CAMBRIDGE SYSTEMATICS

Traffic Congestion and Reliability

Trends and Advanced Strategies for Congestion Mitigation

final

report

prepared for

Federal Highway Administration

prepared by

Cambridge Systematics, Inc.

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Texas Transportation Institute

September 1, 2005

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Table of Contents

List of Tables

List of Figures

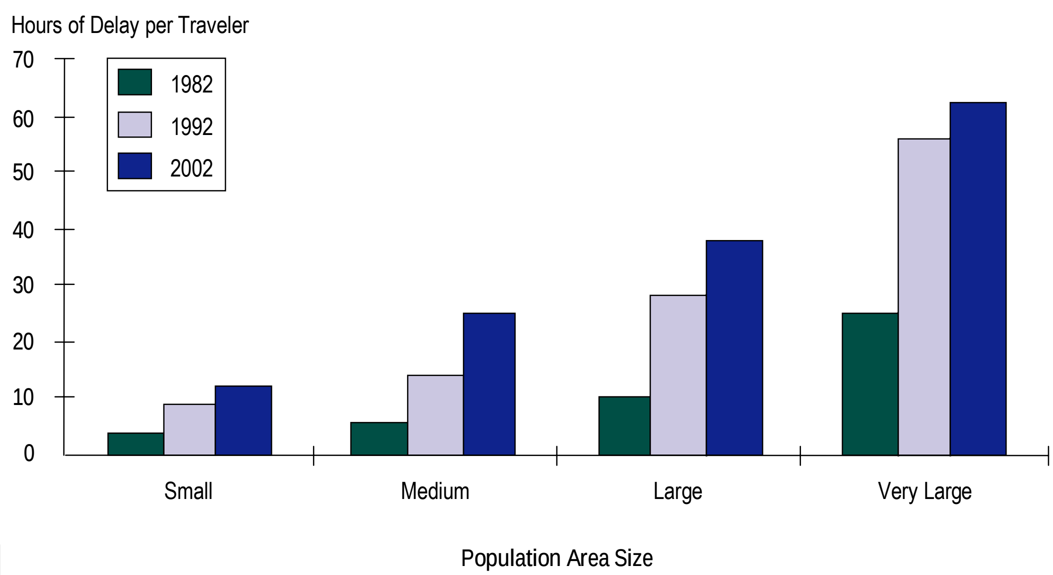
Executive Summary

Overview

The report *Traffic Congestion and Reliability: Trends and Advanced Strategies for Congestion Mitigation* provides a snapshot of congestion in the United States by summarizing recent trends in congestion, highlighting the role of travel time reliability in the effects of congestion, and describing efforts to reduce the growth of congestion. This is the second in an annual series developed by the Federal Highway Administration's (FHWA) Office of Operations.

Much of the report is devoted to communicating recent trends in congestion. (See Figure ES.1 for an overview of congestion trends.) One of the key principles that the FHWA has promoted is that the measures used to track congestion should be based on the *travel time experienced by users of the highway system.* While the transportation profession has used many other types of measures to track congestion (such as "level of service"), travel time is a more direct measure of how congestion affects users. Travel time is understood by a wide variety of audiences – both technical and non-technical – as a way to describe the performance of the highway system. All of the congestion measures used in the report are based on this concept.

Figure ES.1 Congestion Has Grown Substantially in U.S. Cities over the Past 20 Years



Source: In their most recent annual report on the state of congestion in America's cities, the Texas Transportation Institute noted that congestion has grown substantially over the past 20 years. While the largest cities are the most congested, congestion occurs – and has grown – in cities of every size. A more complete discussion follows later in this section. (The 2005 Urban Mobility Report, http://mobility.tamu.edu.)

The report pays particular attention to the concept of ***travel time reliability*** – how consistent travel conditions are from day-to-day – and strategies aimed at improving reliability. The variation in travel times is now understood as a separate component of the public's and business sector's frustration with congestion problems. Average travel times have increased and the report discusses ways to reduce them. But the day-to-day variations in travel conditions pose their own challenges and the problem requires a different set of solution strategies. The topics covered in this year's report include:

- Characteristics of congestion and travel reliability;
- Significance of reliability to travelers;
- Recent trends in congestion, especially reliability;
- Strategies to address congestion problems; and
- New tools and initiatives for dealing with congestion.

