low bridge clearance
Control at crossings	<ul style="list-style-type: none"> • Bridge control • Tunnel control • Mountain pass control • Weigh station control • Toll station control
Control during construction and maintenance operations	<ul style="list-style-type: none"> • Advisory of upcoming construction/maintenance • Speed advisory • Path control
Special-use lane and roadway control	<ul style="list-style-type: none"> • Reversible lanes • Exclusive lanes • Contraflow lanes • Restricted roadways • Temporary freeway shoulder use control

For the purpose of this Handbook, Changeable message signs have been classified into two categories, namely: those that have a fixed number of messages available for display; and those that essentially have an unlimited message capability (References 4, 5, 6)

13.2.6.1 Fixed Number of Messages

Signs with a fixed number of messages (Figure 13-2) include the following:

- **Fold-out:** A fold-out sign is a conventional highway sign with a hinged viewing face. This type of sign can either display two messages (one with the hinged face closed, one with it open) or show a message only when the hinged face is open (no message is displayed when the hinged face is closed). Typically, signing materials that conform directly to the Manual on Uniform Traffic Control Devices (MUTCD) are used to make each message. For freeway applications, they are most often used to indicate icy bridge or other hazardous roadway conditions, or to indicate whether truck weigh stations are open or closed.
- **Rotating Drum:** Rotating drum signs are made up of one to four multifaced drums, each containing two to six message elements (i.e., lines). Three-sided drums are used as well, and are sometimes referred to “prism” signs. Each face of each drum portrays one line of a fixed message, and pivots about its axis in order to display the appropriate face for a given message. Newer technology uses multiple louvers creating each “line” of the message. Colors and lettering characteristics that conform to the MUTCD can also be used on rotating drum signs.
- **Neon or Blank-Out Signs.** Neon signs use neon tubing to form characters and messages that are to be displayed. Two basic sign designs are possible:
 - Separate each message on the sign face.
 - Stack the neon tubing for each message one over another.The stacked design has reported drawbacks, in that emitted light will be diffused as it passes through the overlaid neon tubing, reducing its legibility. Conversely, the separate message design will require a fairly large sign face in order to display even a moderate number of messages.

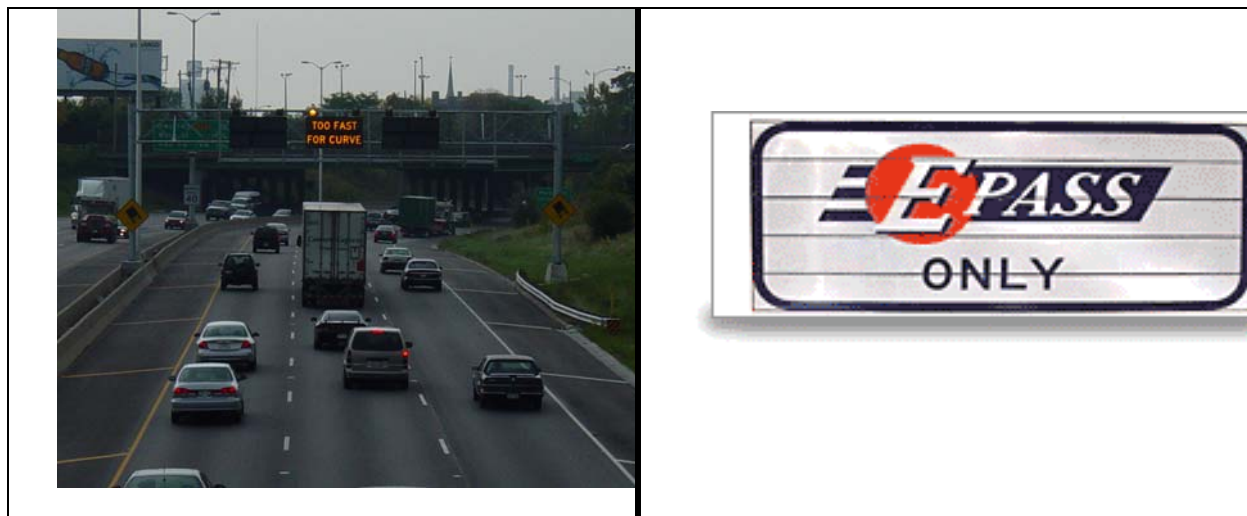
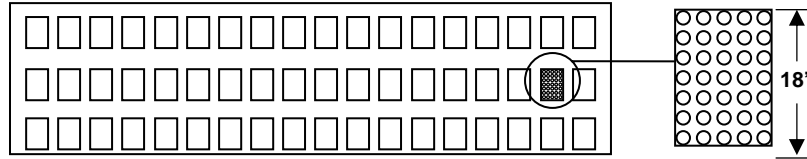


Figure 13-2: Example of Signs with Fixed Number of Messages

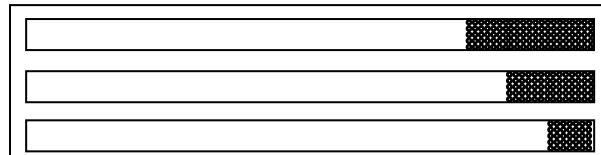
13.2.6.2 “Unlimited” Number of Messages

These CMSs display characters and symbols in a matrix format, which are generally designed in the following three patterns (7):

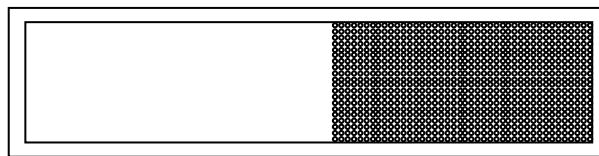
- Character Matrix:** In this format, each character of the desired message is composed of a 5 X 7 matrix of pixels. The number of character per line varies, depending on the manufacturers and the desired usage, although most transportation agencies deploy three-line, 18-character CMSs. Practically all highway CMSs display messages which use capital letters because the configuration of the 5 X 7 matrix does not lend itself to displaying lower-case letters.



- Line Matrix:** In this format, the display lines are separate from each other, with each line consisting of continuous matrix of pixels, as shown below.



- Full Matrix:** In this format, the entire display consists of continuous matrix of pixels, as shown below.



It should be noted that although line matrix and full matrix CMSs provide flexibility in displaying different characters and symbols varying in sizes, it has been shown that in many cases, fewer characters can be displayed on a line of continuous matrix or full matrix CMS than can be displayed on a line with character matrix because of the width required for proportional characters.

13.2.6.3 Matrix Technologies

Matrix technologies include the following:

- Reflective Disk Matrix.** These types of CMSs were very popular for freeway management purposes in the 1970s due to their low energy requirements relative to light-emitting CMS technologies. The viewing face of a reflective disk matrix CMS is comprised of an array of permanently magnetized, pivoted indicators that are flat matte black on one side and reflective yellow or a similar color on the other. The indicators may be square, rectangular, or circular in shape. An electrical current activated when a given pixel is to be turned flips the indicator from a black matte finish to the reflective side. A major disadvantage with disk signs is the need to illuminate the sign at night, sometimes causing glare or blurring

problems. Another potential problem is tendency for some of the disks to stick over time due to excessive dirt or moisture. Only a few new CMS use this technology today, except in concert with light emitting devices (i.e., hybrid signs as discussed later) or for small specialty signs (e.g., patron fare displays at toll plazas).

- **Shuttered Fiberoptic Signs.** Fiberoptic CMSs funnel light energy from a light source through fiber bundles to the sign face. In a matrix configuration, the shuttered fiberoptic CMS positions the ends of the fiber bundles on the sign face in an array similar to that used for other matrix signs. The light sources for all of the fiber bundles remain on constantly, and shutters at the ends of the bundles open and close to create the characters needed to display each message. These signs have experienced very low failure rates. The one potential disadvantage is the relatively narrow cone of vision, making sign placement relative to the drivers' eyes an important consideration.
- **Light-Emitting Diode (LED) Signs.** Light-emitting diodes (LEDs) are semiconductors that glow when voltage is applied. Typically, several individual LEDs are "clustered" together in order to create each pixel. LEDs have the added benefit of being able to display signs in full color. The reliability of LED lamps is very high. Like fiber optic CMS, the cone of vision is relatively narrow.
- **Hybrid CMS:** Hybrid CMS combine reflective disks with a light-emitting technology (i.e. fiber optic, LED). Hybrid signs offer several advantages – great visibility when the sun is shining directly on the sign face, and no need for external lighting on the sign at night. Hybrid signs also have the disadvantages of both sets of technologies.



Figure 13-3: Examples of Light-Emitting Matrix CMS Technologies
(Courtesy of Virginia DOT)

13.2.6.4 Sign Location and Design

The most critical locations for installing permanent CMSs are in advance of interchanges or highways where drivers have the opportunity to take some action in response to messages displayed on CMSs. A CMS should not compete with existing roadway signs. At times, relocation of some static signs may be required in order to install a CMS at a critical location. In general, a CMS should be permanently installed at the following locations: (4, 7)

- Upstream from major decision points (e.g., exit ramps, freeway-to-freeway interchanges, or intersection of major routes that will allow drivers to take an alternate route).
- Upstream of bottlenecks, high-accident areas, and/or major special event facilities (e.g., stadiums, convention centers).

- Where regional information concerning weather conditions such as snow, ice, fog, wind, or dust is essential.

The ease with which a sign can be detected in the environment (conspicuity) and the ease with which the message can be read (legibility) will enhance the effectiveness of motorists' visibility of the CMS and its message. In addition, the manner in which the message is displayed must be considered (e.g., if the message is too luminous, it can be easily detected but difficult to read because of glare.) Factors that affect the legibility of light-emitting CMSs include the character height; font style; character width (spacing and size of pixels); spacing of characters, words and lines; size of sign borders; and contrast ratio. (7)

The CMS designer and operator need to know about the actual site characteristics in the vicinity of the CMS. These characteristics dictate the amount of information that can be displayed. Among the items of interest are the following: (5)

- The operating speed of traffic on the roadway;
- The presence and design characteristics of any vertical curves affecting sight distance;
- The presence of horizontal curves and obstructions such as trees, bridge abutments, or construction vehicles that constrain sight distance to the CMS around the curve;
- The location of the CMS relative to the position of the sun (for daytime conditions);
- The presence, number, and information on static guide signs in the vicinity; and
- Whether or not rain or fog is present to degrade visibility to the sign.

Other design considerations include: sign size (which affects message length as well as support structure requirements), maintenance access (e.g., walk-in housings, front access), technology, viewing angle and distance, character size, and sign position relative to sun during various times of day and days of the year.

As discussed later, the maximum length of a message that should be displayed is primarily dictated by the amount of information drivers can read and comprehend during the period when they are within the legibility distance of the CMS. The maximum length of a CMS message is also controlled by the characteristics of the sign. These include the type of sign (LED, fiberoptic, etc.), the number of lines available, and the number of characters on each line. Each of these characteristics can have an effect on how far away the CMS can be read and, consequently, how much information can be presented to motorists. It should be the responsibility of the TMC manager/supervisor to assess the CMS characteristics and determine the maximum length of message to display.

Too often agencies will purchase CMSs before signing objectives and messages are determined. Often, this causes disappointment in the CMSs when these agencies cannot display the desired messages, or when the signs provide lower than expected target value and legibility for the environmental conditions present at the site. (4) Conversely, agencies may end up purchasing a more expensive CMS with capabilities that exceed their actual needs. (Additional information on developing CMS messages is provided in Section 13.3)

13.2.6.5 Portable CMS

The use of trailer-mounted CMS provides an agency with a great deal of flexibility. The signs, which are typically much smaller than permanent, over-the-road CMSs, are used most

commonly for temporary applications, such as maintenance and construction activities. They are usually diesel- or solar-powered and use wireless (cellular) communications to a central management point, making them a very attractive and flexible tool.

Portable changeable message signs are usually located at the side of the road, and do not sit as high as an overhead sign, which can impair drivers' visibility. Most are 3-line, 8 or 9-character signs, and although most have the capability of displaying multiple phases, they tend to be used with simple short messages to allow drivers to read and comprehend the message. The MUTCD states that no more than two phases shall be used to display a message. These signs use all of the aforementioned technologies. Figure 13-4 shows a portable CMS in a work zone.



Figure 13-4: Portable CMS in Operation in a Work Zone

13.2.6.6 Standards

The U.S. DOT strongly encourages state and local agencies to use DMS²⁵ standards. DMS standards are mature, they have undergone significant testing, and they offer immediate benefits for agencies by 1) providing interoperability between DMS and other NTCIP-compatible field devices running on common communications channels, and 2) enabling simplified administration of DMS subsystems, leading to easier overall administration. (8)

As of the time of writing this Handbook, the DMS NTCIP working group is drafting Version 2 of NTCIP 1203, *Object Definitions for Changeable Message Signs*. Version 2 represents a major upgrade in the functionality of the DMS standard. NTCIP 1203 allows integration of DMS devices and products from multiple manufacturers into a single system using standard communications and data. Version 2 adds features such as graphics and device status reports. This version also restructures the standard to make it easier for end users to specify product

attributes and/or capabilities. A major benefit of Version 2 for end users concerns customization. Version 2 adds features and functions, such as color, that could be obtained previously only by deviating from the standard through customization.

The "Specification Guide for Procurement of NTCIP-compliant Dynamic Message Signs (Reference 9) is a tool by which practitioners may develop a meaningful NTCIP procurement specification to purchase interoperable and interchangeable DMS. As a rule, the document does not require specific features; rather it defines how the user may include such requirements within a specification. For example, the sample wording in reference indicates how one would specify how many messages the sign should store, but does not specify a quantity as that is a project-specific decision. It is emphasized that reference is "not intended to be an educational tool explaining the concept of operation for DMS"; rather it assumes the reader / specification writer has an understanding of DMS functions and technologies.

13.2.7 Highway Advisory Radio

Although not as widely used as CMS, Highway Advisory Radio (HAR) is another means of providing highway users with information in their vehicles. Traditionally, information is relayed to highway users through the AM radio receiver in their vehicles. Upstream of the HAR signal, users are instructed to tune their vehicle radios to a specific frequency via roadside or overhead signs. Usually, the information is relayed to the users by a prerecorded message, although live messages can also be broadcast.

Highway advisory radio (HAR) is an effective tool for providing timely traffic and travel condition information to the public. It has various advantages and disadvantages. Its most important advantage is that it can reach more travelers, or potential travelers, than Changeable Message Signs (CMS). While CMS's reach only those motorists at a particular point, and can only convey a short message, HAR has the advantage of being able to communicate with any persons in their broadcast range. Further, the amount of information that can be conveyed is much greater. Its primary disadvantages are that it is restricted to low power, and this leads quite often to poor signal quality (since it is affected by many outside forces such as weather), and it requires the driver to take an action (i.e., turn on the radio or change the station or both). This can lead to poor listenership.

HAR is an element of the Federal Communication Commission's (FCC) Traveler Information Systems designation. They are permitted under strict FCC guidelines and regulations associated with technology and operations. They are licensed as a secondary user, which means simply that they cannot interfere with a primary user, i.e., a commercial broadcast station. As a secondary user, HAR broadcasts are restricted in signal strength, a level that limits their transmission range to no more than three or four miles from the transmitter. A number of technologies are available for HAR transmission, using both AM and FM bands.

Typically, HAR has been implemented using 10-watt AM transmitters. This is because, beginning in 1977, it was the only technology permitted by the FCC for traveler information. As such, this technology implementation has also proven to be the most effective. Other means involve very-low power AM transmission, where multiple transmitters are spaced closely together to form a large area of coverage. This application, however, has not proven very successful. As late as 2000, the FCC ruled to allow the use of low-power FM transmission for TIS. This technology has limited application to-date.

Urban areas typically present a unique set of challenges to HAR application. Tall buildings present an obstacle to uniform transmission since the FCC restricts antenna height to approximately fifty (50) feet. High-power electric lines can incur noise on the transmission that negatively impacts broadcast quality.

Messages are broadcast in the field from transmitters that play stored messages. These messages are transmitted to the field from a “central” location, which can be a traffic control center or any telephone. In its simplest form, no central system is needed, only an analog phone line to the transmitter so that an operator can record a message in the transmitter for broadcast. This is labor intensive if an agency maintains a number of transmitters, and traffic conditions change throughout the day. Its advantage is that it is inexpensive, and message can be sent to a transmitter from anywhere a phone exists, even from a cell phone. Alternatively, a central message distribution system is used to record new messages, store pre-recorded messages, and distribute messages to the transmitters (simultaneous if necessary). This is typically a PC-based system with security access control.

13.2.7.1 Field System

The transmitters and other broadcast components are located in the field. (Figure 13-5) There are multiple technologies available for HAR application.

10-Watt AM Transmission (FCC Licensed)

This is the most common HAR application. When properly maintained and installed, 10-watt transmitters have a broadcast radius of approximately 3-5 miles depending on topography, atmospheric conditions, and the time of day. Frequencies used are generally located at the extreme ends of the AM band using specific frequencies based upon the availability of “holes” in the spectrum left by government and commercial stations. New FCC rules permit HAR to be broadcast on any frequency between 530 kHz and 1710 kHz provided an FCC license is obtained. The FCC rulings have also opened up the former dedicated HAR frequencies, 530 kHz and 1610 kHz, to commercial broadcasting, thereby increasing the potential for interference or possibly the loss of a license.

The characteristics of the broadcast are also affected by the frequency used. The lower ranges of the band (e.g., 530 kHz) are adversely affected by power lines (because of its long wavelength). It also has problems with signal fade, which causes distorted transmission for a reasonable distance along the outer (fringe) areas of the coverage area. Because of this, it is uncommon to find any commercial broadcasters on this end, which is an advantage. On the other end of the spectrum, power lines have less impact on the signal, and a crisper fringe transmission.



Figure 13-5: Highway Advisory Radio Station Along Freeway

Digital Highway Advisory Radio

Digital HAR eliminates many limitations of traditional dial-up systems, and improve quality of messages being broadcast to the traveling public. While dial-up systems typically operate over analog phone lines, advanced computer-controlled systems use digital signal processing to optimize performance.

Compared to traditional dial-up systems, “digital HAR” offers increased speed of message updating, centralized management of multiple stations, enhanced reliability, superior audio quality, ease of operation, and automated event logging. The time required for an operator to update audio at a remote site from the central control unit can be as little as two seconds. This can be accomplished through a simple “drag & drop” operation using a specialized Windows program. A Windows environment also easily allows for control of multiple HAR stations from a single central location.

Digital control provides closed loop operation assuring that messages and commands are received exactly as downloaded. There is no guessing about what is occurring at the remote sites. Analog phone lines typically limit audio bandwidth to about 2.5 kHz reducing the quality of the audio motorists receive on their vehicle radios. If desired, digital messages can be downloaded to remote HAR sites at CD quality provided that FCC imposed bandwidth limitations are satisfied.

Low-Power AM Transmission (No FCC License Required)

Low-power HAR has been developed as a means of tightly controlling the broadcast zone and thereby limiting interference from adjacent zones. Low power HAR differs from the previously discussed 10-watt HAR in that its broadcast radius (per transmitter) is generally limited to 500 feet to 1500 feet. By FCC regulation, each transmitter is limited to a maximum 0.1 watt power input to the final frequency stage, and the total length of the transmission line, antenna, and ground lead can not exceed 3 meters. Whereas this limits its broadcast range, it also provides for a reasonably well-defined area of influence, which, through an inter-connection and synchronizing process, permits upwards of 100 transmitters to be coordinated into larger and well-defined saturation zones. Once a car leaves this broadcast area, the signal quality becomes too weak to be heard. This permits a second zonal configuration to be established nearby, transmitting a different message on the same frequency.

By using this concept, a series of zones all operating on the same frequency, may be established whereby unique site-specific messages may be transmitted to provide condition updates in advance of decision points. Aside from the flexibility provided in establishing multiple message zones, low-power HAR may also broadcast over any available AM radio frequency without the need to obtain additional FCC licensing approval. Though the ability to install a system without FCC approval provides the user with great flexibility in installing a system wherever desired, there is no guarantee that once installed, it will not be interfered with by some future more powerful transmission.

The relatively low signal strength must compete with a variety of obstacles, including overpowering commercial broadcasts, signal skip (particularly at night), and poor signal propagation. These difficulties can be overcome by saturating an area (zone) with multiple transmitters and synchronizing their broadcasts. However, this concept is relatively new and, very expensive as the number of transmitters required is large.

Low-Power FM Transmission (FCC License Required)

LPFM service is available to noncommercial educational entities and Travelers' Information Station entities, but not commercial operations or individuals. Maximum effective radiated power for these stations is 100 watts, and the LPFM stations will not be protected from interference caused by full service stations that make changes to their operations. A construction permit or license is required before construction or operation of a LPFM station can be initiated.

Low-power 100-watt FM transmitters, when installed properly, have a broadcast radius of approximately 3-5 miles depending on topography and atmospheric conditions. 10-watt transmitters have an effective range of 1-2 miles in radius. At present, LPFM licenses are not being issued for HAR. The FCC only opened the application process for frequencies for a short time period. The FCC is non-committal about if and when this technology will again be available for HAR.

13.2.7.2 Deployment strategies

HAR can be broadcast in two ways: Point or Wide-Area coverage.

- In Point broadcast, a single transmitter is used to broadcast over a given area. This is typically used at diversion points or areas of recurring congestion to notify motorists of queues and congestion. This type of implementation is popular with travelers because the information is specific to them. This is the most common application for HAR, and typically utilizes 10-Watt transmitters. It is the simplest to manage in terms of equipment to maintain.
- Wide Area Broadcast transmits a signal to a larger coverage area using multiple synchronized transmitters. This is an effective strategy when a single message is applicable to a large coverage area, and the coverage area is sufficiently large for a motorist to hear the longer message length. The fact that a long single message, that is pertinent to specific travelers for only a part of the message is indeed a disadvantage. Studies have shown that travelers want brief, specific information, pertinent to their location and situation. They are not likely to listen for long periods of time until their information is broadcast. Technically, synchronization is difficult to accomplish between transmitters because both the time and repeated voice signal must be in sync.

13.2.7.3 Portable and Mobile Systems

Portable systems permanently installed on trailers and mobile systems installed on service or maintenance vehicles can be of value in providing timely dissemination of information to motorists during short-term deviations from normal highway conditions. This is particularly true in areas where there is limited or no normal coverage or the permanent transmitter site has failed. These systems can be solar powered, generator powered, or battery powered. (Figure 13-6). Portable / mobile systems can be set up at decision points where a route guidance system directs motorists to an alternate route. This will increase motorist comfort level by reinforcing their confidence that they are following the alternate route instructions correctly.



Figure 13-6: Portable Highway Advisory Radio Station

13.2.7.4 Message Distribution

A number of decisions pertaining to the message distribution must be made. One alternative is centralized recording, storage, and playback of messages where transmission lines for audio connectivity and time synchronization with selected transmitters need to be considered. In this alternative, messages are created and stored at a central operations center. The audio is typically retrieved from a digital recorder system and is transmitted via a distribution network to the appropriate HAR controller for radio broadcast. Distribution circuits/lines of this type are commonly referred to as transmission lines because they transmit the actual audio signal to the transmitter. However, the bandwidth on these transmission lines is limited, thereby affecting the quality of the audio signal once it reaches the transmitter site. This quality is further degraded by bandwidth limitations on AM channels. This can be partially corrected by the installation of audio compensation equipment at each transmitter site. In addition to the audio transmission, separate circuits or functionality must be used to control the remote transmitter. This architecture is also subject to single point failures at the central operations center.

A second alternative is distributed recording, storage, and playback where all system functionality is remote to the field HAR station. In this case, data circuits would be used to select the message to be transmitted, control the transmitter, and provide the timing synchronization, if required. A library of standard messages, phrases, and/or individual words are created at, or under the supervision of, a central operations center. The audio information for these "canned" messages is either downloaded into message storage at the HAR site or is transported there and installed in the station's recorder/player. As with central site storage, an ITS central processor could be used to create or select the appropriate message, phrase, or word combinations. Message selection for broadcast, and control of the transmitter controller and digital recorder/player are all done via remote commands from the central site. The type of distribution circuits / lines used are commonly referred to as control circuits because they "control" the remote equipment. Because they must be capable of sending a live message to a transmitter from the central operations center, these lines must also function as transmission circuits when necessary. A distributed storage system is inherently more robust and less vulnerable to single point failures than a centralized system.

13.2.7.5 HAR Signing

HAR signs, indicating the frequency at which traffic information is available, are typically installed throughout each zone. These signs usually include flashing beacons that are activated only when a message of some predetermined level of importance is being broadcast and a legend reading (or similar) "TRAFFIC ALERT WHEN FLASHING." (Figure 13-7) This technique permits the system to continuously broadcast "default" messages in each zone during non-congestion periods, while alerting the motorist to an urgent/emergency message by turning on the flashing beacons, thus preventing motorists from tuning to the HAR frequency only to hear the default message time and time again -- situations that could negatively impact system credibility. CMS can also be used to alert the motorist to the broadcast of a message of the utmost importance.

These signs can be controlled through phone lines, or with cellular or paging technology, and can be solar powered with battery back up. They offer a great deal of flexibility, by allowing only the pertinent signs to be activated. For instance, while two signs (one in each direction) may be

associated with a particular transmitter, only one would be activated for a downstream incident, thereby eliminating any loss in credibility by notifying traffic in both directions, one of which, the information is irrelevant.



Figure 13-7: Highway Advisory Radio Sign

13.2.7.6 Automatic Highway Advisory Radio (AHAR)

Automatic highway advisory radio (AHAR) provides a method to overcome the need for HAR signing and manual tuning to the HAR frequency. The traveler information is the same as traditional HAR; the automatic part of the system is tuning the radio to the HAR frequency. The AHAR transmitter sends out a leading message, which is picked up by a special in-vehicle receiver when the vehicle enters the AHAR zone. The message automatically tunes the radio to the AHAR station and mutes any regular radio broadcast until the AHAR transmission is complete.

A form of AHAR has been implemented in Europe via the “Radio Data System [RDS] Traffic Management Channel [TMC]”. This system relies on a silent data channel broadcast via FM from existing radio stations.

13.2.8 **Telephone-based Traveler Information**

An in-vehicle communication technology that has seen dramatic growth in the past few years is cellular telephones, which gives the motorist the ability to call special “hotline” systems for traffic information from within their vehicle. Originally, these systems allowed motorists and transit users to call for information to assist in pre-trip decisions from their homes. Information can now be accessed en route via cellular telephone, and decisions can be made whether to alter travel routes. The creation of call-in systems has been a popular traffic impact mitigation strategy for many major urban freeway reconstruction projects in recent years.

This type of in-vehicle communication has the advantage over HAR of giving the motorist some control over the type and amount of information he/she wants to obtain through the touch-tone

menus. In addition, it is also possible to generate two-way communication between the motorist and the information source.

Recommendations for establishing cellular telephone-based systems include the following:

- The caller should only be charged for airtime according to his or her cellular calling plan. No additional fees should be charged.
- The telephone number must be easy to remember and dial.
- The information must be concise.
- If a menu system is used, a long and tedious menu selection process should be avoided.
- A sufficient number of telephone lines should be provided to prevent the majority of users from receiving a busy signal.
- If a system is going to be used to gather information from users, there must be a method of ensuring the accuracy of the incoming information.
- “Official” use of tipster information should include procedures for verifying that information.
- If incident information is to be received, a human operator is recommended so that secondary questions can be asked to clarify confusing or unclear reports.

As with HAR systems, this technology also requires action by the motorist to access information. Depending on the users calling plan, there may also be significant operating costs associated with this technology, (as any calls made using cellular telephones must be paid for by either the motorist, or a public agency, or else absorbed by the corporation providing cellular telephone communication capabilities in the region). Finally, there is some concern that cellular telephone usage while driving may degrade motorist attention and operating capabilities. Manufacturers have developed “hands-free” telephones (typically with headsets) that allow motorists to listen and talk without holding the telephone receiver. Moreover, some states (e.g., New York) have adopted a hands-free law requiring operators of motor vehicles to use hands-free assistance when using a mobile phone. Nevertheless, the need to push the telephone buttons to go through a menu of information operations can defeat the “safety” purpose behind hands-free devices, unless the telephone service has voice recognition capability (i.e., saying a number instead of pushing the keypad button).

13.2.8.1 511

Understanding the importance of consistence and simplicity in providing telephone-based traveler information, in 1999, the U.S. Department of Transportation (USDOT) petitioned the Federal Communications Commission (FCC) to designate a nationwide three-digit telephone number for traveler information. This petition was formally supported by 17 State DOTs, 32 transit operators, and 23 Metropolitan Planning Organizations and local agencies. On July 21, 2000 the FCC designated “511” as the national traveler information number.

Simply put, 511 is an abbreviated three-digit dialing code; a short cut to a ten-digit telephone number for obtaining traveler information from a telephone. In petitioning the FCC, USDOT had to demonstrate the need and benefits for such a number. To that end, the USDOT identified the following: (10)

- Over 300 telephone traveler information systems in the U.S. could benefit from one such number
- Demonstrated value of traveler information services to the public
- 72% call volume increase N11 vs. easy 7-digit number

- 10-digit dialing makes numbers harder to remember
- Area code expansion making 7-digit numbers less plausible

Further benefits are realized. 511 puts a “face” on ITS and transportation operations, while increasing attention on the potential for traveler information services. With 511, transportation agencies can offer easier access to information via telephone, and have the same number work in multiple places. It is not uncommon for traveler information numbers to change across jurisdictional boundaries, creating confusion among motorists.

A number of issues must be addressed when implementing a 511 service. The following system considerations are taken from the 511 Deployment Coalition’s, “511 America’s Travel Information Number, Implementation Guidelines for Launching 511 Services”, version 1.1, June 2002 (Reference 12):

- **System Access Quality:** The ability of the telephone system to reliably and quickly answer calls.
- **Hours of System Operation:** The days and hours that 511 service should be available to callers.
- **ADA Implementation:** Complying with accessibility laws and regulations.
- **Environmental Justice:** The relationship of 511 and environmental justice principles that prevent discrimination against minority and low-income populations.
- **Standards:** 511 and National ITS standards.
- **Privacy:** Privacy protections for callers.
- **911 Linkage:** Relationship of 511 services to 911 services.
- **511 Branding:** The creation of a brand identity for 511 services to manage consumer expectations.
- **Number Allocation and Service Coordination:** Organizing and coordinating transportation agencies in a given region to determine what 511 services will be offered, by whom and in what geographic area(s).
- **Inter-regional Interoperability:** How 511 services interconnect.

To reduce the potential for service confusion and inconsistency, the 511 Deployment Coalition offers other guidelines for implementing 511 services. The guidelines include: (12)

- **Content guidelines** that focus on defining the information that should be provided by a basic 511 service. The guidelines recommend that every 511 system deployed in the United States provide at minimum the basic content as defined in the document. It is this basic content that callers will associate with the core of 511. A summary of some possible optional content categories also is provided.
- **Consistency guidelines** that address steps that implementers can take increase the degree of uniformity and consistency of 511 service across the country. The consistency guidelines cover 15 separate issues, such as user interface, and time stamping of information.

As of the end of 2002, 32 “511” programs have been, or are readying to be, implemented in 27 states. In December 2002, a total of 741,841 “511” calls were received totally over 978,000 minutes of usage. (11). These systems differ greatly, from simplified versions where a live operator answers and responds to all calls of all nature to automated systems where the caller

is routed through a menu system to obtain information specific to their travel location. An example is shown in Figure 13-8.

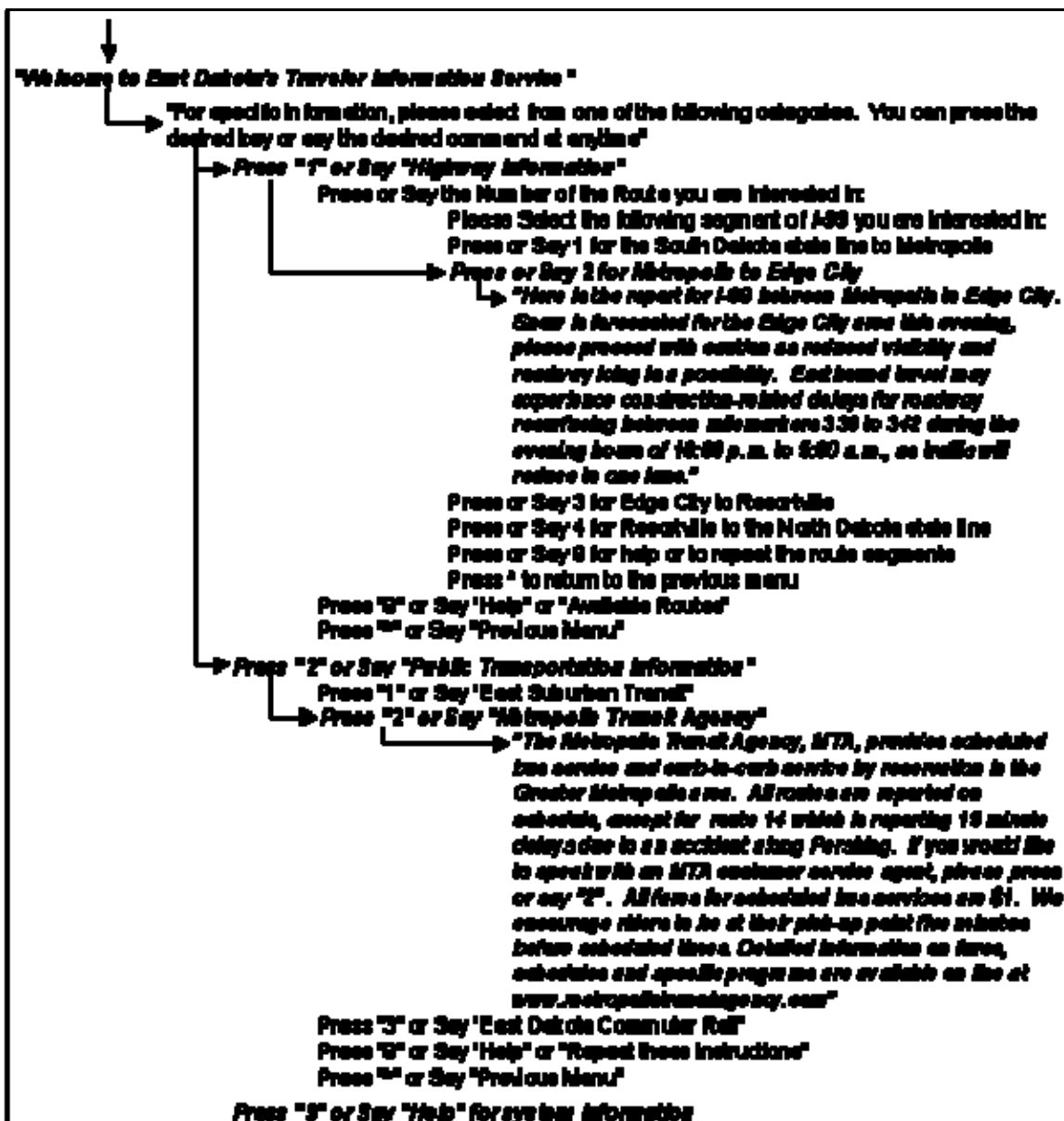


Figure 13-8: Example of a Basic 511 System

(Reference 11)

Additional information on 511 is available from “Resource 511”, a repository of information for the 511 deployment community (e.g., marketing ideals, implementation guidelines, evaluation), available at <http://www.deploy511.org>.

An example of a 511 scheme is “CARS-511”. CARS-511 is a road reporting system that utilizes information, which was created within the CARS multi-state database of highway events. CARS-511 provides timely information to travelers who can access this information via a telephone by simply dialing “5-1-1” on the touch pad. Authorized staff use CARS to input construction, accidents, delays, and other roadway, weather and tourism information into state-wide databases, using standard web browser software. CARS servers also support routine DOT dispatch, press release and emergency response activities.

The information entered into CARS is then continuously updated to the CARS-511 system. CARS-511 provides traveler information through a variety of categories including urgent reports, routine reports, road weather and it also provides transfers to outside phone numbers that provide transit-related information. Eight of the ten CARS Pooled Fund States have elected to participate in the CARS-511 initiative. These States are Alaska, Iowa, Kentucky, Maine, Minnesota, New Hampshire, New Mexico, and Vermont. CARS-511 was first launched with the Minnesota DOT on June 30, 2002.

13.2.9 In- Vehicle Devices

13.2.9.1 Commercial Radio

The public has learned to depend upon the media to provide them with “almost” real-time traffic information. Commercial radio has proven to be a good means of providing travelers with traffic information both in and out of their vehicles. Traffic and roadway condition reports have become standard programming items on many commercial radio stations. Commercial radio has the best potential of reaching the greatest number of commuters, since most of them have radios (and listen to them) in the vehicles they drive to and from work.

The primary disadvantage of using commercial radio relates to the accuracy of the information and the level of detail provided. Traffic reports often are transmitted only when normal scheduling permits. Most major metropolitan areas have stations that report traffic every 10 minutes; but the available time is limited, meaning that only the worst situations are reported. Moreover, with other stations, there may be considerable time delays between when an incident occurs and when it is reported. The accuracy of the information provided by commercial radio is a function of the time between the broadcaster’s last communication with the incident reporting source and the number of incidents that have occurred and/or have been cleared during that time.

Some transportation agencies have made substantial efforts to improve coordination and cooperation between themselves and the media traffic reporters. For example, some agencies allow private traffic reporting agencies to place personnel in the traffic management center to obtain information on traffic conditions and expected agency responses in an accurate and

timely manner. Other means of working with the media include providing the media with real time data feeds, congestion maps, and video feeds.

13.2.9.2 Video Display Terminals

A video display terminal (VDT) mounted in the dashboard, with wireless communications, is another form for providing information to motorists in their vehicles. This is primarily a private sector industry, which has not been used widely for information distribution. These systems can be used to provide motorists with route guidance and navigational information in one of two different formats. One approach is to present the driver navigation and route guidance information in the form of maps or equivalent displays. With these systems, a global picture of the traffic network can be provided. Recommended routes can be highlighted on the video map display as well. In another approach, simple symbolic signals (e.g., arrows, text instructions, or a combination of both) guide the driver along a recommended route. Some systems use a variety of displays depending upon whether or not the vehicle is in motion, the functions selected, and level of informational and navigational displays available.

In-vehicle VDTs offer a number of advantages over available technologies in providing information to motorists while driving. These include the following:

- Travel information is more readily accessible to the driver (providing continuous access to current position, routing, and navigational information).
- Computer-generated navigational maps and displays are logical extensions of traditional forms of providing drivers with route guidance and navigation information.
- Information can be displayed in text, graphics, or both and tailored to the needs and desires of each motorist.

There are also limitations to in-vehicle VDTs. These include the following:

- Drivers have to take their eyes off the roadway in order to receive the information.
- In-vehicle VDTs present the driver with complex maps and diagrams that may create a potential to overload the driver with too much information.
- VDTs may also add to the visual clutter already inside the vehicle.

As technology continues to improve, the Head-Up Display (HUD) has become another alternative to in-vehicle VDTs for presenting visual navigational and route guidance information to motorists. Although originally developed for the aviation industry, several automobile manufacturers are beginning to develop HUDs for presenting vehicle status and navigational information to drivers. A wide variety of options for displaying information may be available using HUDs. Through both icons and alphanumeric text, navigation and route guidance information may be projected directly into the driver's field of view. This is expected to reduce the need for visual scanning between two information sources (the inside instrument panel and the outside environment), and the associated visual accommodation time.

13.2.9.3 Subscription Services

A number of private providers supply traveler information services on-demand as a subscription. Most notably, General Motors' (GM) OnStar is a 24 hours a day, 7 days a week motorist assistance system installed in the vehicle. It provides a wide range of services to the driver including concierge service, telephone service, remote unlocking of the car, notification of air-bag deployment just to name a few. Another feature it provides is route guidance to motorists.

The motorist initiates a call from a button installed in the car, and is connected to a live OnStar operator, and asks for directions. The operator knows the vehicle's location through OnStar's automated vehicle location system, and provides directions for the fastest route. OnStar currently uses third-party wireless analog networks, and is moving to a digital technology, which will allow the service to be expanded to handheld devices as well. 53 current (2003) vehicle models are offered with OnStar, and GM intends to expand to 60 models by the end of 2003. Routing assistance is the most utilized services, and OnStar reports that it handles more than 220,000 routing call per month.

Internet subscription services are addressed in the following section.

13.2.10 Other Methods

13.2.10.1 Television

Television (together with radio) was one of the first off-roadway motorist information technologies available to motorists. Even today, commercial television stations in most major cities provide traffic reports to viewers as part of their morning programs to indicate incident locations, closures, and other traffic "hotspots." These locations are usually shown on some type of wall-mounted or computer-generated map display, often coupled with video images from planes / helicopters, a privately – owned network of cameras, video images from FMS cameras, or some combination. In some instances, the TV reports are broadcast directly from the TMC. Another option is for the cable TV franchise to allow the DOT to provide continuous traffic coverage (e.g., cycling through real time video feeds) during peak periods or throughout the day.

13.2.10.2 Personal Data Assistants (PDAs)

Personal Data Assistants (PDAs) are the next higher level of sophistication in both off and on - roadway information dissemination technology. PDAs are computer products that have enough power to support applications such as time management and handwriting recognition. By adding radio frequency (RF) communications technology, PDAs allow users to interact directly with travel information systems. This interaction allows users to obtain route planning assistance, traffic information broadcasts, and other pertinent information. Through keypad entry, the user can log on to the information system, request pertinent information, and then log off. PDAs offer the user increased communication and information transmission/receiving power over alphanumeric pagers.

13.2.10.3 Computers (Internet & Web Sites)

On-Line services to access the Internet represent an additional means to disseminate pre-trip traveler information. The Internet's effectiveness as a fast and flexible communication medium has spurred explosive growth in all sectors of society. The network is now in daily use by people in all professions.

Most state and many local DOT's have web sites that include traffic information²⁶, with the freeway management system often providing much of the information (e.g., data, maps, video). Several private Information Service Providers also have web sites providing similar information for multiple cities. Many of these sites provide:

- Real-time traffic flow information via color-coded maps

- Road closure information (e.g., for construction or maintenance)
- Real time video images (still captures or streaming video)
- Camera selection.
- Travel advisory information for route planning
- Links to other web sites
- News and weather.

Examples are provided in Figures 13-9 through 13-11. It is worth noting the different legends that are used to describe states of traffic flow and levels of congestion to the traveling public.

Some of the more sophisticated sites provide pre-trip and en-route traveler information with a subscription service (either free, or for a fee, depending on the service) for automated travel advisories via e-mail, pagers / PDAs, or cell phones. When they sign up for the service, subscribers input a travel profile (e.g., primary / alternative routes, times of day) and their choice of device(s) for receiving information. They are then alerted whenever there is an incident or other travel problem on these routes during their travel schedule.

13.2.11 Emerging Trends

As previously discussed, “511” telephone-based traveler information is still emerging as a trend through the Nation. Each implementation brings with it new lessons and different approaches.

13.2.11.1 Amber Alerts

Another trend in traveler information relates to the use of traveler information devices to inform motorists of abducted children. The Amber Alert Plan Program is a voluntary program where law enforcement agencies partner with broadcasters to issue an urgent bulletin in the most serious child abduction cases. These bulletins notify the public about abductions of children. The USDOT recognizes the value of the Amber Plan Program and fully supports the State and local governments' choice to implement this program. (13)

Alerts of recent serious child abductions may be communicated through various means including radio and television stations, HAR, CMS, and other media. Under certain circumstances, using VMS to display child abduction messages as part of an Amber Plan Program has been determined to be consistent with current FHWA policy governing the use of VMS and the type of messages that are displayed. The FHWA, in fact, recently issued a policy memorandum that supports the use of CMS for Amber Alerts. This memorandum may be viewed at the following URL: <http://ops.fhwa.dot.gov/Travel/reports/amber.htm>.

A key factor in the success of the Amber Plan Program is the need for public agencies to develop formal Amber Plan policies that include a sound set of procedures for calling an Amber Alert. If public agencies decide to display an Amber Alert or child abduction messages on a CMS, the FHWA has determined that this application is acceptable only if it is part of a well-established local Amber Plan Program, and public agencies have developed a formal policy that governs the operation and messages that are displayed on CMS. Care must be exercised to ensure that the message displayed does not exceed the reading and information processing capabilities of the motorists.

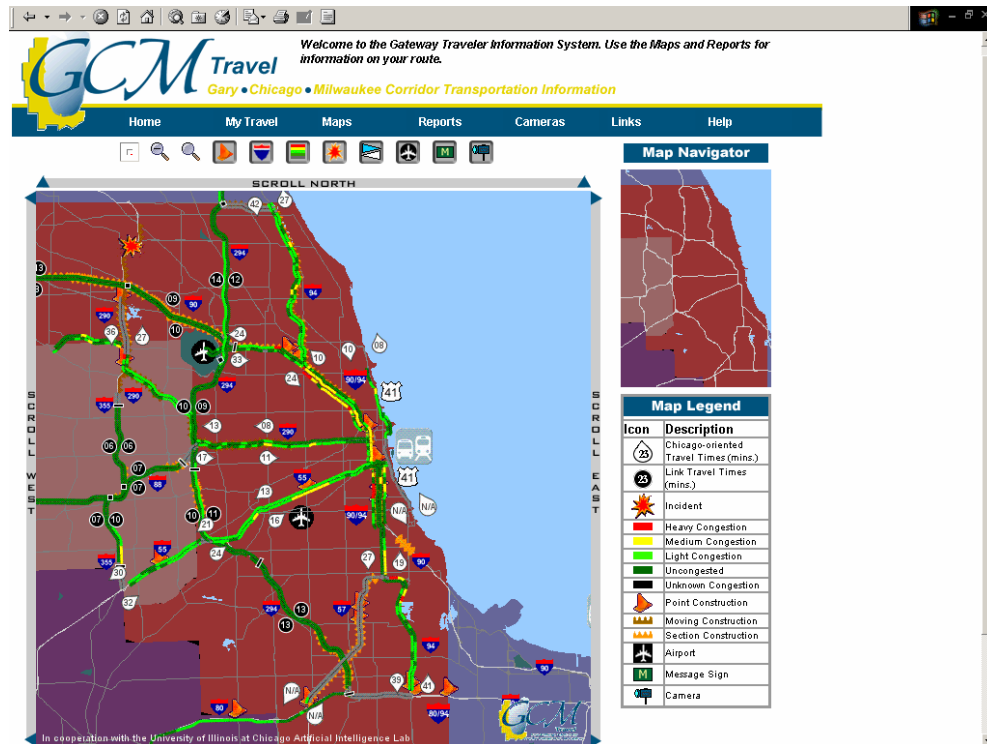
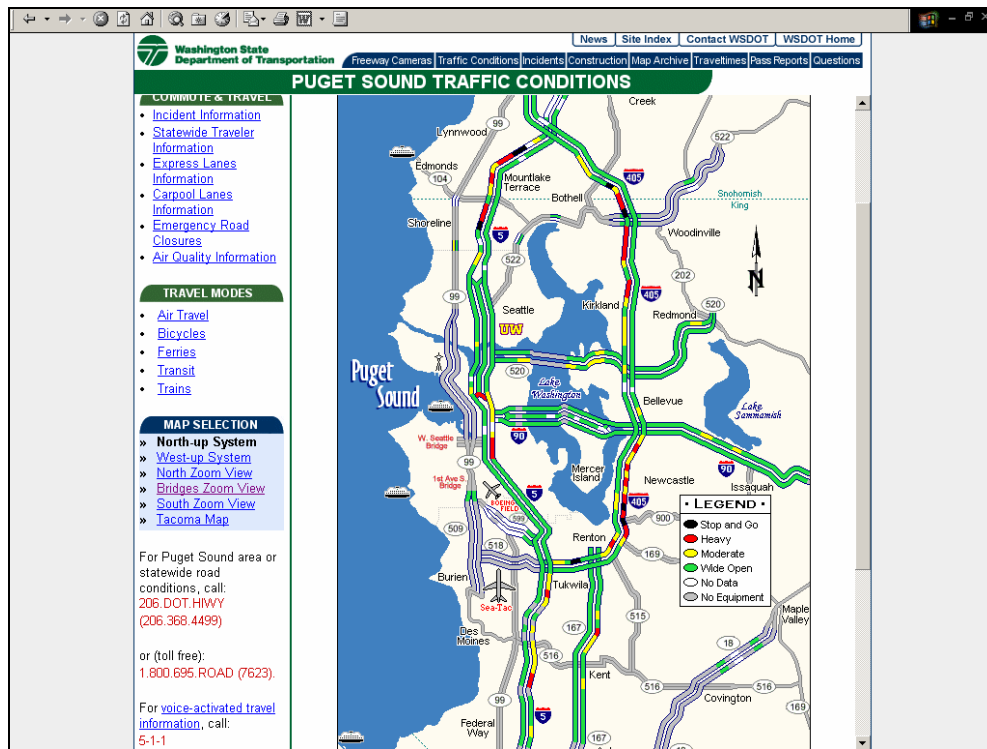


Figure 13-9: Examples of Traveler Information Websites

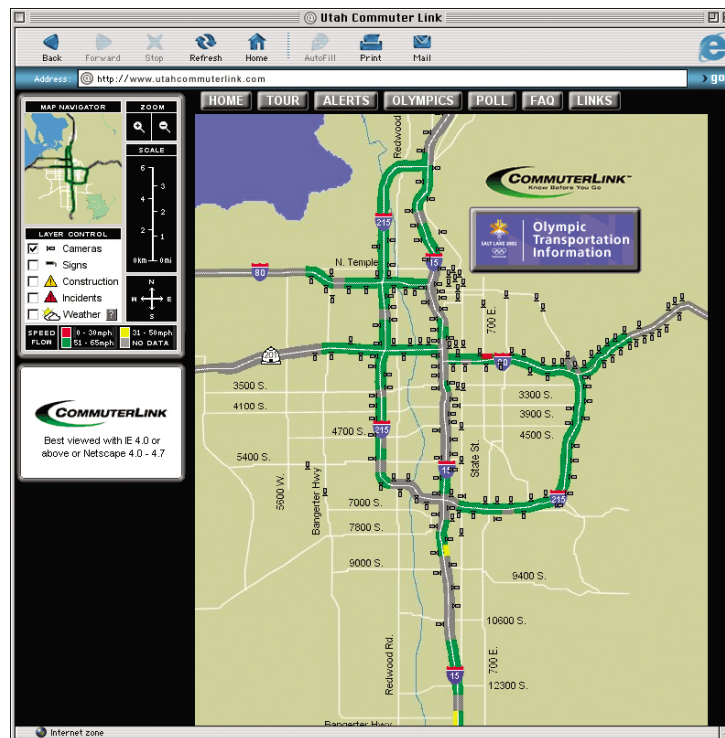
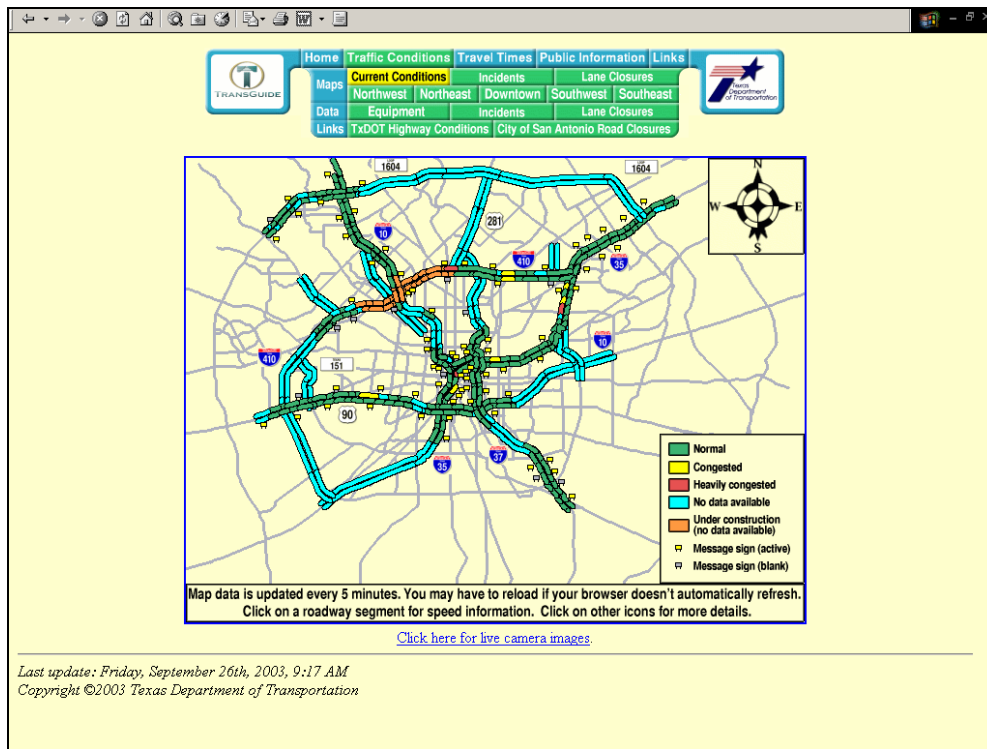


Figure 13-10: Examples of Traveler Information Websites

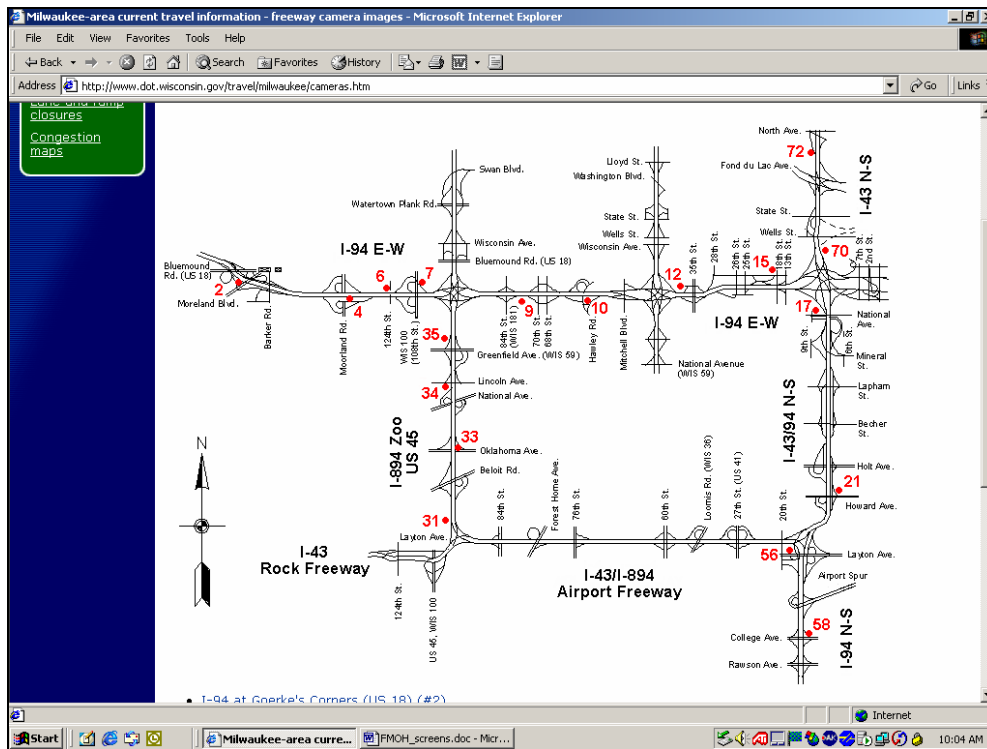


Figure 13-11: Example of Traveler Information Websites (CCTV Selection and Viewing)

13.2.11.2 Integrated Network of Transportation Information (INTI)

A recent initiative, primarily driven by ITS America, is the “Integrated Network of Transportation Information (INTI). The creation of an INTI is one of the programmatic themes contained in the “National ITS Program Plan: A Ten-Year Vision” (14). As stated in that document, an Integrated Network of Transportation Information will:

- “Create, operate, maintain and update the information management mechanisms to gather, analyze, coordinate, extrapolate, and store the data and interact with adjoining external systems. This will necessarily be done at multiple levels by a large number of organizations under consistent guidelines for information gathering, validating, sharing, and coordinating.”
- “Implement appropriate policies, procedures and security technologies to ensure that the system is secure and that only authorized stakeholders have access to data.”