WHAT IS CONGESTION?

Congestion is relatively easy to recognize—roads filled with cars, trucks, and buses, sidewalks filled with pedestrians. The definitions of the term *congestion* mention such words as "clog," "impede," and "excessive fullness." For anyone who has ever sat in congested traffic, those words should sound familiar. In the transportation realm, congestion usually relates to an excess of vehicles on a portion of roadway at a particular time resulting in speeds that are slower – sometimes much slower – than normal or "free flow" speeds. Congestion often means stopped or stop-and-go traffic.

Previous work has shown that congestion is the result of seven root causes, often interacting with one another.

1. **Physical Bottlenecks ("Capacity")** – Capacity is the maximum amount of traffic capable of being handled by a given highway section. Capacity is determined by a number of factors: the number and width of lanes and shoulders; merge areas at interchanges; and roadway alignment (grades and curves).
2. **Traffic Incidents** – Are events that disrupt the normal flow of traffic, usually by physical impedance in the travel lanes. Events such as vehicular crashes, breakdowns, and debris in travel lanes are the most common form of incidents.
3. **Work Zones** – Are construction activities on the roadway that result in physical changes to the highway environment. These changes may include a reduction in the number or width of travel lanes, lane "shifts," lane diversions, reduction, or elimination of shoulders, and even temporary roadway closures.
4. **Weather** – Environmental conditions can lead to changes in driver behavior that affect traffic flow.

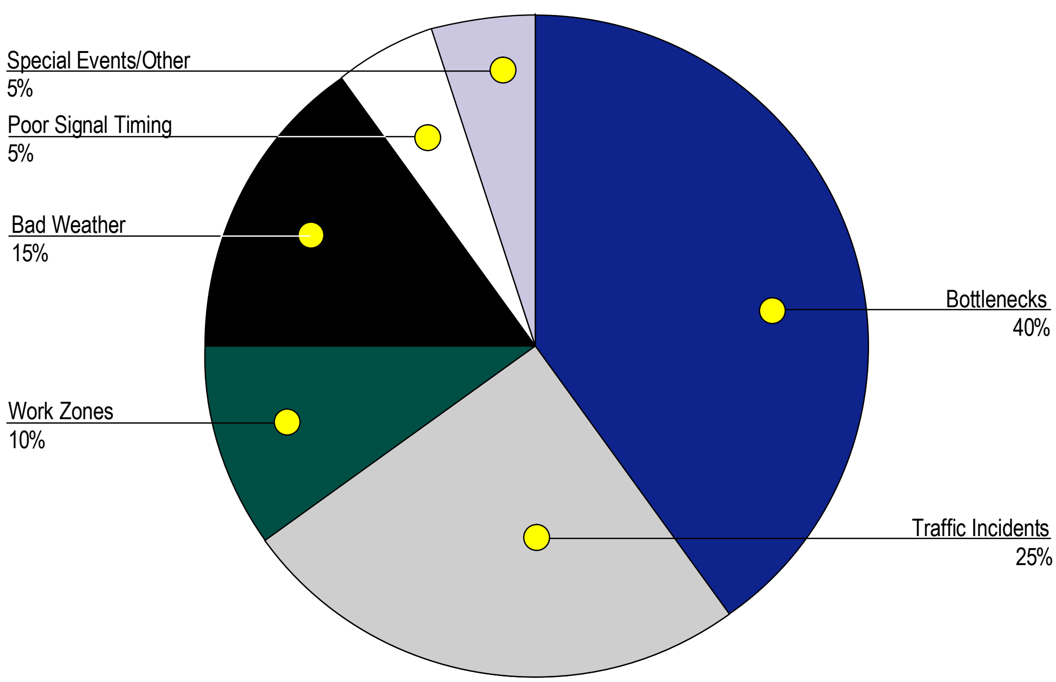
5. **Traffic Control Devices** – Intermittent disruption of traffic flow by control devices such as railroad grade crossings and poorly timed signals also contribute to congestion and travel time variability.

6. **Special Events** – Are a special case of demand fluctuations whereby traffic flow in the vicinity of the event will be radically different from "typical" patterns. Special events occasionally cause "surges" in traffic demand that overwhelm the system.

7. **Fluctuations in Normal Traffic** – Day-to-day variability in demand leads to some days with higher traffic volumes than others. Varying demand volumes superimposed on a system with fixed capacity also results in variable (i.e., unreliable) travel times.

National estimates of congestion by source are useful to guide FHWA's program and to identify which areas should be emphasized (Figure ES.2). However, local conditions vary widely – developing methods for estimating congestion sources on individual highways would be highly useful to transportation engineers "in the trenches" trying to decide how to craft mitigation strategies. FHWA is currently researching this issue and is developing a methodology to allow transportation engineers to estimate the sources' contribution to total congestion using local data.

Figure ES.2 The Sources of Congestion
National Summary



Source: http://www.ops.fhwa.dot.gov/aboutus/opstory.htm.

Congestion results from one or more of the seven sources on the highway system. The interaction between multiple sources is complex and varies greatly from day-to-day and highway-to-highway. The problem is that with the exception of the physical bottlenecks, the sources of congestion occur with maddening irregularity – nothing is ever the same from one day to the next! One day commuters might face low traffic volumes, no traffic incidents, and good weather; the next day traffic might be heavier than normal, it might be raining, and a severe crash may occur that blocks lanes on the roadway.

As if the congestion picture was not complicated enough, consider further that some events can cause other events to occur. For example:

- Abnormally high congestion can shift traffic to other highways or cause travelers to leave later, go to other destinations, or choose not to go at all.
- High congestion levels can lead to an increase in traffic incidents due to closer vehicle spacing and overheating of vehicles during summer months.
- Bad weather can lead to crashes.
- The traffic turbulence and distraction to drivers caused by an initial crash can lead to other crashes.

Because of the interconnectedness of the sources, significant payoffs can be expected by treating them.

In addition to causing delay to travelers, the sources of congestion also produce another effect: variability in congestion conditions. This variability in congestion is known as ***travel time reliability***, in other words, how "reliable" travel conditions are day-to-day, and is of intense interest for transportation professionals dealing with congestion.

THE IMPORTANCE OF TRAVEL TIME RELIABILITY

Congestion has not only grown over the past two decades, it has become more volatile as well. Congestion levels are never the same from day-to-day on the same highway because the variety of traffic-influencing events that influence congestion are never the same. Because travel conditions are so unreliable on congested highways, travelers must plan for these problems by leaving early just to avoid being late. This means extra time out of everyone's day that must be devoted to travel – even if it means getting somewhere early, that's still time we could be using for other endeavors. Commuters could be late for work or after-work appointments, business travelers could be late for meetings, and truckers could incur extra charges by not delivering their goods on time. And all because of unreliable travel conditions on our highways!

What is Travel Time Reliability and What Are Its Causes?

Travel time reliability is defined as how much travel times vary over the course of time. This variability in travel times from one day to the next is due to the fact that underlying conditions vary widely. The seven sources of congestion – especially traffic-influencing "events" such as traffic incidents, weather, and work zones – that contribute to total congestion also conspire to produce unreliable travel times, because these are never the same from day-to-day. Transportation professionals have for many years referred to this event-driven variability in travel conditions as ***non-recurring congestion*** *since it happens differently every day. Travel time reliability, then, is just a more formal way of describing what has been historically called non-recurring congestion.*

By its very nature, roadway performance is at the same time consistent and repetitive, and yet highly variable and unpredictable. It is consistent and repetitive in that peak usage periods occur regularly and can be predicted with a high degree of reliability. (The relative size and timing of "rush hour" is well known in most communities.) At the same time, it is highly variable and unpredictable, in that on any given day, unusual circumstances such as crashes can dramatically change the performance of the roadway, affecting both travel speeds and throughput volumes.