The INTI was the subject of a workshop entitled “INTI - Moving Toward and Integrated Network of Transportation Information: From Information to Integration”, held in Houston, TX in February 2003. The INTI was presented at this workshop as consisting of three building blocks – **gathering** data, **sharing** data, and **using** data. Also presented were several key attributes and issues, including:

- Implementation should not be heavily infrastructure-based; rather, the long-term path is heavily vehicle-based (but not exclusively) both on collection and delivery side.
- Travel time is key; weather information is also important.
- Program will not be Federally mandated (in whole) or controlled; although there may be Federal incentives and, likely, a Federal coordination role.
- Both public and private innovation, commitment, and contribution will be required. It cannot be just a public or private sector initiative.

13.3 IMPLEMENTATION AND OPERATIONAL CONSIDERATIONS

13.3.1 CMS Messages

CMSs are one of the primary links a transportation agency has to the motoring public it serves. Improperly designed or operated CMS messages (e.g., displaying messages that are too long for motorists to read at prevailing highway speeds, or that are too complex or inappropriately designed leading to motorist confusion) can adversely affect both traffic flow and the transportation agency's credibility. The design and display of messages on CMSs introduce many challenges to transportation agencies and freeway practitioners. Recommendations to meet these challenges are presented in the *Guidelines for Changeable Message Sign Messages Manual* (Reference 5), which is a consolidation of the most current and best information on the design and display of effective CMS messages for incident and roadwork events.

Some of the more relevant issues identified in the Guidelines are briefly summarized below.

- **Efforts must be made to ensure that CMS messages are standardized and consistently applied throughout a state or region**—The messages displayed must be

"transparent" to travelers in the state or region. Therefore, messages need to be presented in a consistent manner and order based on motorists' expectancies.

- **Steps can be taken when developing CMS messages to enhance motorist understanding of messages**—In developing messages, factors that enhance understanding of messages include the following:
 - Simplicity of words,
 - Brevity,
 - Standardized order of words,
 - Standardized order of message informational units,
 - Understood abbreviations when abbreviations are needed, and
 - Standardized applications of messages.

An efficient, brief, and to-the-point message is a good message. Just because there are spaces available on a CMS does not mean that all spaces should be used for a message.

- **CMS messages should be displayed and changed in a timely manner**—The importance of timely display of CMS messages stems back to credibility. CMS operators do not always have all the information necessary to display messages that provide all of the details for motorists to make decisions. This is particularly true immediately after the operators are notified that an incident has occurred. Information should be displayed as quickly as it becomes available, recognizing that the CMS operator may have to change a message several times over the course of the event as new information becomes available or traffic conditions change.
- **Operating agencies should have written CMS policies and/or operational procedures**—CMS message design and display should be predicated on CMS operational policies and procedures. Although an agency is more likely to have written operational procedures, most do not have written policies. Operational policies dictate some of the requirements for operational procedures.
- **CMS message objectives should be established and messages should be designed before CMSs are purchased**—Too often, agencies purchase CMSs before signing objectives and messages are determined. The consequence is disappointment in the inability of the CMS system to display the appropriate messages because the sign does not have enough lines, and/or the line length is not long enough to display the desired messages. In addition, the CMSs have lower than expected target value and legibility for the environmental conditions present at the site.

A recommended procedure for determining the types of CMSs that will be acceptable for a given application is provided as summarized below. It should be noted that the nine steps of the procedure are interrelated and that the procedure is an iterative process.

- Clearly establish the objectives of the CMS -- The importance of setting signing objectives cannot be overemphasized because the objectives directly influence message content, format, length, and redundancy, and consequently, the size and placement of the CMS. When setting objectives, the agency must be specific in defining: What the problem is that is to be addressed with the CMS; Who is to be communicated with (audience); What type of

driver response is desired; Where the change should take place; What degree of driver response is required; and How the CMS system will be operated.

- Prepare the messages necessary to accomplish the objectives -- The length of the messages will help define the character size, message line length, and number of message lines required on the CMS. It may be necessary to modify some of the messages to reduce their lengths as a result of conditions determined in subsequent steps.
- Determine legibility distance required to allow motorists ample time to read and comprehend the messages.
- Determine locations of the CMS that allows motorists ample distance to read, comprehend and react to the messages -- The CMS must be placed such that the CMS and existing static signs form an integrated and compatible system of information.
- Identify type and extent of localized constraints that might affect the legibility of the CMS -- Field inspections are advisable to ensure that there are no physical obstructions due to bridges, sign structures, geometries, etc. that would adversely affect CMS legibility. In addition, field inspections will also help determine whether or not it is possible to actually install a CMS at the site. Obstruction problems would require that the agency either relocate the CMS or reduce the length of the messages.
- Identify the environmental conditions under which the CMS will operate -- Weather conditions such as snow, rain, etc. and other conditions such as blowing dust, heat, cold, etc. will have an effect on the sign's operation and will, in most cases affect the legibility of the messages. These environmental conditions should be made known to the manufacturer so that the best CMS performance characteristics can be achieved.
- Determine the target value and legibility of candidate CMSs -- An evaluation of the capabilities of the CMSs may dictate the need to reduce the message length or to require the manufacturer to modify the hardware and/or electronics to improve legibility.
- Determine the costs of candidate CMSs.
- Select the CMS that will allow the selected messages to be read under all environmental conditions within the cost constraints of the agency.

13.3.1.1 CMS Credibility

Paramount to the message design and display, CMSs must provide timely, reliable, accurate and relevant information and they must be operated properly to be effective. Credibility is an extremely important consideration in properly operating a CMS system. Regardless of how well a message is designed, motorists will eventually come to distrust the signing system if the messages are not changed at the correct times and updated to reflect current traffic conditions. Each time the information displayed is disproved, the credibility of the system decreases. Eventually the messages are ignored and the CMS system is in jeopardy. There are at least eight reasons why message credibility suffers (5):

- Information is **inaccurate** (e.g., no crash is observed when traffic passes by the location where an incident was displayed on a CMS).
- Information is **not current** (e.g., the message is not consistent with current conditions).
- Information is **irrelevant** to essentially all motorists using that facility.
- Information is **obvious** by inspection, and hence, is redundant (e.g., displaying HEAVY CONGESTION when motorists are driving bumper to bumper in peak traffic).
- Information is **repetitive** (the message is the same each morning when motorists pass the sign). Displaying the same information on a CMS each day for recurrent congestion can result in many motorists ignoring the CMS after a time. When an important message is displayed that will impact their trip, the motorists may not read the message. Some agencies are even considering the use of flashing beacons on CMSs to attract the attention of motorists when important messages are displayed.
- Information is **trivial** (e.g., DRIVE CAREFULLY, SUPPORT YOUR LOCAL RED CROSS, time and temperature). Displaying trivial information can result in many motorists, particularly commuters, ignoring the messages that have no direct impact on their trips and consequently will begin ignoring the CMS. When an important message is displayed that will impact their trip, the motorists may not read the message.
- Information is **erroneous** and can be easily checked and disproved. Traffic speeds and time to reach a destination are examples of information that can be easily disproved. Delay time is more difficult to disprove by motorists.
- Messages are **poorly designed**. The information is poorly structured resulting in messages that are difficult to read and comprehend, or are confusing. The messages may also contain misspelled words.

13.3.1.2 CMS Usage

Once a CMS system is installed, a question always arises concerning when messages should be displayed. There are two schools of thought:

- Display messages only when unusual conditions exist on the freeway; or
- Always display some sort of message regardless of whether or not unusual conditions exist on the freeway.

The *Manual* (5) subscribes to the former of the two approaches because of human factors principles and because of difficulties in designing messages when incidents actually occur during the peak periods. The second approach of always displaying a message leads to violation of the following two important human factors principles – specifically, don't tell drivers something they already know; and use the CMSs only when some response by drivers is required (i.e., change in speed, path, or route).

The Arizona DOT Guidelines (7) indicate, "CMS should be used whenever pertinent messages will assist motorists to make helpful decisions. If, however, a situation arises, which requires the

usage of a specific CMS for more than one ongoing condition; the following priority criteria should be used for displaying messages, in the order listed.

- Safety
- Roadway Closure
- Minor Traffic Impact
- Pre-Warning (e.g., construction lane closures, blocking-incidents, and delay information).
- Test
- Public Service Information

13.3.2 HAR Operations

While HAR is a viable traveler information system, its effectiveness is limited only by its operational application. How the messages are distributed and the equipment that distributes it is very important to a successful program.

The HAR can use either live messages, pre-selected taped messages, or synthesized messages based on information from an ITS traveler information database. The following issues are important in the design and implementation of an effective HAR system.

The audio quality, content, structure, presentation, and length of the advisory message are important parameters in providing an effective messaging system. Sound quality is affected by a number of different items: quality and sensitivity of the automobile receiver; quality of the transmission or control lines used to load the message; quality of the original recording when loaded to the transmitter controller or system controller; characteristics of the voice used to record the message; quality of the transmission and recording equipment; and the quality of the transmitter, antenna, and ground plane system. The only definitive way to ensure the quality of the transmission signal, and clarity and audibility of advisory messages, is by off-the-air monitoring. This type of monitoring involves receiving and monitoring the broadcast messages, using an AM radio receiver, in the same manner that a motorist would receive the messages. A routine monitoring program should be established that ensures all transmitters in the system are monitored off-the-air on a regular basis. Case-by-case and periodic monitoring of advisory messages should also be undertaken to ensure acceptable audio quality.

The message must be clear, concise, relevant, and easy for the motorist to understand. Because a motorist may begin hearing the advisory message at any point in the message, the message should consist of a sequence of independent phrases, so that the listener will not be confused by lack of information in the previous portion of the message. Slow, deliberate speech will provide greater comprehension of messages with detailed content. With traffic advisory messages, the motorists must receive the information before encountering the congested area.

Ideally, motorists should only receive messages relevant to the geographic area they are in or are about to enter; this mandates the need to separate broadcast areas. However, because radio wave propagation differs greatly depending on topography, atmospheric conditions and time-of-day, the potential for interference in overlapping radio coverage areas that use the same transmitting frequency can be significant. Overall systems design and final selection of transmission technologies need to account for these variances.

13.3.3 ATIS Business Planning

Agencies that are considering expanding their ATIS business beyond roadway devices to encompass web sites, partnerships with the private sector (ISP's), etc., need to address several issues – for example, what information will be distributed, to whom, how, potential revenue generation, restrictions, etc. Some of these issues are discussed below.

13.3.3.1 Business Models

A variety of ATIS business models have been used in the U.S., with varied successes. At present, it is safe to say that no one model have proven reliably profitable. Much the same can be said for ATIS in other parts of the world, too. The ATLANTIC (A Thematic Long-term Approach to Networking for the Telematics and ITS Community) Project's ATIS subtask undertook a study of comparing current practices of ATIS, including business models, that have been tried in recent years in countries on both sides of the Atlantic Ocean. – the three communities of ITS experts in Europe, Canada, and US. The significant results as well as the methodology for the comparative analysis are summarized below: (15)

- **Both Europe and North America need to have a complete information value chain for delivery of ATIS services.** The information value chain (or information supply chain) for ATIS describes a complete system from data collection, data fusion, to data distribution. All the links in the system must be operative for ATIS service delivery. Service quality to end-users is only as good as the weakest link in the information supply chain.
- **Broadcast traveler information supported by advertisement has been proven to be viable.** In fact, the broadcast of traffic information supported by advertisement has proven to be viable for years. It is a very viable revenue producing method. Perhaps the next question should be about market development, not about viable advertising revenue. In the US, the Metro Networks model of selling airtime to advertisers during radio traffic reports has been a success. However, given the conglomeration of services that has occurred over the past few years (i.e., Westwood One incorporating Shadow, Metro Networks, and Smart Routes), it could be questioned how viable the competitive broadcast market really is. It should be noted that ATIS is beyond traffic broadcast. ATIS will require a quantum change in data gathering methods, from qualitative "reportage" to quantified data-rich sources. Other models, such as advertising on websites, have not been very successful or profitable. For example, advertising on the SmarTraveler cable TV service was not successful in the US.
- **Public sector agencies should be prepared to underwrite all costs of specific information services they wish to provide.** This is certainly true for information services free at the point of use and offered as a public service, such as Traveler Advisory Telephone Systems, Government Access Channel Traffic TV Systems, and Government Websites. It is also true for some public transportation information systems but not necessarily true for commercial, personalized subscription services and for wireless services to mobile and portable devices. There may be certain services (e.g., subscription-based services) that the public sector would offer only if partnered with another firm that would assume fiscal responsibility for the service. These types of services may be akin to "bells and whistles" in that they would not be deemed essential public services, but could still be very effective in meeting public policy goals. Thus, there may be some services that the private sector can provide, especially for niche markets such as commercial vehicles or business travelers. The public sector would have an interest in seeing these markets served but public support

may not be required. In this case, public sector agencies might consider underwriting the costs of providing the framework necessary to enable those services to be provided, or proceed in partnership with the private sector.

13.3.3.2 Public – Private Partnering

Some differences in philosophies between the public and private sectors must be realized, understood, and overcome. Typically the public sector, or the provider of the data, desires to disseminate the information to the widest possible audience, while the private sector's primary goal is profit-oriented, and the two philosophies must be synergized to realize the ultimate goal of each group. A January 2002 study for FHWA on the subject of sharing public data identified the following findings: (16)

- Agencies have two major objectives in sharing their data with private sector and other public sector recipients: improving transportation operations through better interagency coordination and optimizing the use of the transportation system by providing information to travelers. Enhancing interagency coordination was the top-ranked motive for data sharing.
- Even though their motives are different, public and private sectors are active participants in use of traveler information as a transportation management tool. Almost all agencies directly provide information to the public typically with VMS, HAR, kiosks, and interactive voice response telephones. Although agency data are a fundamental source, private providers generally need to enhance public data before they are marketable. The most common types of information provided are traffic and road conditions, incident information, and planned construction information. Transit data are generally less useful to private providers, and only a third of them report transit delay information.
- Agencies that have data to share protect their interests by placing restrictions on access to data, but firms generally do not find these conditions to be onerous. Two or more conditions on access are common, the most frequent being acknowledgement of the agency as the source of the data when distributed to the public.
- Formal policies on data sharing were reported by half the 34 surveyed agencies and several more have plans to issue one. The principal advantage of a formal policy is that it provides a process for handling requests for agency data.
- In addressing the costs associated with the data sharing process, agencies frequently employ two or more cost recovery mechanisms in data sharing relationships. Most frequently agencies require the receiving party to cover its own cost, such as hardware, software and communications cost to connect to agency data sources. The second most popular mechanism involves a private firm sharing its "value-added" information with the agency.
- The two most controversial topics in the private sector's relationships with agencies regarding agency data are revenue sharing and exclusivity. The idea of revenue sharing is optimistically viewed by many agencies, although in practice it has not had much success. The private sector tends to oppose revenue sharing either because of practical difficulties in administering it or because it violates the principle that public data should be available to all taxpayers for free.

There can be little doubt, then, that the private sector must be a full-fledged partner in deploying and managing traveler information dissemination systems (e.g., the INTI). Moreover, private sector participation will likely go beyond using, value-adding, and delivering public data; and also include the generation and collection of information. While this approach is appealing (and probably necessary), past experience has shown that it is not always an easy process. As noted above, there are several issues that must be addressed if effective partnerships are to be established for the collection of information, including:

- **Data ownership** – When a private entity is involved in the collection of traffic flow information, it is important to establish ownership early in the process, so that the rights of each party to use, distribute, and/or sell the data are defined.
- **Exclusivity** – Many public agencies are legally required to disseminate any data collected with public funds to all requesting organizations. An agency may therefore be prevented from giving exclusive rights to a private sector organization with which it has entered into a “surveillance” partnership, forcing the private sector partner to compete with other entities that have not made a similar investment.

13.4 EXAMPLES

13.4.1 511 VIRGINIA

511 Virginia is a Virginia Department of Transportation (VDOT) service, contracted to Virginia Tech Transportation Institute (VTTI), who in turn has subcontracts and service contracts with additional parties, including Shenandoah Telecommunications (Shentel) and Tellme Networks, Inc.

The *511 Virginia* service grew out of the Travel Shenandoah regional travel information service that was launched in July 2000, serving the primarily rural part of western Virginia. Situated along 150 miles of the Interstate 81 corridor, Travel Shenandoah covered 11 counties and one VDOT District – Staunton.

Before launching the *511 Virginia* service, the coverage area was expanded to include the entire length of I-81 in Virginia and all major roadways in three VDOT Districts – Staunton, Salem and Bristol (see Figure 1). Today, *511 Virginia* serves 35 counties and a resident population of approximately 1.4 million people. Virginia was the first to offer services beyond traditional transportation-related information including information on food and lodging, tourism and attractions, and shopping. The information is provided via an interactive voice actuated system (no need to press buttons) via the 511 dialing code and also through a companion website, www.511Virginia.org.

In support of the service, VDOT has placed 58 roadside signs along I-81 and the intersecting Interstate approaches in the region to help promote the service. VDOT has also produced public service announcements, rack cards, and other promotional materials. The exact level of marketing to attract and maintain a high-volume, consistent user base is currently unknown. However, consistent marketing and brand awareness are critical to the success of *511 Virginia* and 511 services nationwide. Therefore, all marketing materials produced will use the 511 Deployment Coalition developed and distributed 511 logo and usage guidelines.

13.4.2 AZTech

The AZTech™ Intelligent Transportation System (ITS) Model Deployment Initiative (MDI) is a seven-year project (two-year implementation and five-year operation) to develop an integrated Intelligent Transportation System for the Phoenix metropolitan area. AZTech™ is a unique transportation partnership of public agencies and private corporations who integrate travel and communication systems within the Phoenix metropolitan area. This partnership provides Arizona motorists with traveler information such as real-time traffic conditions, related road closures, and accidents. This information is provided through the use of live traffic cameras, variable message signs and through a large network of fiber optics and communications systems. In addition to the ATIS element, other major components of AZTech™ include regional operations partnership, smart corridors, incident management, system integration, emergency management, data archiving, special event management, regional procurement, and telecommunications (20).

AZTech™ has been successful in building a unique ATIS public-private business model. The Advanced Traveler Information System business model provides the structure for Maricopa County's regional transportation partnership. Bridging the gap between public and private businesses, this partnership enables the private sector to operate a self-sustaining automated traveler information system encompassing state-of-the-art technology.

AZTech™ has finished both Phase 1 and Phase II public-private partnership projects as follows:

- Phase I of the AZTech™ project involved utilizing prominent internet portals, such as MSN and MapQuest, to disseminate information. Personalized traveler information was also provided to commuters utilizing devices such as PDA's and in-vehicle services through GM Onstar.
- Phase II of the AZTech™ project involved increasing its Internet capabilities, as well as setting up notifications to be distributed by fax and through digital TV. Additionally, through one of its partners, AZTech™'s was able to set up real-time traveler information, including travel time, for commercial vehicle operations. Another AZTech™ partner provided traveler information on in-vehicle devices.

The business model allows AZTech™ to participate in the fusion of better traffic data. Both private firms and public companies add value to data collected by and disseminated from AZTech, resulting in better information for all travelers. Proof that this business model has tangible benefits can be found in AZTech™'s involvement in researching and testing the latest technical achievements. Recently, AZTech™ performed a production test of a new personalized traffic service. Using wireless capabilities, real-time travel information was disseminated to users throughout the Phoenix metropolitan area. AZTech™ partners created personal trip profiles on the ATIS private partner service. Alerts were available for dissemination to cellular phone, WAP phone, PDA, pager, fax and email. The user then customized information by entering details such as:

- Personalized freeway route;
- Times of day to activate notification; and
- Level of severity of activated alert.

The user specified the preferred device that was to receive traffic alerts. Any activity reported on a specific route, including incidents, recurring and non-recurring congestion, and construction, was then automatically distributed to the user's specified device.

Another successful outcome of the public-private partnership initiated by AZTech™ has been the introduction of a dedicated traffic cable channel in four jurisdictions. The cable television channels provide information regarding travel conditions through data fusion from the freeway management system at peak travel hours.

With the launch of Phase III, AZTech™ has entered a new era of travel information services. New services include travel time prediction, dissemination, and enhanced Internet services. Additional information can be found on the AZTech™ website at www.aztech.org.

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14. TRANSPORTATION MANAGEMENT CENTERS

14.1 INTRODUCTION

Freeway management is performed through a combination of human (i.e., institutional), and physical (i.e., technical) elements. The human elements are the managers and operators who plan and perform control functions, while the technical elements are those tools, typically ITS, that assist the operators in performing their functions. These two elements are brought together at the transportation management center (TMC). The TMC is the hub or nerve center of most freeway management systems. (Figure 14-1) It is here data about the freeway system is collected and processed, fused with other operational and control data, synthesized to produce "information", and distributed to stakeholders such as the media, other agencies, and the traveling public. The information is used by TMC staff to monitor the operation of the freeway and to initiate control strategies that affect changes in the operation of the freeway network. It is also where agencies can coordinate their responses to traffic situations and incidents.

The role of a TMC often goes beyond the freeway network and the particular responsible agency, functioning as the key technical and institutional hub to bring together the various jurisdictions, modal interests, and service providers to focus on the common goal of optimizing the performance of the entire surface transportation system. Because of its critical role in the successful operation of a freeway management system (and perhaps the broader surface transportation network), it is essential that the TMC be planned for, designed, commissioned and maintained to allow operators and other practitioners to control and manage the functional elements of the freeway management system, and possibly beyond.



Figure 14-1: Transportation Management Center

14.1.1 Purpose of Chapter

This Chapter is a tool for freeway management practitioners of all levels involved with the planning, design, commissioning, operations and maintenance of a TMC. It is not intended to be an all-encompassing, “*Everything You Ever Wanted To Know About TMCs...*” desk reference, but instead, an overview of TMC’s from planning to on-going management, including:

- The elements of a TMC,
- Its role in freeway management,
- Processes for planning, designing, commissioning and managing a TMC (and related ITS elements)

Several excellent references are available regarding the planning, design, implementation, and operation of TMCs. Many of these are referenced herein, including the following Internet sites:

- ITE TMC Committee (<http://www.tmcite.org>). This web site is intended to serve as the “one-stop location, providing a forum to access and facilitate the electronic exchange of information among practitioners interested in TMCs.” (Reference 1)
- The TMC Pooled Fund Study (PFS) (<http://tmc pfs.ops.fhwa.dot.gov>). The goal of the TMC PFS is to assemble regional, state, and local transportation management agencies and FHWA “to identify human centered and operational issues that are common among TMC operators and managers; suggest approaches to addressing identified issues; initiate and monitor projects intended to address identified issues; disseminate results; and assist in solution deployment.” (Reference 2).

Each of these web sites provides information on resources, best practices, and TMC - related studies.

14.1.2 Relation to Other Freeway Management Activities

The TMC serves as a focal point of control and management of infrastructure and procedural functions. Accordingly, there are many freeway management activities that relate directly to TMCs; and to understand the role of TMC’s within the freeway management spectrum, it is important to understand the relationships between these activities and the TMC. Table 14-1 itemizes those related activities and their relationship.

Table 14-1: Freeway Management Activities and Their Relationship to TMCs

Ramp Management and Control (Chapter 7)	The data collected from detection and surveillance components in the field is synthesized at the TMC, and systems and operators in the TMC monitor and manage the ramp management systems. Central software within the TMC often communicates with and controls the operation of the ramp controllers in the field.
Lane Management and Control (Chapter 8)	The data collected from detection and surveillance components in the field is synthesized at the TMC, and systems and operators in the TMC monitor and manage the lane management systems.

HOV Systems (Chapter 9)	For HOV systems using automated gates, overhead lane control signals or dynamic message signs (DMS), these central systems are typically located and maintained at the TMC and the monitored and managed by TMC software and operators.
Traffic Incident Management (Chapter 10)	The TMC is the nerve center for transportation agency management of traffic incidents. In some multi-agency centers that include emergency management dispatch, the TMC can act as the situation or war room for multi-agency response and coordination.
Planned Special Event Management and Control (Chapter 11)	The TMC is the nerve center for the transportation agency management of planned special events. In some multi-agency centers that include emergency management dispatch, the TMC can act as the situation or war room for multi-agency response and coordination.
Emergency & Evacuation Management (Chapter 12)	The TMC is the nerve center for the transportation agency management of emergency and evacuation events. In some multi-agency centers that include emergency management dispatch, the TMC can act as the situation or war room for multi-agency response and coordination.
Information Dissemination (Chapter 13)	Information dissemination is one of the primary roles of a TMC. The TMC is the gathering place for real time information and planned special event information, and it is from the TMC that the information, created from fused and synthesized data, is distributed to stakeholders via roadside infrastructure (DMS and Highway Advisory Radio). TMCs also distribute traveler information to independent service providers and the media for distribution to the public. In some systems, TMCs also provide traveler information directly to the web or telephone information systems (511).
Detection and Surveillance (Chapter 15)	The real time data (e.g., volume, speed and occupancy, location, etc.) from detection and surveillance infrastructure is collected, fused and synthesized at the TMC for use by agency management systems, performance monitoring, control systems, and in determining travel conditions.

14.2 CURRENT PRACTICES, METHODS, STRATEGIES & TECHNOLOGIES

14.2.1 Overview

Reference 1 defines a Transportation Management Center as “a central facility that controls, monitors, and manages the surface street, highway, transit and bridge/tunnel control systems within its control area. To accomplish these tasks, a TMC aims to manage the operation of the

transportation system by communicating travel condition information, making necessary modifications to traffic and transit control systems, and directing response activities. TMCs are a component of transportation management systems, a primary means that transportation agencies can use to manage traffic flow and make better use of the existing transportation system. Within the system, then, TMCs work with other elements (components) to accomplish the goals and objectives of transportation management. These components include field hardware (cameras, variable message signs, electronic toll tag readers, etc.), communications equipment, and the policies and procedures established to deal with various transportation-related events that impact the system. TMCs play a critical role in managing travel on the surface transportation system and support the many interests who provide a variety of services to the traveling public. TMCs can serve as the technical and institutional hub for bringing these interests together within a metropolitan area, entire state, or region.”

TMCs can be either stand-alone facilities or, as is becoming much more the rule rather than the exception, networked with other TMCs to provide regional management²⁷. They can be owned or operated by a single agency, multiple transportation agencies, or multiple agencies with different charges like transportation, emergency service, or media agencies. They operate different days of the week and different times of the day, from weekdays only and only during peak periods to 24 hours a day seven days a week.

Often, when one thinks of a TMC they imagine a building or a room – a control room, two-way radios and police scanners blaring, multiple computer monitors at each work center, closed-circuit television monitors on the wall, people scurrying around – a beehive of activity (e.g., “Houston, Tranquility Base here, the service patrol has arrived”). Surely this is a TMC, but not every TMC. A Traffic Management Center is just that – a *center* or hub for gathering and sharing information, making operational and management decisions, and implementing control strategies to affect these decisions. Whether it is an exclusive building, a floor of a building, or a room in a maintenance shed, it is a place where multiple functions or activities are performed in coordination and perhaps with other stakeholders. It is the focal point that, without it, freeway management in large or complex networks could not be *effectively* performed.

A TMC doesn’t even need to be a physical structure. In this “Virtual TMC” scenario, there is no centralized location where operations occur; but instead, everyone is “attached” to the system remotely. In effect, the system is decentralized. This virtual concept is based upon the premise that much of the effort in traffic management is one of communicating between agencies, and this can be done without the use of expensive TMCs. As noted in Reference 3: “Significant benefits can be realized through decentralized advanced traffic management system (ATMS) designs that enhance the ability for communication among participants in the transportation management process. This approach is compatible with current trends in ITS which eliminate single-agency single-function systems in favor of a more comprehensive approach that includes all participants in the traffic management process. Perhaps the most exciting result of the decentralized design is that it permits the development of a virtual system that provides improved traffic management capabilities while lowering the cost and disruption caused by a centralized system. This is accomplished by eliminating the need for an expensive control center and the requirement for changes in operational procedures and relocation of personnel.”

The basic activities that define the purpose of a TMC are summarized below (from Reference 4):

- **Perform Monitoring:** One of the most common activities undertaken in a TMC is to monitor the transportation facilities that are part of TMC's domain. Monitoring is normally visual and can also be aural. It is common to monitor conditions through the use of a computer workstation graphic display environment. Operators use displays of video images and computer-generated graphics; radio broadcast information (i.e. a police band radio scanner) and operational data reports. Monitoring may be defined as "to watch, keep track of, or check usually for a special purpose or event".
- **Manage Events:** Events are a broad category that includes randomly occurring events (e.g., vehicle crashes, debris on the roadway), planned events (i.e., an expected event for which a schedule has been established, such as a sporting event, lane closure for construction, etc.), and recurring random events (e.g., recurring congestion). Management of these events can involve numerous operator activities (e.g., incident verification and management, coordination with emergency services, adjust ramp meter rates, activate lane signals, utilize CMS / HAR).
- **Provide Services:** Some TMC functions provide services to their constituency on the highways on such a regular basis that these services fall outside of the category of event management. The utilization of Advanced Traveler Information Systems (ATIS)²⁸ within a TMC may very likely include functions that are service oriented. Another example of this type of function is the provision of service patrols, to aid motorists with events such as breakdowns and "out of gas" events.
- **TMC Support:** The category of "TMC Support" is not included in the Figure because support activities that facilitate the operation of the TMC tend to be more "institutional" than operational. The activities of hiring, managing, training, record keeping, interpersonal and interagency communications, and the general upkeep and improvement of the TMC are essential to the operation, but generally are incidental to real time operation (4).

In essence, the TMC serves many purposes: as a real-time command and control center, a communications center receiving and disseminating information, a center where the appropriate response vehicles or equipment is dispatched in response to an incident or other event, a coordination center where multiple agencies gather to coordinate activities for large incidents or planned special events, a training center where operators or stakeholders are trained in the concepts of real-time freeway management, an interface with the media, a storage facility where data collected from field systems are archived for use at a later time for a number of purposes, some not related to traffic management .

14.2.2 Benefits of TMCs

TMCs afford numerous benefits, although studies to date have not separated the benefits of a transportation management system itself from the benefits of housing the system in a center. An NCHRP Synthesis Report on "Transportation Management Center Functions" (Reference 5) identifies the following in its conclusions:

- "A TMC can successfully integrate the primary functions of traffic management and can further optimize the operations of the transportation system"
- "The TMC is a useful centralized location for various agencies to convene and coordinate their involvement in traffic management for a region".

Other potential benefits specific to systems with a dedicated center are listed below:

- Since field devices and their operation can be monitored from a TMC, field maintenance costs can be reduced because maintenance personnel don't have to be dispatched until a problem is confirmed from the TMC.
- When collocated in the same TMC, interaction and cooperation between varying disciplines of an agency can be greatly enhanced. For instance, in snow and ice removal operations, TMC operators work with maintenance personnel by keeping them informed of weather and pavement conditions.
- A dedicated, multi-agency facility is often able to justify investment in assets that increase the overall system reliability (such as an uninterruptible power supply with diesel generator backup power) but would not be practical for distributed sites. This also applies to special skills, such as database or network administration or configuration management, which may only be justifiable for the larger facility.
- Agencies working closely together in a TMC typically produce a more consistent, unified response to a situation, increasing the overall effectiveness of the transportation resources.
- Freeway management systems collect a great deal of traffic data that are beneficial to transportation and enforcement agencies outside of real-time freeway management. It is at the TMC where the data are stored and archived.

14.2.3 Key Considerations During Freeway Management Program Development

The TMC for a freeway management system is such an integral part of a large or complex freeway management and operations program, that the TMC – its functionality, location, layout, staffing, operations, etc. – must be a key consideration in every aspect of developing the freeway management program (e.g., stakeholders, goals and objective, needs, concept of operations, requirements, etc., as shown in the funnel diagram in Figure 3-1). The vision, goals, objectives, operational concepts, and requirements for the overall freeway management program will impact decisions regarding the TMC; just as the TMC designs and operating procedures will impact the freeway management program. Moreover, given the complex technologies associated with a TMC (computers and processors, real – time software applications, communications networks), the development and implementation of the TMC (and associated ITS projects) should utilize a “systems engineering” process and incorporate “configuration management”. These processes are summarized in Chapter 3, and addressed in greater detail in Section 14.3.

14.2.4 Relationship to National ITS Architecture

The TMC represents the physical representation of one or more of the 10 “center subsystems” identified in the National ITS Architecture (e.g., traffic management, emergency management, toll administration, commercial vehicle administration, maintenance and construction management, information service provider, emissions management, transit management, fleet and freight management, archived data management), as well as the location of many of the “terminators” (e.g., operators, managers). Further, the TMC “houses” collected data, thereby performing the functions of an ‘ITS Data Mart’ and “ITS Data Warehouse”, both National ITS Architecture market packages. Moreover, given that a TMC is such an integral part – the focus,

if you will – of a freeway management system, its operation also impacts numerous other Market Packages and User Services.

14.2.5 Technologies and Strategies

The TMC can consist of several “technical” elements, including:

- The physical environment in which the operators and equipment will function.
- Hardware and software to synthesize significant amounts of information and roadway condition data, to determine how the system is operating, and to allow for the adjustment of system operating parameters to accommodate changing travel conditions.
- Operators’ workstations and displays, including the interfaces through which the operators will be presented with information and initiate control decisions.

Many of these TMC elements are discussed in the following sections. Much of the information included herein was extracted from the *Human Factors Handbook for Traffic Management Center Design* (Reference 6).

14.2.6 Physical Design

The TMC’s physical environment consists of design elements that allow the system — both human and machine components — to function effectively. The following lists some physical elements that designers must consider:

- Atmospheric (heating, ventilation, and air conditioning).
- Visual (primary and supplementary lighting).
- Acoustic (background noise and interior acoustical properties allowing operators to communicate).
- Physical design of the workspace (access, dimensions, and fixtures).

The requirements for some of these elements are mandated by public law (e.g., access for the disabled). The design of other features of the TMC should be based on established design practices (e.g., lighting standards for designated work areas). The *Human Factors Handbook for Advanced Traffic Management Center Design* (Reference 6) provides guidelines and requirements that can be used to design the physical environment of a TMC; and should be consulted for more detailed recommendations and specifications.

14.2.6.1 Space Planning

The size of TMCs can vary considerably, depending on the design objectives and functions performed by the system. Factors that affect the design of the center include the following:

- The number of agencies using the TMC and the degree of interagency staffing
- The hours and days of operation.
- The types of information displays that will be used in the center.
- The types of monitoring and control strategies used by the system.
- The extent of space security within and around the center.
- The need for media and public access to the TMC.
- Whether the TMC will function as a communications or dispatching center.
- Whether the TMC will also function as an emergency operations center.

The size of traffic TMCs varies widely throughout the United States. Some TMCs, such as TransGuide in San Antonio, Texas, and Transtar in Houston, Texas, occupy as much as 4,800 m² (52,000 ft²); however, many successful TMCs occupy less space. For example, the TMC in Minneapolis, Minnesota occupies only approximately 950 m² (10,000 ft²).

A typical TMC has the following work areas within the building:

- Operations Room
- Computer and peripheral area.
- Communications area.
- Reception area.
- A gallery for viewing and training.
- A conference room.
- Support offices.
- A break room.
- A media room.

Examples of typical floor plans for a TMC are shown in Figures 14-2 and 14-3.

The operations room is the hub of the TMC. It houses the operators' workstations and display boards/video terminals used to display information about conditions in the network to the operators. The size of the operations room is dictated by the number of operator workstations that will ultimately be in the TMC, and the type and location of the information displays.

The computer/peripheral area houses the computers needed to run the freeway operations center. The size of the computer room depends upon system design decisions regarding how much computer capability will be based at the TMC as compared with that installed at hub locations in the field. Often these rooms require strict environmental controls (i.e., heating and air-conditioning). Many locations also have strict access control for this area. .

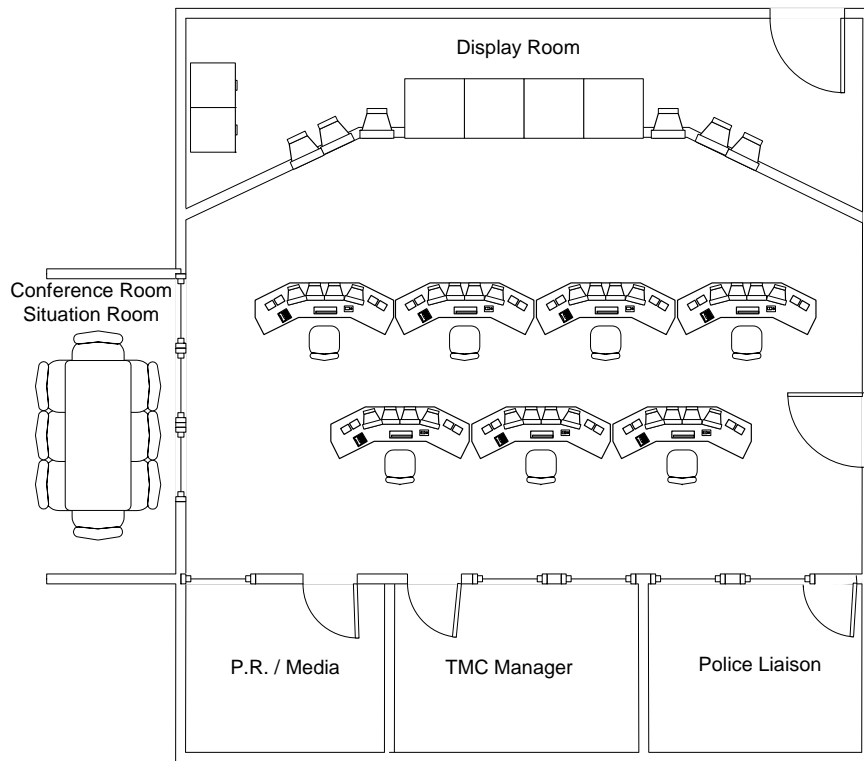


Figure 14-2: Example of a TMC Floor Plan

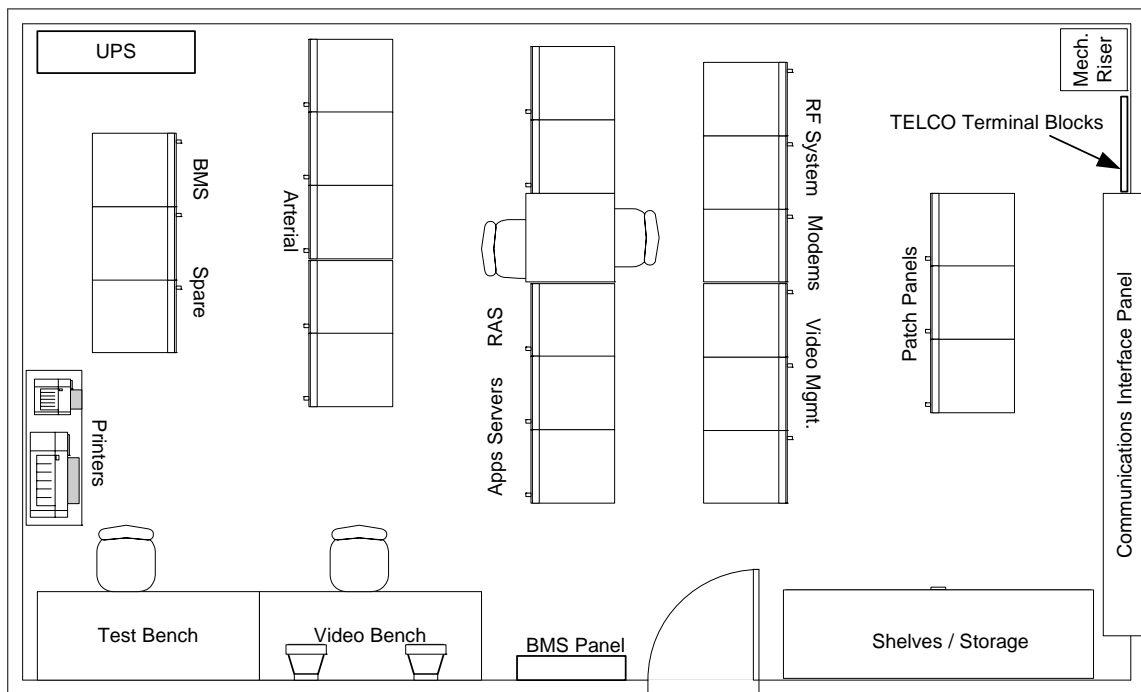


Figure 14-3: Example Layout of a TMC Computer / Peripheral Room

The communications area can be a stand-alone area or can be combined with the computer/peripheral area. The communications area is the terminus for data entering and exiting the TMC from the field. It also serves as the distribution point for transmitting data to the rest of the system (i.e., the computer and video control systems).

Many locations like to provide a gallery or viewing area of the operations room. From this area, tours of the TMC can be conducted without interrupting the operations in the TMC. This area can also be used as a training center where trainees can monitor the operators without disturbing them.

Many TMCs also have an area set aside for the media. Some TMCs use the gallery area to service this function, but others have set aside a separate area as a media area. From this area, the media can watch what is going on in the operations center without interrupting the operations. Often, these areas have several telephones and video terminals that are available for use by the media during incidents or emergencies.

Besides these common areas, office space should be provided to those working in the TMC. The number of office spaces, again, depends upon what functions will be carried out in the TMC. Generally, office space is required for the operations supervisors, the system support staff, the maintenance supervisors, and the engineering and administrative staffs.

Some agencies have included space for their system maintenance personnel at their TMCs. If maintenance operations will be based at the TMC as well, the space provided at the TMC is based on the number of electrical maintenance personnel that will be stationed there. In addition, if the TMC is also expected to serve as an Emergency Operation Center (EOC), then additional space is needed for such items as dormitories, a large kitchen, and showers. Some locales may have mandated structural requirements for an EOC that are more stringent than for regular commercial office space. Finally, some centers house their emergency dispatch vehicles and equipment, and as such, include garage facilities.

14.2.6.2 Physical Attributes

Other notable design features related to the physical plant of the TMC are listed below:

- Raised flooring should be provided for, at minimum, the operations room, computer/peripheral room, and behind the projection display wall to allow for the ease of running communication cabling. It should be noted that good design practice calls for sealing the concrete subfloor in these rooms with a sealer to keep down dust that can be drawn up into equipment through openings in the raised floor for the equipment racks.
- The use of antistatic carpet should be utilized throughout the center. The carpet tiles that cover the raised flooring should be the same size as the raised floor tiles.
- The display wall (and the operator console surfaces) should have a flat, non-reflective finish. Control room walls should be finished in acoustic panels to reduce noise levels.
- No water pipes or tanks should be installed over critical areas such as control room or computer peripheral room. These rooms should, regardless of nearby water sources, have the sub floor graded for water run-off in the unlikely event of a flood.

- Sufficient cable raceways should be provided throughout the building to effectively manage the kilometers of cable necessary.
- Non-reflective glass should be used in the control room.
- Sufficient uninterrupted power supply and back-up diesel generator should be provided to ensure critical system stay available in the event of a power failure.
- Caution should be used in the provision of a truss or stand for the video display equipment so as not to cause electromagnetic interference with video equipment as a result of the accidental magnetism of the stand during welding. It is recommended that these stands be tested for magnetism prior to the installation of the video equipment. Should there be magnetism present, the stand should be de-magnetized prior to the video equipment being installed.
- Accommodation for fire/disaster proof storage for backup of code, documentation, and support software and tools should be provided. Although it is a good idea to archive back-ups off-site, to facilitate disaster recovery there should be some space on-site that will survive a fire and any disaster that the location may be susceptible to.

14.2.6.3 Lighting

Lighting is an important consideration in the design of a TMC. Viewing a large situation map with LED signals or a bank of CCTV monitors, for example, is not compatible with high levels of general illumination. On the other hand, many operators' tasks cannot be performed in low levels of illumination. The lighting scheme and choice of luminaries must be viewed as an integrated whole, and not designed piecemeal (6).

The greatest challenge in designing the lighting in the TMC revolves around the need to provide dim general illumination and higher levels of local illumination. Usually, a low level of illumination is provided in the operations room because of the nature of the tasks and displays used. Most centers provide supplemental lighting at each operator console. Some general recommendations related to lighting in TMCs are as follows (6):

- Indirect lighting should be employed to provide overall illumination for the control room.
- Canister fixtures should be employed to provide supplementary illumination over work areas.
- Adjustable fixtures should be used in work areas where more intense illumination is required.

14.2.6.4 Acoustics

Communications between operators can be critical, especially in emergencies. Common sources of noise in a TMC include alarms, radio/telephone communications, operator conversations, and data processing equipment. Overall, the noise level in a TMC should not so high as to interfere with normal speech between operators. The objective in designing for noise is to balance the different sound sources so that local speech is unaffected, but is sufficient to mask intrusive noise from adjacent spaces. Some general recommendations for reducing the impact of noise in the TMC include the following:

- Identify possible noise sources (including machines, telephones frequently in use, loudspeakers, and radios with speakers) during the design phase and eliminate them.
- If noise sources cannot be eliminated, consider strategies for reducing noise level, including textured or sound-deadening wall and ceiling materials.
- Consider placing noisy functions that are not tied to normal operator activity in a separate room or in an area enclosed by acoustic partitions.

14.2.6.5 Heating and Cooling

Operator comfort and performance can be affected by temperature and air quality. In designing a TMC, designers must be concerned about two issues related to the thermal environment of the TMC – the general heating, ventilating, and air conditioning (HVAC) standards for occupied buildings, and the effects of local thermal conditions related to special equipment such as computers and video display units. Sometimes, special rooms in the TMC, such as the computer/peripheral room or the communications area, may require separate heating and cooling standards. The *Human Factors Handbook for Advanced Traffic Management Center Design* (Reference 6) summarizes the heating and cooling standards applicable to TMCs. General standards that should be considered in the design of the heating and cooling system for TMCs include the following (6):

- Actual ventilation should be ensured by introducing fresh air into any personnel enclosure.
- Within permanent structures, effective temperature shall be maintained at not less than 18°C (65°F), and not greater than 29.5°C (85°F). The temperature of the air at floor level and at head level should not differ by more than 5.5°C (10°F). Heat build-up from equipment under the work surface (around the operator's knees and legs) greater than 3°C (5.5°F) above ambient should be avoided.
- Approximately 45 percent relative humidity should be provided at 21°C (70°F). The humidity should decrease with rising temperatures, but should remain above 15 percent to prevent irritation and drying of body tissues.
- The exhausting of air from instrumentation (video display units, system units, etc.) should be so accomplished as to avoid discomfort to users and others close to the equipment. Units should be designed so that forced-air exhausts are not directed toward the operating position, or toward other workers in their work positions.
- External surfaces that can be touched during operation should have a surface temperature that does not exceed 50° C (122°F). Surfaces intended to be touched during normal operation should not exceed 35°C (95°F).

14.2.7 Operator Workstations

Integral to any TMC are the means by which operators enter and retrieve information. Controls allow the operators to guide certain traffic parameters (e.g., traffic flow) within the limits of the center's mission. Displays provide information that operators need to monitor the status of the system and make control decisions. The operator workstation is often the primary means by

which operators interact with the system. Examples of operator workstations are shown in Figure 14-4.



Figure 14-4: Examples of TMC Workstations

Workstation design is dependent on several issues – the layout and space availability within the TMC, the functions of the freeway management system and how those functions are allocated within the FMS software (including the level of automation), and the software itself. For example, if the decision is made that each workstation will have access to all functions in the center and there are multiple types of systems included – not all of which are able to be operated from the same platform, or some requiring larger displays or different types of interfaces – the design of the workstation will be very different than if all of the functions can be incorporated into the same software package or can be operated on the same platform. Similarly, if the control room is too small to hold separate workstations, customized fixtures designed specifically for the TMC under development may be required.

The layout of workstations and other furniture and fixtures should be specified as part of the overall work space design. In designing workstations, comfort and suitability should be considered as important issues, both of which are supported with many experience-based guidelines.²⁹

Well-designed workstations and supplemental furnishings (e.g., chairs) can prevent discomfort and perhaps occupational injuries (e.g., back strain, cervical stress disorder, carpal tunnel syndrome, and repetitive stress disorders). A good design will contribute to productivity and employee health and morale, while a poor design can actually limit productivity. Designing the workplace to accommodate the characteristics and capabilities of human operators is often referred to as *ergonomics*. The strong movement toward ergonomic suitability has created many sources of information that support proper workstation design; however, an experienced ergonomist or human factors engineer should be consulted before a large investment is made in workstations. If possible, consultation with the TMC Operators should be employed in the design of the work centers

Considerable changes in workstation design have occurred as freeway management systems have evolved over the last three decades. In the past, most TMCs were designed with multiple workstations, each with a specific function. For example, one workstation controlled the video

surveillance system, another controlled the variable message signs, another controlled the ramp metering system, etc. This type of design required the operators to move between a series of workstations to implement a control strategy in a specific situation. Today, most control consoles are being designed so that a single operator can operate all of the subsystems from a single workstation. This generally results in better operational control over the system; however, in some situations, two or more operators may be competing for control of the same camera or monitor. Methods of setting priorities whereby multiple functions can be performed at a single workstation need to be established.

The design of individual workstations in a TMC varies depending upon the functions to be performed by the operators. All workstations should be designed to ergonomic standards. The placement of video display monitors and input devices (e.g., keyboards, mouse, trackballs, switches, etc.) should also conform to recognized standards and guidelines. Common ergonomic design problems include the following:

- Monitors placed above operators' seated line of sight.
- Operators having to look over consoles, monitors, and other equipment to view monitors on the wall.
- Inadequate or improper labeling of control features.
- Console heights not adjustable to extremely short or extremely tall operators.

Glare is one of the most common problems with video display units incorporated into workstations. Glare is generally caused by either lighting sources at the workstation or at other nearby video display units. Glare problems can be eliminated by several means, including providing glare shields between video display units and light sources; covering light sources, including windows; and using task lighting.

14.2.7.1 User Interfaces

The user interface is a software element of the system that connects the operator with machine functions in an easy-to-understand format. If the smooth execution of system functions is desired, interfaces between operators and computers must be designed properly. TMC controls and displays should be designed according to the type and quantity of information that the operators must process, and the capacities and demands of the operators who will use the information they provide.

Many troublesome human factors problems are the result of poor user interface design. Poorly designed controls and displays can affect the operations of the TMC and the operators themselves. Inadequate controls and displays can cause cognitive information processing deficiencies, faulty situation assessments and decisions, inaccurate data and command entry, occupational stress, and a general loss of operating efficiency.

The steps involved in designing acceptable user interfaces include the following:

- Develop an interface concept. This concept should be based upon knowledge of the types of interfaces available, and their strengths and weaknesses. The types of tasks to be performed through user interfaces should be considered and should be what drives the design process, rather than technology.
- Develop criteria to govern the design and evaluation of the interface. These criteria include design requirements, dialog strategies, and training requirements. The criteria should also

be verified by experienced operators, traffic engineers, and others who have experience in interface design.

- Develop a “look and feel” of the user interface and conduct initial testing of the interface, using simulations of various levels of realism. (The level of realism associated with a given simulation is also called *fidelity*.) This type of simulation activity provides an excellent opportunity to incorporate *rapid prototyping*. Rapid prototyping involves using special software tools to develop and evaluate interface prototypes. Rapid prototyping techniques offer speed, flexibility, and realism to the design effort.
- Conduct user evaluation and acceptance testing of the interface. User expectations and perceptions do not always agree with those of the developers. Rigorous evaluation procedures must be employed from the very beginning of the interface design, during the prototyping activities, and as part of software / system acceptance testing. The design of user controls and displays is an iterative process. A given display, although acceptable when viewed on its own merits, may represent an inappropriate design solution when it is integrated into the TMC. Accordingly, an owner or agency should not buy off on the interface (i.e., “accept” it) until all of the software has been integrated and they can test all of the features of the final system through the interface.
- Develop the user interface for the full system implementation.

Examples of user interface screens are provided in Figure 14-5.

14.2.8 Other Information Displays

In addition to workstations and the associated user interface, other methods may be used to display information to operators in a TMC, including video monitors, individual large-screen displays, and video walls. A dominant feature in nearly every TMC is an information display board or screen. These display walls are used to provide a broad overview of the status of the system (e.g., traffic flow conditions on roadways, status of equipment, locations of vehicles, video images) to operators, managers, and visitors in the TMC. They are typically used to display graphic information and video. Two different kinds of information displays are generally used in TMCs – individual large screens and video walls.



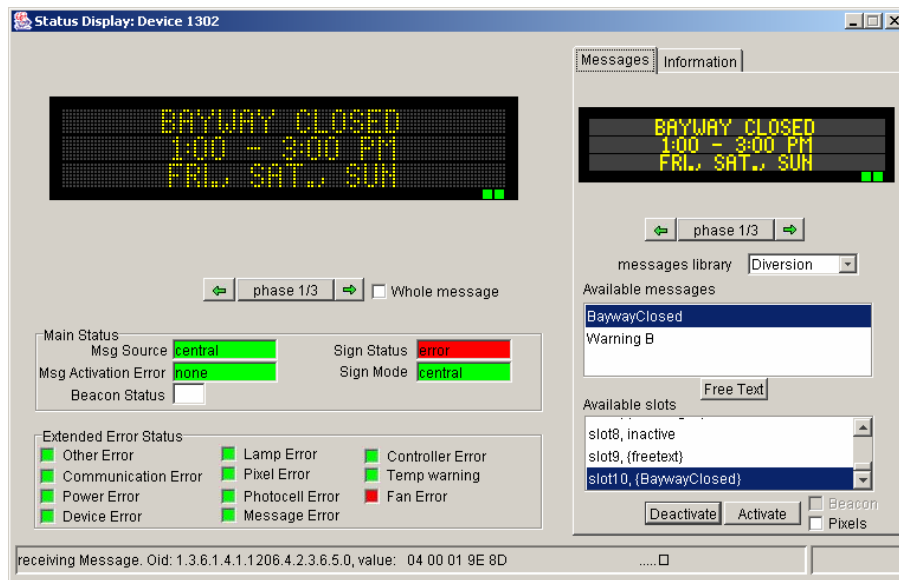


Figure 14-5: Examples of User Interface Control Screens

14.2.8.1 Individual Large Screen

These display walls are comprised of a single or multiple screens, ranging in size from approximately 45” to 120” in diagonal. The difference between this type of display wall and a

video wall is that a screen is large enough to display a suitable amount of information legibly to persons in the TMC. Besides showing status information on computer-generated maps, operators can also display live video from CCTV cameras and television images on the screen. Because the images are usually generated by computer, the operator can zoom to various levels of detail on the display. The primary disadvantage of projection television, however, is that the resolution can sometimes make the image become blurry. Furthermore, because of its sensitive optics, it frequently requires realignment and adjustments. Figure 14-6 shows an example of a TMC with a projection television map display.



(Source: NYS Department of Transportation & Monroe County Department of Transportation)

Figure 14-6: Projection Television Display Wall in a TMC

14.2.8.2 Video Walls

Video walls are used in most new freeway management TMCs. A video wall is a matrix of television monitors used as a single display. Each individual monitor can be used to display a single image or can be used to compose part of a larger display. In effect, it allows the display wall to be widowed or tiled much like a personal computer. By using a video wall, the operators in the TMC have the flexibility of customizing the presentation of the information as conditions warrant. Figure 14-7 shows an example of a TMC with a video display wall.



(Source: Missouri DOT)

Figure 14-7: Video Display Wall in a TMC

14.2.8.3 Design Guidelines and Recommendations

The following guidelines and recommendations are provided to help in designing visual displays in TMCs:

- Avoid too much detail on large maps or status boards.
- Limit the number of colors for maps, target symbols, alphanumeric headings, etc.
- If moving objects are displayed on a map, keep the number at a minimum and display only those that move slowly.
- If color-coded object information is to be used on a large map display, use only a neutral color, such as gray, for the map background; this allows the color targets to have maximum effect (contrast).
- When front projectors are to be used to project information on a large map display, ensure that the projectors are positioned so that they are not readily visible (i.e., causing obstructions and glare) to the operating personnel.
- Determine and provide the properly sized alphanumeric characters and/or symbols on the large-screen displays for the maximum viewing distances at which each set of characters and symbols must be read.
- Use unambiguous coding techniques to help operators in discriminating between old and new data. Color codes should agree with commonly accepted practices.
- Orient maps with north to the top.

14.2.9 Automation

The role of the operator in a system can be defined in terms of whether a human or a machine makes the decisions (i.e., closes the loop) in a task or process. The role of the operator in the decision-making process can be placed into four categories:

- **Direct performer** – the operator performs all the functions of the system.
- **Manual controller** – the machine components are heavily involved in the decision-making process as sensors and effectors, but the actual loop-closing aspect of the function is solely the responsibility of the human.
- **Supervisory controller** – a machine component is allowed to close the loop under supervision of a human operator who may intervene and adjust or override the machine's decision.
- **Executive controller** – the machine is totally responsible for performing all functions of the system; the operator is only there to keep the machine operating.

The acceptable level of automation varies from site to site. In some locations, the long-term system goal is to be fully automated while, at other locations, the goal is for the operator to continue to be a critical element in the operation of the system. Each philosophy has significant implications with regard to the overall design of the TMC, the workstations and the user interface.

A continuum of operator roles exists that defines how much automation is needed to accomplish a function. At one end of the continuum, a function is allocated solely to the human, and at the other end, solely to the machine. In between, performance of the function is shared by human and machine components. As shown in Figure 14-8, the continuum can be divided into four major regions; each region defines a generic operator role in relation to automation. Because it is a continuum, how much automation occurs varies within each region.

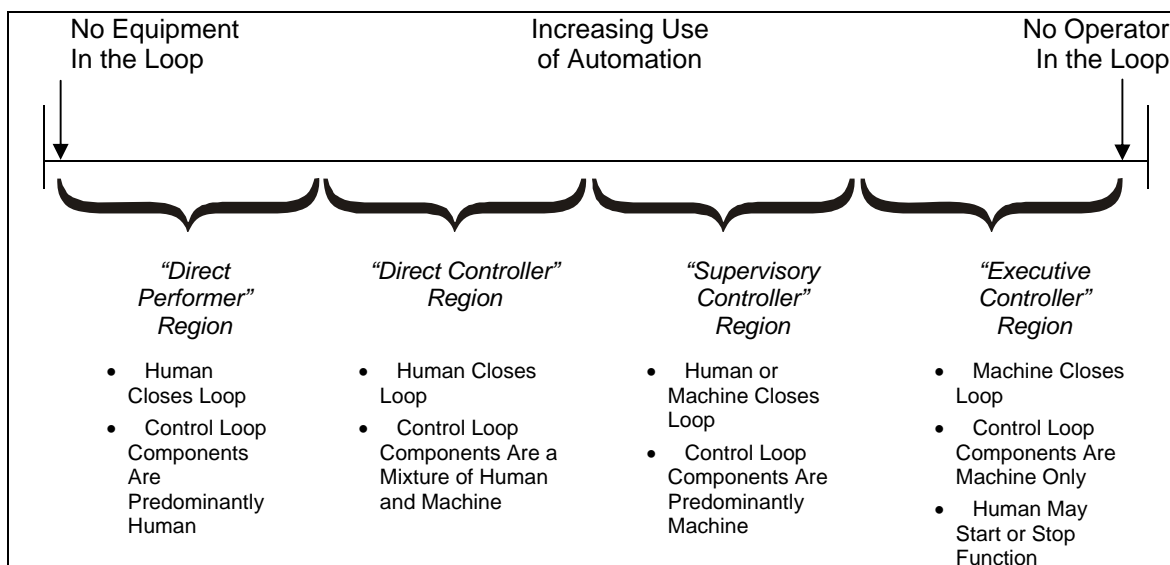


Figure 14-8: Machine and Human Sharing of Functions

How much automation is acceptable in a TMC varies from center to center, depending upon the experience of the operators, the operational goals and philosophy of the agency, and the sophistication of the system. In many locations, routine functions in the TMC can be automated. For example, different TMCs use different methods for generating messages for display on changeable message signs, including the following:

- Messages are entered manually.
- Messages are entered manually with computer assent.
- The operator chooses from selection of canned messages.
- The computer determines a response plan with the assistance of an operator, with the operator implementing the plan.
- The computer determines a response plan and implements the plan with no operator intervention.

Automation systems should be designed to help and support the operators. Operators should be fully aware of what information the system software has, what the automated systems is doing, why it is doing it, and what it is going to do next. At a minimum, the operator should be able to switch off the automated system to prevent future problems or to correct improper decisions. If automated systems are to be used, the level of automation should be gradually increased throughout implementation. Initially, an operator should be present in the control room to review and approve all automated system actions. A detailed log of automation failures should be kept. As failures are eliminated, the role of the operator in the decision-making process can be reduced.

14.2.10 Communications Systems

In general, system designers need to be concerned with four types of communications systems when designing a freeway management system:

- Communications system that links the field devices with the TMC and permits the transfer of data and commands. Data communications can generally be transferred with slow-speed, low-capacity media, which video generally requires high-speed, high-capacity media. (This is discussed in Chapter 17)
- Communications system that links the computer systems inside the TMC, which are responsible for processing information and commands, generating displays and reports, and interfacing with the TMC operators. Most freeway management systems in operation today use local area networks (LANs) to connect their computer and display equipment in the TMC.
- Communications system that permits operators in the TMC to converse with other personnel (and also the public) by voice.
- Communications system that links the systems inside the center with other centers (other traffic management centers, transit centers, emergency services centers, etc.) or the media. (This is discussed in Chapters 16 and 17)

14.2.10.1 Local Area Networks

The term Local Area Network (LAN) is commonly used to describe the type of communications system that links the digital computers internal to the TMC. By definition, an LAN is any

telecommunications system that serves a limited geographic area (typically a single building or campus). The term “network” refers to the fact that multiple users are interconnected.

No single LAN design is ideal for use in a TMC. The design of the LAN needs to support the functions and the types of data exchanges in the TMC. The simplest type of LAN permits the exchange of information between computers and computer-like devices (such as word processors, operator workstations, database managers, etc.). More complex forms of LANs are required to support the transmission of video and audio information besides data.

While the complexity of the LAN varies depending on the type of data being transmitted, every LAN has the following basic components:

- **User workstations** (as discussed in a previous section of this chapter). In TMC applications, workstations may consist of conventional PC computers, intelligent workstations, or terminals.

- **Supporting processing equipment.** Supporting processors, known as servers, are connected to the LAN to execute functions that cannot be provided by individual workstations. Generally, servers are used for the following applications:
 - Execute large computer programs that exceed workstation capacities.
 - Provide centralized data storage and retrieval functions (file servers).
 - Interface with external communication facilities (communications servers).
 - Interface with peripheral devices.The capacity of the supporting processors can vary from that of a personal computer to that of a microcomputer computer.

- **Peripheral devices.** In most TMCs, a variety of peripheral devices are supported on the LAN, including the following:
 - Printers.
 - Plotters.
 - Telex.
 - Fax machines.
 - Modems.
 - Optical character readers.
 - Scanners.

In some systems, the LAN is also used to support video and voice transmissions via connections to television equipment and the telephone system. In larger LANs, a special processor, known as the network control station, is often used to monitor the communications traffic on the LAN continuously, and to accumulate statistics on workstation usage, transmission quality, and network configuration.

When planning a LAN system, the first consideration should be the selection of the type of system or topology that is most appropriate for the application requirements. Generally, three types of topology (i.e., physical shape) are commonly used in designing LANs: a star topology, a bus topology, and a ring topology. Figure 14-9 illustrates each of these topologies. Advantages and disadvantages of each topology are summarized in Table 14-2.

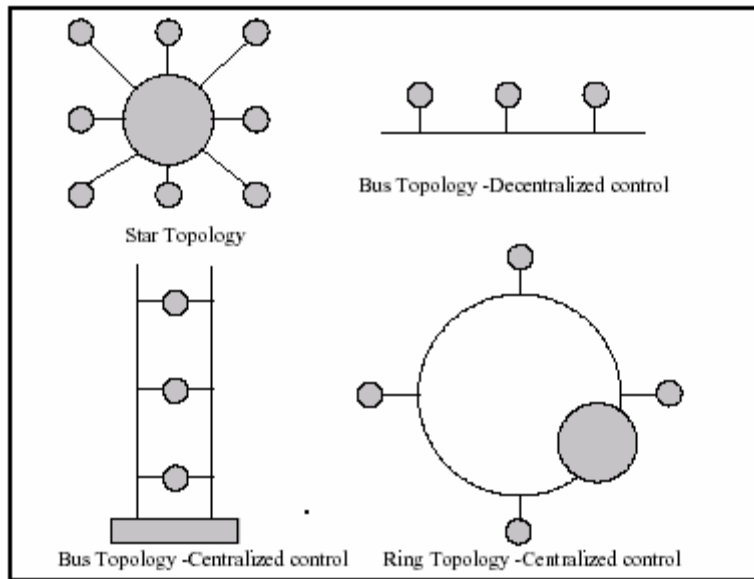


Figure 14-9: Examples of Common LAN Topologies

Table 14-2: Common LAN Topology Advantages and Disadvantages

Topology Type	Attributes	Advantages	Disadvantages
<ul style="list-style-type: none"> Star 	<ul style="list-style-type: none"> Communications protocols generally controlled by central processor Polling techniques used to initiate data transfers Used by popular computer operating systems 	<ul style="list-style-type: none"> Permits use of lower cost workstations. 	<ul style="list-style-type: none"> All workstations disabled in the event of a central computer failure. System expansion costly.
<ul style="list-style-type: none"> Bus 	<ul style="list-style-type: none"> Topology on with both the Ethernet and token bus protocols based Individual workstation initiates data transfers 	<ul style="list-style-type: none"> Network growth can be readily accommodated. 	<ul style="list-style-type: none"> Each processor must provide the capacity required to execute the user's application software. Generally results in more expensive workstations.
<ul style="list-style-type: none"> Ring 	<ul style="list-style-type: none"> Each node receives "token" transfer data. A token is a digital code that allows workstations access to the network. Each node transfers data in turn. 	<ul style="list-style-type: none"> "Tokens" can be passed in either direction around the ring. 	<ul style="list-style-type: none"> Limited exclusively to token passing techniques.

Connections between LAN nodes can be established over twisted-pair cable, thin coaxial cable, standard coaxial cable, or optical fiber. Each of these alternatives has increasing capacities. Twisted-pair (telephone) cable is smaller and cheaper than other communications media, but is subject to electrical and radio interference. Coaxial can carry higher frequencies and data rates than twisted-pair but is more difficult to manipulate physically. Optical fiber is popular because of its small cable diameter, protection against electromagnetic or radio interference, low attenuation, and large bandwidth, but is generally more expensive to install than the other media. Factors that influence the selection and implementation of communications media used in the LAN include the following:

- The amount of data being transferred between devices (i.e., capacity levels).
- The potential for external interference.
- The physical distance between devices.
- The need for future expansion.

The ability to diagnose and predict its own failure is an important factor in designing an LAN. Simple layouts and well-established procedures should facilitate quick repair. In addition, system planners should anticipate expansion needs in the design of the system. The internal design of the building should incorporate adequate routing ducts and conduits to hold all future growth needs. In addition, access rooms should be provided to ease the job of adding and maintaining an LAN.

14.2.10.2 Voice Communications

Systems within the TMC are also needed that allow operators to talk with individuals outside the TMC. The types of voice communication systems needed within a TMC depend primarily upon the functions to be performed by the system, existing communications systems, local availability, and agency preference. Voice communications are commonly used in TMCs for the following purposes:

- Communications with incident response teams and emergency responders including fire, police, emergency medical service providers, hazardous material teams, etc.
- Communications with operations and maintenance field personnel.
- Communications with operations and dispatch staff in other centers or from outside agencies.
- Communications with motorist call boxes.
- Transmission of dispatch information, data, and calls.
- Communications with management and administrative staff, both internally and with outside agencies.

Common types of voice communications systems included in the TMCs include intercom, direct line telephone connects, switching telephone systems, radio, and cellular telephones.

14.2.11 Software Architectures

Software applications – residing on servers, workstations, and field device processors – provide the functionality (including the user interface) for a freeway management system. Software application architectures have evolved over the years, progressing from mainframe (host based) character cell terminal applications to some form of networked PC computing to some form of client server based application architecture. Throughout this evolution, many terms were invented to describe these architectures, often with multiple or confusing meanings. For the purpose of this section, the definitions are provided in Table 14-3.

Table 14-3: Client / Server Definitions

Term	Definition
Client / Server:	The off loading of database query analysis and other compute intensive functions from the client (user interface) computer to the server computer.
Internet:	(capital I) Worldwide network (of networks) primarily used for the sharing of information between two or more parties. Information distribution technologies.
internet / intranet:	(lowercase i) Network or network of networks not directly connected to the Internet or protected from the Internet by combinations of hardware and software, but utilizing communication protocols identical to those used on the Internet.
Networked PC computing:	A graphical user interface implemented at the end-user's desktop (primarily Microsoft Windows) where some or all of the computing, formally performed on the mainframe (host) is done in part or completely on the user's desktop computer. Ushered in the advent of powerful graphical user interface applications.
Thick Client:	Server based computing solutions where some of the "work" is moved from the desktop back to a centralized server while preserving the benefits provided by the powerful graphical desktop environments.
Thin Client:	A network dependent Web browser based user interface, responsible for gathering user input and the display of the application's results. Applications run on the server, not on the client (desktop). A PC, or a network computer can support this form of thin client.
Web Browser:	Software used to display text and graphic information encoded using protocols based on Internet standards.

At the time of writing this Handbook, many system implementations have utilized a large distributed client-server / thin client / internet protocol based architecture, based on the technologies of the Internet. This approach has both advantages and disadvantages:

- Web browsers and environments supporting web browsers are multi-platform, allowing for the selection of hardware and software from many different providers. Because the technology is the technology of the Internet, companies both large and small continue to

improve what is available, making it unlikely that the solution will become an unsupported technological dead end.

- Using a generic user interface device with a stable local configuration reduces downtime due to device failure. When a user interface device fails, it is easily swapped out and replaced because there is little or no customization in the environment. This differs from the PC environment where a user generally configures and expands what the device is used for, often requiring time consuming reconfiguration.
- When the server is down, all clients are affected (In this architecture, all of the work is done on the server, and a loss of the server prevents all clients from doing work.) This disadvantage can be addressed with redundant equipment supporting the server.
- Some ITS functions and applications may require performance in some areas that cannot be met using only HTML – for example, a full-featured GIS based display. Displaying equipment status change updates on a map by re-loading the entire map image will be slow (and possibly unusable by an operator) and wastes network bandwidth. Several approaches can address this issue. One is to build customized “plug-ins” to handle the display of specialized graphic display items; although this requires that a version of the plug-in be created (written) for each operating system platform supported. Alternatively, small programs can be written in the JAVA language and sent to the browser when they are needed. This approach work across platforms, but may not reach the display performance of a thick client GIS system.
- Unlike the thick client approach – where application access by users is through a piece of complex customized software residing on a computer of its own – anyone with a browser who is connected to the network potentially has access to the functions of the system. Thus, it is relatively easy to distribute any portion of the information contained in the system to users outside of the network, either within or outside of the organization. This is because the underlying environment is ubiquitous and almost all consumers of the information have the necessary components to access the system. Depending on what portion of the system is to be exposed to users outside of the core users, software in the server can be configured to accommodate almost any security scheme (to prevent unauthorized users from gaining access to the system.) Moreover, the thin client application architecture can yield a system where a center-to-center user interface is straightforward to implement and support. This can be accomplished by allowing users in one facility access to the systems at another facility simply by having them reference a user interface on the other facility through their web browser.

14.2.12 Security

Security surrounding TMCs largely depends on the nature of the center and its objectives. Because of the vast differences in the purposes and capabilities of these centers, the appropriate levels of security to protect them vary widely, as do the perceptions of security risk. Many original freeway management TMCs around the country were developed strictly as a traffic control measure and, as such, their operators did not see any particular threats to the facility. This stemmed from a perception that there would be little intrinsic value in attempting to attack or otherwise break into such a facility. In contrast, many facilities currently being brought on-line incorporate police, transit, emergency management, and traffic operations. These

facilities are perceived to represent a much more likely target for computer hackers, theft of data, and, given the events of 9-11, potential terrorist activities.

Several generic security measures can be taken to limit physical access to facilities. Effective security is an interplay of three elements: natural and architectural barriers, including anything from landscaping strategies that discourage access, to the number, location, size, and type of doors and windows; human security, including the protection provided by guards and other personnel; and electronic security, provided by any one of the array of systems now available.

Obviously, location of the facility will play a central role in determining what security measures are appropriate. Here again, the needs of staff should be considered in selecting what countermeasures are employed. Communication systems, power supplies, access points, physical integrity of the building, and several other issues are all directly affected by security considerations. In addition, what countermeasures can be used is affected by building codes regarding access and egress during emergencies such as fires. Yet another layer of regulatory codes is associated with the Americans with Disabilities Act, which can affect aspects ranging from physical security barriers to systems that must accommodate both the blind and deaf. Security systems also must be designed so that they are not too obtrusive, intrusive, or otherwise intimidating to employees.³⁰

Computers in the TMC are also a source of security concern for many operating agencies. According to one source, the majority of all computer security losses have been attributed to errors or omissions. Major sources of other computer security losses include dishonest and disgruntled employees, and external threats such as disasters. Only a small percentage of security losses were credited to outside sources, such as hackers. Nevertheless, because of the publicity surrounding hackers and viruses, an undue amount of attention is often focused on protecting against external threats. The extent of the risk to computer systems will vary greatly from agency to agency. Risks include those against the data network and the data itself. The determination of how much security is necessary reverts to the need for risk assessment. Multiple layers of firewalls and other security measures may be warranted in some systems. Several publications are available that offer further detailed exploration of computer security measures that can be implemented.

14.2.13 Data Archiving

As discussed in Chapter 4, in order to monitor the long – term performance of the transportation network, the real time operations data collected by a freeway management system (FMS) must be systematically retained and reused – a process known as “data archiving” or data warehousing. It is commonly the TMC – which collects large amounts of data for use in real-time traffic management – where this data are archived for some future use.

ITS data archiving is defined as the systematic retention and re-use of transportation data that is typically collected to fulfill real-time transportation operation and management needs. It is also known as data warehousing or operations data archiving. Transportation operations and their respective sensors and detectors are a potentially rich and detailed source of data about freeway system performance and characteristics. Table 14-4 inventories data items that can potentially be collected by freeway management system applications and operations groups

Table 14-4: ITS Data Relevant for Archiving

(Reference 7)

ITS Data Source	Primary Data Elements	Real-time Uses	Possible Multiple Uses of FMS-Generated Data
Freeway traffic flow surveillance data	<ul style="list-style-type: none"> • Volume • Speed • Occupancy • Travel time (e.g., probe vehicles) 	<ul style="list-style-type: none"> • Incident detection • Ramp meter timing • Congestion / queue identification • Traveler information 	<ul style="list-style-type: none"> • Congestion monitoring • Link speeds for planned air quality models • AADT, K- and D-factors • Saturation flow rates • Pre-planned TMC operations • Performance monitoring • Management systems and decision-making
Visual and video surveillance data	<ul style="list-style-type: none"> • Time • Location • Queue length • Vehicle trajectories • Vehicle classification • Vehicle occupancy 	<ul style="list-style-type: none"> • Incident detection • Coordinate response • Congestion / queue identification • Traveler information 	<ul style="list-style-type: none"> • Congestion monitoring • Car-following and traffic flow theory
TMC-generated	<ul style="list-style-type: none"> • Link congestion indices 	<ul style="list-style-type: none"> • Incident detection 	<ul style="list-style-type: none"> • Congestion monitoring
Traffic flow metrics	<ul style="list-style-type: none"> • Stops /delay estimates 	<ul style="list-style-type: none"> • Traveler information • Control strategies 	<ul style="list-style-type: none"> • Effectiveness of prediction methods

14.2.14 Emerging Trends

Much has happened in the development and operation of TMCs over recent years; and like most technology-based endeavors, such changes and advancements can be expected in the future. Some of the emerging trends are not necessarily new, but are the result of technologies becoming more mature, and therefore, more commonplace. Not all of these trends are technical in nature; some are institutional. Those emerging trends include:

- Automation of system functions is becoming more common today as advanced computing techniques and control theory, such as neural networks and fuzzy logic, become more understood in our industry. The use of knowledge-based “expert systems” to assist operators with decision making is another example
- Emerging standards, such as the National Transportation Communications for ITS Protocol (NTCIP), for communication between centers, and between TMC and field devices.
- Use of call center technology and computerized telephony for both call center functions (receiving calls from motorists) and distributing information to travelers (e.g., highway advisory telephone or 511 systems).

- Since the horrific events of 9/11, there is an emphasis throughout the country on assessing means to protect the physical roadway infrastructure, particularly bridges and tunnels that are potential targets. The TMC will most likely become the monitoring point where operators will respond to alarms of stopped vehicles on bridges or in tunnels. Moreover, the TMC may be considered a critical asset itself, thereby affecting the design of the facility and its access, as well as operational procedures.
- As previously discussed, the TMC is becoming a data mart / warehouse, where large amounts of data are gathered, archived, and stored for non-real-time uses such as evaluation and planning purposes.

TMCs are becoming coordination and communication hubs for maintenance activities. For example, the using the TMC to house maintenance managers and dispatchers during snow emergencies, when the emphasis is not necessarily on moving congested traffic, but on monitoring the roadway's physical condition in order to direct snow removal. Utilizing Roadway Weather Information Systems (RWIS) data brought into the TMC and monitoring weather forecasts, maintenance managers and dispatchers at the TMC have real-time information on roadway ice & snow conditions in order to manage the snow removal team.

A similar example is that of maintenance management systems linking the traffic management system with the maintenance work order development process within an agency to automatically issue maintenance work orders on field equipment. As noted in Reference 8 ("Freeway Management and Operations; State of the Practice"), the "state-of-the-art in management systems incorporates managing systems operations and system assets with managing maintenance activities. State-of-the-art management systems often utilize inter-agency archive data systems to store and retrieve information pertaining to the management activities. Examples of management systems include:

- Incorporating freeway management assets in **asset management systems**. Asset management is an emerging concept for public agencies. Asset management is geared toward optimizing resource allocation across transportation assets that are very broadly defined. It is generally viewed to provide improved decision making for investments in new capacity, improvements, preservation, and operations. Information is needed on a broad array of assets, but is usually focused on the roadway, structures, guardrail and barrier, signs, and other traditional roadway features. Asset management allows agencies to track the condition of their current system and the adequacy of their annual expenditures. Asset management systems are not specifically designed for electronic systems, but electronics can be entered into the system and tracked.
- Establishing **network management systems** for fiber optic and other telecommunication systems. Just as a system is needed to manage the maintenance of freeway management system components, a system is needed to manage the maintenance of the telecommunications network. These systems identify the devices that are attached to the telecommunication system, track the individual strands of fiber or pairs of twisted pair cable that are used by devices, and identify the specific telecommunications equipment included in the system.
- Utilizing **configuration management systems** to help freeway system managers locate and identify the current versions of software, documents, procedures and models of

hardware and firmware in use in their system. These systems are focused on tracking components and documentation that are part of a central system, both those in the central location and those in remote locations. The systems track replacement and upgrades of equipment and the software resident in the equipment. The idea behind these systems is to know what may have changed if a systemic problem is uncovered. Very often, systems used to manage telecommunication networks are used for hardware configuration management. In fact, freeway management telecommunication systems should be included in the overall configuration management system. The network management systems mentioned above can facilitate this inclusion. System configuration management is a relatively new concept in transportation and is an outgrowth of the emphasis on software configuration management.³¹

14.3 IMPLEMENTATION & OPERATIONAL CONSIDERATIONS

Before the first brick can be laid for a TMC facility or any system hardware or software can be procured, there are a number of issues to be examined and understood. For example – What is the mission of the TMC? How will it operate? What systems will be included in it? Who will operate the systems included? How will the system be managed and maintained over time?

It is generally accepted that the best way to answer these and similar questions – for TMCs, for ITS – based systems, or for any large and complex systems (usually incorporating computers and software) – is to utilize the “systems engineering” process as introduced in Chapter 3 and discussed in greater detail below. At the same time, it must be emphasized that, as noted in the conclusions in the NCHRP synthesis on TMC functions (Reference 5), “some of the most critical issues affecting TMC design and deployment are policy issues, including jurisdictional, modal, institutional, and administrative concerns”.

14.3.1 Systems Engineering

The literature contains many definitions for “systems engineering”. The FHWA Technical Report “Building Quality Intelligent Transportation Systems Through Systems Engineering” (Reference 9) contains the following definition:

“Systems engineering is the process by which we build quality into complex systems. It uses a set of management and technical tools to analyze problems and provide structure to projects involving system development. It focuses on ensuring that requirements are adequately defined early in the process and that the system built satisfies all defined requirements. It ensures that systems are robust yet sufficiently flexible to meet a reasonable set of changing needs during the system’s life. It helps manage projects to their cost and schedule constraints and keeps realism in project cost and schedule estimates.”

Another way of describing system engineering is that it is a “requirements driven development process.” That is, user requirements are the overriding determinant of system design, component selection and implementation. There should be no “gold plating” and you only pay for what you really need. The Systems Engineering process is more than just steps in system design and implementation; is a life cycle process. It recognizes that most systems are built incrementally and/or expand over time. The basic steps in the process do not change, but are spread out over time. There is an even stronger need to provide feedback and assessment with each incremental deployment phase so that future phases build on and expand the system, rather than simply replace elements of the earlier phases.

Systems engineering helps accomplish four key activities that impact a project's (and TMC's) success. These are (9):

- **Identify and evaluate alternatives** – The feasibility of each alternative must be measured from three different points of view: technical feasibility, cost feasibility, and schedule feasibility. *Technical feasibility* addresses whether we can build, maintain, and operate a system alternative, given the technology and people available to us. *Cost feasibility* looks at whether we can build, maintain, and operate a system alternative with the funds available for it. *Schedule feasibility* considers whether we can build a system alternative within the time frame allotted for its development. Usually we have to make trade-offs, deciding which alternative offers the better value.
- **Manage uncertainty and risk** – If we could accurately predict the future, it would be easy to avoid mistakes and problems. However, in real life, we need to deal with uncertainty and risk. Systems engineering focuses on three aspects of risk management: identification, analysis, and mitigation.
- **Design quality into our systems** – This is accomplished by addressing those factors that can negatively affect quality. Paraphrasing the International Organization for Standardization (ISO), we can define quality as “the totality of features of a system that bear on its ability to satisfy stated or implied needs.” Among the factors that can negatively affect the quality of a system are its *complexity*, its *inflexibility*, its *lack of standardized components*, and its *reliability and availability*.
- **Handle program management issues that arise** – this requires a good project plan, one that is complete, comprehensive, and communicated. It should including all tasks that must be performed, accurately estimate the resources required to accomplish each task, assign the appropriate resources to each task, define all dependencies among tasks, identify all products or other criteria whose completion signifies that a task is done, and determine how to measure progress against plan when managing the project.

Another management consideration is that the process is most effective when the managers and engineers have *domain knowledge* about the system being built (including TMCs). *Domain knowledge* is a fundamental understanding of the technology and functions involved in the system being built. In an ITS system, for example, *domain knowledge* includes transportation engineering or transit system management. Without *domain knowledge*, a manager and systems engineer are not as effective.

ITS project development – including TMC hardware and software – has increasingly used the structured systems engineering approach as a means to improve the chance for success. FHWA sponsors a 2-day course entitled “An Overview of Systems Engineering” (10) and has produced several technical documents on the subject (9, 11), with the stated goal “to introduce systems engineering to managers and staff working on Intelligent Transportation Systems (ITS) projects, if they aren’t already familiar with its practice”. Another course on applying systems engineering to ITS projects – “Applied Systems Engineering for Advanced Transportation – is offered over the Internet (for a fee) by the Consortium for ITS Training and Education (CITE) (Reference 12). The Federal Highway Administrations Final Rule 940 (13) on ITS Architecture

and Standards requires that “all ITS projects be developed using a systems engineering analysis commensurate with the project scope”.

References 9 and 10 utilize the “V” (or “VEE”) model as a way of showing the systems engineering process and relating the different stages in the system life cycle to one another. The “V” model, illustrated in Figure 14-10 shows the early stages in building a system / TMC as steps along the left leg of the “V,” the decomposition leg of the process. The steps on this decomposition leg break the system down into its pieces, proceeding from development of a Concept of Operations for the system / TMC, through the definition and refinement of the system’s requirements (going from high-level to detailed requirements), to the system / TMC design stage, which also goes from high-level to detailed design. At the bottom of the “V” is the Implementation stage, which represents the transition from decomposition (the conceptual level) to re-composition (the physical level). During this stage, the system’s / TMC’s design is transformed into actual products. On the right-hand leg of the “V” are the re-composition steps, where all the parts of the system / TMC are tested and put together. As one proceeds up the right-hand leg, the system’s building blocks are combined into larger and larger pieces, resulting in a finally assembled and installed (i.e., complete) system / TMC.

The “V” model helps to emphasize the importance of evaluation in all stages of a system / TMC project. In the early stages of the system life cycle (the left leg of the “V” model), one is using mostly inspection and analysis as evaluation tools. In the later stages of the system life cycle (the right leg of the “V” model), the primary evaluation tool is testing. Regardless of which leg of the “V” model one is on, evaluation efforts are combined with system development activities.

Each of the “steps” / activities shown in the “V” model are summarized below in general terms, followed by a brief TMC – focused discussion. It is emphasized that while the systems engineering process is oriented towards ITS, TMCs, and individual projects, the various steps identified in the V - diagram nonetheless closely parallel the “steps” identified in Chapter 3 (i.e., the “funnel diagram in Figure 3 – 1) for establishing a freeway management and operations program.

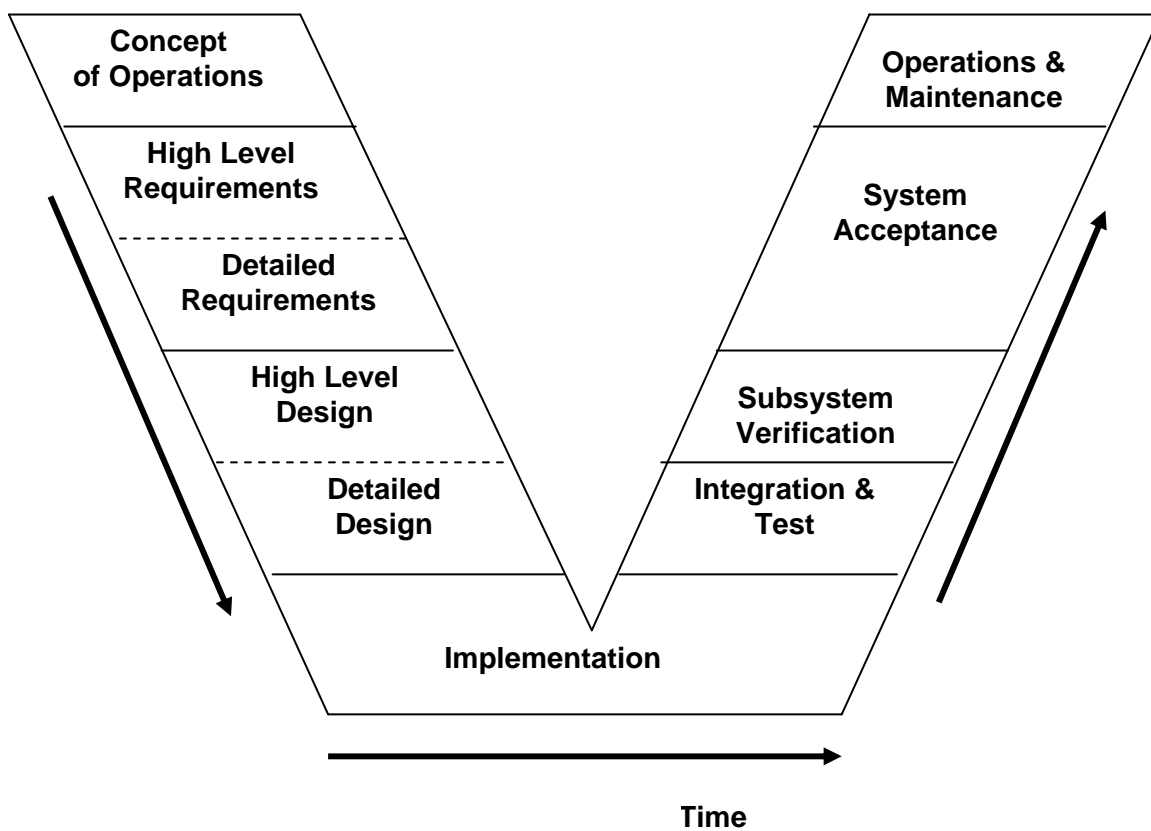


Figure 14-10: “V”
Diagram

14.3.1.1 Needs Analysis

The *needs analysis* determines problems that need to be solved. In conducting a needs analysis, there may be some preliminary steps that you have to take to put your effort into the proper context. (11). They are:

- **Understand the local institutional environment** – There are a number of local factors that could affect the requirements on ITS / TMC projects. These include the political situation (e.g., what can realistically be done, in light of who wields political power and what power they have); receptivity to innovation and new ways of doing business (e.g., will local operators and citizens fight some or all proposed changes to the transportation system); willingness to invest in ITS solutions; and local laws and regulations.
- **Determine Stakeholders** – A *stakeholder* is anyone who has an interest in the success of the ITS project (a “stake” as it were). *Stakeholders* include users, politicians, and the public. Each *stakeholder* has some idea of what he or she wants the system / TMC to do, and their particular needs ultimately determine which ITS components are implemented, and how available funds get apportioned to improve local transportation and satisfy the local constituency. It is therefore important to determine the potential users of all ITS services under consideration (including the TMC) and their primary concerns; others who may be

affected directly or indirectly by ITS services and the TMC, but who will not be users; and persons or organizations with a strong material interest in success or failure of ITS solutions. The stakeholders are sources of requirements and they are also ones who validate or verify the requirements. In particular, the principal stakeholders – the ones for whom this system is key to doing their job, including those agencies that will ultimately be housed within the TMC – must be identified. A list of potential stakeholders for a freeway management system and TMC is provided in Table 3-1 (in Chapter 3).

As part of the needs analysis, it also important to recognize and understand the broader vision, goals, and objectives that have been established for the surface transportation network and the freeway management program. The functions that are ultimately allocated to the center should support these goals and objectives – that is, the TMC (and any ITS-based system) should be viewed as a tool for accomplishing the goals and objectives of the agencies involved.

14.3.1.2 Concept of Operations

The *concept of operations* is a formal document that provides a user-oriented view or “vision” of the system / TMC. It is developed to help communicate this vision to the other stakeholders and to solicit their feedback. To develop a *concept of operations*, several basic questions must be asked, among which are: do we know who all the users will be; do we know how the users will interact with the proposed system; is how we plan to operate the system consistent with all systems with which it must interact; and have we coordinated with all other agencies affected by this system (11).

The content of a Concept of Operations document is spelled out in a standard³² from the Institute of Electronic and Electrical Engineers (IEEE), one the major U.S. standards bodies. Table 14-6 illustrates the outline of a Concept of Operations document, as specified in that standard (9).

Table 14-5: Outline - Concept of Operations (Source – Reference 9)

Title page
Preface
Table of Contents
List of figures
List of tables
1. Scope
2. Referenced documents
3. Current system or situation
4. Justification for and nature of changes
5. Concepts for the proposed system
6. Operational scenarios
7. Summary of impacts
8. Analysis of proposed system
9. Notes
Appendices
Glossary

A few key points are provided in Reference 9 regarding this outline.

- The last subsection in the *Justification* section documents assumptions and constraints. Putting assumptions and constraints in writing makes it easier to communicate them to all interested parties. And, if any assumptions or constraints change during the project, one can go back and see what effect they had and what impact a changed assumption or constraint would have on how the system evolves.
- The fifth Concept of Operations section, *Concepts for the proposed system*, gives one the opportunity to lay out the system and explain how he/she thinks it will work, once it's in operation. This is a key section, because it shows the intended users of the system how the new system will affect them. It's a good tool for setting or managing user expectation for the new system.
- The sixth Concept of Operations section, *Operational scenarios*, allows one to describe specific cases of system use. Some like to use flow diagrams to illustrate operational scenarios; others like to use a narrative approach, sort of a "Day in the Life of ..." approach.

TMC Concept of Operations

The importance of early planning cannot be overstated. The "1-10-100 rule" states that for every dollar spent rectifying an error or problem in the planning stage would cost \$10 to rectify in design and \$100 in implementation or operation stages. The agency desiring to implement a TMC faces a significant challenge in defining to its system designer exactly what the agency wants designed, what functions and features are to be included, and how the agency wants it designed. Without this guidance, the designer may either make a "best guess" at the agency's needs and desires, or may come forward with a solution which was developed to meet the needs of another (possibly quite dissimilar) agency and transportation situation. There are many systems in the world today that were built flawlessly, and operate exactly as they were designed. Unfortunately, they weren't designed with operational specifics and don't do what the agencies need them to do.

As noted in the "Transportation Management Center Concepts of Operation Implementation Guide" (Reference 14)³³:

"An agency implementing a TMC should plan the TMC as carefully as it would plan any high-cost, high-visibility investment. An important tool in such planning is a "concept of operations." It develops answers to the questions "What do we want to do?" and "How do we do it?" for the TMC. It also guides many areas of preparation for the facility. It looks closely at the functions which the TMC must perform and the broader functions whose performance the TMC supports. The concept of operations is often the first detailed examination of the idea for implementing a TMC. It will provide guidance and direction to help ensure that the subsequent procurements result in the type of facility and systems that best serve the agency's needs, and which represent an effective utilization of limited budgetary funds. It will also assure that the operational needs of the TMC are consistent with the resources and policies of the responsible agencies. Thus, a path can be laid for successful operations and maintenance, realizing the maximum possible benefit from the investment."

Reference 14 identifies the following examples where the TMC Concept of Operations can serve an important purpose:

Functions	The concept of operations may be the first definitive expression of how the TMCs functions will be performed. Thus, it can support resource planning for the physical space requirements, hardware and software specifications, the staffing, and some allocation of responsibilities between the implementing parties.
Consensus Building	The concept of operations can serve, at successive levels of detail, as a component of consensus building by the partners performing those functions, who have already begun to define the requirements, as well as the mission/vision/goals/objectives of the TMC.
Training & Documentation	The concept of operations also addresses the training program required for the staff and the documentation that they will require in performance of their duties.
Interactions	The concept of operations should also identify the interactions between organizations involved in performing the TMC's functions. Thus, it will identify the points at which agencies or functions within an agency interact, and how that interaction may take place: <ul style="list-style-type: none">- Who initiates- What information is provided- What response is needed- What communications means are applied- How the response is confirmed- What form the feedback loop takes to assess effectiveness, modify the response if needed, and terminate it when appropriate.

The Concept of Operations for the TMC should also identify its purpose or role in the overall freeway management program. The functions of a TMC can vary from location to location, depending upon the local operating goals and visions / philosophies for the freeway management program. The development and design of the TMC needs to support the desired operating philosophy. For example, an agency whose primary goal is information dissemination may want to design a TMC that allows easy access to the information in the system by outside users; while an agency that wants close interaction with other operating agencies (fire, police, emergency services, etc.) may want to provide a physical location in the TMC for those agencies to have staff (e.g., dispatch their emergency response personnel and resources). Common roles/functions of a TMC in freeway management systems include the following:

- A location for coordinating and implementing freeway management strategies and controls.
- A dispatching center for incident management and maintenance forces.
- A location for doing maintenance and repairs of malfunctioning or damaged field equipment.
- A central location for distributing freeway traffic and travel information to travelers, elected officials, and the media.
- A command post for coordinating the response to major emergencies or weather events.

TMC Joint Operations

A major question that must be addressed during the initial planning stages and the Concept of Operations is what agencies need to be in the TMC, the responsibilities of their respective staffs within the TMC, and how they will interact. Depending upon local needs and operating

philosophy, operating personnel can come from a variety of agencies and entities, including state transportation agencies, regional and local transportation agencies, police and emergency service providers, local transit authorities, and private media and traffic reporting services.

The resulting joint operations can be structured administratively to occur in different ways, such that varying levels of functional and management control are centralized or individual control is maintained. Joint operation can be structured through the following:

- Sharing physical resources that are common to each agency's operation, but operating each system or agency component individually. This could occur through use of a common communications system.
- Operating individual or multiple systems under one designated management structure where operational control is centralized. This could occur by time of day where peak periods are under central control and off-peak is under local jurisdictional or functional agency control. Typically, the participating parties establish operating guidelines that are carried out by an individual agency or group, with the goal being to establish coordinated ongoing operations.
- Delegating day-to-day operations to another agency or group (including a private entity). This type of operation could entail turning the operations and maintenance of individual devices over to another agency under a defined set of conditions (e.g., Transcom operation of certain CMSs and HARs in the region surrounding New York City).

The ability to engage in joint operations is not an easy accomplishment and usually occurs because of ongoing relationship building. A variety of strategies can be undertaken to foster cooperative joint operations. No one individual technique or action is appropriate for all areas; instead, each community must assess its own unique situation. Strategies that can be employed to foster cooperative and joint operations in a TMC include the following:

- Ensure that each agency is represented in defining goals and objectives and in the initial stages of planning and developing the traffic management program. An invitation to be involved in the planning and design of the TMC should also be extended.
- Emphasize how the program can include projects that address the needs and problems of each agency. Look for ways to widen the focus of the initial goals of the system to help other agencies improve their operations.
- Approach joint operations with an open attitude about how overall results can be enhanced by sharing resources.
- To facilitate sharing and build trust among agencies, start joint operations with a relatively small and noncritical task. Building confidence and trust around these smaller elements will facilitate the accomplishment of larger tasks in the future.
- Develop an open-ended and flexible system architecture such that new systems and changes in hardware and operating procedures can be accommodated easily.
- Add functions and responsibilities under joint operations at a manageable rate.

- Develop standard operating procedures for how the devices in the system can be used by each agency in the control room. These operating procedures should be scenario-based and describe the roles and responsibilities of each agency in the scenario.
- Cross-train the staff from each agency so that they can do the jobs of the other agencies' staffs, and so that each operator has an understanding of the roles, responsibilities and limitations of each agency in the TMC and can serve as a backup or substitute in crises.
- Provide a mechanism for positively, reviewing and debriefing each other's operations with the idea of improving the overall operations and capabilities of the system.

14.3.1.3 Requirements

In this stage, a determination is made – in a more detailed manner than in the *concept of operations*, what the system / TMC should do. This stage can run through several iterative cycles of defining, reviewing, and refining the requirements. A key point related to this phase is that the end product must be a set of requirements on whose meaning everyone agrees.

Requirements are statements of the capabilities that a system / TMC must have (i.e., “functions”), geared to addressing the mission-oriented objectives of the organization for which the system is built. For requirements to be most useful, they should be statements of what is desired, not descriptions of how the need should be satisfied – that is, good functional requirements are written without specifying implementation details.

Functional requirements are based on facts, not “wish lists” or misperceptions about what’s needed to do a job. Questions should always be asked such as: “What’s the reason for this requirement?” “What critical purpose does it meet?” “What happens if we don’t provide this capability?” In particular, measures should be established that permit the quantification of requirements. It’s better to have a requirement that states the need to support “10,000 devices” than one that says you have to be “able to expand the system to accommodate future growth.” The first requirement can be verified; the second is not verifiable. (11).

Written requirements are important. A written requirements document captures what you’re trying to achieve with this system in a tangible form, one that others can read and review and interpret. Attributes of good functional requirements include (11):

- **Necessary**. Something that must be included or an important element of the system is missing and other system components can’t compensate for its absence.
- **Concise** (minimal, understandable). Stated in language that is easy to read, yet conveys the essence of what is needed.
- **Attainable** (achievable or feasible). A realistic capability that can be implemented for the available money, with the available resources, in the available time.
- **Complete** (standalone). Described in a manner that does not force the reader to look at additional text to know what the requirement means.

- **Consistent.** Does not contradict other stated requirements nor is it contradicted by other requirements. In addition, uses terms and language that means the same from one requirements statement to the next.
- **Unambiguous.** Open to only one interpretation.
- **Verifiable.** Must be able to determine that the requirement has been met through one of four possible methods: inspection, analysis, demonstration, or test.

One way to eliminate ambiguity is to conduct a System Requirements Review or “walkthrough”. A System Requirements Review brings in representatives from each stakeholder and walks them through each requirement one-by-one. This is a critical step in the process of getting requirements done properly. It’s important to make sure that all the stakeholders interpret all requirements the same way. This is a critical step in the overall process – if everyone doesn’t have the same interpretation, some will have expectations that won’t be met, and the wrong capabilities may end up being implemented.

TMC Requirements

A *Mission Analysis* is an exercise that may be useful to agencies in identifying the functions and operational requirements of a TMC. Traditionally, two methods are used to conduct a mission analysis: a mission profile and scenario development.

- A mission profile is a detailed description of normal system operations that occur during a given system activity or over a given interval of time. It consists of listing all the activities to be done by various elements in the total system— operators, supervisors, automated subsystems, sensors, etc. The list also includes any activities done simultaneously (e.g., automated tasks done by system hardware, operator assessments, operator decisions). Activities are described at a high level and no attempt is made to define the roles of the operators or automated system in doing them. This technique provides an organized, high-level framework of system requirements that will support subsequent, detailed design analysis.
- With the scenario development technique, descriptions of specific scenarios— non-routine but typical situations that would burden (challenge) the capabilities of the TMC—are sometimes useful in providing an understanding of the TMC’s functions and operational concepts. The scenarios should describe what actions and information are needed to manage traffic during different operating situations such as freeway incidents, major traffic stressors (e.g., large athletic events, inclement weather), or strategic planning episodes.

Table 14-6 lists some possible generic functions of freeway management TMCs. Note that these functions describe what it is the system does; it does not define whether activities are done by humans, by automated equipment, or by a human using a computer.

Table 14-6: List of Possible Generic Functions Performed in Freeway Management TMCs

Input	Throughput	Output	Support
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<ul style="list-style-type: none"> • Detect vehicle locations • Detect Vehicle Speeds • Detect vehicle types • Sense roadway surface conditions • Receive BIT reports • Receive ad hoc component status reports • Sense visibility conditions • Verify incident data • Monitor incident clearance • Receive traffic volume reports • Receive probe vehicle reports • Receive ad hoc travel time reports • Receive ad hoc roadway condition reports • Receive O-D Data • Receive commercial rail traffic data • Receive ad hoc commercial rail traffic reports • Receive weather service data • Receive ad hoc weather reports • Receive interagency incident data • Receive ad hoc incident response reports • Receive interagency emergency response data • Receive ad hoc emergency response data • Receive interagency data from alternate transportation modes • Receive ad hoc reports from 	<ul style="list-style-type: none"> • Assess current load • Anticipate near-term traffic conditions • Select best traffic control option • Determine need for ITMS support • Track special vehicles • Predict traffic conditions given options • Determine remedial maintenance needs • Assess predicted traffic conditions given options • Assess traffic management effectiveness • Determine software upgrade needs • Determine hardware upgrade • Determine personnel upgrade needs • Determine preventative maintenance needs • Determine source of anomalies • Identify anomalies in traffic patterns • Assess current load • Anticipate near-term traffic conditions • Select best traffic control option • Determine need for ITMS support • Track special vehicles • Predict traffic conditions given options • Determine remedial maintenance needs • Assess predicted traffic conditions given options 	<ul style="list-style-type: none"> • Control railroad crossings • Post route advisories on information outlets • Provide route advisories to other users • Post speed advisories on information outlets • Provide speed advisories to other users • Post travel advisories on information outlets • Provide travel advisories to other users • Post mode selection advisories on information outlets • Provide mode selection advisories to other users • Transmit electronic maintenance requests • Issue special maintenance requests • Issue upgrade requests • Transmit electronic incident services requests • Control railroad crossings • Post route advisories on information outlets • Provide route advisories to other users • Post speed advisories on information outlets • Provide speed advisories to other users • Post travel 	<ul style="list-style-type: none"> • Store electronic network data • Retrieve electronic network data • Store electronic incident data • Store hardcopy of incident reports • Retrieve electronic incident data • Retrieve hardcopy of incident reports • Perform database management • Provide traffic management training • Provide maintainer training • Provide incident management training • Provide special events training • Develop strategic traffic management plans • Develop special event traffic management plans • Store electronic network data • Retrieve electronic network data • Store electronic incident data • Store hardcopy of incident reports • Retrieve electronic incident data • Retrieve hardcopy of incident reports • Perform database management • Provide traffic management training • Provide maintainer training • Provide incident management training
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<ul style="list-style-type: none"> • alternate transportation modes • Receive interagency special events reports • Receive ad hoc special event reports • Receive public comments • Receive requests for public relations activities • Receive requests for historical data • Receive requests for simulation studies 	<ul style="list-style-type: none"> • Assess traffic management effectiveness • Determine software upgrade needs • Determine hardware upgrade • Determine personnel upgrade needs • Determine preventative maintenance needs • Determine source of anomalies • Identify anomalies in traffic patterns 	<ul style="list-style-type: none"> • advisories on information outlets • Provide travel advisories to other users • Post mode selection advisories on information outlets • Provide mode selection advisories to other users • Transmit electronic maintenance requests • Issue special maintenance requests • Issue upgrade requests • Transmit electronic incident services requests 	<ul style="list-style-type: none"> • Provide special events training • Develop strategic traffic management plans • Develop special event traffic management plans
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14.3.1.4 Design

This stage involves deciding “how” each requirement in the system is satisfied. The FHWA course on Systems Engineering (10) defines system design as the “appropriate selection of system components and their interconnection so as to meet the system requirements, and the preparation of specifications that describe the design.” The design stage consists of several activities, including generating alternatives, assessing the alternatives (e.g., technical and operational feasibility, institutional compatibility, life-cycle costs, constraints), considering the conditions that impact operations and maintenance (e.g., staff capabilities and availability, environment, available facilities, training and documentation needs) and standards. The “ilities” – reliability, maintainability, availability, and affordability – must also be considered.