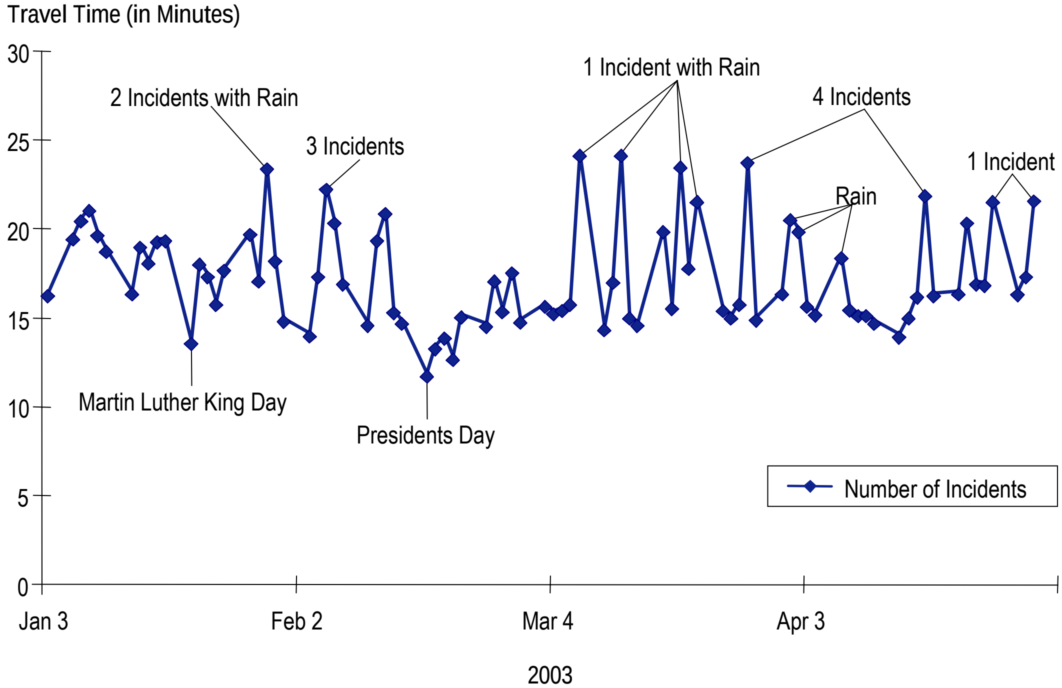
The traveling public experiences these large performance swings, and their expectation or fear of unreliable traffic conditions affects both their view of roadway performance, and how, when and where they choose to travel. For example, if a road is known to have highly variable traffic conditions, a traveler using that road to catch an airplane routinely leaves lots of "extra" time to get to the airport. In other words, the "reliability" of this traveler's trip is directly related to the variability in the performance of the route she or he takes.

How Do We Measure Travel Time Reliability?

Travel time reliability can be defined in terms of how travel times vary over time (e.g., hour-to-hour, day-to-day). Commuters who take congested highways to and from work are well aware of this. When asked about their commutes, they will say things like: "it takes me 45 minutes on a good day, but an hour and 15 minutes on a bad day" or "it takes me an additional 10 minutes if I leave 15 minutes later."

Figure ES.3 typifies this experience with data from State Route 520, a major commuter route, in Seattle, WA. If there was no congestion on this 11.7 mile segment, travel times would be around 12 minutes; on President's Day this was the case. On other days, the average travel time was 17.5 minutes, or an average speed of 40 mph. But when events (traffic incidents and weather) are present, it could take nearly 25 minutes, or 43 percent longer than average. Commuters who take State Route 520 corridor must plan for this unpredictable variability if they want to reliably arrive on time – the average just won't do.

Figure ES.3 Weekday Travel Times
5:00-6:00 p.m., on State Route 520 Eastbound, Seattle, Washington



In other words, they have to build in a ***buffer*** to their trip planning to account for the variability. If they build in a buffer, they will arrive early on some days. This may not necessarily be a bad thing, but the extra time is still carved out of their day – time they could be using for other pursuits besides commuting.