It is important to ensure, as the design evolves and becomes more detailed, that the design retains its internal consistency. If groups working independently on parts of the system design fail to communicate effectively, it may be difficult to make the system’s pieces mesh during implementation. This can be accomplished via design reviews. Design reviews generally fall into two major categories: Preliminary Design Reviews and Critical Design Reviews. A Preliminary Design Review (PDR) is conducted on each component of the system. The PDR assesses the progress, technical adequacy, and risk mitigation involved in the selected design approach; determines whether the item being reviewed is compatible with defined performance requirements; estimates the degree of technical risk remaining; and verifies the existence and compatibility of all interfaces involved. The Critical Design Review (CDR) is conducted when the design for each component is complete. The CDR ensures that the item under review satisfies all requirements allocated to it; ensures that the item is compatible with all other items in the system; and assesses whether there is any remaining risk associated with the item (9).

TMC Design

To ensure proper design, it is important to begin with a *user-centered approach* to developing a TMC. A user-centered approach applies system engineering and human factors principles to developing a system design that focuses on what the system is supposed to accomplish rather than on technology, with the selection and acquisition of system components based on the validated functional requirements. The distinguishing features of a user-centered development philosophy as compared with other approaches include the following:

- **The focus is on the operator, not the designer.** In the user-centered development, the user (i.e., the operator) is viewed as a critical system component. The characteristics, capabilities, and limitations of the user need to be defined and considered during the requirements analysis and design of the system. Ideally, the user should be involved in the planning and design processes at their earliest stages and this involvement should continue throughout the design and testing phases.
- **The process is iterative.** Systems are best developed through an *iterative* process, in which a design is tested and validated in a series of stages. This is particularly important in TMC development, where the multiple iterations can uncover problems — and opportunities — that are not apparent until they are viewed in the total system.
- **The process extends throughout the life cycle of the TMC.** The fact that a new TMC has been built and put into operation does not suggest that it is “complete.” As the managers and operators of the TMC become familiar with the system, they will make recommendations for adding many excellent features and procedural changes to improve their abilities to control traffic on the freeway.

The design process for a TMC includes defining the functional relationships, data requirements, and information flows. This involves the following activities:

- Allocating TMC functions to operators, computer/machine components in the system, or a combination of both.
- Analyzing the tasks required to complete each function.
- Establishing how data flow from one function to the next.

Each of these tasks is discussed below.

Function Allocation – In the design of the TMC, function allocation involves assigning system functions to machine components, human operators, or a combination of human and machine components. Using criteria similar to those shown in Table 14-7, each function (or process) is assigned to a human or machine component. Properly allocating functions is critical to ensuring that operators in the TMC perform tasks that are within their capabilities and do not become overloaded. The *Human Factors Handbook for Advanced Traffic Management Center Design* (6) presents techniques for allocating functions to human operators and machine components.

Table 14-7: Criteria for Assigning Functions to Humans and Machines.

Humans Excel in ...	Machines Excel in ...

Detection of certain forms of very low energy levels	Monitoring (both men and machines)
Sensitivity to an extremely wide variety of stimuli	Performing routine, repetitive, or very precise operations
Perceiving patterns and making generalizations about them	Responding very quickly to control signals
Ability to store large amounts of information for long periods — and recalling relevant facts at appropriate moments	Storing and recalling large amounts of information in short time periods
Ability to exercise judgment where events cannot be completely defined	Performing complex and rapid computation with high accuracy
Improving and adopting flexible procedures	Sensitivity to stimuli beyond the range of human sensitivity (infrared, radio waves, etc.)
Ability to react to unexpected low-probability events	Doing many different things at one time
Applying originality in closing problems (i.e., alternative solutions)	Exerting large amounts of force smoothly and precisely
Ability to profit from experience and alter course of action	Insensitivity to extraneous factors
Ability to perform fine manipulation, especially where misalignment appears unexpectedly	Ability to repeat operations very rapidly, continuously, and precisely the same way over a long period
Ability to continue to perform when overloaded	Operating in environments that are hostile to man or beyond human tolerance
Ability to reason inductively	Deductive processes

The allocation of functions in the TMC is usually the first point in the design process at which critical decisions must be made about the role of the operator. It is also a point at which mistakes, if not identified and corrected in design iterations, can cause serious design deficiency. One common misconception that occurs in allocating functions is the presumption that a single set of functions should be handled solely by an operator, and another set should be handled solely by machines. In fact, many critical functions in the TMC can best be handled by the integrated efforts of humans and machines. Identifying these partly automated tasks requires detailed study and analysis. Failing to identify them properly and assign proper interface strategies causes serious operational problems. General guidelines and design considerations for allocating functions in a TMC include the following:

- If environmental constraints limit human performance, the function should be allocated to a machine.

- Events that cannot easily be perceived by humans (such as changing levels of traffic moving past a point on a freeway) should be allocated to machines.
- When a function requires a response that is beyond the speed or accuracy of human capabilities, it should be allocated to a machine.
- If the speed and volume of information derived or needed by a function is beyond the capabilities of a human, it should be allocated to a machine.
- If the information produced by a function is beyond the memory capabilities of a human, it should be allocated to a machine.
- If a function is to be performed continuously, it should be allocated to a machine.
- If the interruption of, and response to, unusual or unexpected events are required, the function should be allocated to a human.
- Allocate functions so that they make the best use of human abilities.
- Avoid decisions based solely on the ease or difficulty of automation; consider how allocating different functions between humans and machines affects total system performance.
- Avoid allocating functions in such a way that both humans and machines are forced to work at their peak limits all or most of the time.
- Allocate functions to humans so that they can recognize or feel that they are making an important and meaningful contribution to the performance of the system.
- Allocate functions between humans and machines so that a natural flow and processing of information can occur.
- Assign tasks that require extremely precise manipulations, continuous and repetitive tasks, or lengthy and laborious calculations to a machine.
- Design human/system interfaces on the presumption that the human might at some point have to take control of the system.
- Use hardware and software to aid the operator; do not use the operator to complement a predetermined hardware/software design.

Task Analysis – After functions have been allocated to human operators and system components, the next step in designing a TMC is to identify the tasks that make up system functions. Each function includes one or more tasks. A task is an independent action, carried out either by an operator or by a machine that results in an identifiable outcome. Tasks can

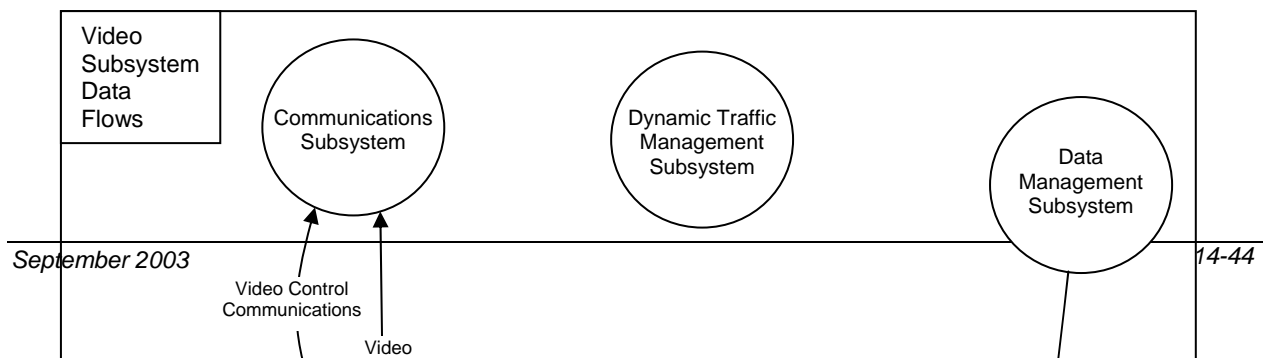
frequently be decomposed into discrete subtasks that represent activities that are distinct enough to be analyzed separately, but are clearly contributing to the identified task.

Once the tasks have been identified, they can be grouped to form operational flow or process diagrams. The operational flow diagrams allow designers to identify the actions, information requirements, processes, and decisions that need to be made to accomplish a function. Operational flow diagrams are useful tools in the design process, because they allow designers to readily identify the following elements:

- The types of data required in the TMC.
- The decision-support aids needed to complete operational tasks.
- The data-storage requirements of various processes and tasks in the TMC.
- The types of outputs and decisions produced by each task.

Data Flows – Establishing data flows is a critical step in designing a TMC. Data flows describe the type and frequency of data needed to execute each function of the TMC. This step in the design process is important because it allows system designers to assess the communications requirements of each component in the TMC. Establishing the data flows also helps to identify the structure of the data streams needed to operate each function of the system.

One way to depict data flow is through data flow diagrams. With data flow diagrams, large circles are used to represent sources and destinations of data. The sources/ destinations can be either subsystems or functions within subsystems. Lines connecting data sources and destinations are used to represent the type of data that flows between two elements of the system. Each data type is labeled so that designers know what information is flowing between components. An example of a typical data flow is provided in Figure 14-11. Data flow diagrams need to be prepared for each level of design detail and for each subsystem within the TMC.



1.

Figure 14-11: Typical Data Flow Diagram

Select System Technologies / TMC Layout – Only after the functions of the TMC have been identified and the data flow requirements assessed should designers begin designing the physical layout and the support elements and related technologies of the TMC. In planning the TMC, system designers need to be concerned with the following elements:

- The physical environment in which the operators and equipment will function.
- The design and operations of the operators' workstations.
- The design of the controls and displays that the operators will use to operate the system.
- The design of the interfaces through which the operators will be presented with information and initiate control decisions.

These technologies and TMC elements are discussed in previous section 14.2.

Another important design issue is system expansion. Freeway Management Systems (FMS) can expand operations in many ways, including an increase the number of freeways and/or roadway facilities covered; adding new freeway management functions; accommodating joint or cooperative operations of several agencies from one location; and serving as a command post for major emergencies. With these potential expansion scenarios in mind, it is critical that agencies plan and design for future expansion in the TMC by providing the following:

- Adequate space in the operations room to install additional operator consoles/ workstations.
- Sufficient space and capacity to install additional computers and peripherals.
- Spare or expandable communications capabilities.
- Additional office space for personnel from different operating agencies.

14.3.1.5 Implementation

This stage of the systems engineering process transforms the design(s) into a product. It may involve building parts of the system from scratch or integrating the different pieces that you buy.

However it is done, it makes the system real. Activities during this stage focus on ensuring that what gets built matches the agreed-upon design. One specific subset of systems engineering activities during this stage is software engineering, designed to ensure the quality of the software in the system. These activities include walk-throughs of developed programs (where programmers review the work of another programmer, to determine whether any errors exist). In addition, software engineers define standards for code development and ensure that these standards are followed. But the systems engineering activities aren't solely directed at software. It is also important to ensure that hardware developed (or modified) during this stage also matches the agreed-upon design. Hardware inspections are one technique for quality control during this stage (9).

TMC Procurement Methods

Various methods exist for implementing TMCs and ITS-based systems. An important aspect of TMC procurement relates to the separation of the physical building or plant with that of the intelligent transportation systems within.

- **Low-Bid Contracting:** This is probably the most common procurement practice for TMCs, as it is for most procurement with the public sector transportation community. Low-bid contracting is the selection of a bidder based upon having the lowest quoted price, while meeting a set of specifications published by the procuring agency. It has remained a popular choice because of its reliability and intrinsically cost-effective format. This type of contracting however places a significant burden on the procuring agency to publish detailed, unambiguous specifications. The result of a poor specification is usually a significant cost and schedule overrun due to specification modifications and sometimes debates with and claims from the contractor. A re-bid of the contract may result, too, if the specification isn't complete and other non-selected bidders protest. This always has a significant effect on the agency's timeline for commissioning.
- **Systems Management Contracting:** This bidding system serves to contract with a "systems manager" who installs specific systems within the TMC. The physical building and hardware are bid separately. The systems manager is also responsible for procuring the necessary hardware or 3rd party commercial software, developing and delivering the application software, integrating the systems, and providing training and documentation. This method is not the most common, however, it is becoming more so. It is an advantageous method for complex TMCs with multiple systems.
- **Life-Cycle Costs Contracting:** This method is a competitive bid where the award is based upon the initial capital cost plus the cost of operation over a specific period of time. Life cycle is based upon the life of the "item" with initial capital costs capitalized to reflect annual costs. Determining when an item is obsolete can present difficulties for this method. This method is not a common one for freeway management TMCs.
- **Prequalification:** This process is employed by a procuring agency to ensure that all those that bid are capable of meeting the minimum requirements prior to requesting detailed proposals or quotes. It is a two-step process: step 1 evaluates potential bidders to see if they have the means and experience to undertake a project, while step 2 involves evaluating quotes and awarding to the lowest bidding qualified contractor. Because of the complex nature of TMC, the prequalification method is a good tool and therefore, quite common.

- **Design-Build Contracting:** This method is fairly common, and involves contracting to first have the TMC designed and then implement the project. It is common for these projects to be implemented in stages in order to better control the direction of the project and ensure that budget and time constraints can be measured and met. This method can be cumbersome to contractors when a negotiated fixed price for the design-build is determined, and during the design phase, significant changes are requested that impact the build cost. This risk can be mitigated with a thorough specification and a contracting mechanism that provides staged scoping and cost estimating.
- **Request for Proposal Contracting:** This method is very common for procuring engineering or consulting services. After the issue of a request for proposal containing a detailed project statement from a contracting agency, prospective bidders prepare and submit a proposal that may include an understanding of the issues, detailed scope of work, experience and staff qualifications, cost estimate and schedule. The contracting agency selects a bidder outright or selects a “short-list” of bidders for further discussion and evaluation. This is often times tied to the low bid method of contracting.

Software Procurement

There are many software products that serve to support the functions of a TMC, such as detector processing, ramp metering, control and monitoring of DMS, incident management, etc. These software packages can be commercial-off-the-shelf software or contractor developed products. It is likely that in the implementation of a TMC, application software will need to be developed or existing contractor software modified. The procurement of software (i.e., software development and integration) does not meet the normal linear process that highway or even TMC construction projects follow. Further, it is complicated with ownership and intellectual property rights.

The topic of software procurement is extremely complex. The reader is referred to a couple of detailed references that provide extensive information on the topic of ITS software procurement. The references are AASHTO's, “ITS Software: Effective Acquisitions Practices”, and FHWA's “The Road to Successful ITS Software Acquisition”. Another software related issues is that of configuration management, which is discussed in Section 14.3.

14.3.1.6 **Integration and Testing**

The testing stage overlaps implementation. It starts with *unit testing* (i.e., the testing of individual pieces of the system) as soon as any pieces are available. It continues with *string or integration testing*, which ensures that individual pieces work together as intended and which tests interfaces at the lowest level within the system. Last is *system testing*. This involves a full end-to-end test of the complete system and comes in two major “flavors.” The first is the final integration test by the system developer. The second is the “acceptance” test, where the end user(s) of the system make sure that it does what it's supposed to do. The acceptance test, however, is conducted in the next stage (9).

TMC Integration and Testing

From the perspective of a TMC implementation, testing during software development is important because it (hopefully) uncovers errors in the logic of the programs. Although it is

unlikely that all execution paths through a program can be covered, it is important to identify test coverage that ensures all mission-critical functions are thoroughly tested.

Hardware components within the TMC need to be exercised as part of the testing process to ensure that they perform as expected and as the system requires them to. The practitioner should recognize that hardware testing needs to take place under realistic conditions of use, not just a “laboratory” environment.

As different elements of the TMC are installed, they also need to be evaluated to ensure that they meet accepted principles of human factors engineering. Human factors testing and evaluation should not be a one-shot, pass-or-fail activity conducted near the end of the implementation phase. Instead, human factors testing and evaluation should occur throughout the design and implementation process. The most important principle to follow in testing and evaluating the human factors elements of the design is to *test early and often*. Testing should be conducted by individuals who have experience in conducting human factors evaluations. From a contractual standpoint, it is important to ensure that this effort is included in the contractor’s scope of services.

14.3.1.7 System Acceptance

During this stage, the completed system is tested prior to putting it into production use. Users and operators should participate in the system acceptance process. During this stage, in preparation for the system acceptance process, the users and operators of the system are trained so they understand how to use it to do their jobs (9). (Note – As discussed below, training occurs throughout the systems engineering process).

TMC Training

The training of operators is critical to the success of a freeway management system. Operators need to be provided with three levels of training: technical, operational, and managerial. Both formal and informal training is needed before the system becomes implemented, as the system goes on-line, and after the system has been operating for some time.

How much training is required by operators in a TMC depends on the functions to be performed and the level of technical competence of the operations staff. Technical training is required in a variety of areas associated with system operations and maintenance, including diagnostic procedures for all hardware as well as for new upgrade procedures. The basic level of training needed by system operators includes the following:

- General principles, operating philosophies, and concepts of freeway management.
- An overview of the system, including the system schematics, field subsystems, communications, central subsystems, and proposed or planned system functions to be added.
- Operation and interpretation of system software and displays.
- Basic radio and communications codes and procedures.
- Standard operating procedures.
- Communicating with other agencies such as fire, police, etc.

At most TMCs, new operators generally receive one-on-one, on-the-job training with an existing operator. Besides basic training, operators need to be provided with continuous advanced training. This advanced training can be adaptable to specific issues and needs of the

operations and maintenance staff. Areas in which advanced training may be provided include the following:

- Emergency response procedures.
- Traffic flow and control theory/philosophy
- Control algorithm basics
- Hazardous material spills procedures.
- Major accident and disaster clearance procedures.
- Roadside fire response.
- Multijurisdictional extended pursuits.
- Release of information to the media.

Training is necessary for other personnel in the TMC who perform roles other than operation. These include system engineers, software engineers, and electronic technicians who must maintain the systems within. Training for these functions must include:

- System Planning – training in system configuration and deployment planning. Elements include the following:
 - System overview
 - System security
 - Communications server/channel device assignment
 - Graphics development
 - Network configuration and remote access
 - Data management
- System Operations - training including:
 - System configuration
 - System logging and events
 - Status monitoring
 - Alarms and paging
 - Links and MOEs
 - System startup and shutdown
- System Administration –training covers the following topics:
 - System installation and configuration
 - Troubleshooting
 - Data backup and restoration
 - Report generation
 - System maintenance

Methods of providing training include videotape, simulated events or tabletop exercises, site visits to other TMCs, lectures and coursework, and computer / workstation simulations.

Sufficient training should also be provided when a new element or application is added to an existing system. This is usually accomplished through contract specifications with training line items. In preparing for training, the following should be specified:

- The maximum number of persons to attend each formal training session.

- The minimum number of days for each training program (Defining what a day is may also be important.)
- Who will develop and supply all the necessary manuals, displays, class notes, visual aids, and other instructional materials for the training program.
- Outlines of lectures and demonstrations, and samples of all training materials. These materials should be submitted to the agency for review some specified time before their proposed use. Agency approval should be specified before the training courses can be scheduled.
- Where training is to be conducted (e.g., at a local site designated by the agency or at the contractor's facility). If the training is at a contractor's facility, the specifications also need to define who is responsible for paying the transportation and subsistence costs of the agency personnel.
- When training should be conducted (i.e., during normal business hours of the agency and the training site.)

14.3.1.8 Operations and Maintenance

This should be the longest stage, the one in which the practitioner uses and maintain the system for the remainder of its existence. Maintenance involves all processes that keep the system performing satisfactorily, including upgrades of equipment and software to later versions to enhance the system's performance as its volume grows. When you deal with an upgrade or major change to a system, the life cycle starts over, for that piece of the system that is being modified. It's also important to recognize that you have to keep monitoring the system's performance against its original performance requirements. This is particularly important as demand on the system increases. You may have planned for some growth in demand; you need to know when you reach that limit (9)

TMC Operations

Important considerations for TMC operations – such as hours of operation, staffing, documentation, and configuration management – are discussed below in Sections 14.3.2 - 14.3.5.

14.3.2 Hours of Operation

In many areas, TMCs operate continuously while others operated for certain periods. As TMC's move toward performing a greater number of control and surveillance functions, the time periods of TMC operations will likely be extended. Larger, regional TMCs are generally the most suitable for 24-hour, 7-day operation. For local TMCs, minimum coverage would be two weekday shifts, one each for the morning and evening peak periods. Some agencies, although operating their TMCs continually, do not always have dedicated personnel for the entire operational period. During "off-hours" maintenance personnel may periodically monitor equipment malfunctions or TMC equipment operation. In some cases, the system hardware and software provide self – monitoring capability and automatically notify an on-call operator or supervisor when an unexpected event arises. Another option is to "transfer" late night and weekend operations to a regional 24/7 TMC. (5)

The issues associated with the TMC hours of operation need to be addressed during the Needs Analysis and Concept of Operations, taking into consideration the overall functionality of the TMC, the tasks that will be conducted there, and a variety of local conditions that may affect staffing coverage.

14.3.3 TMC Staffing

No rigid rules exist for determining the number of operators in a TMC. The number of operators in a control room primarily depends on the functions that are being performed, the number of facilities covered, and the operating philosophy of the center. The total number of staff will depend on the hours of operation. In general, staffing for 7 – day, 24 hours-per-day operations entails three assignment shifts, each 8 hours per day.

Table 14-8 illustrates the ultimate staffing requirement of a traffic operations center in Rochester, New York. The primary function of the TMC is to detect and clear incidents from the freeway at all hours of the day. It also supports those individuals involved in the continued planning and operation of the system, and houses the staff responsible for developing strategies for special events, providing lane closure recommendations for construction contracts, and responding to major traffic incidents.

The types of personnel needed in the TMC of a freeway management system may include the following:

- TMC manager / director
- Supervisors (definable for operations, engineering, maintenance, law enforcement, etc.)
- Workstation operators and analysts
- Transportation and electrical engineers
- Electronic/maintenance technicians.
- Communications specialists/operators.
- System administrators (for computer hardware)
- System engineers
- Software developers / programmers.
- Inspectors (for field equipment)
- HAR broadcasters
- Radio dispatchers
- Administrative staff
- Public relations and media relations personnel
- Trainees / interns

Table 14-8: Staffing Requirement for Regional TMC in Rochester, NY

Time of Day (Hour Beginning)	Number of Staff			Total
	Supervisor	Sr. Operator	Operator	
12:00 AM	1	1	1	4
1:00 AM	1	1	1	4
2:00 AM	1	1	1	4
3:00 AM	1	1	1	4
4:00 AM	1	1	1	4
5:00 AM	1	4	3	9
6:00 AM	1	5	4	11
7:00 AM	1	5	5	12
8:00 AM	1	5	5	12
9:00 AM	2	5	5	13
10:00 AM	2	4	5	12
11:00 AM	2	4	4	11
12:00 PM	2	4	4	11
1:00 PM	2	4	4	11
2:00 PM	2	4	4	11
3:00 PM	2	5	5	13
4:00 PM	2	5	5	13
5:00 PM	1	5	5	12
6:00 PM	1	5	5	12
7:00 PM	1	4	4	10
8:00 PM	1	1	3	6
9:00 PM	1	1	2	5
10:00 PM	1	1	1	4
11:00 PM	1	1	1	4

Typical Staffing Distribution Requirements (Monday - Friday)

Time of Day (Hour Beginning)	Number of Staff			Total
	Supervisor	Sr. Operator	Operators	
Daily	1	1	1	4

Typical Staffing Distribution Requirements (Saturday)

Time of Day (Hour Beginning)	Number of Staff			Total
	Supervisor	Sr. Operator	Operator	
7 AM - 8 PM	1	1	1	4
8 PM - 7 AM	1	0	1	4

Typical Staffing Distribution Requirements (Sunday)

Generally, those centers whose functions include significant interaction with police officers in the field should consider including a police liaison officer on their staffs. A police liaison officer fosters stronger interagency cooperation and can aid in dispatching appropriate police

responses to incident scenes. Certainly the same can be said for the fire department, other modal agencies or jurisdictions, and the media.

14.3.3.1 Qualifications

Overall, the level of qualifications for TMC operators should be directly related to the design of, and functional allocation within the center. If the operators' functions are repetitive, predictable, and non-critical, operators with low qualifications can be used; however, if unique problems are frequent, rapid reactions are required, and/or criticality is high, operators need to have higher levels of training and expertise. As a rule, operators must possess good verbal skills, a degree of computer literacy, and good reasoning skills. Some agencies also require operators to have a good working knowledge of the freeway system and some dispatching experience.

The qualifications for TMC operators also vary from center to center. For example, some TMCs use operators taken from the agencies' technical staff of traffic engineers or computer scientists. Often, these operators have other assigned technical duties, or may be given special projects to work on along with their duties in the TMC. A few centers require their operators to have college engineering or technical degrees. Several TMCs employ part-time students as operators, who are under the supervision of a manager or a senior operator. The student operators can be classified as "interns" that do not require agency full-time positions, and can often be very cost effective for the level of qualifications and abilities. If set up correctly, with the cooperation of the universities, the hiring process can be done primarily through the universities, and sometimes that universities will contribute tuition to the interns.

Operators should possess the following characteristics, regardless of how much education and experience they have:

- Ability to make good judgment calls quickly and accurately.
- Ability to handle stressful situations.
- Good oral and written communication skills.
- Good technical skills and good interpersonal skills in dealing with nontechnical personnel.
- Ability and willingness to follow standard operating procedures.
- Initiative to learn more about the operations of the other functions in the TMC.
- Willingness to provide suggestions/ideas to promote a more efficient operation.
- Computer literacy.
- Good understanding of the transportation language.

14.3.3.2 Staffing Sources — Agency versus Outsourcing

Being able to attract and maintain qualified TMC personnel can be difficult for many agencies. Agencies have two basic options for staffing their TMC – personnel from within the agency, or by outsourcing. A pure agency staff has the advantage that managers and team leaders have a single personnel management system to deal with, and team cohesiveness is easier to establish and maintain. Further, agencies have a higher degree of ownership and therefore may have more initiative to make changes to the operation of the system. Outsourcing involves hiring private personnel to perform some or all of the functions in the TMC. The primary advantage of outsourcing is the immediate availability of highly qualified personnel. Seasonal and special events can be adequately staffed with limited training and start-up time. In addition, private employment agencies are not subject to the civil service regulations and policies that

public agencies must follow. Private agencies can be more competitive and can pay the market salary rates that make it easier to attract and retain qualified people.

To some degree, many agencies already employ outsourcing techniques to perform some functions in the TMC (such as computer maintenance, software development, etc.). Those types of positions that can potentially be outsourced include the following:

- Field and electronic technicians with communications or electronics experience.
- Team managers or leaders from a variety of backgrounds.
- TMC and communications technicians with knowledge, experience and training from other private sector hardware and software systems.
- System programmers and computer systems analysts with knowledge and familiarity of control algorithms.

Agencies should have managers or supervisory staff that are familiar with all aspects of the TMC functions so they can adequately manage the outsourcing contracts, and so they can effectively champion the needs of the TMC and FMS within the agency.

14.3.4 Documentation

Operating manuals document the procedures used by an agency to deal with the operations of their transportation system. The Management and Operations Committee of the ITS Council of ITE developed an *Annotated Outline for a Traffic Management Center Operations Manual*. It can serve as a checklist for an agency's manual and includes the sections noted in Table 14-9.

Other TMC documentation includes the following:

- **System Administration Manuals:** System administration documentation for a TMC includes manuals, papers and plans of the equipment and infrastructure that exist at or are attached to the TMC. These can include manuals for individual subsystems within the TMC or the network plans, configuration and layout of the LANS and WAN, as well as database schema, configuration and maintenance needs.
- **Maintenance Manuals:** Maintenance manuals are necessary for all of the hardware in the TMC. These documents are typically provided by the hardware suppliers and are vital for use in training the maintainers of the TMC hardware.
- **Other Documentation:** It is important during any project related to the TMC to document the processes and developments of the project. Therefore, there should be a strong emphasis on project documentation to aid future engineers in long-term maintenance efforts. Other related documentation includes equipment warranties, acceptance test results, and software source code documentation.

Table 14-9 Operators Manual Table of Comments

1. Emergency and Other Contact Numbers
2. Daily Operation
 - 2.1. Management Center Functions
 - 2.2. Personnel
 - 2.3. Hours of Operation
 - 2.4. Staffing
 - 2.5. After Hours On-Call Roster
 - 2.6. Remote Operation
 - 2.7. Security Procedures
 - 2.8. Maintenance Checklist
 - 2.9. Startup/Shutdown
 - 2.10 Failure Recovery
 - 2.11 Agency/Jurisdictional Contacts
 - 2.12 Notification Procedures
 - 2.13 Contact With Media
3. Control System Operation Procedures
 - 3.1 Operator Interface
 - 3.2 Operational Procedures
 - 3.3 Incident Management
4. Maintenance Procedures
 - 4.1 Routine Maintenance
 - 4.2 Preventive Maintenance
 - 4.3 Spare/Backup Equipment
 - 4.4 Emergency
 - 4.5 Contract Maintenance
5. System Operations Logs
 - 5.1 Operations
 - 5.2 Maintenance
 - 5.3 Events
 - 5.4 Systems Reports
 - 5.5 Traffic Data
 - 5.6 Risk Management
6. Operational Concepts
 - 6.1 Traffic Control Concept Strategy
 - 6.2 Traffic Monitoring
 - 6.3 Data Analysis And Warehousing
 - 6.4 Interagency Coordination
 - 6.5 Inter-jurisdictional Coordination
 - 6.6 Emergency Procedures
7. TMC Description/System Field Devices
 - 7.1 Location
 - 7.2 Access/Security
 - 7.3 Layout
 - 7.4 Fire Suppression
 - 7.5 Power Source/Location
 - 7.6 HV/AC
 - 7.7 Data Communications
 - 7.8 Voice Communications
 - 7.9 Network Communications
 - 7.10 Field Device Descriptions

14.3.5 Configuration Management

Freeway management programs (and their associated freeway management systems and TMCs) are ongoing endeavors. More often than not, the program and systems are implemented in small increments, with functions and areas of coverage being added over time. The institutional landscape – which influences policy and funding decisions – is also subject to change during the life – cycle. Changes in program and system requirements are therefore inevitable. A goal of a freeway management practitioner should not be to avoid making changes, but to keep the requirements change process under control through a process known as “Configuration Management.” Configuration Management includes procedures and techniques that allow the practitioner to consider and evaluate the impacts of proposed changes, and then to track and document those changes that are made.

Configuration management is a part of the systems engineering process and a critical element in the life of any system. It is particularly important in those systems that are software intensive, such as TMCs. But configuration management principles and procedures are also applicable in the broader context of a freeway management program. The concept can and should be expanded to include operations and management strategies – not just technical systems. In other words, the term “configuration” in configuration management can refer to the entire set of items that make up a freeway management program, including policies, system hardware and software, documentation, operational procedures, freeway geometrics and associated infrastructure (e.g., signing and lighting), incident management strategies, work zone procedures, and anything else that makes up the description and embodiment of a the program.

The process is described in more detail in the document “*Configuration Management (CM) for Transportation Management Systems*” (Reference 15), the contents of which are summarized below. It is noted that the processes and procedures of CM have been developing in the information technology community for many years. Accordingly, Reference 10 makes use of a standard developed and refined in the IT industry – the Electronic Industries Alliance (EIA) Standard 649 *National Consensus Standard for Configuration Management (ANSI/EIA-649/-1998)*, referred to EIA 649. Reference 15 is oriented towards ITS – based transportation management systems. But as is the case with other “systems” processes described herein, by changing a few key terms (e.g., “system” into “program”, “TMS’ into ‘freeway operations”) and expanding the context, the CM process can be “converted” and used for the overall freeway management and operations program.

14.3.5.1 Introduction

There are two fundamental purposes of Configuration Management (CM) – to establish system integrity, and to maintain system integrity. A system with integrity is one in which:

- All components are well defined and documented
- A working baseline is always available to implement and provide transportation management services
- Integration with other regional systems can readily be accomplished
- A high degree of traceability exists, allowing one to easily identify how system functions are provided.

In other words, a system with integrity is one that is available and functional.

CM provides a holistic approach for effectively controlling system change. It helps to verify that changes to subsystems are considered in terms of the entire system, minimizing adverse

effects. Changes to the system are proposed, evaluated and implemented using a standardized, systematic approach that ensures consistency. All proposed changes are evaluated in terms of their anticipated impact on the entire system. CM also verifies that changes are carried out as prescribed and that documentation of items and systems reflects their true configuration. A complete CM Program includes provisions for the storing, tracking and updating of all system information on a component, subsystem and system basis. This provides TMS managers with an up-to-date baseline of their system.

The CM process may be (and ideally should be) applied throughout the system life cycle. This allows TMS management to track requirements throughout the life cycle through acceptance and operations and maintenance. As changes are inevitably made to the requirements and design, they must be approved and documented, creating an accurate record of the status of the system. The general CM process is described graphically in Figure 14-12.

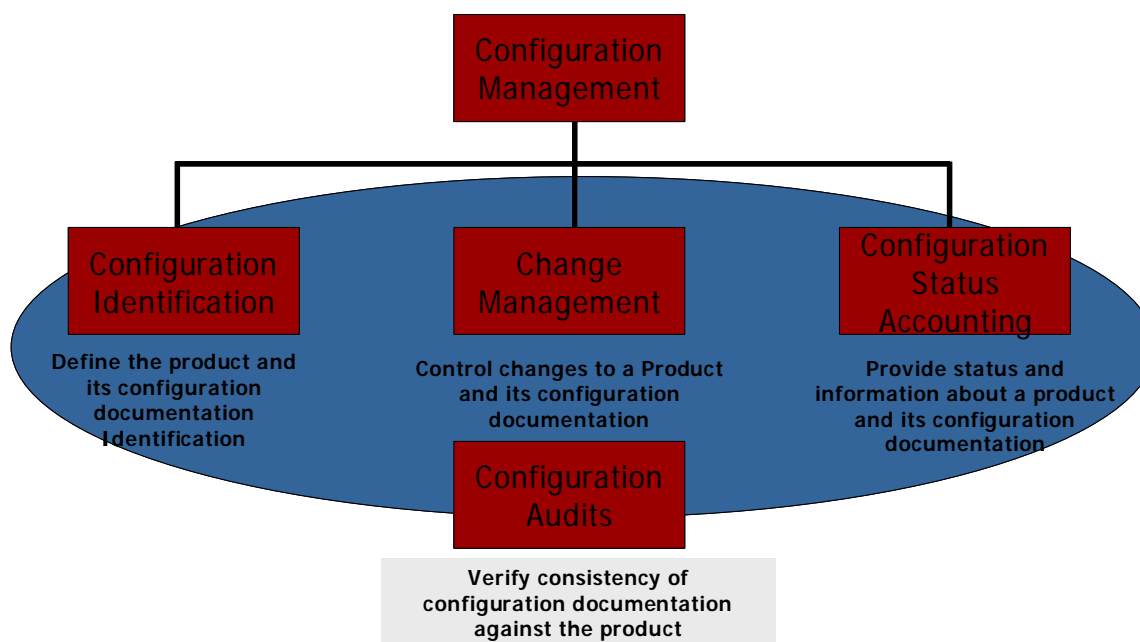


Figure 14-12: Configuration Management Process (Reference 15)

14.3.5.2 CM Plan

While not shown in Figure 14-13, a CM Plan is integral to the process. The CM Plan is the document that will guide the CM Program of a particular group. Typical contents of a plan include items such as:

- Personnel
- Responsibilities
- Resources
- Training requirements
- Administrative meeting guidelines
- Definition of procedures
- Tools/tool use

- Organization CI activities
- Baselineing
- Configuration Control
- Configuration Status Accounting
- Naming conventions
- Audits and Reviews

Plans typically are established at the outset of the CM Program and undergo changes as the system evolves and areas where the plan can be improved are identified.

14.3.5.3 Configuration Identification

Configuration Identification refers to the activities and processes dedicated to creating and maintaining full documentation describing configuration items (CIs). A CI may be defined as anything that has a function in the TMS. Therefore, system components, classified in the broad categories of software, cabling, and hardware, are considered as configuration items, in addition to system requirement and design documentation. With most systems, this effort must begin with legacy systems that will be reused in the system being developed. The goal of Configuration Identification is to provide a unique identifier to each item to help track the changes to that item and to be able to understand its place in the system. This, in turn, supports traceability and the change management process.

14.3.5.4 Change Management

Change Management, or Control, is the process by which:

- The need for a change is identified,
- The impact of the change on the system (i.e., value, cost, schedule) is analyzed,
- The proposed change is evaluated by a review body and, if approved,
- The approved change is incorporated into the existing system with its appropriate documentation.

Change requests are submitted to the relevant administrative body for review. This body is normally referred to as a Change Control Board (CCB). The CCB will review the proposed change, determine its effect on the overall system and decide whether or not to proceed with it. An important part of Change Control is ensuring that the change itself is documented and that the relevant Configuration Item's documentation now reflects that change.

The primary benefit of an effective Change Control procedure is that proposed changes are evaluated in terms of their impact on the entire system. Change Control allows the changes to be reviewed by personnel with a variety of interests and areas of specialty. This minimizes the negative impacts of changes on other components of the system. Change Control also ensures that the changes are properly implemented, and within schedule and cost constraints.

14.3.5.5 Configuration Status Accounting

Configuration Status Accounting is the record keeping and reporting function of the configuration management process, ensuring that all of the relevant information about an item – documentation and change history – is up to date and as detailed as necessary. Configuration Status Accounting involves the following tasks:

- Collecting, cataloging and maintaining all configuration documentation,
- Tracking and reporting the status of all proposed changes,
- Tracking and reporting the implementation status of all approved changes, and
- Configuration of all system hardware, include those in operational inventory.

Configuration Status Accounting provides a methodology for updating all relevant documentation to ensure that the most current configuration is reflected in the Configuration Identification database, thereby providing decision makers with the most up-to-date information possible. A typical Configuration Status Accounting system involves establishing and maintaining documentation for the entire life cycle of an object. It is ideally carried out in conjunction with Change Control.

14.3.5.6 Configuration Audits

The term “audit” is traditionally thought of in the context of financial statements. Configuration Auditing is based on the same fundamental concept, but it is a process of analyzing Configuration Items and their respective documentation to verify and ensure that the documentation reflects the current situation. In essence, while Change Control ensures that change *is* being carried out in adherence with the CM Plan, Configuration Audits ensure that the change *was* appropriately carried out. Configuration Audits are used to confirm that designs or documentation achieve their goals by systematically comparing the requirements with results of tests, analyses or inspections. They are thorough examinations of Configuration Items, comparing the associated documentation and change histories to ensure that the documentation reflects the current state of the Configuration Items.

The most important goal of this process is to prevent lost time on future changes due to inaccurate documentation. If discrepancies are located between the documentation and the Item, the personnel carrying out the audit will prescribe a course of action for remedying the problem.

14.3.5.7 Baselines

The concept of a “baseline” is central in Configuration Management, and in order to effectively implement a configuration management program in a transportation management system, one must fully understand baselines. The concept of a baseline is not new or complex – in fact it has been a key foundation for many civil engineering activities in the past. In surveying, a baseline is a boundary line with fixed end points and known direction. In other words, a baseline is a well-defined, well-documented reference that serves as the foundation for other activities. A baseline in Configuration Management is the same thing – it is a stable, well documented, and thoroughly tested version of the system at some point in its lifecycle. All configuration management activities center upon ensuring that all changes to a baseline are carefully considered and documented so that future baselines will be solid.

Establishing baselines and managing changes to baselines are the key functions of configuration management. Baselines are extremely important to system managers. For example, in the event of system failure, the last established baseline can be recovered in order to maintain system availability. In addition, well maintained and managed baselines allow for smooth transitions when systems are integrated with external entities, or when new contractors or consultants are brought on board to work with the system.

The process of establishing and managing baselines involves identifying what baselines need to be established and when they should be established. The first step of this process is assessing the agency’s information requirements and what system elements are to be included in baselines. The next step is determining when it is necessary to institute baselines. It is important to understand that a transportation management system will not have simply a single baseline. In fact, during the life cycle of the system, multiple baselines will be established and maintained. Baselines should typically be established at key system lifecycle milestones, as shown in Table 14-10. (Note – These system baseline definitions can be expanded to include all activities of a freeway management program as shown in the previous “funnel diagram” and discussed at the beginning of this chapter.)

Table 14-10: Baselines in the System Life Cycle (Reference 15)

	<p><i>Concept of Operations Baseline</i> – This baseline is established at the conclusion of the system conception stage. In most cases, this baseline may be considered the formal <u>concept of operations</u> document developed for the system.</p>
	<p><i>System Baseline</i> – This baseline may be considered to be the final functional requirements developed for the system.</p>
	<p><i>Subsystem Baseline</i> - This intermediate baseline between the functional baseline and the development baseline falls after the requirements are completed and preliminary design work has established a mapping of high-level functions to system components.</p>
	<p><i>Development Baseline</i> – This baseline may be considered to be the detailed design document completed before system development begins. Once system development begins, there will be significant pressure to change system design due to a myriad of reasons (desired new functionality, changes in technology, impediments to development, etc.) It is essential to carefully control these changes to design to maintain the integrity of the system.</p>
	<p><i>Product Baseline</i> – This baseline essentially documents the “as-built” design that reflects the completed system. The product baseline is the result of the series of changes that have been made to the original developmental baseline during the system development process. Ideally, if the developmental baseline is under configuration control, the product baseline will simply be the evolution of the developmental baseline through the various system acceptance and verification tests, as governed by the configuration control board.</p>
	<p><i>Operational Baseline</i> – Given the constant pressure for change, transportation management systems are truly “living” systems. In other words, the product baseline will change with time to adapt to the necessary changes. During system operations, it is essential to maintain the operational baseline to reflect changes that have been approved through the configuration management process and implemented.</p>

14.4 EXAMPLES

14.4.1 Regional Traffic Operations Center - Rochester, New York

Opened in the winter of 2002, the Regional Traffic Operations Center (RTOC) is a joint transportation facility that was financed by Monroe County Department of Aviation, Monroe County Department of Transportation, and the Federal Highway Administration. The RTOC tenants include staff from Monroe County Department of Transportation (MCDOT), New York State Department of Transportation (NYSDOT), New York State Police (NYSP), and the Monroe County Airport Authority (MCAA). It is a true example of inter-agency partnership and cooperation where personnel of many different agencies who share common goals are working together under one roof. Each agency came in with a different set of needs, as can be seen by this diverse list:

List of Tenants

New York State Department of Transportation	New York State Police	Monroe County Airport Authority	Monroe County Department of Transportation
<ul style="list-style-type: none"> • Highway and Traffic Signal Dispatch • Expressway Management • Traffic Signal Maintenance 	<ul style="list-style-type: none"> • Troop E Zone 1 Headquarters • Local Patrols 	<ul style="list-style-type: none"> • Snowplowing • Field Maintenance • Runway/Taxiway Lighting Shop 	<ul style="list-style-type: none"> • Highway and Traffic Signal Dispatch • Highway Lighting Shop • Traffic Signal Maintenance

The NYSDOT, MCDOT, and NYSP share a common Traffic Operations Center (TOC) area for dispatch and system monitoring functions, which serves as the centerpiece of the building. These agencies represent the designers, maintainers, operators, and law enforcers of the highway system for the greater Rochester area. The exchange of information flows readily between personnel of the various agencies, facilitating prompt resolution of trouble situations and the occasional unusual service call from a citizen. The building is further complemented by MCAA's Airport Operations unit, which similarly is focused on transportation and dispatching.

The TOC serves as the focal point for the Intelligent Transportation System in the Rochester area, including weather radar, pavement condition sensors, video images, traffic signal control, dynamic message sign control, and highway advisory radio broadcasting. Sharing of the facility has introduced a new collegial spirit as we work together to share resources, information, and problem solving skills. New and different viewpoints, approaches to problem-solving, and routine activities are food for thought and discussion. These result in new synergies that were not possible heretofore.

A large video wall display serves as the central focus of the room. Placed in an ideal location viewable throughout the TOC, the display provides the visual integration of each agency's respective systems. Control of the video wall is available, to a limited degree, to each party. The display elements available include a City/County map of various monitored signalized intersections and freeway segments, video camera data, weather data, news, and roadway sensor data. The display system is expandable and will accommodate future interfaces such as the soon-to-arrive freeway incident management mapping and database.

The RTOC facility also contains a public/media viewing area and a situation/conference room (equipped with its own video projection system). Elsewhere in the building, facilities exist for the

installation and support of traffic signal and highway lighting systems. Personnel working in these areas respond to trouble calls and perform service on various traffic signals and highway lighting located within the City of Rochester, Monroe County, and New York State Region Four (which envelopes the surrounding Counties). A well-equipped Signal Laboratory performs system integration / construction services as well as electronic system repair to component level.

One specialty of the RTOC facility is highway incident/ emergency response. The NYSP are a primary response unit for freeway related incidents, while NYSDOT and MCDOT each have deployable resources and remote control of traffic signals and highway message signs. This team can provide on site investigation, maintain traffic flow both at the scene and on adjacent routes, and disseminate information as needed to provide a high level of public safety. For larger scale situations, the facility is conveniently located across the street from the Emergency Operations Center (EOC). A direct fiber optic link between the RTOC facility and the EOC allows video images to be sent to the EOC for projection onto its large screen displays.

14.4.2 Maryland CHART

The Maryland State Highway Administration's (SHA) Statewide Operations Center (SOC) is the hub of the SHA's CHART system. CHART is the highway incident management program initiated in the mid 80' as "Reach the Beach"; a program between the SHA and the Maryland State Police (MSP) to coordinate efforts to assist motorists along the busy corridors leading to the resort beaches on the coast. The program expanded into a statewide program headquartered in Hanover, Maryland where the integrated SOC is located. The 24/7 SOC is supported by part-time satellite Traffic Operations Centers (TOCs) located near College Park, Baltimore, Rockville, and Annapolis. This hub and satellite architecture provides statewide coverage, allowing information to be distributed based on geographical needs and/or expertise, and allows operations to be managed from several different locations. In essence, this centralized communications architecture, and distributed operations architecture allows for statewide control from any of the centers.

Operators at consoles in the control room can monitor traffic on freeways and arterials with the CHART System, monitor and verify incidents with a sophisticated video management system controls dozens of camera throughout the network, and manage a traveler information system of dynamic message signs (DMS), travel advisory radio (TAR), and the internet. Operators can also record TAR messages from their integrated consoles. An MSP liaison works from the center on program and management issues, while a Trooper works from a console in the control room.

During winter months, the SOC acts as the Emergency Operations Center (EOC). As the EOC, SHA maintenance personnel and traffic controllers work together to monitor remote weather information systems throughout the State, and manage snow/ice removal along with traffic, by dispatching plow and salt vehicles, distributing traveler information on roadway conditions and communicating with the media to keep travelers informed of conditions.

The 17,000 square foot, two-story SOC facility has six large screen rear projection systems on a two story high, 40 feet long projection wall. It contains five 6'x8' rear projection systems, one 9'x12' rear projection video wall and twelve 20-inch color NTSC monitors. It also houses a

computer / electronics room with the central computer systems, multiple offices associated with the Program, a large training room and conference room / situation room / viewing area. A snack bar / kitchenette is available to the operators for their comfort.

The satellite TOCs are located in State Police Barracks, and operators there can perform any of the functions of the SOC. These TOCs operate from AM peak period to PM peak period, and house Emergency Service Patrols vehicles and staff, as well as Emergency Response Vehicles and staff.

A CHART workstation is also located at the Maryland Transportation Authority's TMC for their use to manage CCTV cameras and DMS along their network. If necessary, this workstation could manage the SHA's statewide network.

14.5 REFERENCES

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15. DETECTION AND SURVEILLANCE

15.1 INTRODUCTION

In a traffic management system, the detection and surveillance component supports the process in which data are collected to describe or characterize traffic flow conditions on the highway. The data are used to supply information about conditions on the roadway to other system components. Thus, detection and surveillance provide the information needed to perform the following traffic management functions:

- Measuring traffic flow and environmental conditions.
- Formulating control decisions.
- Disseminating traveler information.
- Monitoring and evaluating system performance.
- Supporting other freeway management and operations functions such as incident detection and verification, planned special event and emergency management, ramp management, and transportation planning.

- The requirements for these functions, in terms of the types and accuracies of data and information, and the spatial and temporal resolution of the data needed, depend on the specific application and the manner in which the application is implemented. For example, traveler information may require average speed / travel time information collected at selected intervals along the roadway and available in real time. On the other hand, transportation planning needs – particularly inputs for network analysis models – may require additional information (e.g., volumes, vehicle classifications) at different spacings, and the ability to warehouse the information for subsequent analyses.

Detection and surveillance are not limited to collecting and monitoring traffic condition information alone, nor in some instances are they automated in nature. Detection and surveillance are utilized to gather weather and pavement data, which provide operators and maintenance staff additional information to support their traffic management responsibilities.

Road and weather information systems also are being used to manage snow removal, icy roadway treatment, detect limited sight distance problems caused by fog or smoke, and detect high water levels along roadways. While a great deal of traffic detection data are gathered via automated means, manual detection, most notably via cellular telephone calls from motorists, is also a viable and reliable data acquisition strategy.

15.1.1 Purpose of Chapter

This chapter is a resource for practitioners involved with all aspects of freeway management who utilize freeway condition and traffic flow information in the performance of their duties. It provides an overview of surveillance and detection sensor technology options to assist in planning, implementation, and maintenance of these systems. The topics include discussions of:

- Elements of detection and surveillance systems,
- Their role in freeway management,
- Issues involved in planning and commissioning these systems and technologies,
- Emerging trends,
- Examples

- With respect to sensor technologies, the *Traffic Detector Handbook* (Reference 1) is the most complete and up-to-date reference available from FHWA. Another useful source of information

concerning sensor technologies and their applications to ITS is Reference 2. Accordingly, traffic detection discussions in this chapter are addressed at a high-level summary. Other surveillance options (i.e., not addressed in Reference 1) are also described, including probe-based surveillance, video surveillance (i.e., the use of real time video images of the freeway), and road-weather information systems (RWIS). Recent evaluations of sensors and technologies to vehicle detection and traffic flow measurement are found in References 4 through 10.

15.1.2 Relationship to Other Freeway Management Activities

Practically every freeway management activity is related to or dependent upon detection and surveillance in some manner, and to understand the role of detection and surveillance within the freeway management spectrum, it is important to understand the relationships with these activities. The following table 15-1 lists those related activities and their relationship to the other chapters of this Handbook.

Table 15-1: Freeway Management Activities and Their Relationship to Detection

Activity	Relationship
Performance Monitoring (Chapter 4)	The development and evaluation of performance measures is dependent on the collection and warehousing of data regarding freeway traffic flow. Additionally, this information is used to calibrate simulation models.
Ramp Management and Control (Chapter 7) Lane Management and Control (Chapter 8)	Both ramp and lane management rely on real time traffic data. Traffic data necessary includes volume, speed and occupancy data for algorithm calculations. Further, video surveillance is important for ramp and lane management to allow an operator to verify conditions prior to making lane configuration changes or opening a ramp for a reversible lane.
Traffic Incident Management (Chapter 10) Planned Special Event Management and Control (Chapter 11) Emergency & Evacuation Management (Chapter 12)	Critical to the success of these management strategies is monitoring real-time traffic conditions to determine an anomaly in traffic flow, which signify to an operator the possibility of an incident. Video surveillance, too, is a key element to verifying and diagnosing an incident. Weather-related conditions that create incidents, such as fog or icy pavement conditions, are detected using Remote Weather Information Systems.
Information Dissemination (Chapter 13)	In many cases, the detection and surveillance subsystems provide the real-time data necessary to develop the information to disseminate to travelers. For instance speed or vehicle location data collected from the detection subsystem is translated to congestion indices or travel time measurements to inform travelers of conditions on the roadway. Video from surveillance systems is commonly placed on web sites to allow pre-trip travelers to survey conditions on the roadway.

Activity	Relationship
Traffic Management Centers (Chapter 14)	In many cases, it is the Traffic Management Center where detection and surveillance data is bought for processing and management. Traffic Management Centers house the central systems that control and manage the detection and surveillance systems.
Regional Integration (Chapter 16)	Information from the detection and surveillance subsystem is shared across jurisdictional boundaries and information conveyed to the traveler can be "regional" in nature, i.e., the effected area may not be in the local control area of the system, but may still effect local travelers.

15.2 CURRENT PRACTICES, METHODS, STRATEGIES, AND TECHNOLOGIES

15.2.1 Overview

Information is crucial for successful operations of the transportation network. As noted in a FHWA TEA-21 reauthorization proposal (3):

“Operating the highway system to achieve security, safety, and reliability objectives requires an ability to know what is happening on the system. Real-time information on highway system performance and weather conditions / events is vital to assist highway professionals in managing the available capacity, responding to disruptions to capacity (including emergencies, evacuations, and security threats), and to system users in planning the timing, mode, and route for their trips”.

In essence, the many benefits of the various freeway management strategies – as discussed in other chapters herein – cannot be fully realized unless practitioners are aware of the real time conditions on the freeway network. The required information varies widely depending on the service being provided, how often data needs to be collected, and how accurate it needs to be. For example, traveler information and traffic management services require information of different types and accuracies concerning pavement conditions. A traveler may only need to know whether the pavement is wet or icy, whereas a traffic management and operations department concerned with snow and ice control requires additional and more detailed and accurate information.

Many different technologies are utilized for collecting detection and surveillance information, including in-roadway and over-roadway sensors for measuring traffic flow parameters, vehicle probes for collecting data on travel times and origin-destination information, closed circuit television (CCTV) systems for viewing real time video images of the freeway, road weather information systems (RWIS) for monitoring pavement and weather conditions, and manual methods such as gathering information from drivers via their cellular telephones.

15.2.2 Benefits

Detection and surveillance, whether highly technical and automated, or simple and manual, are the cornerstone of any freeway management program. Freeway management strategies and ITS technologies can assist in reducing congestion, improving safety, and enhancing mobility. However, without the capability to know the current freeway operating conditions, coupled with the cooperation and coordination among personnel in the responsible agencies, the potential benefits of these strategies and technology systems may not be realized. To that end, it is not a

simple matter to quantify benefits from detection and surveillance alone, but instead to understand the benefits realized from freeway management strategies and ITS technologies that rely on detection and surveillance. Some benefits of particular importance include:

- Reduction in delay and congestion related to early detection and diagnosis of incidents.
- Reduced secondary accidents as a result of early incident detection.
- Reduction in road maintenance costs (i.e., labor, materials and equipment) associated with the use of Road Weather Information System (RWIS) technologies and winter road treatment strategies (e.g., anti-icing, snow plowing)
- Improved traveler information

In summary, most of the benefits realized by ITS applications are the result, in some way, from the real-time information provided by the detection and surveillance subsystems.

15.2.3 Key Considerations During Freeway Management Program Development

Given that detection and surveillance are integral parts of a Freeway Management System (FMS) and the overall freeway management program, it follows that detection and surveillance must be duly considered throughout whatever process is used to develop and deploy the FMS / freeway management program. Of particular importance (referring back to the “funnel diagram” in Chapter 3) are the following:

- **Coordinate with regional / statewide transportation planning:** The surveillance subsystem should be designed to provide the traffic information necessary to support the decision-making processes and to develop the various transportation plans mandated by Federal law.
- **Stakeholders:** Many of the freeway management stakeholders will have specific information requirements. Their needs in this regard should be reflected in the development of the surveillance subsystems.
- **Concept of Operations** lays out the program concept, explains how things are expected to work once it's in operation, and identifies the responsibilities of the various stakeholders for making this happen. Information needs – without describing actual surveillance technologies – must be an integral part of the Con Ops.
- **Determine Performance Measures:** The performance measures provide the basis for evaluating the transportation system operating conditions and identifying the location and severity of congestion and other problems. The surveillance subsystem can provide the mechanism for collecting the data necessary for quantifying the operation of the network.
- **Operations and maintenance:** If the surveillance subsystem is not adequately implemented and maintained, a serious constraint on the overall operation of the freeway can result.

15.2.4 Relationship to National ITS Architectures

As indicated in Chapter 3, the National ITS Architecture provides a common structure or framework to promote compatibility and interoperability among systems, products, and services. The architecture defines the functions that must be performed to implement a given service, the physical entities or subsystems where these functions reside (e.g., the roadside or the vehicle), the interfaces / information flows among the physical subsystems, and the communication requirements for the information flows.

The National ITS Architecture can serve as the basic building block of the functional requirements definition process for detection and surveillance. The functions described in the National Architecture must then be detailed to match the needs and desires of the local agencies. The National ITS Architecture defines various ITS elements and strategies in terms of market packages. This concept recognizes that various ITS components must work together to achieve system goals. They are “tailored to fit separately or in combination-real world transportation problems.” Market packages relevant to detection and surveillance include:

- **Network Surveillance Market Package.** This market package includes the roadside sensors with appropriate control and communication infrastructure to interface with other market packages such as traffic management and traveler information.
- **Probe Surveillance Market Package.** This market package is an alternative to traditional network surveillance elements and does not require the extensive distributed roadside infrastructure but does require wireless communication between probe vehicles and other market packages such as freeway control and surface street control.
- **Emissions and Environmental Hazards Market Package.** This market package provides emissions and hazards information.
- **Incident Management Market Package.** This market package includes incident detection capabilities through roadside surveillance devices (e.g., CCTV).
- **Road Weather Data Collection.** This market package collects current road and weather conditions using data collected from environmental sensors deployed on and about the roadway.
- **Weather Information Processing and Distribution.** This market package processes and distributes the environmental information collected from the Road Weather Data Collection market package. This market package uses the environmental data to detect environmental hazards such as icy road conditions, high winds, dense fog, etc. so system operators and decision support systems can make decision on corrective actions to take.

15.2.5 Types of Data

The measurements that have traditionally been used to monitor traffic operations on freeways include the following:

- **Volume** – Used to measure the quantity of traffic. Volume is defined as the number of vehicles observed or predicted to pass over a given point or section of a lane or roadway during a given time. Volume is typically used to track historical trends and to predict the future occurrence of congestion on specified freeway sections.
- **Speed** – An important measurement in determining the quality of traffic operations. Speed is frequently used to describe traffic operations because it is easy to explain and understand. Speed measurements are typically taken for individual vehicles and averaged to characterize the traffic stream as a whole. Measured speeds can be compared to optimum values to estimate the level of operations for a freeway or to detect incidents. For example, an alarm for an incident detection system might be triggered if average speeds fall below a target value.
- **Occupancy** – Defined as the percent of time a given section of roadway is occupied by a vehicle and can be used as a surrogate for density. Occupancy is measured using presence detectors and is easier to measure than density. Occupancy is measured on a

lane-by-lane basis, with values ranging from 0 percent (no vehicles passing over a section of roadway) to 100 percent (vehicles stopped over a section of roadway).

Although volume, speed, and occupancy have been the traditional types of data collected by a surveillance system, today's traffic management centers also rely on other types of data for traffic management purposes. Examples of other data include the following:

- Vehicle travel times.
- Vehicle location.
- Bus location.
- Emergency vehicle location.
- Queue length.
- Pavement condition (e.g., dry, wet, icy, freeze-point temperature, chemical concentration).
- Atmospheric condition (e.g., temperature, humidity, rain, snow, fog).

Both real-time and historical data may be used for traffic management purposes. Real-time data is needed in a freeway management system for monitoring current traffic operating and environmental conditions, detecting incidents, and implementing control strategies. Historical data refers to past traffic conditions on a given section of freeway. Historical data can be used for several purposes, such as establishing a record of past traffic conditions on a certain freeway section; comparing real-time data to historical data to determine irregular traffic patterns; monitoring performance, such as before/after analyses to determine the effects of implementing certain traffic management techniques; and calibrating simulation models for analyzing potential improvements and establishing priorities for deployment.

15.2.6 Traffic Flow Sensors

A traffic flow sensor is a device that indicates the presence or passage of vehicles and provides data or information that supports traffic management applications such as freeway mainline and ramp control, incident detection, and gathering of vehicle volume and classification data to meet state and federal reporting requirements. (1)

While inductive loop detectors have been used extensively on freeways, other sensors such as magnetometers, video image processors, microwave radars, passive and active infrared sensors, and acoustic sensors are finding their way into freeway traffic management applications that require vehicle detection. These sensors can provide data not available from inductive loop detectors and enhanced safety for the personnel that install and maintain them. Vehicles themselves can become "probes" for obtaining information on travel times. Additional surveillance requirements may require other technologies, including video, road surface and weather information, and infrastructure security.

The *Traffic Detector Handbook* (1) and Reference 2 describe the theory of operation, installation, and applications of the various sensor technologies in depth. Sensor types are divided into in-roadway and over-roadway classes, defined as follows:

- An **in-roadway sensor** is one that is embedded in the pavement of the roadway, embedded in the subgrade of the roadway, or taped or otherwise attached to the surface of the roadway. Examples of in-roadway sensors include inductive loop detectors, which are sawcut into the pavement; and magnetometers, which may be placed underneath a paved roadway or bridge structure
- By contrast, an **over-roadway sensor**, or *non-intrusive sensor*, is one that is mounted above the surface of the roadway either above the roadway itself or alongside the roadway, offset from the nearest traffic lane by some distance. Examples of over-roadway sensors are

video image processors that utilize cameras mounted on tall poles adjacent to the roadway or traffic signal mast arms over the roadway; microwave radar, ultrasonic, and passive infrared sensors mounted in a similar manner; and laser radar sensors mounted on structures that span the lanes to be monitored.

The following sections present brief overviews of the current technologies available for surveillance and technology. These are taken from the *Traffic Detector Handbook* and References 2 and 3. Following the section on sensors, Tables 15-2 and 15-3, from the *Traffic Detector Handbook* and Reference 2, summarize the strengths and weaknesses of commercially-available sensors and itemize the traffic output data (typical), communications bandwidth, and cost of commercially available sensors, respectively.

15.2.6.1 Inductive Loop Sensors

An inductive loop detector senses the presence of a conductive metal object by inducing currents in the object, which reduce the loop inductance. Inductive loop detectors are installed in the roadway surface. They consist of four parts: a wire loop of one or more turns of wire embedded in the roadway pavement, a lead-in wire running from the wire loop to a pull box, a lead-in cable connecting the lead-in wire at the pull box to the controller, and an electronics unit housed in the controller cabinet as shown in Figure 15-1. The electronics unit contains an oscillator and amplifiers that excite the embedded wire loop. The electronics unit also supports other functions such as selection of loop sensitivity and pulse or presence mode operation.

When a vehicle passes over the wire loop or is stopped within the area enclosed by the loop, it reduces the loop inductance, which unbalances the tuned circuit of which the loop is a part. The resulting increase in oscillator frequency is detected by the electronics unit and interpreted as a detected vehicle by the controller.

Conventional inductive loops are constructed by cutting a slot in the pavement and placing one or more turns of wire in the slot as indicated in Figure 15-2. The wire is then covered with sealant. The size, shape, and configuration of the loop vary depending upon the specific application, ranging from the common 6- x 6-ft (1.8- x 1.8-m) loops³⁴, to long rectangular loops 6- x 40- to 70-ft (1.8- x 12- to 21-m) for actuated signal control. Because of the flexibility of its design, the inductive loop detector is capable of detecting a broad range of vehicles.

15.2.6.2 Magnetic Sensors

Magnetic sensors are passive devices that detect the presence of a ferrous metal object through the perturbation (known as a magnetic anomaly) they cause in the Earth's magnetic field. Two types of magnetic field sensors are used for traffic flow parameter measurement. The first type, the two-axis fluxgate magnetometer, detects changes in the vertical and horizontal components of the Earth's magnetic field produced by a ferrous metal vehicle. It detects stationary and moving vehicles. Fluxgate magnetometers are cylindrical in shape and are inserted into holes drilled into the roadbed from the top of road surface.

The second type is the magnetic detector, more properly referred to as an induction or search coil magnetometer. It detects a moving ferrous metal vehicle by measuring the distortion in the magnetic flux lines induced by the change in the Earth's magnetic field produced the vehicle. Magnetic detectors are inserted horizontally below the roadway. Since they provide only passage data and not occupancy or presence data, their use is limited to special applications. Another device similar to the magnetic detector is the microloop probe. As a vehicle passes over the microloop, the change in inductance is sensed by a conventional inductive loop detector electronics unit.

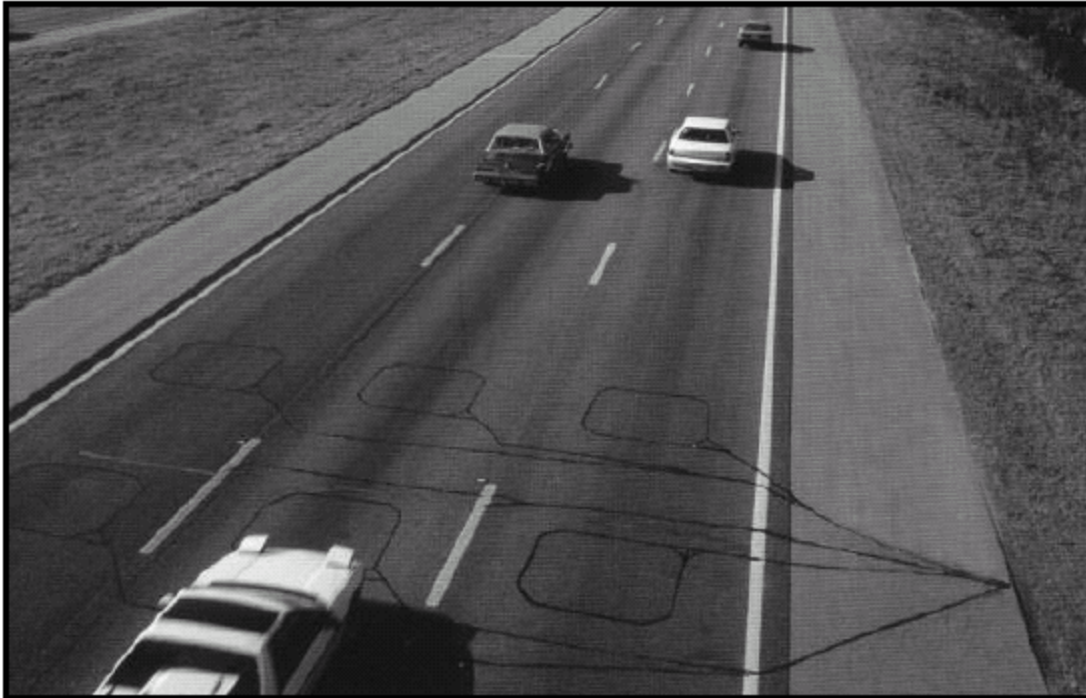


Figure 15-1: Inductive Loop Detector System
(Reference 1, 2)

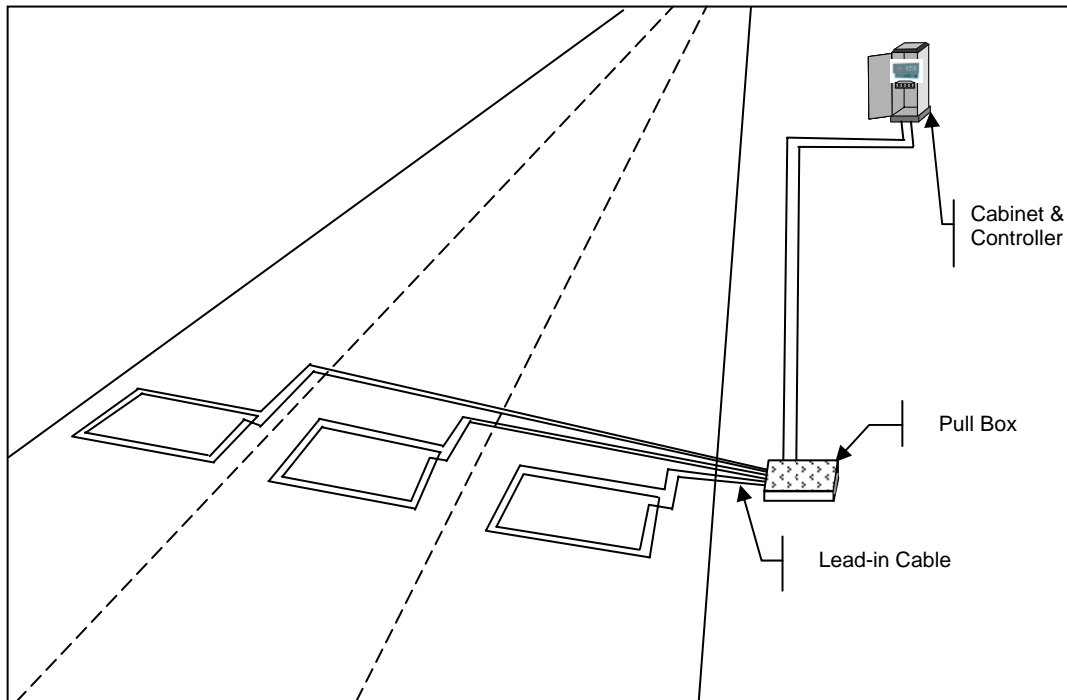


Figure 15-2: Inductive Loop Configuration Example

15.2.6.3 Microwave Radar

Figure 15-3 illustrates the operation of microwave radar sensors. A portion of the transmitted energy is scattered by the vehicle back toward the sensor, where it is detected and converted into vehicle and traffic flow information by the sensor alone or in conjunction with a roadside controller.

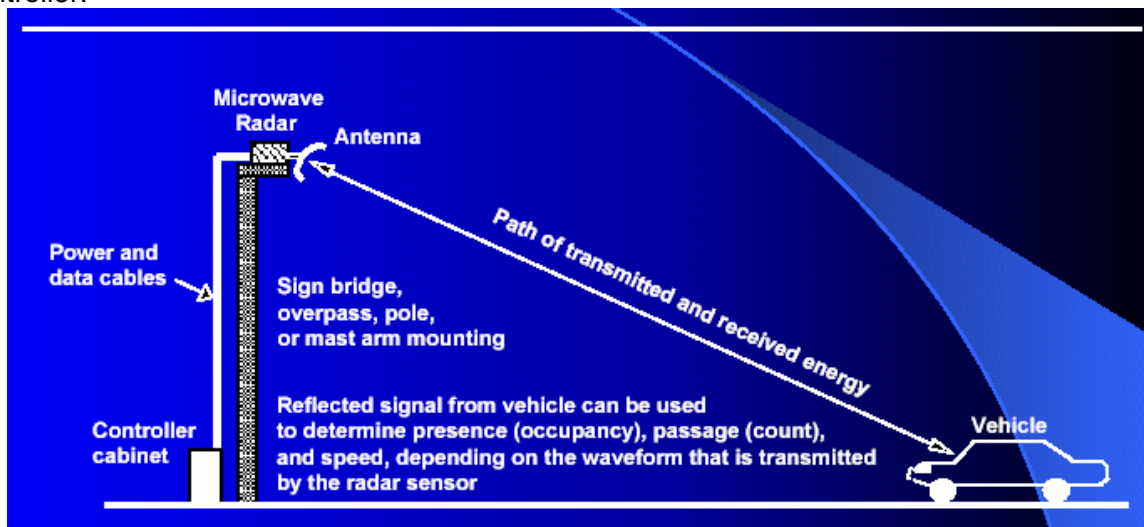


Figure 15-3: Microwave Radar Operation

(Reference 1,2)

Two types of microwave radar sensors are used in roadside applications, those that transmit continuous wave (CW) Doppler waveforms and those that transmit frequency modulated continuous waves (FMCW). The Doppler sensor is also referred to in some literature as a microwave or microwave Doppler sensor. The constant frequency signal (with respect to time) allows vehicle speed to be measured using the Doppler principle. Accordingly, the frequency of the received signal is decreased by a vehicle moving away from the radar and increased by a vehicle moving toward the radar. Vehicle passage or count is denoted by a frequency shift in the received signal. Vehicle presence cannot be measured with the constant frequency waveform as only moving vehicles are detected.

The FMCW microwave radar sensor varies the transmitted frequency with respect to time in a prescribed manner. These sensors detect vehicle presence and vehicle passage. Therefore, they can detect stopped vehicles and provide measurements of lane occupancy, vehicle count, speed, and vehicle length grouped into several length bins.

15.2.6.4 Video Image Processing

Video cameras were originally introduced to traffic management for roadway surveillance based on their ability to transmit closed-circuit television imagery to a human operator for interpretation. Present-day traffic managers utilize video image processing to automatically analyze the scene of interest and extract information for traffic surveillance and management. A video image processor (VIP) system typically consists of one or more cameras, a microprocessor-based computer for digitizing and analyzing the imagery, and software for interpreting the images and converting them into traffic flow data. A VIP can replace several in-

ground inductive loops, provide detection of vehicles across several lanes, and perhaps lower maintenance costs. Some VIP systems process data from more than one camera and further expand the area over which data are collected.

Video image processors can classify vehicles by their length (usually three length classification ranges are available) and report vehicle presence, volume, lane occupancy, and speed for each class and lane. VIPs that track vehicles may also have the capability to register turning movements and lane changes. Vehicle density, link travel time, and origin-destination pairs are potential traffic parameters that can be obtained by analyzing data from a series of image processors installed along a section of roadway.

15.2.6.5 Passive Infrared Sensors

Active and *passive* infrared sensors are manufactured for traffic flow monitoring applications. Passive infrared sensors transmit no energy of their own. Rather they detect energy from two sources:

- Energy emitted from vehicles, road surfaces, and other objects in their field-of-view, and
- Energy emitted by the atmosphere and reflected by vehicles, road surfaces, or other objects into the sensor aperture.

Passive infrared sensors are mounted overhead to view approaching or departing traffic. They can also be mounted in a side-looking configuration. Infrared sensors are utilized for volume, speed, and class measurement; and for detection of pedestrians in crosswalks. Figure 15-4 illustrates the passive infrared sensor mounted for multiple detection zones.

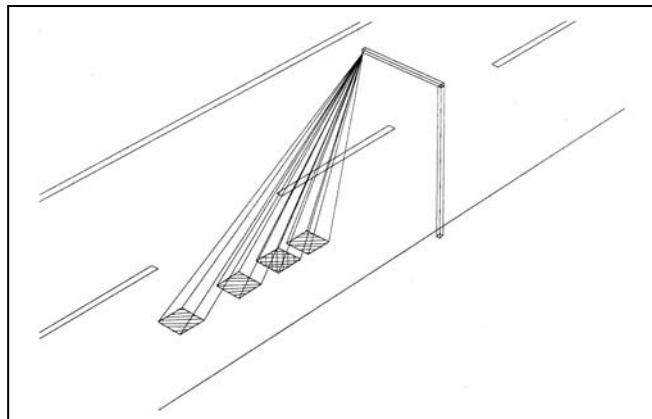


Figure 15-4: Multiple Detection Zone Configuration In a Passive Infrared Sensor (1)

15.2.6.6 Laser Radar Sensors

Laser radar sensors are active devices that transmit and receive infrared energy. They illuminate detection zones with low power energy transmitted by laser diodes operating in the near infrared region of the electromagnetic spectrum at 0.85 μm . A portion of the transmitted energy is reflected or scattered by vehicles back towards the sensor. Models are available that scan infrared beams over 1 or 2 lanes or use multiple laser diode sources to emit a number of fixed beams that cover the desired lane width. An example of a laser radar beam-scanning configuration is shown in Figure 15-5. Laser radars provide vehicle presence, volume, speed, length assessment, queue measurement, and classification. Multiple units can be installed at the same intersection without interference from transmitted or received signals. Modern laser

sensors produce two- and three-dimensional imagery of vehicles suitable for vehicle classification. Their ability to classify 11 types of vehicles has found application on toll roads.

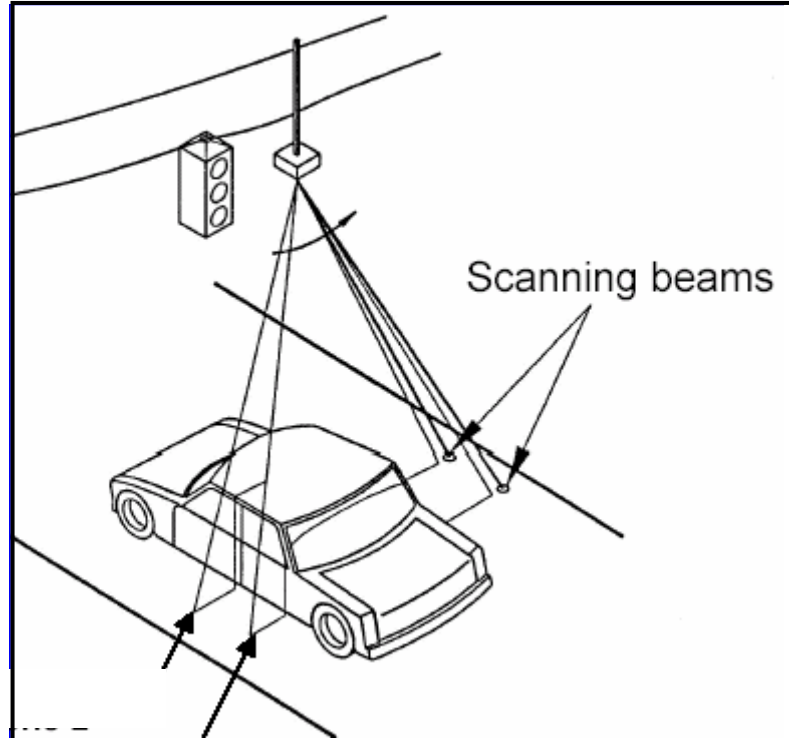


Figure 15-5: Scanning Infrared Laser Radar Two-Beam Pattern Across a Traffic Lane

(Drawing courtesy of Schwartz Electro-Optics, Orlando, FL).

15.2.6.7 Ultrasonic Sensors

Ultrasonic sensors transmit pressure waves of sound energy at a frequency between 25 and 50 kHz, which are above the human audible range. Most ultrasonic sensors operate with pulse waveforms and provide vehicle count, presence, and occupancy information. Pulse-shape waveforms measure distances to the road surface and vehicle surface by detecting the portion of the transmitted energy that is reflected towards the sensor from an area defined by the transmitter's beamwidth. When a distance other than that to the background road surface is measured, the sensor interprets that measurement as the presence of a vehicle.

Pulsed energy transmitted at two known and closely spaced incident angles allows vehicular speed to be calculated by recording the time at which the vehicle crosses each beam. Since the beams are a known distance apart, the speed can be calculated as beam separation distance divided by the time to traverse the beams. The preferred mounting configurations for range-measuring, pulsed ultrasonic sensors are looking from an overhead position and side viewing as shown in Figure 15-6. Constant frequency ultrasonic sensors that measure speed using the Doppler principle are also manufactured. However, these are more expensive than

pulsed models. The speed-measuring Doppler ultrasonic sensor is designed to interface with the highway infrastructure in Japan.

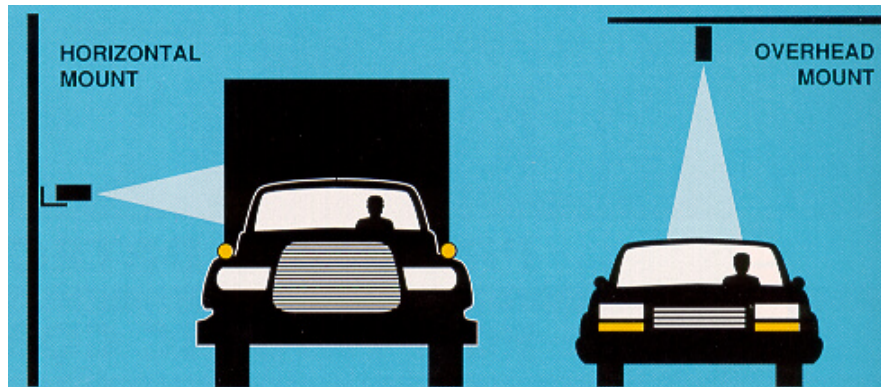


Figure 15-6: Mounting of Ultrasonic Range-Measuring Sensors (1)

(Courtesy of Microwave Sensors, Ann Arbor, MI)

15.2.6.8 Passive Acoustic Array Sensors

Acoustic sensors measure vehicle passage, presence, and speed by detecting acoustic energy or audible sounds produced by vehicular traffic from a variety of sources within each vehicle and from the interaction of a vehicle's tires with the road. When a vehicle passes through the detection zone, an increase in sound energy is recognized by the signal processing algorithm and a vehicle presence signal is generated. When the vehicle leaves the detection zone, the sound energy level drops below the detection threshold and the vehicle presence signal is terminated. Sounds from locations outside the detection zone are attenuated. Single lane and multiple lane models of acoustic sensors are marketed. Both detect the sounds produced by approaching vehicles with a two-dimensional array of microphones. (Figure 15-7)



Figure 15-7: Acoustic Array Sensor Mounted Along Roadway

(Courtesy of SmarTek Systems, Woodbridge, VA)

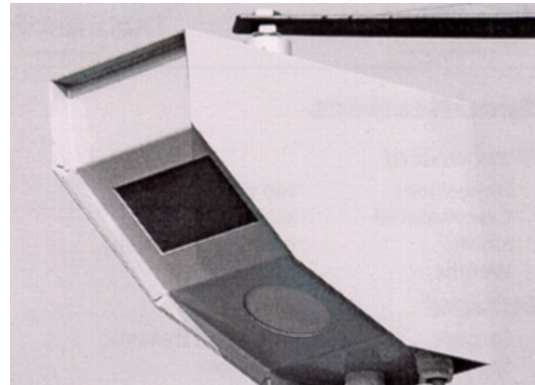
15.2.6.9 Sensor Combinations

Figure 15-8 illustrates sensors that combine passive infrared presence detection with ultrasound or CW Doppler microwave radar. The passive infrared-ultrasonic combination, shown in the left portion of the figure, provides enhanced accuracy for presence and queue detection, vehicle counting, and height and distance discrimination.

The passive infrared-CW Doppler radar sensor, in the right portion of the figure, is designed for presence and queue detection, vehicle counting, speed measurement, and length classification. It relies on the radar to measure high to medium vehicle speeds and the passive infrared to measure vehicle count and presence. At medium speeds, the multiple detection zone passive infrared automatically calibrates its speed measurements against the radar's. This calibration permits the infrared to measure slow vehicle speeds and detect stopped vehicles.



ASIM DT 272 Passive Infrared-Ultrasonic Sensor



ASIM DT 281 Passive Infrared-CW Doppler Microwave Radar Sensor

Figure 15-8: Passive Infrared Combination Sensors (1)
(Photographs courtesy of ASIM Technologies, Uznach, Switzerland)

Table 15-2: Strengths and Weaknesses of Commercially Available Sensor Technologies (1,2)

Technology	Strengths	Weaknesses
Inductive Loop	<p>Flexible design to satisfy large variety of applications. Mature, well-understood technology. Large experience base. Provides basic traffic parameters (e.g., volume, presence, occupancy, speed, headway, and gap). Insensitive to inclement weather such as rain, fog, and snow. Provides best accuracy for count data as compared with other commonly used techniques. Common standard for obtaining accurate occupancy measurements. High frequency excitation models provide classification data.</p>	<p>Installation requires pavement cut. Improper installation decreases pavement life. Installation and maintenance require lane closure. Wire loops subject to stresses of traffic and temperature. Multiple detectors usually required to monitor a location. Detection accuracy may decrease when design requires detection of a large variety of vehicle classes.</p>
Magnetometer (Two-axis fluxgate magnetometer)	<p>Less susceptible than loops to stresses of traffic. Insensitive to inclement weather such as snow, rain, and fog. Some models transmit data over wireless RF link.</p>	<p>Installation requires pavement cut. Improper installation decreases pavement life. Installation and maintenance require lane closure. Models with small detection zones require multiple units for full lane detection.</p>
Magnetic (Induction or search coil magnetometer)	<p>Can be used where loops are not feasible (e.g., bridge decks). Some models are installed under roadway without need for pavement cuts. However, boring under roadway is required. Insensitive to inclement weather such as snow, rain, and fog. Less susceptible than loops to stresses of traffic.</p>	<p>Installation requires pavement cut or tunneling under roadway. Cannot detect stopped vehicles unless special sensor layouts and signal processing software are used.</p>
Microwave Radar	<p>Typically insensitive to inclement weather at the relatively short ranges encountered in traffic management applications. Direct measurement of speed. Multiple lane operation available.</p>	<p>CW Doppler sensors cannot detect stopped vehicles.</p>
Active Infrared (Laser radar)	<p>Transmits multiple beams for accurate measurement of vehicle position, speed, and class. Multiple lane operation available.</p>	<p>Operation may be affected by fog when visibility is less than 20 ft (6 m) or blowing snow is present. Installation and maintenance, including periodic lens cleaning, require lane closure.</p>
Passive Infrared	<p>Passive sensors measure speed.</p>	<p>Passive sensor may have reduced vehicle sensitivity in heavy rain, snow & dense fog. Some models not recommended for presence detection.</p>

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Technology	Strengths	Weaknesses
Ultrasonic	Multiple lane operation available. Capable of overheight vehicle detection. Large Japanese experience base.	Environmental conditions such as temperature change and extreme air turbulence can affect performance. Temperature compensation is built into some models. Large pulse repetition periods may degrade occupancy measurement on freeways with vehicles traveling at moderate to high speeds.
Acoustic	Passive detection. Insensitive to precipitation. Multiple lane operation available in some models.	Cold temperatures may affect vehicle count accuracy. Specific models are not recommended with slow moving vehicles in stop-and-go traffic.
Video Image Processor	Monitors multiple lanes and multiple detection zones/lane. Easy to add and modify detection zones. Rich array of data available. Provides wide-area detection when information gathered at one camera location can be linked to another.	Installation and maintenance, including periodic lens cleaning, require lane closure when camera is mounted over roadway (lane closure may not be required when camera is mounted at side of roadway) Performance affected by inclement weather such as fog, rain, and snow; vehicle shadows; vehicle projection into adjacent lanes; occlusion; day-to-night transition; vehicle/road contrast; and water, salt grime, icicles, and cobwebs on camera lens. Requires 50- to 70-ft (15- to 21-m) camera mounting height (in a side-mounting configuration) for optimum presence detection and speed measurement. Some models susceptible to camera motion caused by strong winds or vibration of camera mounting structure. Generally cost-effective when many detection zones within the camera field-of-view or specialized data are required.

Table 15-3: Traffic Output Data (Typical), Communications Bandwidth, and Cost of Commercially Available Sensors (1)

Output data (typical), communications									
Sensor Technology	Count	Presence	Speed	Occupancy	Classification	Multiple Lane, Multiple Detection Zone Data	Communication Bandwidth	Sensor Purchase Cost ^a (each in 1999 US \$)	
Inductive Loop	✓	✓	✓ ^b	✓	✓ ^c		Low to moderate	Low ⁱ (\$500 - \$800)	
Magnetometer (two axis fluxgate)	✓	✓	✓ ^b	✓			Low	Moderate ⁱ (\$900 - \$6,300)	
Magnetic Induction Coil	✓	✓ ^d	✓ ^b	✓			Low	Low to moderate ⁱ (\$385-\$2,000)	
Microwave Radar	✓	✓ ^e	✓	✓ ^e	✓ ^e	✓ ^e	Moderate	Low to moderate (\$700-\$2,000)	
Active Infrared	✓	✓	✓ ^f	✓	✓	✓	Low to moderate	Moderate to high (\$6,500-\$3,300)	
Passive Infrared	✓	✓	✓ ^f	✓			Low to moderate	Low to moderate (\$700-\$1,200)	
Ultrasonic	✓	✓		✓			Low	Low to moderate (Pulse model: \$600- Moderate (\$3,100-\$8,100)	
Acoustic Array	✓	✓	✓	✓		✓ ^g	Low to moderate		
Video Image Processor	✓	✓	✓	✓	✓	✓	Low to high ^h	Moderate to high (\$5,000-\$26,000)	

^a Installation, maintenance, and repair costs must also be included to arrive at the true cost of a sensor solution as discussed in the text.

^b Speed can be measured by using two sensors a known distance apart or estimated from one sensor, the effective detection zone and vehicle lengths.

^c With specialized electronics unit containing embedded firmware that classifies vehicles.

^d With special sensor layouts and signal processing software.

^e With microwave radar sensors that transmit the proper waveform and have appropriate signal processing.

^f With multi-detection zone passive or active mode infrared sensors.

^g With models that contain appropriate beamforming and signal processing.

^h Depends on whether higher-bandwidth raw data, lower-bandwidth processed data, or video imagery is transmitted to the TMC.

ⁱ Includes underground sensor and local detector or receiver electronics. Electronics options are available to receive multiple sensor, multiple lane data.

15.2.6.10 Sensor Subsystem Architecture

Many systems utilize a field processor (e.g., 2070 controller) for collecting and processing raw data (including error checking) from multiple sensors comprising a detector station, prior to transmission of the information to the Traffic Management Center (TMC). Information transmission may be on a periodic basis (e.g., once every 20 seconds to a minute), or on an exception basis (e.g., information is transmitted only when a significant change occurs in the traffic flow, such as a major change in average speeds). Additional information on 2070 controllers can be found in the *Traffic Detector Handbook* and in the *Traffic Control Systems Handbook*.

15.2.7 **Probe Surveillance**

By using vehicle-locating technologies, the vehicle itself can become an important surveillance tool for monitoring traffic conditions in the roadway network. Vehicles, acting as moving sensors (or probes), can provide information about traffic conditions on each link traversed. This information can be transmitted to a central computer system where it can then be merged with information from other sources to provide an accurate representation of actual travel conditions in the transportation system. Probe surveillance can typically provide the following measurements:

- Link speeds.
- Link travel times.
- Origin and destination of vehicle traveling through system.

Technologies that enable the use of vehicles as probes include the following:

15.2.7.1 Automatic Vehicle Identification (AVI)

AVI systems permit individual vehicles to be uniquely identified as they pass through a detection area. Although there are several different types of AVI systems, they all operate using the same general principles. A roadside communication unit (i.e., ‘reader’) broadcasts an interrogation signal from its antenna. When an AVI-equipped vehicle comes within range of the antenna, a transponder (or tag) in the vehicle returns that vehicle’s identification number to the roadside unit. The information is then transmitted to a central computer where it is processed.

The most common application of AVI technology is for automatic collection of tolls, known as Electronic Toll Collection (ETC). In this application, toll charges are electronically deducted from the driver’s account when he or she passes through a toll plaza. Because tolls are collected automatically, the vehicle can pass through the toll plaza without stopping. By placing readers at selected intervals along the roadway, AVI technology may also be used as a means of using these vehicles as probes, automatically collecting travel time information. (Note: One such system – TRANSMIT – is described in the “Examples” section at the end of this chapter)

Classes of transponders, based on the degree to which they can be programmed, include the following:

- Type I. Type I transponders are read-only tags that contain fixed data, such as a vehicle identification number. They can initially be programmed either at the manufacturing facility or by the agency issuing the transponder; however, they cannot be reprogrammed without returning the transponder to the manufacturer.

- Type II. These transponders have read/write capability. In these transponders, some of the memory contains permanent information (such as vehicle identification number) and cannot be reprogrammed. However, additional memory can be provided and may be reprogrammed or written remotely from the reader. This type of transponder is typically used in toll systems to record time, date, and location of entry, and account balance for vehicles.
- Type III. These transponders are also known as “smart cards.” They have extended memory and are capable of full two-way communication. With this system, vehicles can be warned of incidents, congestion, or adverse weather conditions, enabling drivers to take alternative routes. This type of system requires sophisticated technology for both the roadside and vehicle-based equipment.

15.2.7.2 Automatic Vehicle Location (AVL)

AVL systems enable the location of a vehicle to be determined and tracked as it traverses the transportation network. These systems have many uses for many different customers, including the following:

- Emergency Services - aid in dispatching emergency vehicles.
- Maintenance Departments – track the location and progress of incident response vehicles as well as winter maintenance vehicles (which may be equipped with mobile environmental sensors).
- Transit Agencies - track vehicles and provide passengers with arrival time estimations through information displays.
- Delivery Companies - plan the most efficient dispatch of fleet vehicles.
- Private Citizens – determining their location and most appropriate routing in unfamiliar territory; also to recover a stolen vehicle.

This technology can also be used to determine the severity of congestion or the occurrence of an incident, by obtaining probe reports from vehicles traveling in the network. Software in a control center can automatically monitor travel speeds and transit times of vehicles equipped with AVL technology. There are numerous techniques and technologies that can be used for locating the vehicle, including the following:

- **Dead Reckoning and Map-Matching:** Dead-reckoning systems monitor the vehicle's internal compass and odometer and calculate its position by measuring its distance and direction from a known central starting point. Dead-reckoning systems frequently get off track and can be corrected using a technique called map matching. Map-matching systems store a map of the vehicle's coverage area in a database and assume that when a vehicle changes direction, it must have turned from one road on to another. When a vehicle does make a turn, map-matching systems alter the vehicle's record location to the nearest possible point at which the turn could have taken place. Because of the low degree of positional accuracy of dead reckoning and map matching, most AVL systems use more advanced technology options.
- **Signpost.** When vehicles, such as transit buses, regularly travel a fixed route, many fleet operators have found that sign-post-based positioning systems offer an alternative to more advanced AVL technologies. Antennas are placed at locations throughout the vehicle's route and record the time when the vehicle passes nearby. Probe – based surveillance using toll tags and readers constitute a form of signpost-based AVL system. With some transit-based

systems, the “signpost” also transmits the location of the signpost (and, therefore, the bus itself) to the bus; and the bus then transmits this information to central via radio communications.

- **Ground-Based Radio Navigation.** In “terrestrial” or “ground-based” radio navigation, the AVL vendor sets up several receiving antennas in a metropolitan area. Each appropriately equipped vehicle broadcasts a radio frequency (RF) signal to all nearby receiving antennas. By measuring the time it takes for the signal to travel to the antenna, the distance from the vehicle to the antennas can be determined. When the vehicle’s signal is received by three or more antennas, the vehicle’s position can be uniquely determined. A recent approach to radio navigation involves cellular telephones – determining a vehicle’s location by measuring signals resulting from cellular phone usage within the vehicle. A disadvantage of radio-navigation is that RF signals have difficulty transmitting through large obstructions, such as mountains, tunnels, parking garages, and metropolitan canyons formed by the large buildings that line many downtown city streets.
- **Global Positioning Systems (GPS).** Global positioning systems (GPS) use a network of satellites that are continuously orbiting the Earth to locate any object anywhere on the planet. The satellites are available free-of-charge to anyone with a device capable of receiving the satellite signals. The U.S. Department of Defense (DOD) launched the satellites in order to track objects of interest on the ground. The position of the objects is determined measuring how long a radio signal takes to reach the object from multiple satellites. GPS is by far the most accurate global navigation system ever devised, with accuracies in the range of 5 to 30 feet. Similar to radio-navigation, GPS signals have difficulty transmitting through large objects. The signals also have trouble transmitting through opaque objects, such as leaves on trees
- **Differential GPS.** Differential GPS improves upon the accuracy of standard GPS. With differential GPS, a receiver placed at a known location calculates the combined error in the satellite range data. By knowing the error, correction factors can be applied to all other receivers in the same locale, virtually eliminating all errors in measurements.

15.2.8 Manual Detection and Surveillance

Freeway surveillance techniques classified as manual strategies often provide information and data that support incident detection. Frequently, manual reports help detect incidents faster than many automatic incident detection methods. Many existing freeway management systems throughout the United States detect a significant portion of incidents either through service patrols, cellular calls and/or call boxes as summarized below:

- **Cellular telephones.** This method of incident detection is becoming more important resource as the number of cellular telephones on the roadways increases. Some traffic management systems, in coordination with enforcement agencies, have established free cellular call numbers for reporting incidents or requesting aid. These toll free numbers connect the caller directly to the traffic management center or to other agencies responsible for responding to incidents.
- **Freeway service patrols.** Another effective method for monitoring traffic conditions and detecting incidents is freeway service patrols. A freeway service patrol consists of a team of trained drivers who cover a particular area of freeway, monitoring traffic operations. Many

different vehicles are used for freeway service patrols around the United States, including light trucks, mini-vans, and tow trucks. The most noticeable benefits of service patrols are those involving traffic incident management, as discussed in Chapter 10, *Traffic Incident Management* herein.

- **Call boxes / Emergency telephones.** Call boxes or emergency telephones (Figure 15-9) may also be used to detect incidents or to locate motorists in need of help. These devices are located on the side of the freeway and are typically spaced from 0.40 km to 0.80 km (0.25 to 0.50 mi) apart. Motorists can stop and use these devices to report a problem.



Figure 15-9: Call Box

15.2.9 Video Surveillance

Closed circuit television (CCTV) systems have been used for many years to provide visual surveillance of the freeway system. Control centers typically use CCTV systems for the following purposes:

- Detecting and verifying incidents.
- Monitoring traffic conditions
- Monitoring incident clearance.
- Verifying message displays on changeable message signs.
- Monitoring environmental conditions (e.g., visibility distance, wet pavement).

For fixed location CCTV systems, video cameras are permanently mounted either on existing structures along the freeway or on specially installed camera poles (see Figure 15-10). This type of system consists of various components, including the following:

- Video camera unit.

- Mounting structure (existing or newly installed).
- Controller cabinet housing the camera monitoring and control equipment.
- Communication system connecting camera to control center.
- Video monitors and camera controls located in control center.

CCTV systems allow control room personnel to visually monitor sections of roadway and to react directly to the actual conditions on the roadway. Since operators can lose interest if required to constantly view CCTV monitors, and may fail to notice incidents immediately after they occur, current systems are being designed to automatically position cameras at suspected incident locations (as signaled by incident detection algorithms) and to alert the operator.



Figure 15-10: CCTV Camera Assembly

(Courtesy of Wisconsin DOT)

15.2.9.1 Cameras

Current CCTV technology allows viewing of $\frac{1}{4}$ to $\frac{1}{2}$ mi (0.4 to 0.8 km) in each direction if the camera mounting, topography, road configuration, and weather are ideal. The location for CCTV cameras is dependent on the terrain, number of horizontal and vertical curves, desire to monitor weaving areas, identification of high-incident locations, and the need to view ramps and arterial streets. Each prospective site must be investigated to establish the camera range and field-of-view that will be obtained as a function of mounting height and lens selection.

Two key measures of CCTV camera operation are light *sensitivity* and camera *resolution*. Sensitivity describes the amount of light needed to make a useful image, while resolution is the number of lines reproduced from the camera signal in making a video image on a monitor useful. The amount of available light is one of the most important factors affecting CCTV camera performance in traffic applications. Therefore, cameras must be sufficiently sensitive to view traffic conditions during morning and evening peak periods, even in winter when illumination may be very low during morning and evening 'rush' hours. Light levels at intersections and interchanges typically range from 2 to 3 foot-candles (FC), while light levels can be less than 0.1 FC at roadway sections between intersections / interchanges. Cameras should also provide good horizontal resolution since this parameter helps determine image quality and ability to discern details. This is particularly important for viewing at a distance.

Video cameras compatible with National Television Standards Committee (NTSC) standards are available in either monochrome or color. Traditionally, monochrome cameras offered better resolution in low-light conditions, although improvements in color video imaging and processing technologies have closed that gap. In general, monochrome cameras have several advantages over color cameras. Specifically, monochrome cameras:

- Perform well under a greater variety of light conditions, including infrared;
- Are more light-sensitive overall;
- Provide higher resolution;
- Have a higher signal-to-noise ratio;
- Last longer; and
- Cost less than color cameras.

Monochrome cameras require illumination at the faceplate of only 0.13 FC, equivalent to full moonlight, to produce a full video image. For an 80% video level, monochrome cameras require 0.01 FC at the faceplate, equivalent to a clear full moon, and 0.0016 FC, equivalent to a clear quarter moon, to achieve a 30% video level. A 30% image is recognizable in black and white.

In contrast, color cameras require a minimum illumination of 0.8 FC at the faceplate, equivalent to the ambient light level at sunrise or sunset, to produce a full video image. For an 80% video level, color cameras require 0.07 FC at the faceplate, equivalent to twilight. At this level, however, the camera image may not reproduce color effects properly. Color cameras generally require full-spectrum illumination for proper color rendition. Further, good color saturation (intensity) is important in a color camera. Insufficient color saturation results in a "washed out" image, and over-saturation can make an image appear excessively vivid. Color camera resolution is 480 TV lines horizontally and 350 TV lines vertically.

The performance gap between color and monochrome cameras is converging to the point where, except for the most demanding low-light situations, differences in video quality and resolution are indistinguishable. Color cameras have a distinct advantage over monochrome cameras in providing color information that can aid incident verification, assessment and management. Color video can also integrate visually with other color graphics and workstation displays. Although the ability to reproduce color at low-light levels diminishes significantly, color cameras can easily differentiate headlights, taillights and red brake lights in low light. In areas of consistent traffic, vehicle headlights should illuminate the field of view sufficiently to benefit from a color CCTV system.

Another strategy for CCTV surveillance in low-light conditions is using cameras with adjustable shutters (integration cameras). By slowing the shutter speed, adjustable cameras can increase frame exposure times allowing more light to reach the camera image-sensing device. The tradeoff of slower shutter speeds in a high motion (i.e., moving traffic) environment is a blurred image. The improved visual presentation and additional information color video provides outweigh possible quality erosion in low-light levels. Further, in an arterial application where street lighting is used, low light level presents are less of a risk.

Both analog and digital cameras are marketed for freeway management application, as summarized below:

- **Analog.** The main component for analog cameras is the Charge Coupled Device (CCD) sensor. The CCD sensor is a solid-state imaging technology available in a compact, inexpensive format. CCD cameras are typically available in a variety of imager size formats, including 2/3", 1/2", 1/3" and 1/4". The two most common, proven CCTV camera sensors are the interline transfer and frame transfer CCDs. Both CCD devices provide good quality video and good sensitivity.
 - Interline CCD is the most commonly used system type for security and surveillance applications in traffic management, mass transit, airports, and military applications. Interline CCD sensors are smaller than frame transfer imagers, have longer service life, require less periodic maintenance, produce no geometric distortion, are immune to vibration, magnetic fields and direct exposure to sunlight or headlight, and consume minimal power. The interline transfer CCD image device eliminates overload streaking because it is not sensitive to infra-red, improves dynamic range, and also provides high resolution.
 - The frame transfer CCD imaging device provides extraordinary resolution, and is very well suited to full-motion video monitoring under consistent illumination levels. However, the frame transfer device uses larger individual photocells and is thus more sensitive. The frame transfer device requires a larger chip area, so it costs more and has a higher level of "smear" than interline transfer devices. Smear occurs when an illumination source overloads the imager, resulting in the appearance of bright vertical lines on the image. Both types of CCD devices have some smear, but it is more pronounced in the frame transfer device.
- **Digital.** An alternative to analog video technology is Digital Signal Processing (DSP), which is becoming a traffic management standard since the cost of the technology has dropped over the last 5 years. DSP magnifies a CCTV image through a process called "electronic zooming", which increases the effective zoom of a camera by up to 8 times. This process is

basically enhanced “pixel replication,” a process using pixels more than once in creating output images. Electronic zoom increases the display size of only a portion of the camera sensor area, however, and resolution actually decreases during DSP because fewer sensor pixels make a display covering the entire monitor screen. The expanded image is actually an “artificial zoom,” and lacks the resolution of an optical zoom. Other features of DSP are image stabilization and scene brightness balance.

15.2.9.2 Lens

CCTV system lenses are available for purchase separately from the camera. Since the lens is a vital component in determining CCTV surveillance range, it is prudent to consider lens capabilities separately from the camera. Of course, evaluation of any camera-lens pair is also necessary before recommending a particular lens-camera combination. It should also be noted that, while it may be prudent from a maintenance standpoint to standardize the lenses used, each application (location) has unique characteristics that will define the optimum lens.

The focal length of a lens (typically measured in millimeters) measures the distance from lens to camera imager, and determines the camera field-of-view. As focal length increases, the viewing area decreases and is magnified, making distant objects appear larger. Short focal length lenses have a wide field of view and display more of a scene. Long focal length lenses have a telephoto effect and provide more detailed views of distant targets.

Field of view (i.e., the height and width of a scene) and depth of field (i.e., the minimum and maximum distances from the lens at which a subject is in sharp focus) are two major considerations in selecting a camera lens for CCTV traffic applications. The following equations illustrate the relationship between focal length and object area using the typical ½” format imager³⁵:

$$H = \frac{6.4 \times L}{F} \quad \begin{array}{l} F = \text{lens focal length in mm} \\ H = \text{horizontal dimension of the object in mm} \end{array}$$
$$V = \frac{4.8 \times L}{F} \quad \begin{array}{l} V = \text{vertical dimension of the object} \\ L = \text{distance from the lens to the object in mm} \end{array}$$

Typical CCTV camera lenses come in a variety of configurations. For example:

- Lenses are available in ¼”, ½”, 2/3” and 1” formats compatible with camera imager formats.
- Zoom lens magnification ratios range from 6:1 to 22:1, depending on the focal length range.
- Common zoom lens focal length ranges are 4-86mm, 8-48mm, 8-80mm, or 16-160mm.
- Using a camera and lens of the same format size (for example, ½”) results in a focal length equivalent to that of the lens.
- Adapting larger format lenses to smaller format cameras will result in a corresponding increase in the effective focal length of the lens. This is one way to extend the range of a given lens.
- Extenders placed between the camera and lens can also increase focal length by a factor of 1.5 to 2.0.

The amount of light a lens can collect is important in selecting a camera-lens pair. The lens F-stop measures the amount of light that can reach a sensing device through the lens, and is

equivalent to the focal length divided by the aperture. The higher the F-stop number, the less light is transmitted through the lens. Zooming a lens out for distance viewing, or decreasing the aperture, will increase the F-stop resulting in less light being collected by the lens.