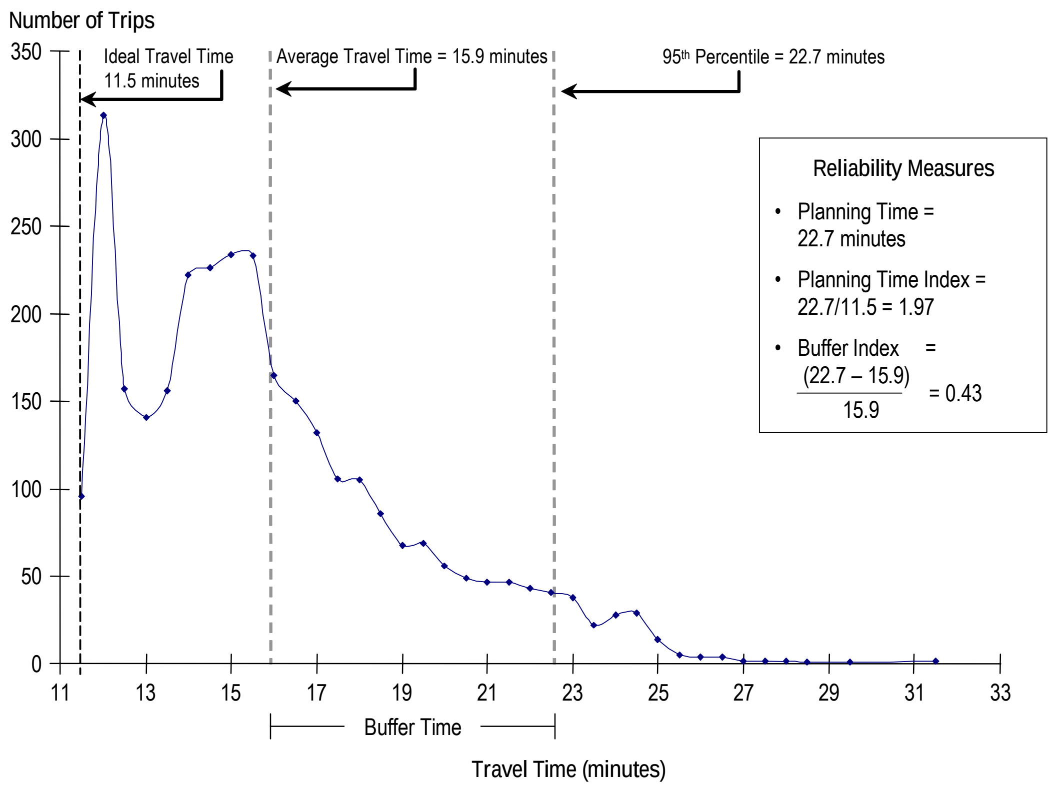
We use this buffer to measure travel time reliability. Several statistics can be developed from this information, but we have found the ***Buffer Index***, to be a particularly useful one. This is calculated as the extra travel time needed to accomplish a trip 19 times out of 20 chances in relation to the ***average*** travel time for that trip. In the State Route 520 example, this is: (25 minutes – 17.5 minutes)/17.5 minutes = 43 percent. Tracking changes in the Buffer Index over time indicates whether reliability is improving or degrading.

MEASURING RELIABILITY

Because reliability is defined by how travel times vary over time, it is useful to develop frequency distributions to see how much variability exists. Calculating the average travel time and the size of the "buffer" – the extra time needed by travelers to ensure a high rate of on-time arrival – then helps us to develop a variety of reliability measures. These measures include the Buffer Index, the Planning Time, and the Planning Time Index (see Figure ES.4). They are all based on the same underlying distribution of travel times, but describe reliability in slightly different ways:

- **Planning Time –** The sheer size of the buffer (the 95th percentile travel time).
- **Planning Time Index –** How much larger the buffer is than the "ideal" or "free flow" travel time (the ratio of the 95th percentile to the ideal). In the 11.5-mile long corridor shown, the ideal travel time is 11.5 minutes, assuming that vehicles will travel at 60 mph when no congestion is present.
- **Buffer Index –** The size of the buffer as a percentage of the average (95th percentile minus the average, divided by the average).

Figure ES.4 Distribution of Travel Times, State Route 520 Seattle, Eastbound, 4:00-7:00 p.m. Weekdays (11.5 Miles Long)



WHAT VALUE DOES PROVIDING RELIABLE TRAVEL TIMES HAVE?