Zoom lenses also come equipped with pre-set capabilities. Potentiometers coupled with motorized zoom and focus functions provide position feedback to the Camera Control Receiver/Driver (CCR/D). This feature allows users to position cameras quickly and effortlessly at pre-set positions, a vital function for long-distance viewing at maximum lens zoom. With so much magnification, slight changes in camera position can change the camera view dramatically. In addition, presets are necessary for applications providing control over the Internet or other non full-motion solution.

Neutral Density (ND) lens spot filters are required in outdoor camera applications to prevent iris shutdown in the presence of bright point sources of light. Infrared (IR) lens filters are also required for use with color cameras to prevent distortion of the visible color spectrum.

15.2.9.3 Pan & Tilt

Using a pan/tilt (P/T) platform, CCTV system operators can change camera position about the 360-degree 'azimuth' axis, and adjust camera elevation up or down (within a 90 degree range). Together with a zoom lens, the P/T allows operators to view a scene within any direction about the camera, and within the lens field-of-view and distance ranges. Adjustable limit switches on the P/T restrict the range of motion to that required for a particular installation (or to block out certain views, such as residential areas). The speed of the pan/tilt mechanism determines the *rate* of camera coverage, while horizontal and vertical camera movements determine the coverage *area*.

P/T is accomplished with either an external unit that the camera, lens, and enclosure attached to, or a "dome" where the camera, lens, and P/T mechanism are enclosed in an aesthetic dome enclosure. External units typically have a pan speed of 6.0 to 9.0 degrees/second (plus or minus 1 degree), and a tilt speed of 4.0 to 4.5 degrees/second (plus or minus 0.5 degrees). However, one manufacturer has recently introduced a high-speed pan/tilt drive with a maximum pan rate of 40°/second and a tilt rate of 20°/second and a continuous 360° pan range.

Dome enclosed systems provide much higher P&T speeds – typically able to pan and tilt at 90-100 degrees/second. Dome systems also have more range than external units, having the ability to look straight down. It should be noted that the Dome cameras are "horizon limited". They can't look up at the sky or up a nearby steep hill very well. However, unless the camera is to be placed in very hilly terrain, this is not a major drawback for roadway traffic monitoring. Cameras in a dome system cannot be seen by motorists, which make them much less intrusive than external P&T systems.

Like the lens pre-sets, pan/tilt pre-sets allow pre-positioning cameras at desired locations. Pan/tilt pre-sets can also "reset" cameras to revert to a pre-determined direction at the end of a viewing session. This procedure can ensure that cameras are not left pointing in an undesirable direction. Like the lens pre-sets, the P/T pre-sets use potentiometers to feedback relative azimuth and elevation position to the CCR/D (Camera Control Receiver/Driver).

15.2.9.4 Environmental Enclosure

An environmental enclosure is usually necessary to protect delicate camera and lens equipment from environmental hazards such as weather and pollution. As with P/T units, the enclosure can be a separate component housing the camera and lens and mounted on an external P/T unit, or a dome enclosure housing the camera, lens and P/T mechanism. Each of these enclosures can be:

- Atmospheric vented enclosures are generally less expensive than others, provide better cooling, and require relatively little maintenance, or
- Self-contained, pressurized enclosures provide better camera and lens protection because the units are sealed. However, they do not provide the same level of cooling, and require periodic re-pressurization.

On the component enclosure, an externally mounted sun shroud, shading the camera housing from direct sun, can reduce internal temperatures by about 10 to 15 degrees Fahrenheit. The shroud also helps deflect sun glare and rain from the enclosure window. On a dome system, the dome itself is the sunscreen. An internal heater can help prevent fog formation due to temperature and humidity differentials on the front enclosure window or dome.

15.2.9.5 Camera Control Receiver/Driver

A Camera Control Receiver/Driver (CCR/D) decodes camera, lens and P/T control commands into control signals that the individual devices use during operation. The CCR/D can also manage zoom lens and P/T pre-set positions. CCR/D units typically store up to ten programmable pre-set positions by associating lens and P/T potentiometer settings with a given position. Each pre-set position defines a complete setting. The CCR/D uses this information to drive lens and P/T motors to acquire that position. Fully variable control of all P/T azimuth positions is also possible by associating potentiometer readings with compass point directions. This option allows finer camera control, but with greater complexity and expense. Preset positions are repeatable up to one degree of accuracy.

Scene blocking is another CCR/D feature that may be desirable for freeway surveillance. Using this feature, an operator or system administrator can program a section of the viewing area to be blocked out during panning operations. Scene blocking can prevent operators from viewing inappropriate areas such as private backyards, apartment buildings and hotels. A variation of this feature freezes the image as the camera pans across the blocked viewing area and resumes normal real-time viewing when the camera reaches the end of the blocked area. In external P/T units, physical "stops" are installed on the unit to prevent the unit from panning or tilting beyond a determined point. In either case, these settings are typically performed at initial set-up, and seldom require any further maintenance.

15.2.9.6 Video Communications and Formats

Video can be transmitted either as analog or digital video. Transmission of analog video requires large amounts of bandwidth. For transmission distances of more than 500 feet, analog video must usually travel over coaxial cable or fiber optic cable.

Digital video requires that the analog video source be converted to digital "data". This is accomplished via a CODEC (coder-decoder). The process is very similar to the conversion of

voice from analog to digital, but is substantially more complex. Several different types of video CODECs are available to serve a wide variety of communication needs. The CODEC provides two functions. First, it converts the analog video to a digital code. Second, it “compresses” the digital information to reduce the amount of bandwidth required for transmission. In the process of converting from analog to digital and back to analog, the video image loses some quality. The compression process also adds a small loss of video quality. Each of the following CODECs has its own set of video image quality loss characteristics.

- **H.261** CODECs are used primarily for video conferencing. The analog to digital process sacrifices motion for video and audio quality. They typically use POTS (or DDS) services to reduce total cost of operation and are designed to provide simultaneous multiple connections for group conferencing. However, they can use T-1 and “fractional T-1” circuits for better image quality.
- **DS-3** CODECs were developed for use in distance learning systems, providing full motion, full video and audio quality for the classroom situation. Communication is accomplished via broadband links. The communication links can be leased DS-3 service, or privately installed copper or fiber optic networks.
- **JPEG** (Joint Photographic Group Experts) and **Motion JPEG** are some of the most widely used CODECs for video surveillance purposes. However, they were primarily developed for the purpose of storing images electronically. Each still image is converted to an electronic data image and transmitted. The still images are assembled at a receive decoder and displayed at a rapid rate to provide motion. They can be used with POTS communication circuits, fixed low speed data circuits, or broadband copper and fiber optic communication links. They are also used in wireless applications such as spread spectrum radio, or CDPD cellular.
- **MPEG** (Moving Picture Experts Group) CODECs were developed to provide a better quality motion image compression. There is less image quality lost in the conversion and compression processes. However, the primary purpose of MPEG CODECs is to provide “real-time like” motion pictures via the Internet (also called Streaming Video). The overall process creates a storage buffer so that there is always a slight delay between the request to view and the start of the motion picture. For the average user of the Internet, this is not a problem. CODEC manufacturers using the MPEG-2 standard for traffic surveillance purposes have adapted this standard to create a real-time video transmission. However, this does have a minimal impact on final image quality. The MPEG-4 standard was developed for Internet streaming video, but is also being adapted for “real-time” surveillance purposes.

15.2.9.7 Portable CCTV Systems

Portable CCTV systems can serve several purposes including the following:

- Short-term traffic monitoring in areas with non-recurring congestion (e.g., work zone, critical incident, detours etc.).
- Traffic monitoring at special traffic generators (e.g., stadiums, parades, etc.).
- Traffic monitoring along evacuation routes
- Determination of optimum camera location for fixed location CCTV systems.

Portable CCTV systems are typically mounted in a light truck or van or on a trailer (see Figure 15-11). Components of a portable system include the following:

- Camera with pan—tilt-zoom capability.
- Telescopic boom.
- Television monitor and video recorder
- Camera control unit for controlling pan, tilt, and zoom functions.
- Generator for powering equipment; or battery power with solar charging
- Air compressor for operating telescopic boom.
- Wireless communications



Figure 15-11: Portable CCTV Assembly

(Photograph courtesy of Lawrence A. Klein, Placentia, CA)

15.2.10 Environmental Sensors

Observation and prediction of weather events and their roadway impacts are important in the development and implementation of operational strategies and response plans. Better road weather data (i.e., timely, accurate, and relevant) are critical to effective freeway management and operations in adverse weather. The type of weather event that is occurring will influence decisions of traffic managers. Weather events can range from relatively localized phenomena (thunderstorms, fog, and tornadoes) to major events that may require evacuation over a wide area (hurricanes, floods). Specific weather may vary over different parts of a network (rain, ice, snow) resulting in a need for different responses. Transportation managers need the ability to gather and process information on the location, characteristics, and duration of weather events, as well as the ability to predict their impacts (11).

Effective response requires that transportation managers be able to gather and process information that describes the key characteristics of a weather event. Operational strategies should reflect the best understanding possible of such weather event characteristics including:

- **Severity** – Precipitation type and amount, temperature, visibility, and wind speed are among the specific measures that will describe the severity of the weather event. The degree of potential risk to life and property will vary greatly and influence the response.
- **Area of Impact** – The size and characteristics of the geographic area impacted by the event will have a major influence on operational strategies. Weather events may influence an area beyond the range of individual jurisdictions, requiring additional coordination activities. A common terminology and clear understanding of weather events and their impacts are needed to define the area of impact.
- **Time of Day** – The operational strategies implemented will vary based on time of day. Events occurring during peak hours will require different, and more complex, strategies than those required during periods of light travel. Events occurring during morning peak will require a different response than those occurring during evening peak.
- **Lead Time** – The lead time prior to the weather event will influence the response of the transportation managers. Transportation managers need an understanding of forecast accuracy and risk factors in order to deploy the appropriate level of resources.
- **Event Duration** – The anticipated duration of the weather event, as well as the start and stop times, will also influence operational strategies. Contingency plans must be part of the strategy in case the event is either longer or shorter than anticipated. Events starting just prior to or during peak periods will require different response plans than those events that start during periods of light travel (11).

15.2.10.1 RWIS

A road weather information system (RWIS) is a combination of technologies that collects, transmits and disseminates weather and road condition information. The component of an RWIS that collects weather data is the environmental sensor station (ESS). An ESS is a fixed roadway location with one or more sensors measuring atmospheric, surface (i.e., pavement and soil), and/or hydrologic (i.e., water level) conditions (Figures 15-12 and 15-13), including:

- Atmospheric sensors – air temperature, barometric pressure, relative humidity, wind speed and direction, precipitation type and rate, visibility distance
- Surface sensors – pavement temperature and condition (dry, wet, ice, freeze point, chemical concentration), subsurface temperature, subsurface freeze/thaw cycles)
- Hydrologic sensors (stream, river and tide levels)

Data collected from environmental sensors in the field are stored onsite in a Remote Processing Unit (RPU) located in a cabinet. In addition to the RPU, cabinets typically house power supply and battery back-up devices. The RPU transmits environmental data to a central location via a communication system. Central RWIS hardware and software collect field data from numerous ESS, process data to support various operational applications, and display or disseminate road weather data in a format that can be easily interpreted by a user. Environmental data may be integrated into automated motorist warning systems, and transmitted to TMCs, emergency operations centers and maintenance facilities for decision support. This information may also be used to enhance forecasts and supplement mesoscale environmental monitoring networks (i.e., mesonets) (25).



Figure 15-12: Environmental Sensor Station

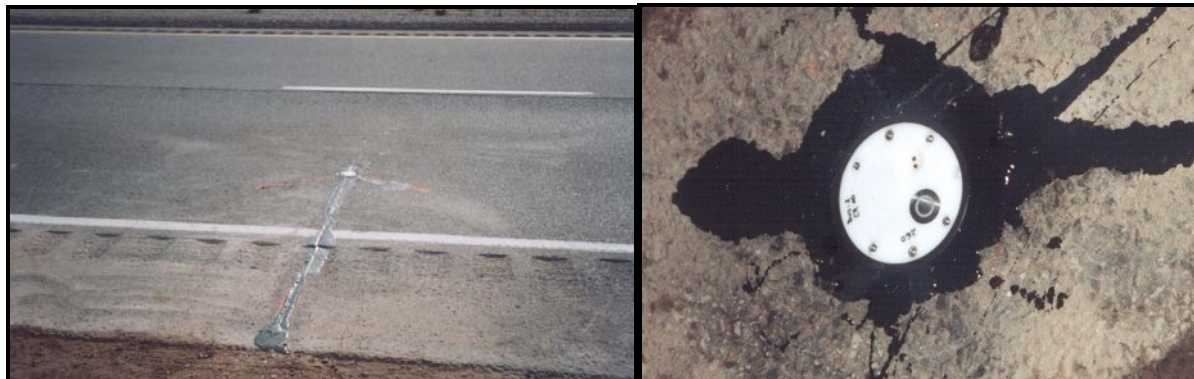


Figure 15-13: Surface Sensor

Weather service providers (who are often RWIS/ESS vendors) also use the data to develop tailored weather services and products, including pavement temperature / bridge icing forecasts, ice and snow prediction, optimization of treatment routes and resource allocation, and thermal mapping. The latter is a process to quantify the variation in nighttime road surface temperatures across the roadway network. This variation can be 10⁰ F or greater (depending on exposure,

altitude, traffic, and road materials), which can impact which areas may become icy before others.

Transportation managers utilize environmental data to implement three types of road weather management strategies – advisory, control and treatment. Advisory strategies provide information on prevailing and predicted conditions to both transportation managers and motorists. Control strategies alter the state of roadway devices to permit or restrict traffic flow and regulate roadway capacity. Treatment strategies supply resources to roadways to minimize or eliminate weather impacts. Many treatment strategies involve coordination of traffic, maintenance, and emergency management agencies. Winter maintenance managers utilize road weather information to assess the nature and magnitude of threats, make staffing decisions, plan treatment strategies, minimize costs (i.e., labor, equipment, materials), and assess the effectiveness of treatment activities (by agency staff or subcontractors). Traffic managers may alter ramp metering rates, modify incident detection algorithms, vary speed limits, restrict access to designated routes, lanes or vehicle types (e.g., tractor-trailers) and disseminate road weather information to motorists in order to influence their travel decisions. Some Traffic Management Centers integrate weather data with traffic monitoring and control software. Emergency managers may employ decision support systems that integrate weather observations and forecasts with population data, topographic data, as well as road network and traffic data. When faced with flooding, tornadoes, hurricanes, or wild fires; emergency managers may use this data to evacuate vulnerable residents, close threatened roadways and bridges, and disseminate information to the public.”

RWIS standards fall into the following three categories:

- Siting standards focus on installing ESS in locations that generate the most accurate and appropriate weather condition observations.
- Calibration standards are procedures for testing the accuracy of ESS observations.
- Communication standards include protocols for exchanging data between RWIS devices and other ITS elements, and display and message set standards for communicating weather and road condition information to end users.

The information requirements and spacing of information collection points for weather monitoring depends on a number of factors, including:

- **Average annual precipitation** – the greater the precipitation (e.g., snowfall), the need for more roadway information at closer intervals. Similarly, areas / segments with significant rainfall and / or icing potential (as determined from thermal mapping) will also need roadway information.
- **Level of winter maintenance activities** – an organization that regularly implements proactive treatment strategies (e.g., anti-icing before snowfall) will typically need more road weather information than an agency that performs reactive treatment (e.g., plowing and spreading abrasives after snowfall).
- **Terrain** – areas of higher elevation, with steep upgrades / downgrades, and/or plains subject to high winds and blowing snow, may need a greater coverage of weather information.

- **Microclimates and thermal influences.** Weather information is required wherever there is a significant change.
- **Spot problems** – areas with very local influences (e.g., fog, high winds, frequent icing) necessitate a focused coverage of partial weather information as a minimum.

Additional information on RWIS and ESS is available from the FHWA publication entitled “Best Practices for Road Weather Management, Version 2.0” (Reference 25).

15.2.11 Emerging Trends

A number of trends in technology and application are emerging in the Nation. Some of the traffic sensors noted earlier in this Chapter are gaining more and more application. These include the passive acoustic array, ultrasonic, passive infrared, and the combination sensors. Others technologies and applications show promising results for future implementation.

15.2.11.1 Probe Surveillance

As discussed in Chapter 13 on Traveler Information, it is envisioned that the Integrated Network of Transportation Information (INTI) will not be heavily infrastructure-based; rather, the long-term path is heavily vehicle-based (but not exclusively) for the collection of information. This will require widespread utilization of vehicle probes using GPS and/or cellular phone triangulation, with the result that the standard design considerations of point detection and element spacing along the roadway infrastructure may no longer be applicable. (Note – Probe surveillance using electronic toll tags is not a “cutting edge” technology. In fact, in terms of infrastructure requirements, it is very similar to other “point detection” technologies in that AVI readers are required at selected intervals along the highway to read the tags.)

15.2.11.2 Remote Sensing

Aerial surveillance has long been used to monitor the operation of the surface transportation network. “Observers” in aircraft (fixed wing or helicopters) fly over the freeway and monitor the conditions in real-time, using two-way radios to communicate with the traffic operations center or with service patrols on the freeway. This approach can be relatively expensive when one considers the expense of leasing or operating an aircraft; although it does have the benefit of being able to cover a large area.

An emerging trend is the use of remote sensing via unmanned aerial vehicles, similar to airborne platforms / drones used by the military, and satellites. Information gathered from satellite, aircraft, and unmanned aerial vehicles can be used to estimate arterial and freeway traffic characteristics over long time scales and large geographic areas, including those where data were previously unavailable. The spatial coverage provided from air- and satellite-based sensors can potentially support the development of new metrics that better represent highway utilization and congestion. (1)

Florida DOT is currently experimenting with an unmanned airborne platform that can be programmed to fly a prescribe route and transmit real time video images to a TMC. Other possibilities include the integration of digital video, global positioning systems (GPS) and automated image processing to improve the accuracy and cost-effectiveness of data collection and reduction. A number of experiments have been used to estimate vehicle speeds directly

from video images in near real-time by using image registration and edge detection technologies. Similar techniques have been used to derive other traffic characteristics, such as, densities, travel times, delays, turning counts, queue lengths, and platoon dispersion. (15)

15.2.11.3 Networked Video

As technology expands, and the security of the Internet improves, users are looking at cheaper means to distribute video to a wider audience. This audience includes operators, response personnel, emergency service providers and the public. Using the Internet as the communications infrastructure, live streaming video for a wide variety of applications can be distributed to numerous users. With this technology, transportation industry users can utilize their existing CCTV systems to:

- Monitor and respond quickly to incidents
- Monitor critical infrastructure for security purposes
- Archive video for later review for special projects, traffic flow studies, and construction monitoring
- Provide remote access to video for related uses in law enforcement and emergency response
- Create public goodwill by providing video feeds to commuters and media outlets

This capability is available to any user with a standard Internet browser. With excellent bandwidth management, providers can allow hundreds of users to monitor images and provide users with pan, tilt and zoom capability.

15.2.11.4 Maintenance Decision Support System

FHWA is supporting the development of the next generation of road weather information systems called the Maintenance Decision Support system (MDSS) for winter road maintenance decision makers. The program is designed to respond to changing weather conditions and their impacts on the highway system. It was designed with the needs of state Departments of Transportation in mind, and allows winter maintenance managers to:

- View predicted weather conditions throughout the state
- Become aware of the potential for deteriorating road conditions before they occur
- Predict impacts of weather on road conditions
- Plan treatment scenarios based on available resources
- Receive treatment recommendations based on proven rules of practice

The primary goal of MDSS is to get proper weather, road condition, and resource information into the appropriate people's hands so that they can make proactive decisions to manage the transportation system before and during adverse weather conditions.

15.2.11.5 Security

As noted in Chapter 12, another emerging trend is the development and deployment sensor technologies in support of Homeland security – such as devices that automatically and immediately detect potential threats (e.g., stopped vehicles) along the roadways and near transportation centers, and commercial vehicle technology for sensing and identifying hazardous materials.

15.2.12 “Infostructure”

Another emerging trend is the concept of a national “Infostructure”. The document entitled “Operating the Highway System for Safety, Reliability and Security; TEA-21 Reauthorization Proposal” (3) includes the following statement: “To provide timely, comprehensive information to managers and users of highway-based transportation systems, a program to implement and operate an information infrastructure or “infostructure” of traffic and infrastructure monitoring and data sharing is proposed.” As discussed herein, the need for an Infostructure (and the associated real time information) exists, as does the technical means to collect and process the associated information. What is missing is the actual deployment. The level of surveillance information currently available is relatively limited. For example:

- Less than 25 percent of the urban freeways in our largest cities are instrumented for traffic surveillance. Moreover, given the current rate of deployment (Figure 15-14), it will be some time before an adequate portion of the freeways in the largest urban areas are instrumented for collecting the information so as to enable truly effective operations and management.
- Arterial surveillance is virtually non-existent, mostly involving simple vehicle presence detection for signal control
- Only 25 transit agencies in our 78 largest cities have automatic vehicle location systems on their fixed route buses, and
-
- 15 percent of all fatal crashes occur during adverse weather conditions, yet road weather data collection stations exist at an average spacing of over 130 miles on the National Highway System.

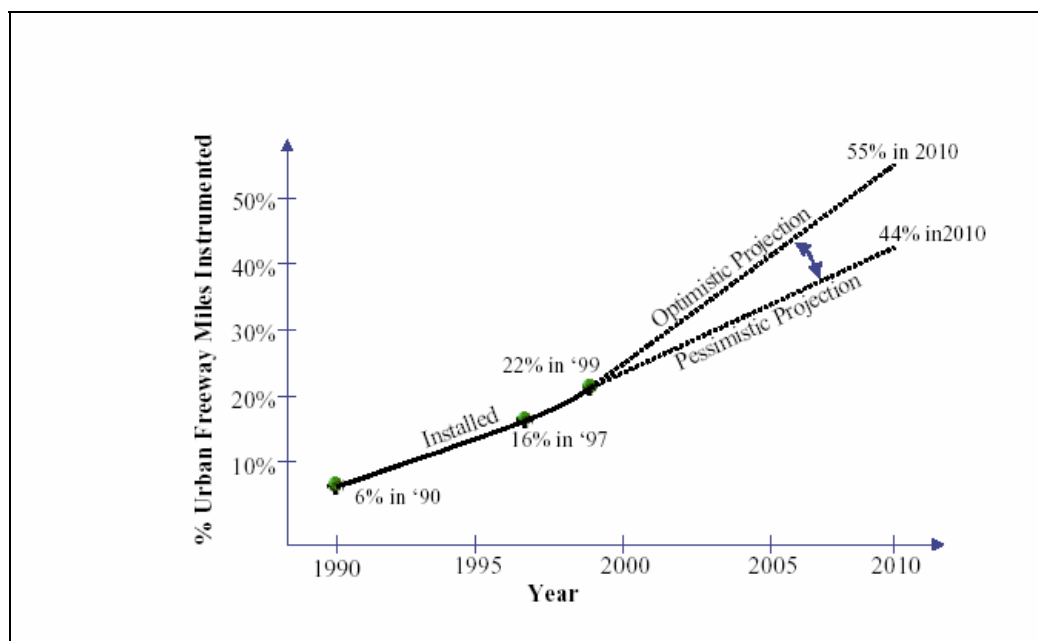


Figure 15-14: Projected Growth in Freeway Surveillance

Moreover, as discussed in Chapter 12, a related issue (and a relatively new concern) is that of homeland security. The ability of the surface transportation network to cope with such contingencies requires additional information and operational capabilities – for example, to identify potential dangers (and then respond) before anything can happen, to detect any such catastrophic incidents, to facilitate first responder access and military deployments, and to effectively route evacuations from major metropolitan areas.

These facts provide compelling evidence that incentives and / or new approaches are required to accelerate the development and deployment of an information infrastructure. The FHWA has recognized this need, sponsoring several efforts to define an initial vision for this Infostructure. Additionally, per the aforementioned paper summarizing reauthorization issues, the “ITS information infrastructure” is identified as “one of the four significant areas of change that are necessary to achieve an adequate emphasis on operations in Federal surface transportation programs.

An initial vision and concept for the Infostructure – a “strawman” view of sorts – has already been developed and documented (12). As currently envisioned, the Infostructure program “would support both national and State/local interests. The national program element would include:

- Statewide (and regionwide) reporting of capacity reducing events on the National Highway System (e.g. crashes, work zones, road weather events) using a consistent reporting format, such as is already being done in the I-95 Corridor Coalition, Arizona, Utah, and a few other States.
- System performance and weather monitoring of freeways, key arterials (including evacuation routes), and transit systems in large metropolitan areas (those with populations exceeding 1 million). This could be accomplished through deployment of electronic monitoring infrastructure, acquisition of data from private sector sources, or a combination of these approaches.
- Monitoring of critical transportation infrastructure (e.g. bridges, tunnels, military routes) for security purposes.
- The State/local element of the program would be focused on producing information for locally determined security, safety and reliability purposes, in order to support traffic management, traveler information, transit management, CVISN (Commercial Vehicle Information Systems and Networks), emergency management, E-911, and security activities and services.”

The next step in the process leading to ultimately deploying the Infostructure is the development of a Concept of Operations, which is currently underway at the time of writing this Handbook. Some of the issues to be addressed by the Infostructure Con Ops include the following:

- **Highway Classifications & Differentiators:** Different types of highways have different operational characteristics. In addition to freeway, arterial, and bridge / tunnel classification, additional differentiators, such as freight routes, evacuation routes, military deployment routes, and routes significantly impacted by snow and other weather conditions, may also impact the type, amount, and accuracy of information required for operations.

- **Types of Information:** Roadway traffic flow information – such as volumes, speeds, travel times, etc. – are obvious information requirements for operating the surface transportation network. Other conditions and functions can affect the information requirements, including:
 - **Incidents and Video Surveillance** – Incidents reduce the capacity of the roadway and can cause the flow to suddenly breakdown. Moreover, there are other concerns associated with incidents beyond their impact on traffic control, including life safety (e.g., getting medical treatment to injured parties as soon as possible) and environmental (e.g., containing and cleaning up any spills of hazardous materials). Video surveillance has proven very useful for incident verification and “diagnosis”.
 - **Inclement Weather** – Capacity and operating conditions may also be affected by inclement weather, requiring information on atmospheric and road surface conditions. This information is also often required to manage winter maintenance activities. The initial Infostructure concept envisions a nationwide “grid” of environmental sensor stations for the purpose of meso-forecasting. The basic information would include atmospheric temperature, humidity, wind speed / direction, and precipitation. Additional information and closer spacing of information collection points (relative to the national grid) may be required depending on a number of factors, including average annual snowfall, level of snow maintenance activities (e.g., anti-icing vs. plowing only), terrain and grades, and spot problems (e.g., fog, high winds, frequent icing)³⁶.
 - **Transit** – An important element of the nation’s highway network is the transit buses that utilize the roadways. In addition to monitoring the real-time operations of the roadways, surveillance of the buses themselves (e.g., location, schedule adherence) was also identified as a potential information requirement.
 - **Security** – The horrific events of September 11, 2001 demonstrated the need for information that would help protect critical infrastructure elements, including major highways, bridges, tunnels, and transit systems. Damage or destruction of a major tunnel, bridge or transit facility could cause significant injuries and fatalities, as well as disrupt the transportation system for an extended period of time. Accordingly, the initial Infostructure vision includes surveillance subsystems to monitor critical infrastructure, major transit facilities, military routes, and freight intermodal connectors and terminals to detect problems quickly and reliably and to facilitate rapid evacuation and emergency response if needed.
- **Information Integration** – In addition to collecting this information, it was determined that the Infostructure should also include some form of statewide and regional integration supporting the exchange and sharing of this information between multiple locations and transportation management centers. This included Statewide reporting of capacity reducing events on the National Highway System (e.g. crashes, work zones, road weather events) using a consistent reporting format.
- **Local and National Needs** – The Infostructure concept currently envisions supporting both national and State/local interests. The national elements could include the information (and at a level of detail) required to support regional / national travel and to manage major incidents and emergencies – for example: travel time information on freeways and key “interstate” arterial – type highways; weather information; statewide reporting of major

capacity reducing events (e.g. crashes, work zones, road conditions); and monitoring of the STRAHNET, emergency evacuation routes, and critical transportation infrastructure. The local element of the program could be focused on producing information for locally determined security, safety and mobility purposes, such as travel time information on “local” arterials, volume information (for input to planning / simulation models), CCTV surveillance, and transit system performance. The distinctions between “national” and “local” may be significant, particularly if they affect funding mechanisms and the respective roles of USDOT, State and local agencies, and the private sector.

- **Federal, Public and Private Roles** – It is currently envisioned that the Infostructure will not be Federally mandated (in whole) or Federal controlled. Rather, USDOT may provide incentives, and will likely play an oversight and coordination role. The exact nature of the federal role still needs to be addressed, as well as the roles and relationships between the public and private sectors in deploying, operating and maintaining the Infostructure.

At the time of preparation of this Handbook, a “Surface Transportation Security and Reliability Information System Model Deployment” (MDI) was just beginning in the Orlando, FL vicinity.

15.3 IMPLEMENTATION AND OPERATIONAL CONSIDERATIONS

The surveillance subsystem and the information it collects supports the other functions of a freeway management program. The process to select and implement the surveillance subsystem should therefore be based on the information needs of these freeway management functions. Some steps in this process are summarized below.

- **Identify and locate operational deficiencies.** This involves identifying those freeways that would greatly benefit from the use of surveillance and traffic management. Areas benefiting the most would be those with significant amounts of congestion, safety problems, or potential weather hazards.
- **Determine functions to be performed by the freeway management system.** This will define the information requirements for the surveillance subsystem. As discussed in previous chapters, potential freeway management functions requiring some sort of data include performance monitoring, simulation and analysis in support of the transportation planning processes, ramp management, lane management and HOV lanes, traffic incident management, special event management, emergency and evacuation management, weather maintenance management, traveler information, etc. At this stage, the focus should still be on what the system will be designed to do, not how it will do it. Therefore, the functions should be defined independent of the available technology. It cannot be overemphasized that the surveillance subsystem provides support to other elements in a freeway management program and traffic management system. Therefore, the functional requirements of a surveillance subsystem are dependent upon the element that it will support. For a surveillance subsystem, the functional requirements typically relate to the type, temporal and spatial frequency, accuracy, and quantity of data required. The data typically used for freeway surveillance have included measures such as volume, speed, and occupancy; however, surveillance should not be limited to these measures only. Additional measures might include travel time, queue length, headway, origin/destination, vehicle classification, etc.

- **Inventory existing surveillance capabilities.** The existing surveillance resources should be identified and evaluated to determine if they are suitable for continued use. The evaluation should include items such as the detection elements, processors, and communication infrastructure. It is important to determine if these components can meet existing needs and if they can accommodate changes in system requirements. Identify selection criteria. The established performance criteria for the surveillance subsystem should be related to the needs of the overall freeway management program and the associated functions. Criteria that may be used in this regard include:
 - Reliability of information collection
 - Accuracy of data
 - Timeliness of data.Each of the above criteria is important in measuring the performance of a surveillance subsystem. For example, a system is not effective if it provides accurate data 30 minutes after it is needed.

- **Identify / Select Alternative Technologies.** There are a number of alternative technologies available for collecting traffic data and other information as described in Section 15.2.5. This information can be used as a starting point for identifying alternative technologies; however, due to continuous technological advancements and system improvements, available systems and their capabilities are constantly changing. During the screening process, the following factors should be considered for each type of surveillance technology included in the analysis:
 - Information provided (vis-à-vis the functional requirements)
 - Location of sensors (i.e., embedded or non-intrusive).
 - Installation, operation, and maintenance requirements.
 - Reliability.
 - Expected life.
 - Life-cycle costs.
 - Communications requirements (bandwidth, media)
 - Processing requirements
 - Requirements for future expansion.

- **Implementation and Testing.** Prior to acceptance, the individual units and components that make up the surveillance subsystem should be tested to ensure proper operation, followed by testing of the entire surveillance subsystem.

- **Evaluation.** After a surveillance subsystem has been installed, it should be continuously evaluated for its effectiveness in meeting the freeway management objectives. Providing measures of traffic operations (e.g., speed, flow, density, etc.). Records should be kept to track system operations and note any problems. An overall evaluation of the equipment should include monitoring the following:
 - System reliability.
 - Ability to provide required data.
 - Timeliness of data.
 - Accuracy of data.
 - Ability to perform under various environmental conditions.
 - Operational and maintenance requirements and costs.
 - Any other problems with system.

- Reliability of detectors.
- Ability to provide needed data.

15.3.1 ESS and RWIS Deployment

Reference 25 (“Best Practices for Road Weather Management”) provides the following overview of issues related to ESS and RWIS deployment. “Several issues must be considered when planning to deploy ESS and implement RWIS. Concerns include procurement and maintenance, data sharing, and institutional issues. Partnerships with neighboring public agencies and the private sector can facilitate data sharing and help defray the initial and recurring costs of field sensors, communications infrastructure, central hardware, and processing software. Another alternative is to fund RWIS component installation as part of larger construction or Intelligent Transportation Systems (ITS) projects. Preventive maintenance funds must also be secured to ensure that sensors are properly calibrated and provide accurate data.

Exchanging environmental data and information with other agencies can minimize surveillance costs. Environmental monitoring networks can be created to collect and integrate data from many sources, store relevant data in centralized databases, and disseminate information in useful formats. Potential data sources include surface weather observation systems deployed by the NWS, the Federal Aviation Administration, the U.S. Geological Survey, the Department of Agriculture, the Forest Service, and the Environmental Protection Agency. The need for redundant infrastructure can be eliminated by coordinating with other agencies.

Another major institutional issue is system acceptance. Potential benefits from ESS and RWIS deployments will not be realized if transportation managers do not use them. The organizational culture, decision-making processes, and technical capabilities of users must be carefully considered during design and implementation. All users desire “timely, relevant, accurate” road weather information. However, these criteria may be defined differently depending on the operational application. For example, a maintenance manager may consider a 24-hour precipitation forecast “timely” for treatment strategy planning, while a traffic manager needs real-time snow accumulation data to adjust traffic signal timing parameters. “Relevant” environmental data is presented to the user in a format that is easily interpreted and suitable for decision support. Software programs must be developed to customize raw data (such as soil temperature) into useful information (such as a pavement temperature forecast based upon air and soil temperatures). Managers have various technological options depending on their weather information needs, operational procedures, and mitigation strategies.”

15.4 EXAMPLES

15.4.1 TRANSMIT - TRANSCOM System for Managing Incidents and Traffic (Probe Surveillance)

TRANSCOM’s System for Managing Incidents and Traffic, known as TRANSMIT, was initiated to establish the feasibility of using Automatic Vehicle Identification (AVI) equipment for traffic management and surveillance applications. AVI technology systems are typically installed at toll booths where they classify oncoming vehicles, then identify them and collect the toll by reading data stored on a vehicle-mounted transponder through wireless communication with a

roadside antenna. In the New York City Metropolitan Area, this application of electronic toll collection is called E-ZPassSM.

The current system includes AVI transponder readers installed overhead at approximately 2.4-kilometer (1.5 mile) intervals in both directions of the roadway. The spacing between readers was selected to maximize the probability of incident detection by minimizing the false alarm rate (maximum of 2 percent) and the mean time to detect an incident (maximum of 5 minutes). Twenty-two locations were included in the project with a total of 65 antennas. When a vehicle with the tag passes an antenna, a signal is sent to the roadside equipment and then it is sent by modem over leased telephone lines (along with date and time) to a central site at TRANSCOM headquarters in Jersey City, NJ. The vehicle tag is scrambled to make sure that the vehicle privacy is assured. The data is then processed in the TRANSCOM Operations Information Center (OIC) to derive travel time and to detect incidents. The processed information is sent to similar workstations located at the Tarrytown, NY Office of the NYSTA, and to the New Jersey Highway Authority (NJHA) headquarters in Woodbridge, NJ.

AVI data may be used for producing incident alarms. There is a distinct advantage to the use of toll tags because of their inherent ability to identify and track individual vehicles, a capability that may only be approximated with the use of a loop detector. However, the disadvantage of the use of AVI lies in the fact that the readers, like loop detectors, are essentially point detectors whose effectiveness will be limited by the spacing between successive readers. If detectors are spaced every few yards then it would be possible to track the trajectory of a vehicle and determine, in a very responsive manner, whether the vehicle is stopped. This unrealistically, low spacing would provide a low mean time to detect and a very high probability of detection. Such close spacing is neither realistic nor fiscally responsible. Obviously, the mean time to detect will increase as the spacing of the detectors increases. Recent studies for TRANSCOM have found that readers spaced at 1½-mile intervals on limited access freeways provide the best coverage for obtaining traffic information.

15.4.2 Washington State DOT Road Weather Information for Travelers

The Washington State Department of Transportation (DOT) has collaborated with the University of Washington to provide travelers with comprehensive, integrated road weather information. The DOT maintains one of the most advanced traveler information web sites, which allows users to access current and predicted road weather conditions on an interactive, statewide map.

15.4.2.1 System Components

The DOT owns 50 Environmental Sensor Stations (ESS) that collect air temperature, atmospheric pressure, humidity, wind speed, wind direction, visibility distance, precipitation, pavement temperature and subsurface temperature. Some stations are equipped with Closed Circuit Television (CCTV) for visual monitoring of pavement and traffic flow conditions. The DOT is also a member of the Northwest Weather Consortium, which collects and disseminates real time data from an extensive environmental monitoring network. This network gathers and disseminates data from over 450 ESS owned by nine local, state and federal agencies. A statewide communication network transmits this ESS data to the Seattle Traffic Management Center (TMC) and to a computer at the University's Department of Atmospheric Sciences for data fusion and advanced modeling.

15.4.2.2 System Operations:

A sophisticated computer model developed by the university ingests ESS data to determine prevailing and predicted pavement temperatures and generate high-resolution, numerical weather forecasts for the entire state. Observed environmental data is integrated with other information including National Weather Service (NWS) forecasts, satellite and radar images, video from 350 CCTV cameras, traffic flow data from inductive loop detectors, incident and construction data, ten mountain pass reports, and audio broadcasts from four Highway Advisory Radio (HAR) transmitters. As shown 15-15, route-specific traveler information is disseminated through the DOT's Traffic and Weather web site (www.wsdot.wa.gov/traffic) and via an interactive voice response telephone service (800-695-ROAD). To make travel decisions, the public may access the web site to view state, regional and local maps with environmental observations, weather and pavement condition forecasts, video from freeway CCTV cameras, information on road maintenance operations, and travel restrictions on mountain passes (e.g., reduced speed limits, prohibited vehicle types).

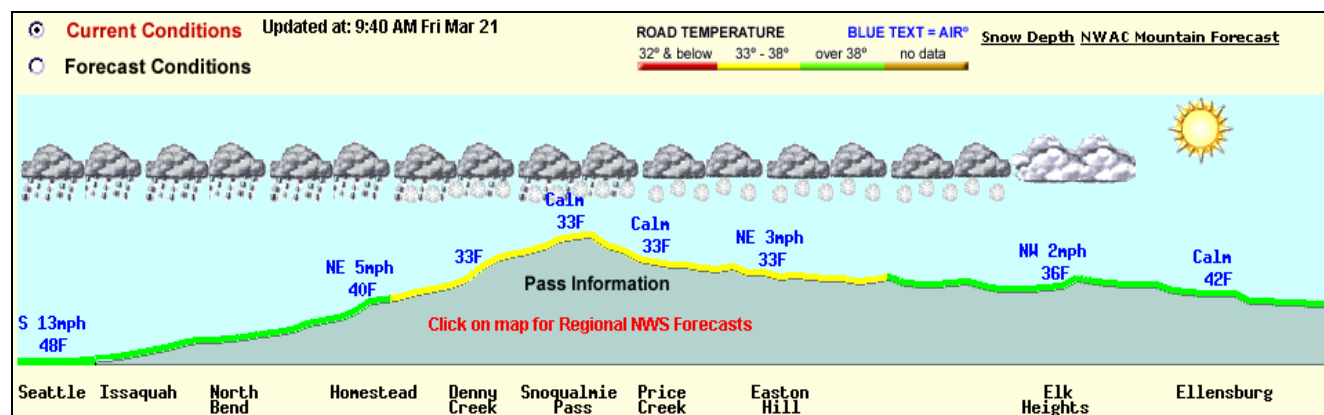


Figure 15-15: Example of Website Showing Current Weather Conditions

15.4.2.3 Transportation Outcome

Road weather data available through the web site and telephone service allows users to avoid hazardous conditions, modify driving behavior, and reduce crash risk. A user survey found that travelers feel safer when they have access to real-time road weather information. The survey also revealed that users frequently access the web site to prepare for prevailing conditions along a selected route (i.e., 90 percent of respondents), for general weather conditions (i.e., 86 percent), to check weather for a specific recreational activity (i.e., 66 percent), and to determine travel routes or travel time. Usage logs from the web site indicate that travelers access condition data more frequently during adverse weather events. On average, there were over 3,700 user sessions per day in February 2001. During a snowstorm on Friday, February 16th (before a three-day weekend) site usage increased to nearly 13,000 user sessions. The interactive telephone service typically receives one million calls each winter (i.e., an average of 8,000 calls per day) with call volumes increasing during inclement conditions or major incidents. Maintenance managers also benefit from access to detailed road weather data. This data

serves as support for operational decisions, such as resource allocation and treatment planning. More effective and efficient resource decisions reduce labor, equipment and material costs. The ability to employ proactive road treatment strategies, such as anti-icing, also improves roadway mobility.

15.4.2.4 Implementation Issues:

The web site project was funded by a grant from U.S. Department of Transportation and a 20 percent match from Washington State DOT. To collect environmental data for the site, the DOT wanted to procure ESS from different vendors and display field data on a single user interface. Project managers developed functional specifications and issued a request for proposals to furnish ESS capable of communicating with an existing server using National Transportation Communications for ITS Protocol (NTCIP) standards. After resolving technical issues related to object definitions, one vendor successfully demonstrated that their sensor stations could communicate with another vendor's server. This simplified management of environmental data and avoided the need for additional hardware, software and communications infrastructure. By using the open communication standard the DOT encouraged competition among vendors that reduced ESS procurement costs by nearly 50 percent. The NTCIP will also facilitate future expansion of the environmental monitoring system.

15.4.3 Tennessee DOT RWIS

In December 1990, a chain-reaction collision involving 99 vehicles prompted the design and implementation of a fog detection and warning system on Interstate 75 in southeastern Tennessee. The system covers 19 miles including a three-mile, fog-prone section above the Hiwassee River and eight-mile sections on each side.

TMC managers with Tennessee DOT access a central computer system that collects data from two ESS, eight fog detectors, and 44 vehicle speed detectors. By continually monitoring fog and speed sensor data, the computer system predicts and detects conditions conducive to fog formation, and alerts managers when established threshold criteria are met. Highway Patrol personnel visually verify onsite conditions. The computer system correlates field sensor data with pre-determined response scenarios, which include advising motorists of prevailing conditions via flashing beacons atop six static signs, two HAR transmitters, and ten DMS; reducing speed limits using ten VSL signs; and restricting access to the affected highway section with ramp gates.

TMC managers select pre-programmed DMS messages, pre-recorded HAR messages, and appropriate speed limits (i.e., 50 mph or 35 mph) based upon response scenarios proposed by the system. Under the worst-case scenario (i.e., visibility less than 240 feet), the Highway Patrol activates eight automatic ramp gates to close the interstate and detour traffic to US Route 11.

(24)

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16. REGIONAL INTEGRATION

16.1 INTRODUCTION

The basic institutional fabric of the surface transportation network is multi-jurisdictional, multi-agency, multi-functional, and multi-modal. This structure can lead to a fragmented delivery system for transportation service. At the same time, the public (i.e., the “customers”) generally does not care which jurisdiction or agency is responsible for the road or mode on which they are currently traveling. As taxpayers (and in some cases fare / toll payers), they want and deserve a safe, reliable, and predictable trip; and the ability to determine the real time operating conditions of the network. To achieve this vision of a “seamless” transportation network, the involved agencies and practitioners must recognize and address the many inter-facility, inter-jurisdictional, and inter-modal dependencies. As noted in the introduction to “Regional Planning for Operations Primer” (Reference 1), an introductory document that discusses a formal collaborative activity called “regional planning for operations”:

“More than ever, the safe, reliable, and secure operation of our Nation’s transportation systems depends on collaboration and coordination across traditional jurisdictional and organizational boundaries. Nowhere is this more apparent than in our metropolitan regions where numerous jurisdictions, agencies, and service providers are responsible for safely and efficiently operating various aspects of the transportation system. Many of these operations activities in a metropolitan region must cross agency and jurisdictional boundaries to be successful. They may include traffic incident management, emergency management, communications networks, traveler information services, response to weather events, and electronic payment services. These regional operations activities depend on collaboration, coordination, and integration to be effective and truly benefit those that use or depend upon the regional transportation system.”

The integration of multiple systems within a region – creating an “Integrated Transportation Management System” – provides for the “real-time sharing of information between ITS based systems and the coordination of management activities between transportation agencies, thereby enhancing system interoperability and enabling an areawide view of the transportation network. These systems and agencies provide for the management and operation of a variety of different transportation facilities and functions, including freeways, arterial streets, transit (bus and rail), toll facilities (e.g., bridges, tunnels), airports and seaports, emergency service providers, commercial vehicle operators, and information service providers”³⁷.

Regional integration allows agencies to exchange information and (with authorization) issue commands to field devices. This enables any agency to monitor conditions on other agencies’ facilities, and to implement coordinated responses to incidents and other changes in operating conditions when needed. Such data exchange and coordinated response can be implemented either manually or automatically. Potential applications of regional integration in support of interagency coordination include:

- All agencies and systems providing real-time information to a shared traveler information clearinghouse, where the information is combined into a regional ATIS database for access by Information Service Providers and by users (e.g., via the Internet).

- Freeway and traffic signal systems exchanging information regarding mainline and ramp volumes and incidents such that the signal system can change timing parameters to accommodate traffic diverting from the freeway, and the freeway can adjust metering rates.
- Two or more traffic signal management systems exchanging information to achieve coordinated operation of traffic signals across jurisdiction boundaries.
- An emergency management system reporting an incident or emergency condition to a freeway management system (and other systems), followed by the sharing of incident / emergency status and management information during the response / evacuation process.
- Freeway and surface street traffic management systems supplying information to an emergency management center so that appropriate routes may be identified for routing emergency vehicles and / or evacuations.
- Freeway management system informing adjacent and nearby transportation management systems (e.g., freeway, signal, airport landside operations) of a warning message just posted on a changeable message sign on the freeway in response to a notification of an incident or other problem. Additionally, similar messages may be displayed on CMS belonging to other near-by agencies.

In essence, the goal of regional integration is to bring the operation and management of the surface transportation network into a unified whole, and to incorporate this singular management of the surface transportation network with the management of the broader transportation network. Such “synergy” between multiple systems and agencies is absolutely necessary to achieve the vision of an efficient, effective, and seamless transportation network – one where the various users perceive it as being under single ownership and management. In fact, the definition of the word “synergy” aptly describes the goal of regional integration. From the Greek word “synergos” (working together), it refers to the interaction of discrete agencies and their systems such that the total effect is greater than the sum of the individual effects.

16.1.1 Purpose of Chapter

As noted in Chapter 2, the surface transportation network can be “integrated” in many ways – physical, technical, operational, institutional, and procedural. This chapter focuses on the aspect of “technical integration”, including network topologies, database considerations, related elements of the National ITS Architecture, standards for message sets and protocols, etc. that enable different management centers (e.g., transportation, emergency services, information providers) to readily (and automatically) exchange, store, and access information from one another – a process known as “center-to-center” communications.

The technical aspects of regional integration must not be viewed in isolation from other considerations. Information sharing is a collaborative effort, geared towards identifying problems, coordinating activities, and planning for future investment needs. Technical integration can therefore not occur without institutional integration (e.g., the various agencies agreeing on the need to share information, their respective roles, the information to be shared, standards). Accordingly, the institutional issues associated with regional integration are also discussed herein. Beyond technical and institutional integration, successful regional operations also depend on procedural integration (e.g., coordinated planning and programming processes

that address the entire surface transportation network as a whole) as discussed in Chapter 2. Moreover, after the information has been exchanged between TMCs, something useful needs to be done with it (e.g., coordinated incident management, regional traveler information, adjusted signal timing and ramp metering rates) – that is, there must be operational integration as discussed in nearly every chapter (as it relates to the chapter subject).

The reader is advised of another FHWA document entitled “Coordinated Freeway and Arterial Operational Plans and Procedures”. This technical reference provides direction, guidance, and recommended practices related to the coordinating and managing traffic on freeways and surface streets for a range of typical re-current and non-recurrent congestion causing scenarios.

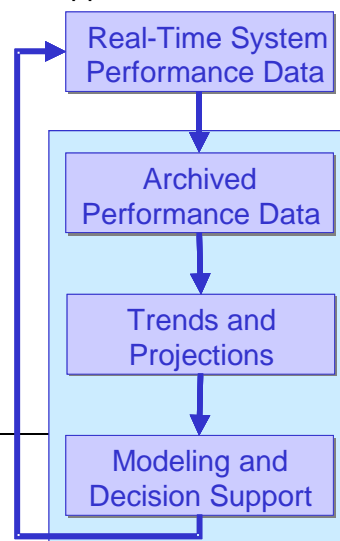
16.1.2 Relation to Other Freeway Management Activities

Regional integration, and the creation of an ITMS, involves a variety of activities that support and complement a freeway management and operations program. Integrated transportation management systems and the associated regional organizations (where they exist) develop policies and plans intended to manage and operate systems and programs in a coordinated fashion. Practically every freeway management strategy discussed in previous chapters is improved – often dramatically – by regional integration. In fact, the real-time information sharing supported by regional integration (and the associated multi-agency coordination) is essentially a prerequisite for the success of several freeway management strategies, including traffic incident management (Chapter 10), planned special event management (Chapter 11), emergency evacuation management (Chapter 12), and information dissemination (Chapter 13). The focal points of regional integration are typically the transportation management centers (Chapter 14) and their respective information as collected by surveillance subsystems (Chapter 15). Moreover, the real-time exchange of this information between centers requires appropriate communication links (Chapter 17).

16.1.2.1 Regional Planning for Operations

Regional planning for operations – a formal collaborative activity discussed in Reference 1 (and summarized in Chapter 2 herein) – and regional integration are closely linked. As stated in the reference (i.e., “Regional Planning for Operations Primer”): “regional planning for operations relies heavily on information sharing among regional operators and other agencies and organizations that affect or interact with transportation facilities (e.g., public safety, goods movement)”. The primer includes the figure below, the shaded areas of which show aspects of information/data sharing (as provided by regional integration) on which regional planning for operations primarily relies. Specific considerations include:

- The strategic thinking associated with planning for operations requires data accumulated over time, that can be mined to discover relationships, trends, and opportunities, and that can then be acted upon. For example, a regional traffic incident management strategy requires collection and analysis of real-time data over time in order to learn where incidents occur, what response is needed, where response assets should be positioned, and how regional agencies and authorities can best collaborate to provide the most effective response possible (1).



- The needed analyses depend on meaningful performance data and a reliable estimate of future requirements based on historical trends and knowledge of future requirements. These analyses enable operators regionwide to evaluate options for achieving agreed-upon performance levels (1).
- The information generated by the analysis is used in outreach and education efforts to bring all stakeholders to a common plan or concept of operations. The regional concept of operations drives decision making (e.g., roles and responsibilities, multilateral operating agreements, standards, and protocols) among jurisdictions and agencies that enables the operators to implement improved practices (1).

16.2 CURRENT PRACTICES, METHODS, STRATEGIES, & TECHNOLOGIES

16.2.1 Overview

The technical integration of two or more systems – thereby creating an Integrated Transportation Management System (ITMS) – involves the implementation of interfaces and communication links between the systems that permit them to exchange information, exchange control status, and / or exchange control commands. This type of communication is referred to as “center-to-center”, and typically involves peer-to-peer communications between any number of systems (computers) in what is called a balanced, many-to-many network. This type of communication is similar to the Internet, in that any center can request information from, or provide information to, any number of other centers.

While reaching the vision of ITMS was difficult in the past, it is now very possible – at least in terms of technical integration – due to the development of various tools including intelligent transportation systems, a national architecture, and the necessary standards to support ITMS. ITS provides the tools to allow operating agencies to share information and resources, and to provide coordinated operations. The National ITS Architecture and associated standards facilitate sharing information and coordinated operations because the meaning of various data elements is known and consistent across agencies.

An ITMS (and the concomitant sharing of real-time information and coordination of operations between multiple transportation agencies) requires a *Regional ITS Architecture*, which is defined in a FHWA Rule 940 (Reference 2) as “a regional framework for ensuring institutional agreement and technical integration for the implementation of ITS projects or groups of projects”. This rule, which became effective in April 2001, requires that the National ITS Architecture be used to develop a local implementation of the National ITS Architecture. The local implementation is referred to as a “regional ITS architecture”. The rule states that “the regional ITS architecture is based on the National ITS Architecture and consists of several parts including the system functional requirements and information exchanges with planned and existing systems and subsystems and identification of applicable standards, and would be tailored to address the local situation and ITS investment needs.” Rule 940 identifies what the regional architecture shall include as a minimum – specifically:

- A description of the region;
- Identification of participating agencies and other stakeholders;

- An operational concept that identifies the roles and responsibilities of participating agencies and stakeholders in the operation and implementation of the systems included in the regional ITS architecture;
- Any agreements (existing or new) required for operations, including at a minimum those affecting ITS project interoperability, utilization of ITS related standards, and the operation of the projects identified in the regional ITS architecture;
- System functional requirements;
- Interface requirements and information exchanges with planned and existing systems and subsystems (for example, subsystems and architecture flows as defined in the National ITS Architecture);
- Identification of ITS standards supporting regional and national interoperability; and
- The sequence of projects required for implementation.