Improving the reliability of travel times is significant for a number of reasons:

- Improvements in reliability are achieved by reducing the overall variability due to the seven sources of congestion, mainly traffic-influencing events. In other words, improvement strategies targeted at reliability decrease the delay due traffic-influencing events (e.g., traffic incidents, bad weather, and work zones). This produces a double benefit: not only is reliability improved (by reducing the variability in travel times) but the ***total congestion delay*** experienced by travelers is also reduced. The value of saving travel time is very high for certain types of trips such as those taken by emergency responders, but just about every traveler realizes value from travel time savings.
- Reducing total congestion saves time and fuel, and leads to decreased vehicle emissions.
- Addressing three of the major components of unreliable travel – traffic incidents, bad weather, and work zones – also leads to safer highways. By reducing the duration of these events, we are reducing how long travelers are exposed to less safe conditions.
- Commuters as well as freight carriers and shippers are all concerned with travel time reliability. Variations in travel time can be highly frustrating and are valued highly by both groups. Previous research indicates that commuters value the variable component of their travel time between one and six times as much as average travel time. And the increase in just-in-time (JIT) manufacturing processes has made a reliable travel time almost more important than an uncongested trip. Significant variations in travel time will decrease the benefits that come from lower inventory space and the use of efficient transportation networks as "the new warehouse." Therefore, in both the passenger and freight realms, evidence suggests that travel time reliability is valued at a significant "premium" by users.
- Reducing congestion at international border crossings leads to lower transportation costs and benefits the national economy as a whole. Further, reducing congestion on U.S. highways for freight moving between Canada and Mexico fosters international trade. Therefore, congestion on U.S. highways has a large influence on the efficiency of international trade.

CONGESTION AND RELIABILITY TRENDS

Examination of the available data on congestion and highway usage over the past decade leads to the conclusion that congestion is getting worse. Highway usage has been growing at roughly two percent per year and is expected to continue doing so. On highways that are already congested, any additional traffic leads to a disproportionately higher amount of congestion – once traffic flow has broken down to stop-and-go conditions, adding more vehicles makes recovery very difficult.

Congestion Is Getting Worse

A good source for monitoring congestion trends is produced annually by the Texas Transportation Institute (TTI).[1] In their 2005 report, TTI's researchers found that congestion levels in 85 of the largest metropolitan areas have grown in almost every year in all population groups from 1982 to 2003. Average urban congestion trends from 1993-2003 include the following:

- Peak-period[2] trips take an average of about seven percent longer.
- Travelers spend 47 extra hours per year in travel compared to 40 hours in 1993.
- The percent of freeway mileage that is congested has grown from 51 percent to 60 percent.

Congestion has clearly grown. Congestion used to mean it took longer to get to/from work in the "rush hour." It used to be thought of as a "big city" issue or an element to plan for while traveling to special large events. There was some "slower traffic" in small cities, but it was not much more than a minor inconvenience. The problems that smaller cities faced were about connections to and between cities, manufacturing plants, and markets.

Consider the following four characteristics of congestion trends, as shown in Figure ES.5:

- **Congestion affects more of the system**. You might encounter stop-and-go traffic on any major street or freeway. Congestion effects have spread to neighborhoods, where cities and residents have developed elaborate plans and innovative techniques to make it harder for commuters to use the streets where kids play as bypass routes for gridlocked intersections.
- **Congestion affects more time of the day**. We are not just seeing these problems in the "rush hour." Peak periods typically stretch for two or three hours

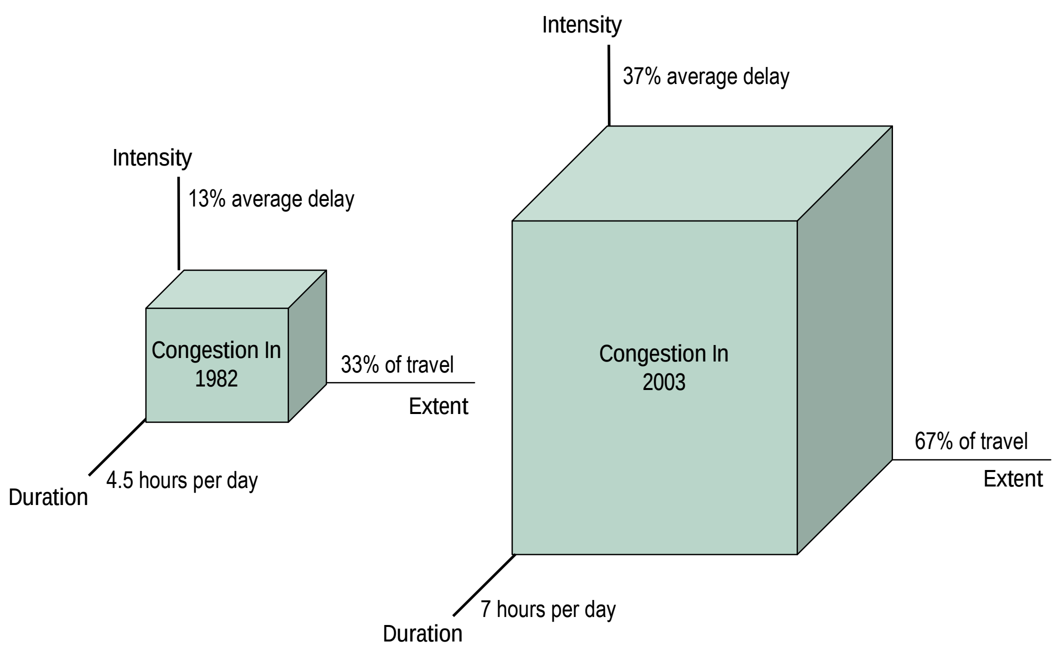
[1] Schrank, D. and Lomax, T., *2005 Urban Mobility Report,* Texas Transportation Institute.