16.2.1.1 Definitions

Several terms are regularly used when describing regional integration and regional architectures, including:

- **Architecture** – In the context of ITS, an “architecture” describes what a system does and, from a high-level perspective, how it does it. It provides the overall framework for system design and deployment; identifying the functions and operations to be performed, the basic subsystems and elements that make up the system and what functions each performs, and the flows of information between these components. In essence, an ITS architecture defines how system elements interact and work together to achieve system goals. From a regional perspective, a regional ITS architecture is concerned with what types of information are exchanged among transportation agencies and their respective transportation management systems and centers, how the center-to-center connections are accomplished, and the additional functionality this integrated information provides to users.
- **Data Dictionary / Message Sets** – In order to share data across subsystems and between systems, a standardized data dictionary is necessary. A data dictionary provides a rigorous, unambiguous definition of the form of data that will be stored in a computer or other processor. It includes items such as: a unique descriptive name, a domain-specific description, range of values, permissible values, minimum and maximum size, relationship to other data elements in the data dictionary, data type of element (integer, real, character), format, etc. Data dictionary elements are bundled into *messages* that can be transferred between computers. These messages comprise the data flows within the architecture. Without a standardized data dictionary, a uniform interpretation of messages and their meanings is not possible. In a simple analogy, message sets are the sentences, whereas the data elements in the dictionary are the individual words.
- **Protocols** – A protocol may be defined as a set of rules or conventions formulated to govern the exchange of information (i.e., data, messages) between two computers or two processes within a computer. Basic elements of a protocol include data format, message sequence, and maintenance of data integrity. Continuing the analogy from above, human speech is a form of protocol typically involving half-duplex communications (i.e., one person speaks while the other listens, and vice versa), an agreed-upon format (i.e., an alphabet, vocabulary, and the associated rules of grammar), an interspeaker delay (i.e., typically a minimum amount of time elapses after one person stops speaking and another begins), and error handling (i.e., “excuse me, what did you say”).

- **Interfaces** – An interface is the point at which systems and centers within the architecture interact. An interface device is typically a combination of hardware and/or software—sometimes referred to “middleware” — that receives information in one protocol or format, and converts it to another protocol or format as required. If a protocol is considered a language, then the interface may be thought of as a translator—receiving information from one system, and transforming this information into a format (or protocol) which can be understood by the receiving system, while retaining the original meaning or content of the information. In essence, the interface device permits disparate components in a system or network of systems to exchange meaningful and useful information.

16.2.2 Benefits

Regional coordination from an operational and organizational perspective is not new. A simple example of the benefit of organizational integration occurred recently in San Antonio, Texas. After a training session on incident management, the operators of the San Antonio Freeway Management System observed about a 40 percent reduction in the clearance time of a major incident due to improved organization.

On the other hand, technical integration of TMCs to enhance multi-agency coordination is relatively new, and little quantifiable data exists regarding these specific benefits. FHWA Rule 940 (Reference 2) states: “Information technology in general is most effective and cost beneficial when systems are integrated and interoperable. The greatest benefits in terms of safety, efficiency, and costs are realized when electronic systems are systematically integrated to form a whole in which information is shared with all and systems are interoperable.”

16.2.3 Key Considerations During Freeway Management Program Development

Freeway management and regional integration have a symbiotic relationship. Regional integration (and the concomitant regional architecture) must be a key consideration in the process to develop a freeway management and operations program. Likewise, freeway management will play a critical role in the development and implementation of a regional architecture. In essence, freeway management solutions should be incorporated into the regional architecture; and regional integration should be incorporated into the freeway management and operations program.

The “Regional ITS Architecture Guidance Document” (Reference 3) provides a systems engineering process for developing a regional ITS architecture in support of regional integration. This process, summarized in Table 16-1, parallels many of the activities identified in Chapter 3 (i.e., the “funnel diagram” in Figure 3-1) for a successful freeway management and operations program. Some of the similarities are summarized below:

Table 16-1: Steps for Developing a Regional ITS Architecture

(Reference 3)

Step #1: Get Started

- Identify Need
- Define Region
- Identify Stakeholders
- Identify Champions

Step #2: Gather Data

- Inventory Systems
- Determine Needs and Services
- Develop Operational Concept
- Define Functional Requirements

Step #3: Define Interfaces

- Identify Interconnects
- Define Information Flows

Step #4: Implementation

- Define Project Sequencing
- Develop List of Agency Agreements
- Identify ITS Standards

Step #5: Use the Architecture**Step #6: Maintain the Architecture**

- **Get Started:** Per Reference 3: “The regional ITS architecture effort begins with a focus on the institutions and people involved. Based on the scope of the region, the relevant stakeholders and one or more champions are identified”. A similar start (i.e., institutional environment, stakeholders) is also required for a freeway management program.
- **Identify Need:** Reference 3 describes this step as follows: “The development and maintenance of a regional ITS architecture is established as a shared objective by the transportation planning and operating agencies in the region. The decision to proceed then should actually be based on a clear understanding and commitment by planning agencies, operating agencies, and key decision makers in the region that a regional ITS architecture is needed and will be put to good use. This implies that a decision to proceed should be accompanied by significant outreach and education on the benefits of system integration and the important role that a regional ITS architecture can play in developing these integrated systems.” By replacing the term “regional ITS architecture” with “freeway management program”, this description could be used in Chapter 3 to describe the “Needs and Services” activities of the funnel diagram.
- **Identify Stakeholders:** The success of the regional ITS architecture depends on participation by a diverse set of stakeholders. The stakeholders in the regional surface transportation system are identified and the process of encouraging their participation in the regional ITS architecture development process is initiated. Without management support, it will be difficult or impossible for those with a working knowledge of ITS in the region to

participate effectively in the regional ITS architecture effort. (3). The same is true for freeway management and operations. As noted in Chapter 3, the stakeholders are sources of the vision, goals and objectives, and requirements, and they are also ones who validate or verify the requirements. Stakeholders should include representatives from each and every “tier” (as discussed in chapter 2), including managers from all the centers that will be connected together in some manner within the regional ITS architecture; those individuals that will be responsible for managing and operating the resulting ITMS, including the development and approval of regional response plans; the managers within those agencies that will be impacted by the regional architecture in some fashion, and who have a strong material interest in success or failure of regional coordination and integration; individuals who are involved in the statewide / regional planning processes, thereby establishing closer links between the regional architecture and the metropolitan transportation planning and decision-making processes governed by Federal law; and the national tier (e.g., FHWA division) to help ensure compliance with Rule 940.

- **Develop Operational Concept:** Just as a freeway management program (and the freeway management system TMC) requires a Concept of Operations, so does the regional ITMS. Reference 3 describes this step as follows: “Each stakeholder’s current and future roles and responsibilities in the implementation and operation of the regional systems are defined in more detail. The operational concept documents these roles and responsibilities for selected transportation services in specific operational scenarios. It provides an “executive summary” view of the way the region’s systems will work together to provide ITS services. The objective is to identify current and future organizational roles in the regional transportation system. Some operational concepts will focus on a definition of each stakeholder’s general role in providing the transportation services in the region. More detailed operational concepts may include a more detailed discussion of how stakeholders will interact to provide specific transportation services.” In essence, the regional Concept of Operations lays out the ITMS concept, explains how things are expected to work once it’s in operation, and identifies the responsibilities of the various stakeholders for making this happen. Moreover, the concept of ITMS operations should include the performance expectations for the regional network. (Note – Additional information on developing a Concept of Operations document is provided in Chapter 14).
- **Define Functional Requirements:** Reference 3 defines this activity as follows: “The tasks or activities (the “functions”) that are performed by each system in the region are defined, documenting the share of the work that each system in the region will do to provide the ITS services. The functional requirements are high-level descriptions of what the systems will do, not detailed design requirements.” This is essentially identical to the activity described in Chapter 3 as “Decisions Regarding Improvements, Systems, etc.”

Rule 940 also states that all ITS projects (funded with highway trust funds) shall be based on a “systems engineering analysis”, and that this analysis shall include identification of participating agencies, requirements definition, analysis of alternative system configurations and technology options, procurement options, identification of applicable standards and testing procedures, and procedures and resources necessary for operations and management of the system. Additional information on the systems engineering process is provided in Chapter 14.

The last step from Reference 3 (i.e., Step #6: Maintain the Architecture) states: “The regional ITS architecture is not a static set of outputs. It must change as plans change, ITS projects are

implemented, and the ITS needs and services evolve in the region. A plan should be put in place during the original development of the regional ITS architecture to keep it up to date. This process is really one of Configuration Control and Change Management. Some of the key aspects of the process are:

- Determine who will be responsible for architecture maintenance
- Define the architecture baseline
- Define the change management process
- Document the process in a Maintenance Plan.”

Additional information on the configuration management (CM) process – the procedures and techniques that allow the practitioner to consider and evaluate the impacts of proposed changes, and then to track and document those changes that are made – is provided in Chapter 14. It is also noted that the CM issue in a multi-jurisdictional environment is exponentially more complex (as compared to a single system) with issues related to leadership, roles and responsibilities, level of authority of the CM team, funding requirements and funding sources, etc.

16.2.3.1 Performance Monitoring and Evaluation

The process described in Reference 3 (and summarized in previous Table 16-1) for developing a regional ITS architecture does not include any consideration of performance measures and evaluation³⁸. It probably should. As noted in Reference 1, regional integration, and the associated information sharing and storage, is a key attribute for successful performance monitoring and evaluation. Additionally, given that a major goal of regional integration is for the entire surface transportation network to be operated such that users perceive it as being under single ownership and management, performance measures should be developed to reflect this, permitting the enhanced operations made possible by regional integration to be properly evaluated.

Qualitative assessment criteria should also be considered. FHWA’s “Self – Assessment Process for Roadway Operations and System Management” (Reference 4) is a tool by which agencies with traffic operations responsibility can assess the effectiveness of their existing roadway operations processes, both in terms of its internal processes and the degree to which it serves its customers. The Self - Assessment tool includes an “Integration” Category for evaluating how well the agency’s operations are coordinated and integrated with those of other modes and jurisdictions, and with “sister” organizations within the agency. Specific areas of the self-assessment are summarized in Table 16-2.

Table 16-2: Self – Assessment Criteria for Regional Integration (Reference 4)

- **Coordination** – The quality of your agency’s coordination with other agencies and organizations, including:
 - Does your agency meet regularly with other agencies and organizations?
 - During these meetings, do you discuss operational issues of common interest?
 - Do you discuss sharing of personnel and resource sharing (communications facilities, equipment required for emergencies, etc.)?

- Have you executed memoranda of understanding defining responsibilities during periods for which operational coordination is required?
- Have you practiced the coordinated operations under controlled conditions?
- Do you review, discuss, and act upon the results of coordinated operations following major events or activities?

- **Integration of Operations** – The quality of your agency’s concept of operations, including:
 - Has your agency participated in the development of a regional concept of operations that defines the operational responsibilities of all agencies and organizations in the region under various types of incident and non-incident conditions?
 - Does this concept of operations describe the interactions between the agencies and organizations?
 - Is the concept of operations reviewed and updated periodically?
 - Have memoranda of understanding been executed by the participants that ensures management acceptance and support of the concept?
 - Is the concept of operations consistent with the regional ITS architecture?

- **Integration and Coordination of Routine Operations** – The degree to which the agency’s routine operations activities are coordinated with other agencies, including:
 - Are equipment failures (e.g. signal failures, etc.) reported by personnel of other agencies?
 - Are signal system operations coordinated across jurisdictional boundaries?
 - Is guide signing consistently installed with consistent messages across jurisdictional boundaries?
 - Are speed limits coordinated across jurisdictional boundaries?

- **Data and Information Integration** – The degree to which your agency recognizes the importance of shared information, and takes steps to facilitate this sharing.
 - Does your agency share both periodic and real-time information with other agencies (including traffic data, incident information, planning information, deployment of field unites, etc.)?
 - Does your agency transfer information between its computer traffic management, dispatch and other systems, with those of other agencies?
 - Are there direct telephone lines between your agency and relevant dispatch centers and traffic management centers of other agencies?
 - Does your agency participate in an integrated Internet display of regional traffic information?
 - Are methods for sharing of critical information clearly defined and well understood by operations personnel?

- **Integration of System Planning and Designs** – The degree of integration that occurs during the planning, design, and implementation of new traffic management and/or dispatch systems, such as the inclusion of other agencies and organizations in the planning process; and the plans reflecting the requirements and services needed by other agencies.
 - Do your plans include information sharing with other agencies?
 - Do your plans make use of relevant information technology and standards?
 - Do your plans follow the guidance of the National ITS Architecture or a regional ITS architecture?
 - Do your plans include integration with legacy systems existing in the region, whenever applicable?

16.2.4 Relationship to National ITS Architecture

Integrated systems operation is a core element of the national Intelligent Transportation Systems (ITS) architecture. Regional integration may be shown diagrammatically as the links / interconnects between the 10 “center” subsystems, defined by the National ITS Architecture (Reference 5, and shown on the high - level diagram in previous Figure 3-4) as follows:

- **Commercial Vehicle Administration** - Sells credentials and administers taxes, keeps records of safety and credential check data, and participates in information exchange with other commercial vehicle administration subsystems and CVO Information Requesters.
- **Fleet and Freight Management** - Monitors and coordinates vehicle fleets including coordination with intermodal freight depots or shippers.
- **Toll Administration** - Provides general payment administration capabilities to support electronic assessment of tolls and other transportation usage fees.
- **Transit Management** - Collects operational data from transit vehicles and performs strategic and tactical planning for drivers and vehicles.
- **Emergency Management** - Coordinates response to incidents, including those involving hazardous materials (HAZMAT).
- **Emissions Management** - Collects and processes pollution data and provides demand management input to Traffic Management.
- **Archived Data Management** - Collects, archives, manages, and distributes data generated from ITS sources for use in transportation administration, policy evaluation, safety, planning, performance monitoring, program assessment, operations, and research applications
- **Traffic Management** - Processes traffic data and provides basic traffic and incident management services through the Roadside and other subsystems.
- **Information Service Provider** - This subsystem may be deployed alone (to generally serve drivers and/or travelers) or be combined with Transit Management (to specifically benefit transit travelers), Traffic Management (to specifically benefit drivers and their passengers), Emergency Management (for emergency vehicle routing), Parking Management (for brokering parking reservations), and/or Commercial Vehicle Administration (for commercial vehicle routing) deployments. ISPs can collect and process transportation data from the aforementioned centers, and broadcast general information products (e.g., link times), or deliver personalized information products (e.g., personalized or optimized routing) in response to individual information requests.
- **Maintenance and Construction Management** – This subsystem monitors and manages roadway infrastructure construction and maintenance activities, including managing, dispatching, and routing fleets of maintenance, construction, or special service vehicles (e.g., snow and ice control equipment). The subsystem participates in incident response by deploying maintenance and construction resources to an incident scene, in coordination with other center subsystems. The subsystem manages the repair and maintenance of both non-ITS and ITS equipment.

It is emphasized that these Center Subsystems are functionally, not physically defined. They should not be viewed as “brick and mortar” facilities. Rather, they represent a cohesive set of functional definitions with required interfaces to other Subsystems. The implementation of a physical TMC will often collocate the functions and capabilities from several of the Center Subsystems.

Market Packages relevant to regional integration include “Multi-modal Coordination” (i.e., establishes two way communications between multiple transit and traffic agencies to improve service coordination) and “Regional Traffic Control” (i.e., sharing of traffic information and control among traffic management centers to support a regional control strategy). Given the diversity of systems (and their associated TMCs) in use, standards are being developed to facilitate communications between these centers. These “C2C” standards are discussed later.

16.2.5 Technologies and Strategies

The appropriate technologies and strategies will depend on the degree of integration and how the exchange information will be utilized, as determined by the stakeholders. Various levels of interaction are possible, for example:

- Communicate via phone, fax
- Share system data / video on “view only basis”
- Share system data / video control during special events
- Share system data / video control day-to-day
- Share system control during emergencies, or during periods when a TMC is not staffed
- Centralize some / all system functions

As one moves down the above list, the level of human involvement in the actual exchange and processing of information becomes less and less. In fact, the first bullet – “communicate via phone / fax” – may be deemed a “manual architecture”, in that it relies completely on human involvement throughout the information exchange process (e.g., an operator at one center calling up or faxing an individual at another center. An “automated architecture” refers to processes where human involvement is minimized, if not completely eliminated, from the center-to-center exchange and processing of information; although the pre-planning, management, and real time use of this shared information undoubtedly requires a significant level of human interaction and decision-making.

The rest of this section focuses on the more automated means of regional integration, where information is transmitted computer – to – computer and included (integrated) into one another’s databases, processing, and displays; noting that a wide variety of permutations exist between manual and fully automated. For example, it may not always be possible or cost-effective to achieve full integration of the exchanged data, in which case, simpler alternatives for information exchange, minimizing the interface requirements (i.e., “semi-automated”), should be considered; such as:

- Existing computer outputs and displays, such as a remote workstation located at other centers (or a display window on the other centers’ workstations that can act as a remote workstation)
- Email interface, in which an email window is available at each operator’s workstations for the exchange of text messages
- Browser – based interface, for displaying HTML (web-like) pages of information. These pages can be developed for the display of dynamic data such as congestion maps, incident information, and other displays

Regardless of the degree of automation and advanced technology used in a regional architecture, the importance of maintaining a reliable “manual architecture” cannot be overemphasized. Regional integration and multi-agency coordination can be significantly enhanced with technology and automation; but as is discussed at the end of chapter 2, it is good human relations that enable such “technical” processes in the first place, and then keep them working effectively to achieve the overall vision of an ITMS encompassing the entire surface transportation network. If the managers representing the various agencies and TMCs

within a region have good communications, empathy, honesty, and trust between one another, then regional coordination is almost assured, regardless of whether the process involves phone calls, automated center-to-center linkages, or some combination thereof.

Regional Integration is more than drawing a straight line between two centers on an architecture diagram. Many technical roadblocks may exist and many technical issues need to be resolved, including legacy systems, network topologies and communications, data and message compatibilities, protocols, and data fusion.

16.2.5.1 Legacy Systems

Regional integration will often involve a mix of new systems and legacy systems. A legacy system is, by definition, currently operational; and may represent the latest technology embodying the principles of open architecture, or may be a closed system with proprietary interfaces, databases, and protocols, as well as limited documentation. In the latter case (i.e., proprietary), full center-to-center integration may not be possible, in which case a simpler system interface (e.g., separate workstation, email / browser interface as noted above) may be the most appropriate approach. Even if the legacy system is not completely ‘closed’ (as compared to an ‘open’ systems architecture), it still may be necessary to add a data exchange protocol to the legacy system to facilitate information exchange.

16.2.5.2 Topology

A topology is defined as the structure of a system defining the paths and switches that provides the communications interconnection among the nodes (computers and TMCs) of a network, and defines the functional responsibilities of each node. It is an axiom of network design that the relationship between computers should mimic the organization it serves. Several topologies exist, but given this axiom, the most likely to be found in a regional center-to-center network are hierarchical and mesh, as summarized below:

- In a **hierarchical** organization, the “boss” should have access to the top computer in the network. This computer will not “know” all the details of the organization, but should be capable of accumulating summary / management level information. Such a topology might be used where a regional organization exists that oversees and/or coordinates “regional” issues (e.g., a major incident or special event where the impacts cross multiple jurisdiction boundaries) on an on-going basis; or for a Statewide system where individual DOT districts maintain most of the day-to-day operational autonomy, but headquarters staff may assume management direction and control during major events.
- A **mesh** organization is one in which all participants are peers. All computers in the mesh can essentially access the same types of information. This type of communications is similar to the Internet, in that any center can request information from, or provide information to, any number of centers. This is the likely approach for a multi-agency architecture where no regional operating entity exists – that is, all centers must interact on an equitable basis. However, even in a peer – to –peer topology, there may be restrictions on the types of information that can be accessed by certain participants (e.g., control of individual devices).

The decision as to which topology to use requires an engineering analysis – considering cost, maturity, expandability, reliability, availability, maintainability, – combined with the objectives and requirements of the region’s entities (e.g., the types of information to be exchanged, and

how often), and the organizational compatibility. In some cases, a mix of topologies may be appropriate – for example, data flows conforming to the mesh organization, whereas control may be implemented by a hierarchical organization.

Center-to-center communications requires network connections between the involved computers. This is typically a local area network, a wide area network, or a dial-up connection. Local area networks typically use agency-owned twisted pair cable or fiber optic cable. Wide area networks typically use commercial telecommunications links such as frame-relay; partial T1 leased lines, packet radio, or leased “virtual private networks”. Dial-up connections typically use ISDN, V.90 or similar modems over plain-old telephone lines. Any type of communication link can be used, as long as it enables use of the Internet transport and routing protocols (e.g., TCP/IP) and has sufficient bandwidth for the planned communications load (frequency and size of messages to be transmitted). Additional information on communications alternatives is provided in Chapter 17.

16.2.5.3 Data Compatibilities

A key issue in regional integration involves data compatibilities – that is, are all the data elements defined in exactly the same way. It is essential that there be perfect understanding between the interfaced systems as to the meaning of the data (both status and control information) being exchanged. For example, when transmitting real time information about travel conditions on the links comprising the surface transportation network, each link must be precisely defined, including the link’s location, direction, start / endpoints, numbering system, type of facility; and what the associated information means (e.g., average speed, travel time, delays) and the units of measurement (e.g., seconds or minutes; feet, miles, or kilometers).

Solutions for achieving compatibility between the databases of different systems include:

- Identical database formats in all systems within the regional architecture (an unlikely solution for multiple agencies)
- A centralized gateway processor that receives all data and translates the information before transmitting to receiving systems. This requires that some form of traffic information network data base structure be defined and maintained in one of the transportation management systems (typically a freeway management system) within the region, or in a separate system, and to which all systems contribute and utilize data. Preferably, this data base structure would utilize the standard data definitions from ITS data dictionaries.
- Common message sets and formats communicated using protocol converter / translator (middleware). With respect to this approach, NTCIP³⁹ standards are being developed for peer – to – peer communications between systems. In addition to the NTCIP C2C standards, ITE and AASHTO have been jointly sponsoring the development of the Traffic Management Data Dictionary (TMDD) and the Message Sets for External Traffic Management Center Communications (MS/ETMCC). A summary of these standards is provided below.

16.2.5.4 NTCIP Center – to – Center Protocols

A key feature of the NTCIP protocols is their support for continuous, automated transmissions of information. Any center can request information from, or provide information to, any number

of systems. Each system can be configured to either accept or reject any request. The “data” sent can be informational or can constitute a “command” to take some action. The user can also establish standing subscriptions for data, if it wants the same data sent repeatedly.

The data exchanges are based on the Internet Protocol (IP), thereby allowing for the use of a variety of off-the-shelf equipment as well as the use of virtually any technology without additional work for the ITS Standards effort. However, the selection of IP does not provide a complete answer for defining how data are exchanged. NTCIP originally provided two alternative protocol choices for center-to-center communications – DATEX and CORBA. These two different protocols were found necessary to meet the variety of requirements for inter-system data exchanges. More recently, there has been increased interest in using XML and related technologies for center- to-center links due to its simplicity and wide accessibility of tools to provide these services (7). While an in-depth discussion of these protocols is beyond the scope of this Handbook, they are briefly described below⁴⁰:

- **Data Exchange Between Systems (DATEX)** – DATEX uses pre-defined messages transmitted by the base Internet protocols (TCP/IP and UDP/IP) in a peer-to-peer network. The base standard at the application level is an ISO standard called DATEX-ASN. DATEX-ASN is based on a traditional, structured messaging model and is an enhancement of the DATEX model currently in use in Europe for all international and some intranational exchanges of traffic information. DATEX was designed to provide simple, cost-effective solutions for basic needs. It is especially well suited for systems requiring real-time, fast data transfer (e.g. traffic signal status data); systems with limited communications bandwidth but high data transfer load; and non-object oriented systems
- **Common Object Request Broker Architecture (CORBA)** – CORBA is a general purpose center-to-center communications protocol based on the information technology (IT) industry standard of the same name. CORBA provides several features to support computer networks connecting object-oriented systems – and assuming sufficient processing power and communications bandwidth are provided – it could be used for all applications between such systems. Object oriented software can take full advantage of CORBA and implement it easily; this is much more difficult to achieve with traditional procedural software.
- **eXtensible Markup Language (XML)** – Its fundamental simplicity, the wide availability of XML tools and a large market of XML knowledgeable personnel, have generated significant interest in XML. XML is a flexible way to create common information formats and share both the format and the data on the World Wide Web, intranets, and elsewhere. It is especially well suited for systems requiring limited, simple data exchanges over communications links with sufficient bandwidth and processors with sufficient processing time available. At the time of finalizing this Handbook, an NTCIP Information Report was published providing an overview of the issues involved in using XML-based technologies for ITS, including two C2C recommendations – develop a more complete SOAP-based XML standard application protocol; and develop a simple file-based approach.

It is feasible to use all of these protocols in the same network, with some centers acting as a bridge, or translator, between the different protocols. The key is in determining where to deploy each protocol.

All three of these approaches – DATEX, CORBA, and XML – are recognized by the ITS standards community. However, at the time of writing this Handbook, none of the three approaches provide complete solutions to C2C communications. For DATEX and CORBA, the base protocols have been defined – that is, how to exchange data; but the standards defining the data to be exchanged have not reached a state of maturity. The XML approach is even less mature in that the industry has not agreed on the exact rules on how to exchange the XML documents. Any near-term deployment should consider the impacts that this may have on the long-term maintainability of a system. The best solution is still likely to deploy one of the recognized standards, but the agency should realize that a future project would likely be required to upgrade the software to address any included features affected by revisions in order to achieve the final mature standard (6).

16.2.5.5 Data Dictionaries and Message Sets

In addition to defining the mechanisms by which data are exchanged, the centers within a regional ITS architecture must also agree on what the information means. ITE/AASHTO have jointly approved the following two related standards⁴¹ developed by the TMDD Steering Committee:

- **Functional Level Traffic Management Data Dictionary (TMDD) Standard**, a set of agreed upon definitions and ways of formatting data for use by ITS systems that have the function of traffic management.
- **Message Sets for External Traffic Management Center Communications (MS/ETMCC)**, providing consistent ways for electronic communication messages to be exchanged among Traffic Management Centers, Traffic Management Systems, and other users and/or suppliers of traffic-related information.

The Functional Level Traffic Management Data Dictionary (TMDD) Standard contains common data definitions, called *data elements*, which are used to transfer data between centers (e.g., roadway speed information being sent to an Information Service Provider). The Standard provides specific definition of selected data element currently in use and that are frequently needed to construct messages used by the ATMS applications (8). Four sections have been developed into the following partitions:

- Traffic Links and Nodes – the traffic network,
- Events, Incidents and Notification Alarms – events perturbing the network,
- Traffic Network, Traffic Signal Control, Traffic Detectors, Vehicle Probes, Ramp Metering, and Traffic Modeling – the traffic control devices, and
- Closed Circuit Television, Dynamic Message Sign, Environmental Sensor Station, Gate, Highway Advisory Radio, and Parking – advanced information gathering or display devices

The Message Sets for External Traffic Management Center Communications (MS/ETMCC) standard contains common groupings of data organized into message sets for use in exchanging information between centers. It is a parallel standard to the TMDD Standard and focuses on the “traffic management” application messages used traditionally by transportation engineers. These messages are grouped based on the application needs and are organized to provide uniform information and interpretation throughout ITS deployment, both within the native system environment and with the external transportation management centers communications. The MS/ETMCC standard contains six message groups: Roadway-Network, Network-State,

Network-Events, Traffic-Requests, Traffic-Device-Status, and Traffic-Control. These message sets provide for a near real-time data exchange between traffic management centers/ subsystems and other types of transportation centers/ subsystems (i.e., Information Service Providers (ISPs), Transit Management, Emergency Management, Toll Administration, and Emissions Management.) (8)

As just one example of a message set, consider “Current Event Information”. As discussed in Reference 9: “Centers need to share event information about current events including incidents, obstructions, traffic conditions, weather conditions, evacuations and natural disasters. Agency responses to these events must also be exchanged with authorized users. Managing event information is one of the most challenging problems in ITS due to the fact that events can have inter-relationships with other events including previous events, weather events or roadway conditions, traffic regulation such as closures or restrictions, congestion, and planned events managed by the same or different agency. Operators and/or automated algorithms at external centers (especially emergency management, transit management, and other traffic management centers) may need to access any or all of this information from the TMC in order to properly manage their resources and/or assist them in coordinating potential joint responses. Table 16 – 3 identifies the message sets for this particular service, indicating the sequence of events that must occur.

Together the standards enable the effective exchange of data and information that are becoming increasingly necessary for system operations and management as recurring congestions levels and the pervasiveness of the effects of major incidents spread over larger areas. The TMDD Standards by themselves are necessary but not sufficient. The MS/ETMCC Standards are needed for the communication to occur in an interoperable fashion. Just using MS/ETMCC Standard may result in some communication but the content may not be understood at all without the TMDD Standard.

Table 16-3: MESSAGE SETS FOR CURRENT EVENT INFORMATION

(Reference 9)

Message Sequence Number: 1

Message Sequence Name: requestEventCurrentInfo()

Message Sequence Documentation: requestEventCurrentInfo

1. *idRequest*

2. *informationEC: (EC user, center name)*

Message Sequence Number: 2

Message Sequence Name: infoEventCurrent()

Message Sequence Documentation: infoEventCurrent

1. *idEvent: unique identifier for the event*

2. *agency name or identifier*

3. *typeClassEvent: event class (always current)*

4. *statusEvent: event status (e.g. new, update, clear/close)*

5. *typeEvent*: type of event
6. *durationEvent*, expected period or expected end date and time of the event
7. *nameLandmark*: jurisdiction, facility, or landmark name
8. *timeStamp*
9. *descriptionEvent*: (current event description)
10. *codeFIPS*: State FIPs code or State and County FIPs code
11. *numberUpdate*: update number

The following optional information shall also be sent if it exists for the event:

12. *additional Location information including:*
 - primary point or landmark name
 - secondary point or landmark name
 - jurisdictions where primary and secondary point or landmark is located
 - linear references of points or landmarks
 - geographic coordinates of points or landmarks (longitude, latitude)
 - direction
13. *article* (e.g. *at*, *approaching*, *near*)
14. *alternate route*
15. *weather condition*
16. *roadway condition*
17. *affected lane information*
18. *agency contact information*
19. *reference to related events*

The following optional action log information shall also be sent if action log elements are distributed:

20. *event identifier* (required, if action log element is sent)
21. *action log element identifier* (required, if action log element is sent)
22. *time stamp* (date and time required, if action log element is sent)
23. *timeline type* (operator text, system update) (required, if action log element is sent)
24. *description of change* (required, if action log element is sent)

16.2.5.6 Data Fusion

A number of transportation management applications – such as real time traveler information (Chapter 13) and data warehousing for performance monitoring and evaluation (Chapter 4) – require that the information from multiple centers be combined. This process of combining information from a variety of systems, and then processing the data to yield better estimates for describing the state of the system, is often referred to as “data fusion”. Reference 10 (“Data Fusion For Delivering Advanced Traveler Information System (ATIS) Services”) discusses various aspects of data fusion, particularly with respect to providing users with integrated traveler information before and during travel. As stated in that document’s introduction, “ATIS systems must work with a broad set of source data and information, combine and qualify the information to yield better traveler information, and disseminate the information when needed by travelers. One component of this complex process is data fusion.” Those same basic concepts also apply to regional integration and freeway management and operations.

Data fusion is used primarily at public agencies to perform spatial or temporal alignment of input data. Major data fusion functions include:

- Raw Data Collection – Transmitting and receiving error-free⁴² data from field sensors or other locations
- Data Identification – Matching the sensed data with the source
- Data Alignment – Configuring identified sensor data to a common spatial and temporal reference/origin, as well as transforming data into compatible representations and/or languages (e.g., XML)
- Data Combination – Performing various association analyses (e.g., statistical correlations, pattern recognition, etc.) to improve detection, classification, and tracking of entities of interest (e.g., cars, surface temperature readings, etc.)
- State Estimation – Predicting the kinematic (time and/or spatial) performance of an entity of interest
- Performance Assessment – Applying techniques to assess fused data quality and fusion processes (10).

Data fusion architecture involves four fundamental components and their interrelationships: the data sources, the data fusion algorithms and database techniques, the communication networks, and the Human-Computer-Interface (10).

16.2.6 Design and Related Considerations

References 3 and 6 discuss several items that need to be considered when designing a regional ITS architecture and the center – to – center linkages, as summarized below.

16.2.6.1 Systems and Centers

It is emphasized that center-to-center communications take place between computer systems, and those computers or systems may be within the same physical “center” or in separate TMCs. The regional architecture issues and design questions really apply to each system, including multiple systems within one center where relevant.

In designing the regional ITS architecture, it is necessary is to identify the number of systems and where they are located, and then to identify the connections between these systems, thereby creating a “framework for integration that will support the exchange of information between ITS systems” (3). If only two disparate systems are to be integrated, there may be an existing interface on one of the two systems that meets all the requirements for center-to-center communications, or could do so with minimal modification; and if so, the best solution might be to replicate such an existing interface on the other system to achieve information exchange without the need for implementing a standard interface in both systems. However, if there are more than two disparate systems involved in the regional architecture – either initially or likely in the future – then modifying all the systems to implement a standard interface is likely to be the most cost-effective solution, especially in the long term.

16.2.6.2 Architecture Functionality and Information Requirements

For a regional architecture, the requirements need to identify the information that will be exchanged. The following activities are specifically identified in the “Regional ITS Architecture Guidance Document” (Reference 3) as “Step 3 – Define Interconnects”:

- **Identify Interconnects:** This is one of the defining moments in the regional ITS architecture development process. The operational concept has identified the integration opportunities in the region in a broad sense. In this step, the connections between ITS systems are

identified, creating a “framework for integration” that will support the exchange of information between ITS systems.

- **Define Information Flows:** Now that the stakeholders have reached consensus on the interconnectivity of the ITS Systems in the inventory, they must define the information that must be exchanged, given the services to be supported. Each information flow is fully described by a source element (where the information originates), a destination element (where the information is sent) and a descriptive name for the information itself. It is often helpful to review the operational concept and services established earlier, and envision the possible scenarios in which information is exchanged. This exercise often brings to light any gaps in understanding the operational concept since it reconciles the information sent by the source ITS System with the information expected by the destination ITS System.

Another important consideration is the frequency of change in status or other data at each center, since changes in operating conditions are what other centers will typically be interested in monitoring – for example, a center that manages only incidents and related information is not likely to generate as much message traffic on the network as one that manages hundreds of traffic signals, each of which changes status every few seconds. Moreover, it is important to define the manner in which the information will be used (i.e., operational integration). Information that will not be used should not be exchanged.

16.2.6.3 Standards

Another step identified in Reference 3 is to “identify ITS standards”, during which “ITS standards (or interim standards) are identified for every information flow in the regional ITS architecture.” It is important to understand that if the agency is planning to prepare detailed procurement specifications for a NTCIP-compliant C2C network, there are several issues that must be addressed in order to satisfy basic specification requirements – specifically, making the appropriate choice of standards for each level within the NTCIP Framework. To effectively make these selections, there needs to be a good understanding of what resources, like existing communications infrastructure and equipment, might be available from each existing system to be integrated into the regional architecture. For example:

- Do systems / centers that will likely interact and exchange information already have a DATEX or CORBA interface? (Note – Although some systems use DATEX-ASN, CORBA, or XML in their internal system communications (module-to-module), it is not necessary for a system to use one of these standards for external communications. Translators are commonly used to convert from an internal communications interface to an external one.)
- Does the center use object-oriented software (a prerequisite for using CORBA)?
- Can one or more connected centers now or in the near future provide gateway/translation services between DATEX and CORBA?
- What communications exist / can be made available between systems? (Note – Center-to-center communications typically involve networks connecting many computers in a peer-to-peer arrangement. These networks typically involve both local area networks (e.g., within a building or adjacent buildings) and wide area networks (e.g., across town or across the nation). The bandwidth requirements will vary for each link in each network, depending on

the amount of center-to-center messaging traffic using that link, and whether or not the network is shared with other applications.)

The specifications for the regional architecture and the associated equipment procurement / installation must not simply include a sentence such as *“All components shall be NTCIP compliant,”* or *“The system shall use NTCIP as the communications protocol.”* These single statements provide no information to manufacturers or systems integrators on the type, scope, and functionality of the system or hardware to be implemented (6)

Practitioner should also realize that the flexibility of ITS standards comes at the price of a more complex system than the transportation systems industry has traditionally used. Therefore, the system may require more sophisticated processors or better communication facilities than traditional systems in order to achieve the same performance level (e.g., response times, etc.). If these issues are overlooked during the design and procurement processes, there could be significant implementation problems or setbacks late in the project in order to provide the necessary performance.

Another factor to consider is whether or not the procurement documents provide realistic expectations. While the ITS standards provide standardized interfaces that are flexible enough to meet various needs, they may be more bandwidth intensive than previous systems and/or they may use a slightly different database design. It is important to make sure that there are realistic expectations at the start of the project in order to ensure that the project will be perceived as a success.

Due to the complexity, number and rate of change of the ITS standards, it is highly advisable to have one or more standards experts on the project team so that known problems can be avoided and new problems can be identified and resolved quickly. This includes making sure that the functional requirements for a project can be met by the subject standard, and, if not, specifying how the project will support these non-standardized features (7).

Finally, if the information requirements require only a small subset of the functionality provided by the NTCIP standards, it may be less expensive to implement a custom interface, or at least a subset of the full standard. However, the cost of future modifications should requirements change, or to add the custom interface to future additional systems, needs to be considered (8).

16.2.6.4 Testing Requirements

The design and installation documents must address how the procured devices and software comprising the regional architecture will be tested and certified as being standards compliant. Just because a system works in the field and appears to be compliant with the standard through a cursory inspection does not mean that the system is, in fact, compliant. The ITS standards are quite complex and problems in the implementation may not become evident until interconnection with a different network is attempted in the future.

Testing for standards conformance can take several forms. The simplest being from the perspective of determining if a system will accept data elements transmitted using the standards, to the more complex notion of ensuring that each systems provides the appropriate functional response for the message that was received. Complex testing also ensures a system does not transmit or make available any restricted information, and that it does not produce

false errors or unpredictable results for messages and data it does not understand or that are addressed to another system. It is important for agencies to plan for, and then rigorously test devices and systems to ensure conformance to the ITS standards.

To avoid discovering problems years after deployment, it is highly advisable to conduct a thorough test of the system upon delivery. This certification of standards compliance may be outsourced as part of the procurement (e.g., through hiring an independent testing lab). It should be realized that the ITS standards are very complex, and it may be impractical to perform comprehensive testing covering every possible center-to-center scenario. However, well-designed test plans can be produced to provide a high level of confidence for a reasonable cost.

The agency should be aware of any time constraints that might be required for the development of new software that comes as a result of implementing a new standard. Before any testing begins, there must be a clear statement and understanding of the requirements that must be met and the minimum acceptable performance levels. All testing should then be based upon, and derived *only* from, these agreed upon requirements. Each requirement has a test, and each test traces to a requirement. Moreover, all tests should have quantitative and measurable results.

16.2.6.5 Other Considerations

Some of the functions that a system may need in a center-to-center communications management software package include the following:

- User interface (e.g., subscription form, data display, status reports, etc.)
- Interpretation and appropriate disposition of incoming messages
- Databases for storing subscriptions and other administrative data
- Interfaces with existing transportation databases and programs
- Network performance monitoring and management
- Event logging and reporting, etc.

None of these functions are specified or provided by the center-to-center protocols or message sets (since they do not have to be standardized). But at least some will need to be provided for a system to manage and make use of center-to-center communications, and should therefore be included in the regional architecture designs. A system may choose to obtain a very elaborate and sophisticated center-to-center communications management package, or a basic one. The former will provide more functions and be easier to use, but will cost more.

Agencies should also be aware of the fact that design documents and procurement requirements may need to address maintenance and subsequent device and/or software upgrades. ITS standards are still relatively new, and changes / updates to the standards can be expected. Moreover, as there are relatively few implementations available, ambiguities may still be discovered in the standard and the standards may be modified in order to correct these problems. Any such change may require a modification to deployed equipment if the equipment is to maintain compatibility with the new version of the standard.

16.2.7 **Emerging Trends**

In many respects, regional integration –especially from the perspective of “technical” integration and an automated ITMS – is itself an emerging trend. As previously noted in this chapter, the

ITS standards for center-to-center continue to be refined and (as of the date of this Handbook) have not yet reached a state of maturity. As noted in the NTCIP Guide (Reference 6), “current (C2C) deployments are split fairly evenly between DATEX and CORBA, with very few XML implementations. It is difficult to suggest how this market will develop.”

The 4th ITMS Conference⁴³, held in Newark, NJ in July 2001, (Reference 11) identified the following major themes and research needs related to technical issues:

- The need for technical guidance and best practice examples on a number of topics was identified as a priority. For example, the need for technical guidance on issues relating to planning, designing, maintaining, and sharing information via different interfaces among different systems was cited.
- Performance measures and evaluations are needed to document the benefits of ITMS. Common definitions, performance measures, and monitoring and evaluation techniques should be developed for ITMS. Ongoing monitoring and evaluation programs should be conducted.

16.3 IMPLEMENTATION AND OPERATIONAL CONSIDERATIONS

Technical integration is only a tool for enhancing regional, multi-agency coordination. Operational integration can still be achieved, often resulting in significant user benefits, through “low – tech” means such as regular meetings, phone calls, faxes, etc. between stakeholders. In fact, the automated exchange of information between ITS-based systems should be viewed as supplementing, not replacing, such “manually-intensive” activities.

The Federal Register in which FHWA Rule 940 is published (Reference 2), includes a background section stating: “Successful ITS integration and interoperability require addressing two different and yet fundamental issues; that of technical and institutional integration. *Technical integration* of electronic systems is a complex issue that requires considerable up-front planning and meticulous execution for electronic information to be stored and accessed by various parts of a system. *Institutional integration* involves coordination between various agencies and jurisdictions to achieve seamless operations and/or interoperability. In order to achieve effective institutional integration of systems, agencies and jurisdictions must agree on the value of being part of an integrated system. They must agree on roles, responsibilities, and shared operational strategies. Finally, they must agree on standards and, in some cases, technologies and operating procedures to ensure interoperability. This coordination effort is a considerable task that will happen over time, not all at once. Transportation organizations, such as transit properties, State and local transportation agencies, and metropolitan planning organizations must be fully committed to achieving institutional integration in order for integration to be successful. The transportation agencies must also coordinate with agencies for which transportation is a key, but not a primary part of their business, such as, emergency management and law enforcement agencies.”

As difficult as the technical issues may be to resolve, successful regional integration is primarily dependent on resolving the institutional issues. During the aforementioned ITMS Conference (Reference 11), separate breakout groups addressed technical and institutional integration. They all reached the same basic conclusions. The groups focusing on institutional integration agreed “that the institutional issues associated with ITMS are frequently more difficult to address than the technical issues”; while the groups focusing on technical integration “identified the link

between institutional and technical issues, noting that institutional concerns frequently influence the technical elements of a project.” In fact, most of the common themes that emerged from the ITMS conference (as documented in the Proceedings – Reference 11), focused on institutional issues, including:

- “The need for transportation agencies to focus on operations as a core mission was identified as a key element. Changing the mindset of these agencies from construction to operations is not an easy process, but is critical to the success of ITMS.
- Institutional issues are frequently more of a stumbling block than technical issues. Interagency coordination and cooperation is key to ITMS. Developing multi-agency partnerships, bridging institutional gaps, and establishing new institutional arrangements are all needed to maximize ITMS.
- Stakeholder Involvement. Develop and distribute information and briefing materials on ITMS for use by transportation professionals in presentations to the public and to elected officials.
- Training, education, and staffing needs are critical to ITMS. Emphasis should be placed on recruiting, retaining, training, retraining, and cross-training personnel at all levels. Educational materials are needed for undergraduate and graduate courses, as well as on-the-job training.”

As noted in the ITMS Conference White Paper on Institutional Barriers (Reference 12), “it is natural for individual transportation entities to be motivated first by their own operational concerns and needs. It is not uncommon for state and local governments to have a rather contentious relationship, be it about funding levels, their respective responsibilities and levels of authority, schools, transportation, etc. ITMS typically requires that “new” players (e.g., enforcement agencies, emergency service providers, private information service providers) be brought into the institutional mix, and there may be a certain amount of cautionary discretion at first, and possibly misunderstandings. Legal considerations and constraints can play a significant role, particularly if some form of “joint” control of ITS devices or combined staffing of an operations center is being considered for the ITMS.”

Institutional barriers can also exist within an individual agency. Different departments within the same agency (e.g., operations, construction, financial) will likely have roles to play within an ITMS; but they may also have overlapping responsibilities, a lack of understanding of the other departments’ missions, and conflicting priorities and policies. An agency may oversee multiple, geographically separated transportation facilities within the same region (e.g., tunnels and bridges), where the day-to-day management and operations of these individual facilities has historically been relatively independent from one another. These intra-agency barriers can prove a greater hindrance to an ITMS than the inter-agency challenges, particularly if senior management within the agency do not understand (or accept) the importance of and the need for ITS and integration (12).

What impetus is there for getting all the affected agencies and entities together to discuss coordinated operations and regional integration in the first place? Perhaps foremost is the need to overcome a sort of “institutional inertia” – to change the mindset within transportation agencies such that their core mission includes operations. It is also possible that FHWA Rule 940 – tying Federal funding for ITS projects to the establishment of a Regional ITS Architecture,

and conformity of these projects with that architecture – may also be helpful in promoting regional integration. Regardless, as noted in References 1, 3, 11, and 12, “champions” are essential to take the lead in this endeavor, to arrange and organize inter-agency meetings, and continuously promote the need and benefits of regional integration. The champions must also have the authority, ability, and credibility to influence decisions within all agencies and groups. Outreach to policy makers is a key part of building support and champions at the political level. In addition to individuals, a lead agency is also often helpful. It may be the MPO, a “regional” transportation agency, or a State DOT. Obviously, the ITMS champion must function as an advocate. At the same time, however, any lead agency must be careful that it is not viewed by the other entities as using the ITMS concept as a means to expand its own influence and control.

Other considerations when dealing with institutional issues include the following:

- **Stakeholder Involvement** – The need for all affected entities to participate in the planning and development of a Regional Architecture and ITMS (as well as a freeway management and operations program) is discussed in Section 16.2, and emphasized throughout this Handbook and in numerous references. A case study on the development of the Regional ITS Architecture / Regional ITS Integration for the NY-NJ-CT region (Reference 13) emphasizes the need to involve as many organizations as possible in the process; that early establishment of interagency communications and relationships is the key to success in the regional ITS architecture development process. In essence, bringing together all the stakeholders can serve to cultivate an interest in coordinated operations and regional solutions, increasing the agencies’ understanding of the importance and need for ITMS. The various participants can identify and focus on common goals, leading to the development of a regional concept that will satisfy these goals. Moreover, it allows each entity to understand the specific functions and perspectives of their partner agencies, as well as their respective institutional constraints and barriers, thereby making the collaborations more productive.
- **Organizational Structures and Processes** – Determining the most appropriate organizational structure for regional integration and coordinated operations depends on the needs of the region, existing institutional relationships and processes, and the visions of the transportation operating agencies and service providers within the region. The organizational structure will vary, but may begin as an *ad hoc* arrangement among a few people or organizations and evolve to more formal arrangements. Figure 16-1 illustrates this range of organizational approaches. The process of regional coordination and integration will often move along a spectrum from little to no information sharing and collaboration, to *ad hoc* relationships built around specific issues or special events, to more formal collaborative relationships with mutually agreed-upon objectives and strategies, and finally, in some instances, to joint ownership and control of transportation facilities and services. This spectrum, illustrated in Figure 16-2, shows some of the ways that a region’s public and private sector entities may interact.

←	LESS FORMAL	↔	MORE FORMAL	⇒
<p><i>Ad hoc</i> arrangements based on near-term issues and personal relationships and interests</p>	<p>Informal working groups that meet regularly to address topics of regional significance</p>	<p>Formally established joint working groups with assigned responsibilities for regional planning for operations</p>	<p>Funded entities with full-time staff and well-defined responsibilities related to regional planning for operations</p>	<p>Legal entities with dedicated resources, authorities, and governing boards that represent agencies and jurisdictions in regional planning for operation efforts</p>

Figure 16-1: Organizational Approaches for Regional Integration (Reference 1)

←	LESS FORMAL PROCESSES	↔	MORE FORMAL PROCESSES	⇒
Coordinating	Cooperating			Collaborating
<ul style="list-style-type: none"> ▪ Informal information sharing ▪ Common use of terms ▪ Coordinated actions ▪ Coordinated service delivery 	<ul style="list-style-type: none"> ▪ Regional information sharing ▪ Regional performance measurement ▪ Regional operating policy development ▪ Regional concept of operations development ▪ Regional ITS architecture development 			<ul style="list-style-type: none"> ▪ Shared regional operations vision ▪ Formal institutional partnering ▪ Integration and interoperability planning ▪ Joint project development ▪ Shared use of resources

Figure 16-2: Spectrum of Regional Integration Processes (Reference 1)

- **Inter-Agency Agreements** – Agreements among the different stakeholder agencies and organizations are required to realize the coordination, cooperation, and integration associated with the regional ITS architecture. The “Regional ITS Architecture Guidance Document” (Reference 3) includes inter-agency agreements as an individual procedural step, in which “a list of the required agreements is compiled and new agreements that must be created are identified, augmenting agreements that are already in place. Each connection between systems in the regional ITS architecture represents cooperation between stakeholders and a potential requirement for an agreement, recognizing that one agreement may accomplish what is necessary to support many (or possibly even all) of the interfaces identified in the architecture. The number of agreements and the level of formality and structure of each agreement will be determined by the agencies and organizations involved.” The ITMS Conference White Paper on Maintenance and Operations (Reference 14) states: “the development of agreements should be started well in advance of when the agreements are needed. An important strategy used for meetings where agreements are discussed is to consider all agencies to be equal and not have one of them be in charge of

the meeting (i.e., meetings are arranged, facilitated and documented by non-agency resources.) This strategy reduced the risk of any agency forcing their agenda on the other agencies just because that agency was responsible for the meeting.” Some common types of agreements are listed in Table 16-5. A major impediment can be getting each agency to approve an agreement. One approach is to keep the agreement at the lowest possible hierarchical level and to keep it informal. Another approach is to have the agreements signed at the highest levels. There are advantages and disadvantages to each approach. With the first approach, high-level support may be denied when it is needed. With the second approach, the legal reviews may take a considerable amount of time and may never be concluded.

- **Document Success Stories** – These need not be traditional benefit/cost studies. It is more important to document real examples of how the quality of transportation operations has been improved with regional integration and ITMS implementations. Without a significant constituency for operations, it will continue to receive limited funding and support. More success stories would be helpful. These success stories should involve innovative applications that cross traditional institutional structures and can be understood for their intrinsic value. Improving the response time of an ambulance through improved integrated operations is a benefit that does not require a benefit/cost ratio to be understood.

Table 16-4: Common Types of Agreements
(Reference 3)

Handshake Agreement

- Early agreement between one or more partners (Not recommended for long term operations.)

Memorandum of Understanding

- Initial agreement used to provide minimal detail and usually demonstrating a general consensus.
- Used to expand a more detailed agreement like an Interagency Agreement that may be broad in scope but contains all of the standard contract clauses required by a specific agency.

- May serve as a means to modify a much broader Master Funding Agreement, allowing the master agreement to cover various ITS projects throughout the region and the MOU to specify the scope and differences between the projects.

Interagency Agreement

- Between public agencies (e.g., transit authorities, cities, counties, etc.) for operations, services or funding
- Documents responsibility, functions and liability, at a minimum.

Intergovernmental Agreement

- Between governmental agencies (e.g., *Agreements between universities and State DOT, MPOs and State DOT, etc.*)

Operational Agreement

- Between any agency involved in funding, operating, maintaining or using the right-of-way of another public or private agency.
- Identifies respective responsibilities for all activities associated with shared systems being operated and/or maintained.

Funding Agreement

- Documents the funding arrangements for ITS projects (*and other projects*)
- Includes at a minimum standard funding clauses, detailed scope, services to be performed, detailed project budgets, etc.

Master Agreements

- Standard contract and/or legal verbiage for a specific agency and serving as a master agreement by which all business is done. These agreements can be found in the legal department of many public agencies.
- Allows states, cities, transit agencies, and other public agencies that do business with the same agencies over and over (e.g., cities and counties) to have one *Master Agreement* that uses smaller agreements (e.g., *MOUs, Scope-of-Work and Budget Modifications, Funding Agreements, Project Agreements, etc.*) to modify or expand the boundaries of the larger agreement to include more specific language.

16.4 EXAMPLES

16.4.1 Transcom Regional Architecture

The New York – New Jersey – Connecticut Region is the most highly populated and one of the most highly congested areas in the country. The region's geography (e.g., numerous river crossings), a significant use of transit, and its complex jurisdictional structure (i.e. numerous agencies responsible for operating the network, often in an overlapping fashion) makes interagency coordination and information sharing essential. The various transportation agencies within the region have long recognized this need. In 1986, 14 agencies formed TRANSCOM (Transportation Operations Coordinating Committee), which now is comprised of the 18 transportation and public safety agencies listed in Table 16-5.

Table 16-5: TRANSCOM MEMBER AGENCIES

MTA Bridges & Tunnels	New York City Police
Connecticut Dept. of Transportation	New York City Transit
Metropolitan Transportation Authority	New York State Dept. of Transportation
New Jersey Dept. of Transportation	New York State Bridge Authority
New Jersey Highway Authority	New York State Police
New Jersey State Police	New York State Thruway Authority
New Jersey Transit Corporation	Palisades Interstate Park Commission
New Jersey Turnpike Authority	Port Authority Trans-Hudson Corporation
New York City Dept. of Transportation	Port Authority of New York and New Jersey

A “regional architecture” for information sharing and interagency coordination – albeit a “low tech”, manually intensive one – was in place from the very beginning. The various agencies and Transportation Management Centers within the metropolitan region would contact the TRANSCOM Operations Information Center (OIC) – primarily by phone – to report major roadway and transit incidents on their respective facilities. These calls were logged, and the OIC operator entered the information into the TRANSCOM system, which in turn disseminated the information throughout the region via a pager network. Other information linkages of this “manual” architecture included faxes (e.g., weekly and quarterly construction activities), two-way radio, and telephone circuits for displaying slow-scan and digitized video from a few closed-circuit television cameras. TRANSCOM staff utilized these data, plus information on agency-specific ITS components, to provide several regional functions:

- Disseminating information on incidents, construction, and other unusual events to affected agencies and other interested parties, including private entities.
- Serving as an interface to the media and private traffic reporting entities regarding incidents and other events that impact the regional transportation network.
- Analyzing the real-time incident information, determining the nature and extent of any regional impacts, developing response scenarios for mitigating these projected problems (e.g., CMS messages), and helping to marshal regional resources for response (e.g., contacting those agencies with operations and control responsibilities to discuss and request implementation of these regional plans.)
- Developing and disseminating a weekly regional summary of the member agencies’ major road/track closings and planned construction activities, and maintains a long-term database of projected construction projects. This regional construction coordination program helps member agencies to avoid unknowingly restricting capacity on adjacent facilities or routes.

These “manual” information linkages proved to be very effective; and are still an integral part of TRANSCOM’s operations. Nevertheless, the environment in which the regional coordination and the associated information linkages operate has been changing for some years. All of the member agencies have been enhancing the management and operation of their respective facilities through the implementation of ITS technologies and strategies. As these systems have come on-line, the quantity and quality of information available to the operating agencies, and to the region as a whole, has increased; as have the opportunities for automating the information linkages between the TMCs.

TRANSCOM and its member agencies recognized the importance of automating center – to – center linkages in the early 1990's. In fact, it was identified as “an absolute necessity for properly managing the increased information with minimal impacts on the staffing requirements at the agency TMCs, while continuing to provide timely response to transportation problems and credible information to the traveling public.”⁴⁴ In 1995, the TRANSCOM member agencies developed a region-wide ITS implementation strategy. This project defined a concept for a regional ITS architecture for TRANSCOM and the member agencies such that the regional transportation network – consisting of expressways, surface streets, and transit routes, and all passing through multiple jurisdictions – is treated as a single “seamless” entity. During the project, discussions with representatives from the various transportation entities within the region revealed a strong consensus as to the specific functions to be incorporated into the regional ITS architecture—specifically, the same functions already being provided:

TRANSCOM:

- Clearinghouse of real-time information covering all critical routes and modes. This database integrates available information from agency-specific systems and TMCs to provide a composite picture of the real-time status of the surface transportation network. This information is made available to all member agencies, TMCs, other operating entities, and private traffic reporting entities.
- Regional coordination support between TMCs, transportation agencies, and public safety agencies during “major” incidents and events (i.e., those in which the impacts cross jurisdiction boundaries).

It is noted that the TRANSCOM Regional ITS Architecture does *not* include operations or control of system components. Such functions are the responsibility of the individual transportation agencies; although the architecture can handle exceptions to this rule whenever the affected agencies agree.

The regional architecture concept was unanimously approved by all TRANSCOM member agencies. Deployment and expansion has been an on-going process. The configuration of the TRANSCOM Architecture, as of the time of writing this Handbook, is shown in Figure 16 -3. The model is relatively heterogeneous; allowing the agency's ITS systems to be as different as necessary to support their local missions. It also allows the integration of existing systems and their databases.

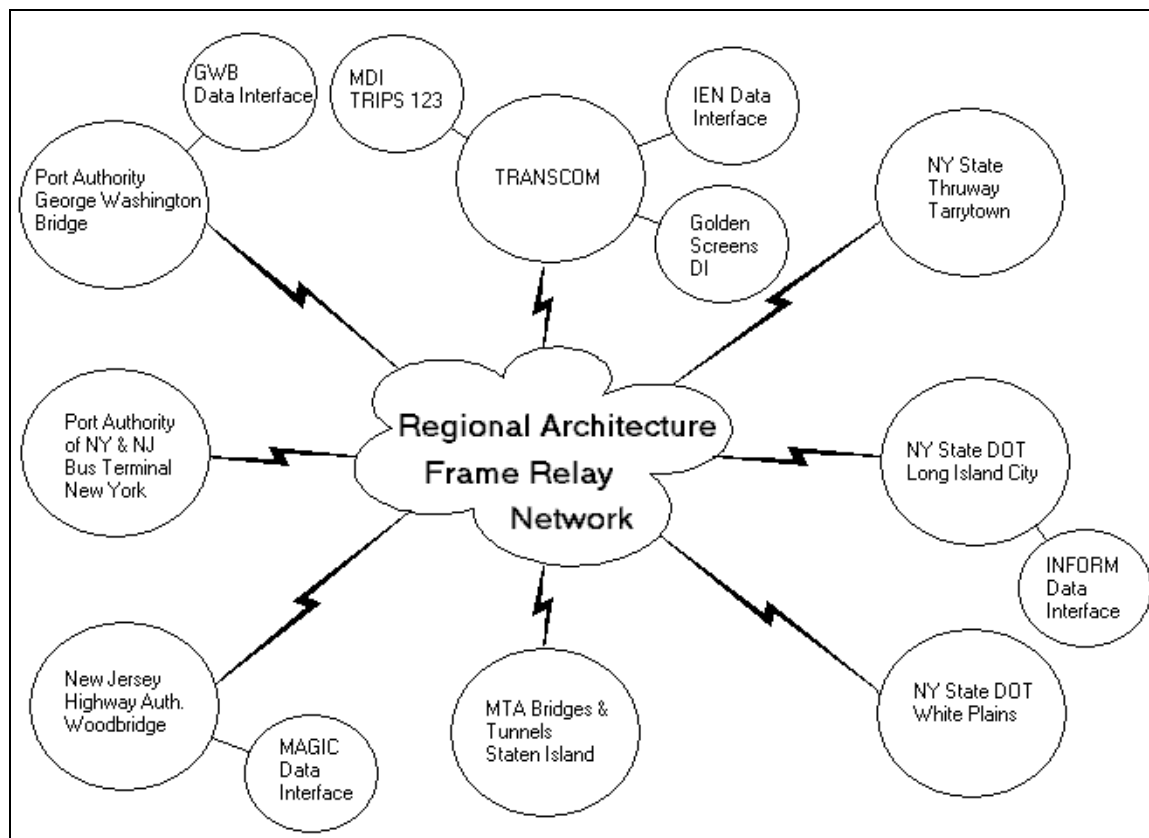


Figure 16-3: TRANSCOM Regional Architecture Network

Specific attributes and elements of this information sharing architecture are summarized below:

- **Regional Workstations** - All user access to the regional network is through workstations. Information is presented to the operators in an integrated fashion, combining graphical, text, and video formats. Graphical displays represent the primary mechanism for interfacing with and navigating through the regional database. The regional transportation network is displayed in a graphical map-based format providing a common, areawide reference for network conditions, the location of incidents, and the position of ITS devices. Examples of the user interface are shown in Figures 16-4 and 16-5.

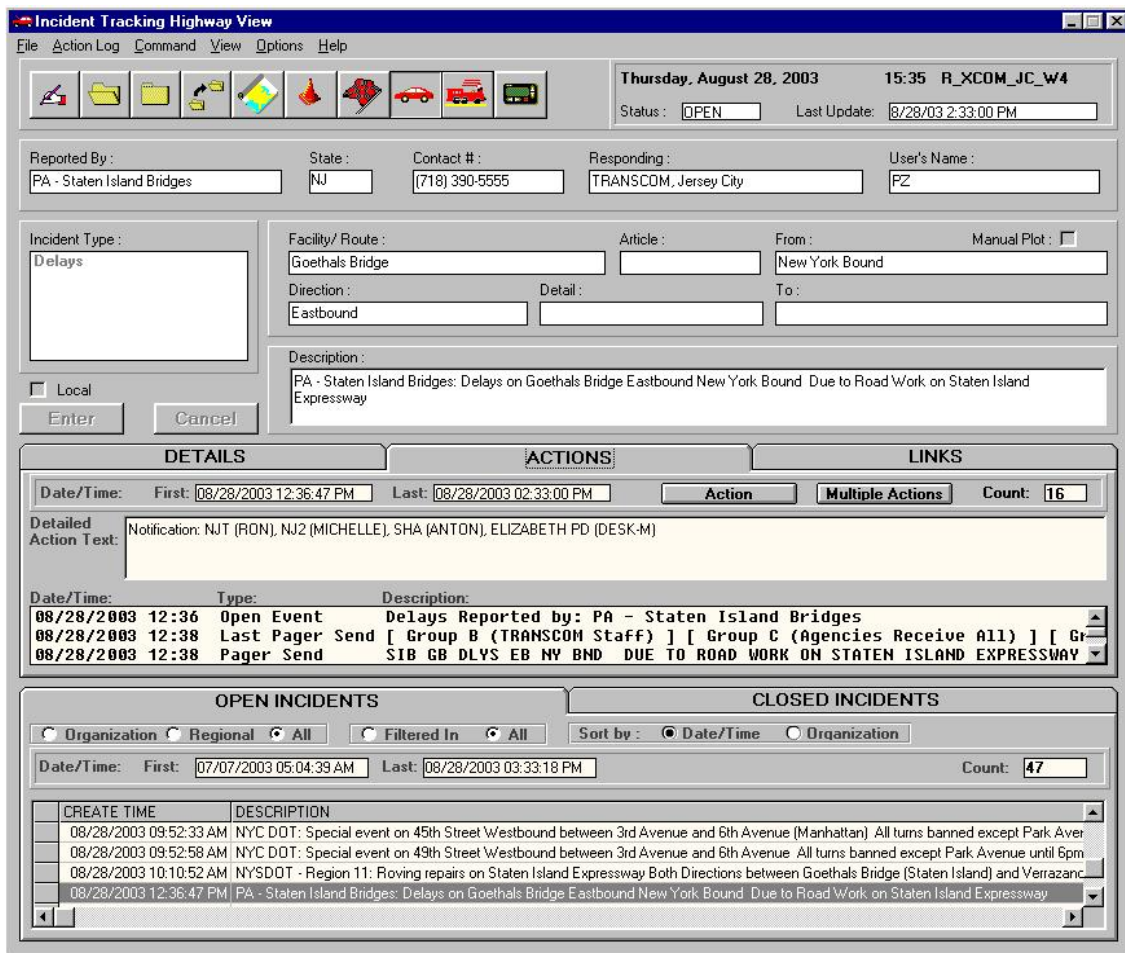


Figure 16-4: TRANSCOM Regional Architecture Event Tracking Interface

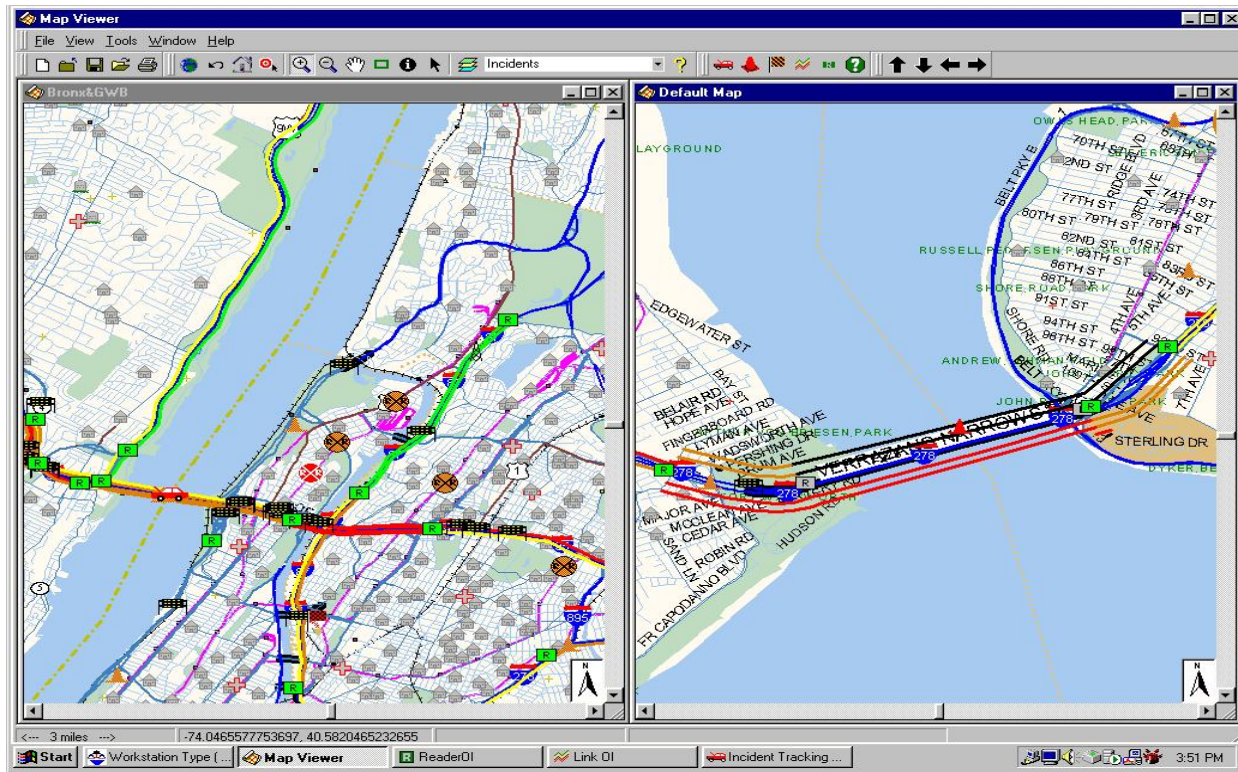


Figure 16-5: TRANSCOM REGIONAL ARCHITECTURE MAP VIEWER INTERFACE

- **Data Interface** - A data interface (DI) is integrated with the central hardware platform at various TMCs. As the name implies, this process – either resident on a separate server, or integrated into the native system – interfaces and communicates with the agency’s ITS system, extracts various data elements from this native system, processes the information as required, converts the data to the TMDD format used within the regional network, and transmits the information to the regional server, using C2C protocol, for subsequent aggregation and distribution to workstations throughout the region.
- **Regional Architecture Database (RAD)** - TRANSCOM receives information from the workstations and DIs, combines and integrates the data with information from other systems into a composite and consistent representation of the region, and distributes the information to workstations throughout the region. The RAD also serves as the primary information source for the TRIPS 1-2-3 traveler information system, including providing the information to the public (free of charge) via a web page and telephone, and a fee-based personalized traveler service.
- **Use of National Standards** – The regional architecture uses national standards to communicate within its expansive network of servers and workstations and subsequently promotes future interoperability with systems that are external to the region, as external systems adopt national standards. The national standards include the use of the NTCIP DATEX center-to-center (C2C) protocol for encoded packet based communications between centers or TMCs as well as the MS/ETMCC Traffic Management Data Dictionary (TMDD).

These standards promote an efficient approach to sharing traffic information between internal and external TMCs.

Overlaying the data architecture is the Interagency Remote Video Network (IRVN), permitting "full motion" video sharing between agencies. The IRVN system allows a TMC operator to interface with the video network and choose the cameras (up to three at any one time) he/she wishes to view. The video encoders convert the NTSC video from the selected cameras (routed through the video switch) to IP real-time streaming video. At the receiving TMC, video decoders convert the streaming video signal for display using a video capture card. Attributes of the IRVN system and user interface include:

- Lists of the TMC locations connected to the network, the cameras available from each TMC, and those cameras (up to three from each TMC at any one time) currently transmitting video over the network.
- If an operator wishes to view a camera already on the network, he/she uses a mouse to click on that camera, and the picture from that camera will then appear on a television monitor. An alphanumeric description will accompany the picture. If the camera is not on the network, IRVN will communicate with the video switch at the TMC where the desired camera is located, resulting in the video from that camera being transmitted over the network.
- A problem will arise if four or more different cameras are selected from the same TMC, because each location can only put three video signals on the network at one time. If this circumstance occurs, the current three video signals will remain on the network, and a message will be displayed to call TRANSCOM for coordination. TRANSCOM will then work with the appropriate agencies to determine which three video signals should be placed on the network.
- Each agency may block any of its video feeds from being placed on IRVN.

A case study developed for FHWA (Reference 14) identified the following major lessons learned from the TRANSCOM regional ITS architecture:

- Early establishment of interagency relationships is important
- Education about ITS and regional ITS architecture is needed within agencies to garner critical senior management involvement and support for ITS and regional efforts
- Federal support, including education and the establishment of standards, has been and continues to be important
- Institutional issues must be considered and respected
- ITS has created a new regionally focused paradigm for transportation planning and operations

16.4.2 Spokane Regional Transportation Management System

In July of 2000, the Spokane Regional Transportation Council documented the ITS National Architecture standards and Implementation Plan for the greater Spokane region, identifying the basic functionality of how data would be collected, used, and shared within the region; and how the region would manage transportation information. The high priority projects identified in the Region's Implementation Plan are identified in Table 16-6.

Table 16-6: SPOKANE REGIONAL TRANSPORTATION MANAGEMENT GOALS

• Construct a regional communications network
• Design and construct a regional transportation management center
• Develop a regional website for transportation, weather and construction information
• Develop a coordinated incident response application
• Design and deploy a regional data warehouse
• Provide traffic control system integration
• Design and construct the I-90 surveillance control and driver information system
• Deploy automatic vehicle location

Progress on all of the goals listed in Table 16-5 is on-going – for example, the region has designed and constructed the Spokane Regional Transportation Management Center (SRTMC), while WSDOT is in contract development to construct the I-90 surveillance and driver information system consisting of CCTV cameras, dynamic message signs (DMS), and several miles of fiber optic communication cable. Accordingly, the regional integration and software activities associated with this project focus on the following regional goals:

- Develop a regional traveler information website
- Develop a coordinated incident response application
- Design and deploy and regional data warehouse
- Provide traffic control system integration

16.4.2.1 Concept of Operations

The Spokane Regional Traffic Management Center (SRTMC) is operated 24/7. The TMC operation is governed by the Operating Board, which is made up of WSDOT, city, county, transit, and the regional planning agency (SRTC). The transportation agencies in the Spokane Region have identified the common goal of implementing a regional architecture that will enable limited view and control of the ATMS systems currently in use in the region. Neither ATMS application, on its own, provides a complete picture of traffic conditions throughout the Spokane Region. Through a common graphical user interface, an operator in the TMC (or from anywhere on the Internet) would have the ability to view data from both control systems in real-time and respond to significant events or incidents on a regional, rather than just a local, basis. The following examples illustrate the type of functions capable through a common, regional-level interface:

- A manager-level user at the SRTMC monitors traffic conditions in the metro area (city, county, state), and identifies an incident on the highway. The user monitors the incident via CCTV and implements a message on a DMS. A diversion route is necessary off of the freeway (which is operated by the State) and onto the local arterial (operated by the City). The TMC operator opens a real-time display of the signal timings of an intersection upstream of the incident location, and determines that the signal timing plan in operation will not be acceptable for the significant increase in traffic volume due to the diversion from the highway. The TMC operator implements from a PC in the TMC a new timing plan that has been previously agreed upon for such a scenario through the regional application. Additionally, the manager places an incident icon on the regional interface, which is automatically updated on the regional traveler information website, and sends an email alert to public subscribers that have signed up for incident alerts.

- A junior-level user is currently monitoring traffic conditions in the SRTMC. An incident occurs on the freeway, but since the junior-level user does not have permissions to assign messages to DMS signs or to modify traffic signal timings on the City streets, the operator notifies the TMC Manager. The manager-level operator, who is not currently on-site at the TMC, launches a web browser with a connection to the Internet, and logs into the regional software application. Through the regional application running in the manager's browser, the manager brings up a CCTV control panel and zooms the camera's image in on the incident site to verify the information from the junior-level staff in the TMC. Upon verifying the incident, the manager assigns the appropriate message to the DMS by estimating the incident delay by viewing the real-time links status. Then the manager selects the appropriate timing plan (pre-configured) through the regional application. At the same time, the junior-level user in the TMC places an incident icon on the regional interface, which appears automatically on the regional traveler information website.
- A planner in the Spokane region is preparing a performance assessment report for the region's transportation network. After logging into the regional software using any web browser with a connection to the Internet, the planner retrieves archived freeway traffic data from the previous six months from the on-line archive. The planner produces several performance charts and plots using tools built-in to the archiving software component and embeds the graphics into the summary report.

The regional goals and concept of operations described above may be translated into the following set of functional requirements for the proposed regional integration and associated software:

- Real-time data from signals connected to different signal systems shall be viewable on the same interface (regional display).
- The location and status of ITS devices in the Spokane region consisting of controllers, CCTV, DMS, and freeway link detectors shall be viewable on the same display.
- The TMC operator shall have the capability to implement changes to signal timing plans on different systems through a common application interface.
- PTZ of CCTV cameras and command of DMS shall be available to privileged users outside of the TMC.
- Data from freeway link detectors shall be archived and available on-line for analysis.
- A traveler information website shall be provided to display current ITS device status and transportation conditions data, including incident and event locations, streaming CCTV video, and an email alerts feature.
- Incident and event data from CARS⁴⁵ shall be integrated into the regional application interface.

16.4.2.2 Architecture

The SRTMS high-level architecture is shown in Figure 16-6. Both ATMS retain their communications connections to field devices. Web Services are used for the majority of the

C2C functionality using XML (extensible Markup Language) over SOAP (Simple Object Access Protocol) and CORBA for the Center-to-Center (C2C) link to carry data objects requiring the Near Real Time Data Service (NRTDS). The XML and SOAP interface provides the data and control interface from each system to the regional application. From the regional application, City and County users can “log in” to the system for secure view and control of all ITS devices. Public users and other partner agencies can be provided “view only” access to the same data by inserting a firewall between the SRTMS and the Internet. From outside the City/County WAN, public and partner agency users access the view-only portion of the SRTMS by browsing to a URL through any basic web browser and privileged users can access the restricted features of the software by logging in via a web browser. This is a significant advantage of using web-services technology for providing the regional center-to-center features.

The implementation of the regional management concept is via a component-based software design centered around a commercially available product. The components of SRTMS are shown in Figure 16-7. The regional map interface is the main framework for the application components and the means by which users log in and are validated to view information (maps, tables, etc.) and access controls, and administrators manage users and access. Other component modules within this framework include:

- Streaming CCTV video, including PTZ and archiving
- PeMS (Data archiving and analysis)
- Response Plan / Strategy Implementation
- DMS control
- Status Viewer
- Event Tracker (interface to CARS)
- Users & Security

The components shown in Figure 16-7 are built in a Web-services framework. Each web service (e.g. DMS data/controls, link data, etc.) is implemented as an application servlet with an interface to the user’s browser using a Java Server Page (JSP). Persistent data (e.g. device locations, street names, ID numbers, etc.) are stored in a standard COTS database and a façade to the data is provided using “session” and “entity” JavaBeans in an applications server. This provides independence of the interface layer (the Java Server Pages and servlets) from the database schema design. In practical terms, these technology selections allow for highly maintainable (bug fixes do not require modifications to many modules), flexible (adding new features is straightforward by re-using existing patterns with new business logic), and scalable (adding new device or device types is managed in a pattern-based way) code.

The main SRTMS interface provides a regional integrated view of transportation operations using web-services. In addition to viewing the status of field devices on a GIS-based map, the interface includes map navigation, layer toggles, access to command and control web pages, and user management and security features to allow various levels of view and control based

on user privileges. Any web browser can be used to access the features of the interface through the Internet, given the appropriate privileges.

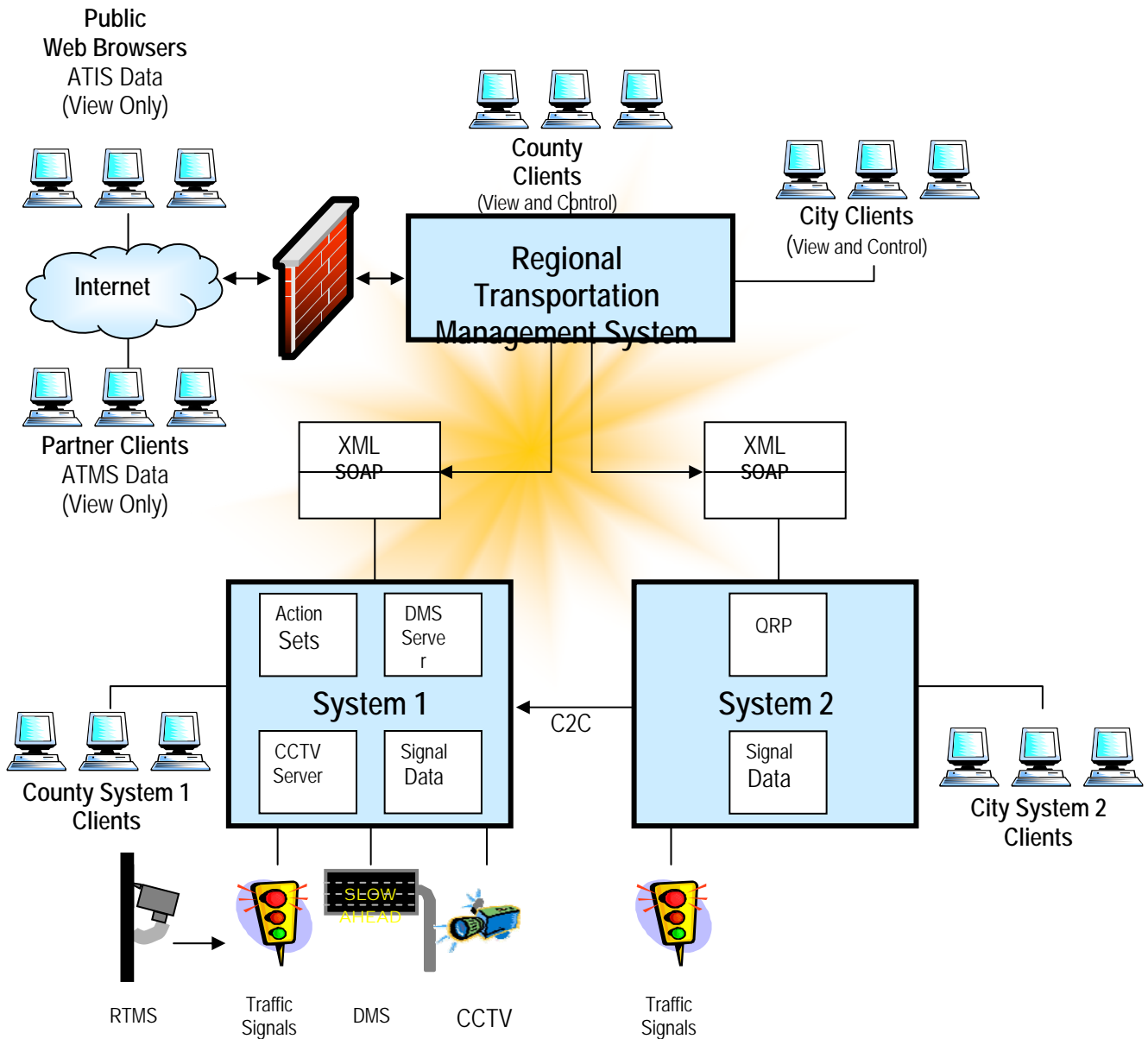


Figure 16-6: SRTMS Architecture

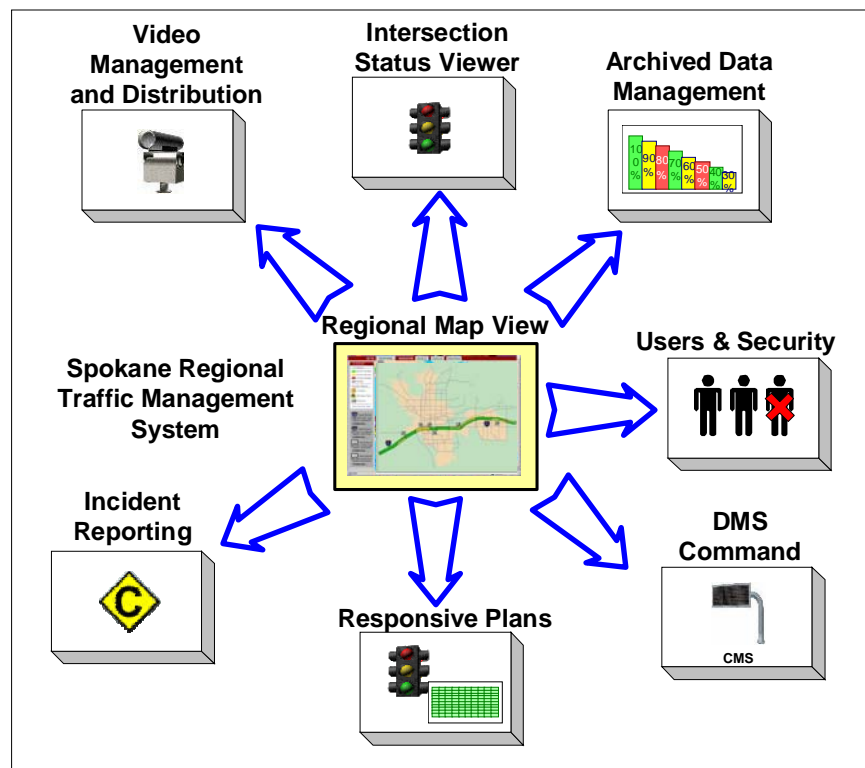


Figure 16-7: SRTMS Components

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17. COMMUNICATIONS

17.1 INTRODUCTION

A communications network provides the means by which information is exchanged between all the entities and components that comprise a freeway management and operations program – for example, between freeway practitioners and other stakeholders; between field devices and a transportation management center (TMC) of a freeway management system; between the TMC and maintenance and incident response vehicles; between TMCs within a region; and for disseminating traveler information to the users of the surface transportation network. This information may consist of voice, data, video, or some combination thereof.

There are multiple communications options (e.g., network architectures, technologies, standards, implementation strategies) available for meeting these needs. It is crucial that the most appropriate options be selected to best support the operational requirements of the freeway management program and the associated ITS – based systems.

17.1.1 Purpose of Chapter

The *Communications Handbook for Traffic Control Systems* (Reference 1) treats all aspects of communications networks in depth, and serves as a comprehensive stand-alone information resource. The “Communications Handbook addresses the various technical issues, and provides information to support planning, design, development, and management of the communications infrastructure to support a freeway management system (and other traffic management systems). This chapter of the Freeway Management and Operations Handbook is intended only as a **summary** of the information contained within the Communications Handbook.

17.1.2 Relationship to Other Freeway Management Activities

The communications network of a freeway management system provides the links by which information is transmitted between a TMC (Chapter 14) and a variety of field elements (i.e., “center – to – field”), such as ramp meters (Chapter 8), lane control signals and variable speed limit signs (Chapter 8), changeable message signs (CMS) and Highway Advisory Radio (Chapter 13), and detectors and cameras (Chapter 15). It also supports the sharing and integration of information between centers (i.e., “center – to – center”) as part of a regional architecture (Chapter 16) in support of traffic incident management (Chapter 10), planned special event management (Chapter 11), emergency management (Chapter 12), and regional traveler information dissemination (Chapter 13).

Of course, the importance of “communications” between freeway practitioners and other stakeholders cannot be overemphasized. As noted in Chapter 2 herein, engaging as many stakeholders as possible in the various processes that involve or impact freeway management helps to promote a framework for collaboration and cooperation. This form of communications may not involve large amounts of data or video (i.e., predominately voice); and is generally not considered as “state – of – the – art” technology; but a freeway management and operations program cannot survive without such communications.

17.2 CURRENT PRACTICES, METHODS, STRATEGIES, AND TECHNOLOGIES

17.2.1 Overview

Freeway Management Systems (FMS) deployed in the 1970's and 1980's used communications technologies based on the transfer of voice. All data had to be converted to something that could be accommodated by an analog voice based infrastructure. FMS communications systems were based on this technology because that's what was available. By 1995, developing technologies began to change the nature of the communications infrastructure. Fiber replaced copper and digital replaced analog. Departments of Transportation have begun to take advantage of the new communications technologies as a means to support the use of new methods and tools in an FMS. The use of fiber optics supports greater data capacities and the ability to use "real-time" video imaging. Recently, wireless communications and the Internet have started to offer effective strategies in support of freeway management and operations.

17.2.2 Benefits

Communications, whether they involve advanced technology or relatively simple means (e.g., the telephone), are an integral part of any freeway management program. As noted throughout this Handbook, freeway management strategies and ITS technologies can assist in reducing congestion, improving safety, and enhancing mobility. However, without the capability to readily exchange information – often in "real time" – between the entities and system components that comprise the freeway management program, the potential benefits of these strategies and technology systems will not be realized. To that end, it is not a simple matter to quantify benefits from communications networks alone, but instead to understand that the benefits realized from freeway management strategies and ITS technologies are dependent on effective and reliable communications.

17.2.3 Key Considerations During Freeway Management Program Development

The communications infrastructure is a critical key element of any FMS (or ITS) system. The communications network typically consumes ten to twenty-five percent of an overall budget for an ITS – based system. Moreover, if not adequately implemented, it can inject a serious constraint on the overall operation. As such, communications considerations and needs should be an integral part of all aspects of the Systems Engineering process discussed in Chapter 3 herein.

The Communications Handbook includes a chapter entitled "Developing the Communications System", which provides a practical approach to the design and system engineering of a communications network that supports traffic and transportation requirements. The chapter provides a step-by-step process that can ultimately result in a communication system requirements analysis and preliminary design.

A theme that is repeated throughout the Communications Handbook is that the design of a communications network to support roadway and transportation functions is **not** a stand-alone process. The determination of functionality and selection of options must be done as an integrated part of the overall traffic management system design, starting with the development of requirements. Moreover, it is important to keep in mind that the communication subsystem is a supporting element of the overall traffic management system. Accordingly, the communication engineer should also be fully aware of the vision and the system concept of operations.

A primary axiom that drives the design of a communications system is - “there are no absolutes”! For most communication systems, there are usually several ways to achieve the desired results. It is important to approach the communications system design with the right attitude. There is a tendency to look at the “gee-wiz” of communications technologies. Project managers and engineers must avoid this potential trap during the requirements analysis. The communications networks are designed and implemented in support of the traffic management system – not vice-versa! At the same time, it is perfectly acceptable to ask the communication engineer to look at system options using leading edge technology. This will give the communication engineer an understanding of project team expectations. In return, the project team is provided with enough information to make the right decisions.

The Communications Handbook offers several key points to consider when developing and designing a communications network for an ITS – based system, including:

- View the communication system as a part of the overall traffic/transportation project. There are many examples of adding the communications network as an afterthought. This eventually causes dissatisfaction with the overall system, resulting in the need to spend additional money to correct communication problems.
- Look at the whole system, not just the immediate implementation project. Many ITS programs are implemented in phases or as part of roadway construction / reconstruction projects. These project sections are, in fact, part of a larger plan. The communications system should be part of the larger overall plan. The communications network must be analyzed and designed to serve the long-term traffic management needs (e.g., what will the ultimate system provide in terms of geographic coverage and functionality). The potential communication needs of other government entities should also be considered in the analysis and design.
- Answer the following primary “questions”
 - **What** is the purpose of the proposed transportation system? Relate the communication requirements to the reason for the project’s existence and its required functionality.
 - **Where** will it be located? Location of the project and the surrounding conditions has an impact on overall design of the physical infrastructure, technology selection, and the cost of construction of a communication network.
 - **When** (over what period of time) will it be deployed? During a relatively short deployment time frame, project planners can assume that communication technology will remain stable. The communication system design team can propose a system without concern that communication technology and process will change. On the other hand, long-term projects can expect to see a need to combine current and legacy equipment into a working system.
 - **Who** will operate and maintain the system? Consider if the communication system will require that operational personnel have a need to activate various functions of the communication equipment and to trouble-shoot communication problems. Answering the question of who will operate and maintain the system will lead to operator and maintenance staff qualification requirements.

- **Why** is the traffic system being deployed? This may seem redundant to the question of “**what**” is being deployed, but at this point the project team will focus on the specific type of traffic system. The communication engineers responsible for analyzing and designing the communications system need to be provided with a good understanding of how various types of traffic/transportation systems work. This will lead to a design of the communication system based on the functions of the traffic/transportation equipment.
- A variety of **How** questions, including how it will be funded, how many devices will be deployed, how much redundancy is required, how will regional integration requirements be met, etc.

17.2.4 Relationship to National ITS Architecture

The National Architecture for ITS does not provide a lot of detail for any specific communications technology. The “communications layer” of the National ITS Architecture provides the “links” between the various “systems” (e.g., center, vehicle, roadside, and travelers) as shown in the ITS architecture “sausage diagram”.

The National ITS Architecture has identified four communication media types to support the communications requirements between the nineteen subsystems. They are *wireline* (fixed-to-fixed), *wide area wireless* (fixed-to-mobile), *dedicated short-range communications* (fixed-to-mobile), and *vehicle-to-vehicle* (mobile-to-mobile).

17.2.5 Technologies and Strategies

A primary axiom that drives the design of a communications system is - “there are no absolutes”! For most communication networks, there are usually several ways (e.g., architectures, technologies) to achieve the desired results. The Communications Handbook includes a chapter (i.e., “Fundamentals of Communication Technology”) that discusses the various elements of a communication system, including transmission media; signaling interfaces for voice, data and video; and transmission protocols.

17.2.5.1 Transmission Media

Transmission media are those elements that provide communication systems with a path on which to travel. Alternatives include the following:

- **Twisted Pair:** Twisted pair is the ordinary copper wire that provides basic telephone services to the home and many businesses. In fact, it is referred to as “Plain Old telephone Service” (POTS). The twisted pair is composed of two insulated copper wires twisted around one another. The twisting is done to prevent opposing electrical currents traveling along the individual wires from interfering with each other. This interference is called “crosstalk”. A broad generalization is that twisted copper pair is in fact the basis for all telecommunication technology and services today. Even the basis for 10-Base-T Ethernet is twisted pair. For some application, twisted pair is enclosed in a shield that functions as a ground. This is known as shielded twisted pair (STP). Twisted pair comes with each pair uniquely color-coded when it is packaged in multiple pairs. There is an IEEE standard for color-coding of wires, wire pairs, and wire bundles. The color-coding allows technicians to install system wiring in a standard manner.
- **Coaxial Cable:** Coaxial cable is a primary type of copper cable used by cable TV companies for signal distribution between the community antenna and user homes and businesses. Coaxial cable is called “coaxial” because it includes one physical channel that

carries the signal surrounded (after a layer of insulation) by another concentric physical channel, both running along the same axis. The outer channel serves as a ground. Many of these cables or pairs of coaxial tubes can be placed in a single outer sheathing and, with repeaters, can carry information for a great distance.

- **Fiber Optic Cable:** Fiber optic (or "optical fiber") refers to the medium and the technology associated with the transmission of information as light impulses along a strand of glass, and referred to as fiber. Fiber optic strand carries much more information than conventional copper wire and is far less subject to electromagnetic interference (EMI). Most telephone company long-distance lines are now fiber optic. Transmission over fiber optic strands requires repeating (or regeneration) at varying intervals. The spacing between these intervals is greater (potentially more than 100 km) than what is normally required for copper based systems. The fiber cable is constructed in several layers. The core is the actual glass, or fiber, conductor. This is covered with a refractive coating that causes the light to travel in a controlled path along the entire length of the glass core. The next layer is a protective cover that keeps the core and coating from sustaining damage. It also prevents light from escaping the assembly, and has a color-coding for identification purposes. The core, coating and covering are collectively referred to as a "strand". Fiber strands are produced in two basic varieties: Multi mode and Single mode. Each variety is used to facilitate specific requirements of the communication system.
 - **Multi mode** is optical fiber that is designed to carry multiple light rays or modes concurrently, each at a slightly different reflection angle within the optical fiber core. Multimode fiber transmission is used for relatively short distances because the modes tend to disperse over longer lengths (this is called *modal dispersion*). For longer distances, single mode fiber is used. Multimode fiber has a larger core than single mode.
 - **Single mode** is optical fiber that is designed for the transmission of a single ray or mode of light as a carrier and is used for long-distance signal transmission. For short distances, multimode fiber is used. Single mode fiber has a much smaller core than multimode fiber. Single mode fiber is produced in several variations. The variations are designed to facilitate "very long reach (distances)", and the transmission of multiple light frequencies within a single light ray.
- **CDPD:** CDPD (cellular digital packet data) is an analog data overlay that has been operation since 1993. This service provides data throughput at 9.6 Kbps, and is an overlay to the analog cellular telephone system. CDPD is being used by a number of communities as a wireless communication link to control traffic signal systems. As the analog cell systems are converted to digital, CDPD is being phased out. The wireless carriers are not providing a substitute.
- **Microwave:** Microwave is a fixed point-to-point service that provides connectivity between major communication nodes. Telephone and long distance companies use the service to provide backup for their cabled (wireline) infrastructure and to reach remote locations. Public Safety agencies use microwave to connect 2-way radio transmitter sites to a central location. The frequencies allocated for this service are in the 6 and 11 gigahertz ranges. All users are required to obtain a license for use from the FCC (Federal Communications Commission). Frequency licenses are granted on a non-interfering (with other users) basis.

Systems can be designed to operate over distances of about 20 miles between any two points. Other frequencies available in the 900-megahertz, 2 and 23-gigahertz range do not require a license. Because these frequencies do not require a license it is up to users to resolve any interference problems without support from the FCC. As with all microwave, the FCC permits only point-to-point uses.

- **Spread Spectrum:** Spread spectrum radio is a technology that “spreads” the transmission over a group of radio frequencies. Two techniques are used. The most common is called “frequency hopping” The radio uses one frequency at a time but at pre-determined intervals jumps to another frequency to help provide a “secure” transmission. The second system actually spreads the transmission over several frequencies at the same time. The method helps to prevent interference from other users. These systems are generally used for distances of less than 2 air miles (put in note about air miles vs. land miles).
- **2 – Way Radio:** 2-Way Radio systems have been in common use since the 1930’s. Originally used by the military, various federal agencies, police, fire and ambulance, and local governments, its use has expanded to include almost every aspect of our social infrastructure, including individual citizens using “Ham Radio” systems. Most commonly used frequencies are in the 30, 150, 450 – 512 and 800 megahertz ranges. Coverage is usually expressed in terms of “air mile radius”. Systems in the 150 MHz band can typically cover 15 to 30 air miles in radius from a single transmitter location. The FCC has been encouraging the use of regional systems that incorporate all state, county and municipal agencies into a single group of radio channels. The available radio spectrum is being re-allocated to accommodate these systems. Today, many Departments of Transportation are joining forces with public safety agencies to create a common radio communication system. This allows for easier coordination of resources to resolve traffic incidents.
- **Free Space Optics:** Free Space Optics (FSO) is another wireless system being used today. Instead of using radio frequencies, this system uses a LASER transmitted through the air between two points. The LASER can be used for transmission of broadcast quality video. These systems are limited to an effective range of 3 air miles.

17.2.5.2 Transmission / Signaling Interfaces

Data can be transmitted in either an analog or digital format. Private line systems (leased from a Carrier) are always point-to-point. Analog Private-line circuits are normally referred to as 3002 or 3004. The 3000 designation refers to available bandwidth. The 2 and 4 refer to the number of wires in the circuit.

Digital Private-line service is DDS (Digital Data Service), T-1/T-3, DS-1/DS-3, Fractional T-1, and SONET. DDS are digital voice channel equivalents. T-1 service is channelized to accommodate 24 DDS circuits. The terms T-1 and DS-1 are often used interchangeably, but each is a distinctly different service provided by telephone companies and carriers.

- **T-1** service is channelized with the carrier providing all equipment. The customer is provided with 24 DS-0 interfaces. Each DS-0 interface has a maximum data capacity of 56 kbps (or can accommodate one voice circuit). The customer tells the carrier how to configure the local channel bank (multiplexer).

- **DS-1** service allows the customer to configure the high-speed circuit. The customer provides (and is responsible for maintaining) all local equipment. The carrier provides (and maintains) the transmission path. The customer can channelize the DS-1 to their own specifications as long as the bandwidth required does not exceed 1.536 mbps, and the DS-1 signal meets applicable AT&T, Bellcor and ANSI standards.
- Customers may purchase **fractional service** to save money. In this case, they don't pay for a full T-1 or DS-1. However, the economies for this type of service are only realized for longer distances. The local links for Fractional T-1/DS-1 are still charged at the full service rate.
- **T-3 and DS-3** services are essentially higher bandwidth variants of T-1 and DS-1. The T-3 provides either 28 T-1s or 28 DS-1s, and the DS-3 provides about 44 mbps of contiguous bandwidth. DS-3s are used for Distance Learning and broadcast quality video. They are also used in enterprise networks to connect major office centers.
- **DSL** (Digital Subscriber Loop) services are DS-1 and Fractional DS-1 variants that use existing P.O.T.S. service telephone lines to provide broadband services at a substantially lower cost. The primary difference between the services is that DS-1 is setup to connect to user locations and is private. DSL service is typically used to provide broadband Internet connectivity.
- **SONET (Synchronous Optical Network)** is the first fiber optic based digital transmission protocol/standard. The SONET format allows different types of transmission signal formats to be carried on one line as a uniform payload with network management. A single SONET channel will carry a mixture of basic voice, high and low speed data, video, and Ethernet. All of these signals will be unaffected by the fact that they are being transported as part of a SONET payload. The SONET standard starts at the optical equivalent of DS-3. This is referred to as an OC-1 (Optical Carrier 1). The optical carrier includes all of the DS-3 data and network management overhead, plus a SONET network management overhead. In North America, the following SONET hierarchy is used: OC-3; OC-12; OC-48; OC-96; OC-192. The number indicates the total of DS-3 channel equivalents in the payload.
- **Asynchronous Transfer Mode (ATM)** is a widely deployed communications backbone technology. This standards-based transport medium is widely used within the core--at the access and in the edge of telecommunications systems to send data, video and voice at high speeds. ATM uses sophisticated network management features to allow carriers to guarantee quality of service. Sometimes referred to as cell relay, ATM uses short, fixed-length packets called cells for transport. Information is divided among these cells, transmitted and then re-assembled at their final destination. ATM services are offered by most carriers. A number of DOTs are using this type of service – especially in metropolitan areas – to connect CCTV cameras (using compressed video), traffic signal systems, and dynamic message signs to Traffic Operations Centers.

Electro-mechanical interfaces for data transmission and signaling normally fall under the following standards: RS-232; RS-422; RS-423; RS-449; RS-485. Each of these standards provides for the connector wiring diagrams and electrical signaling values for communications

purposes. These standards were developed by the EIA (Electronic Industries Alliance) and the TIA (Telecommunications Industry Association).

Ethernet was invented by the Xerox Corporation in 1973 to provide connectivity between many computers and one printer. The original Xerox design has evolved into an IEEE standard (802.3XX) with many variations that include 10Base-T, Fast-Ethernet (100Base-T), and GigE (Gigabit Ethernet). The Ethernet system consists of three basic elements:

- physical medium used to carry Ethernet signals between computers,
- set of medium access control rules embedded in each Ethernet interface that allow multiple computers to fairly arbitrate access to the shared Ethernet channel,
- Ethernet frame that consists of a standardized set of bits used to carry data over the system

Ethernet works by setting up a very broadband connection to allow packets of data to move at high speed through a network. This assures that many users can communicate with devices in a timely manner. The Ethernet is shared, and under normal circumstances, no one user has exclusivity. Ethernet uses a protocol called **CSMA** (carrier sense multiple access). In this arrangement, the transmitting device looks at the network to determine if other devices are transmitting. The device “senses” the presence of a carrier. If no carrier is present, it proceeds with the transmission.

17.2.5.3 Video Transmission

Video is transmitted in either an analog or digital format. Video transmitted in an analog format must usually travel over coaxial cable or fiber optic cable. The bandwidth requirements cannot be easily handled by twisted pair configurations.

Video can be transmitted in a digital format via twisted pair. It can be transmitted in a broadband arrangement as full quality and full motion, or as a compressed signal offering lower image or motion qualities. Via twisted pair, video is either transmitted in a compressed format, or sent frame-by-frame. The frame-by-frame process is usually called “slow-scan video”.

Digital video requires that the analog video be converted to digital “data”. This is accomplished via a CODEC (coder-decoder). The process is very similar to the conversion of voice from analog to digital, but is substantially more complex. Several different types of video CODECs are available to serve a wide variety of communication needs. The CODEC provides two functions. First, it converts the analog video to a digital code. Second, it “compresses” the digital information to reduce the amount of bandwidth required for transmission. In the process of converting from analog to digital and back to analog, the video image loses some quality. Also the compression process injects a loss of video quality. Each of the following CODECs has its own set of video image quality loss characteristics.

- H.261 CODECs are used primarily for video conferencing. The analog to digital process sacrifices motion for video and audio quality. They typically use POTS (or DDS) services to reduce total cost of operation and are designed to provide simultaneous multiple connections for group conferencing. However, they can use T-1 and “fractional T-1” circuits for better image quality.
- DS-3 CODECs were developed for use in distance learning systems, providing full motion, full video and audio quality for the classroom situation. Communication is accomplished via

broadband links. The communication links can be leased DS-3 service, or privately installed copper or fiber optic networks.

- JPEG (Joint Photographic Group Experts) and Motion JPEG are some of the most widely used CODECs for video surveillance purposes. However, they were primarily developed for the purpose of storing images electronically. Each still image is converted to an electronic data image and transmitted. The still images are assembled at a receive decoder and displayed at a rapid rate to provide motion. They can be used with POTS communication circuits, fixed low speed data circuits, or broadband copper and fiber optic communication links. They are also used in wireless applications such as spread spectrum radio, or CDPD cellular.
- MPEG (Moving Picture Experts Group) CODECs were developed to provide a better quality motion image compression. There is less image quality lost in the conversion and compression processes. However, the primary purpose of MPEG CODECs is to provide “real-time like” motion pictures via the Internet (also called Streaming Video). The overall process creates a storage buffer so that there is always a slight delay between the request to view and the start of the motion picture. For the average user of the Internet, this is not a problem. CODEC manufacturers using the MPEG-2 standard for traffic surveillance purposes have adapted this standard to create a real-time video transmission. However, this does have a minimal impact on final image quality. The MPEG-4 standard was developed for Internet streaming video, but is also being adapted for “real-time” surveillance purposes.

17.2.6 Emerging Trends

The “Freeway Management State – of – the – Practice White Paper” (Reference 2) identifies the following area as the “state – of – the – art⁴⁶”: “to transmit data using wireless communication media where wireline communication is either too expensive or is not yet available”.

Another emerging trend (from the perspective of freeway management systems) is the Internet, which is the focus of Chapter 9 of the Communications Handbook. That chapter provides a basic understanding of the composition of the Internet, the World Wide Web (WWW), how it works, and how it can be used as part of an overall communications and operational strategy for Traffic Signal, FMS, and ITS systems. Many DOTs are using the Internet as part of an overall public information strategy. A few have begun to make it part of their internal operational programs

The Internet Protocol (IP) is the basic software used to control an Internet. This protocol specifies how gateway machines route information from the sending computer to the recipient computer. Another protocol, Transmission Control Protocol (TCP), checks whether the information has arrived at the destination computer and, if not, causes the information to be resent. The overall protocol is referred to as TCP/IP – Transmission Control Protocol/Internet Protocol. Recent advances in traffic management systems are utilizing IP for communications with field controllers, and streaming video for video transmission.

The last chapter of the Communications Handbook (Future) provides some insight on the general future of communications systems and provide a listing of current standards efforts that

may have an impact on the use of communications systems for traffic and transportation purposes.

17.3 IMPLEMENTATION AND OPERATIONAL CONSIDERATIONS

The Communications Handbook includes material that focuses on the design, construction and installation of media (both wireline and wireless) for a communication network. As many ITS systems are deployed in stages, it is important that the user agency maintain a consistent design and construction philosophy. This chapter provides useful guidelines on how to maintain consistency in the overall process.

No communications plan is complete without consideration of system operation and maintenance. All communication systems require some degree maintenance and upgrades. The Communications Handbook also addresses these issues.

One of the key issues is who will maintain the communications network and associated equipment – internal staff or outsourced services; and what types of personnel are required and their qualifications. The answer can vary depending on the technology, complexity, and size of the system.

Another important consideration is that of risk assessment. This should be performed during system design as a consideration of redundancy needs, and will also have a direct impact on the maintenance requirements. The communication system is, in most respects, the least failure prone element of an overall system, but potentially has a high risk of being disrupted by outside forces.

Planned system updates will also likely be required. Communication equipment manufacturers will offer firmware updates, and occasionally revise the physical design of the equipment. Very often, these updates are not critical to existing operations and systems. However, agencies should budget for occasional updates, especially if the manufacturer offers a major firmware update. Upgrades to equipment may also be required due to addition of new segments.

17.4 EXAMPLES

Several examples are provided in Reference 1.

17.5 REFERENCES

1 – FHWA; Communications Handbook (Still under development. To be published in early 2004)

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