[2] In most metropolitan areas, the idea of "rush hour" is obsolete – congestion happens for multiple hours on both morning and evening weekdays.

in the morning and evening in metro areas above one million people. Larger areas can see three or four hours of peak conditions. These are just the average conditions. Many cities have a few places where any daylight hour might see stop-and-go traffic. Weekend traffic delays have become a problem in recreational areas, near major shopping centers or sports arenas, and in some constrained roadways.

- **The extra travel time penalty has grown**. It just takes longer to get to your destination. Not just work or school, but shopping trips, doctor visits, and family outings are planned around the questions "How long do I want to spend in the car, bus, or train?" and "Is it worth it?" Peak-period trips required 37 percent more travel time in 2003 than a free flow trip at midday, up from 28 percent 10 years earlier.
- **Nonrecurring congestion exerts a greater influence on total congestion.** As the physical capacity of our roadways is consumed by the growth in traffic we've seen over the past 20 years, they also become more vulnerable to disruptions caused by traffic-influencing events such as traffic incidents, bad weather, and work zones. Further, these events can occur at any time and in places that don't usually experience congestion, thereby spreading congestion to more roadways and more times of the day.

Figure ES.5 Weekday Peak-Period Congestion Has Grown in Several Ways in the Past 20 Years in Our Largest Cities



Source: Analysis of data used in *2005 Urban Mobility Report*, Texas Transportation Institute.

Travel Reliability Is Also Getting Worse

Changes in reliability could be considered a fourth characteristic of congestion trends. The extra travel time and amount of the day and system affected by travel delays is not the same every day. It may not even be as it was predicted 10 minutes ago.

- **1982 –** If your midday trip took 20 minutes, it would take you 23 minutes in the peak. Although no reliability statistics exist from that long ago, analysis of recent data suggest that you would have to add an additional nine minutes to that trip to guarantee on-time arrival at your destination; a total of 32 minutes might be planned for that trip.
- **2003 –** By 2003, that 20-minute free-flow trip took 28 minutes. And if on-time, arrival was important you should allow 40 minutes for the trip.

Only in the last few years have the data been available to assess travel time reliability. Atlanta, Georgia is a city with both a history of detailed traffic monitoring data and significant congestion. Table ES.1 shows that travel times grew increasingly unreliable in several highly traveled freeway corridors over a four-year period. This is indicated by increases in the Buffer Index; as it rises, travel times become more unreliable.

Table ES.1 Reliability Statistics, Atlanta, Georgia
2000-2003

Atlanta Freeway Corridor	Buffer Index			
	2000	2001	2002	2003
I-75A, NB (I-285 to I-20, 7.72 miles)	21%	29%	33%	35%
I-75A, SB (I-20 to I-285, 7.36 miles)	12%	22%	25%	33%
I-75B, NB (I-20 to I-85 Split, 3.73 miles)	48%	59%	58%	100%
I-75B, SB (I-85 Split to I-20, 4.04 miles)	24%	36%	32%	56%
I-75C, NB (I-85 Split to I-285, 8.95 miles)	30%	39%	32%	35%
I-75C, SB (I-285 to I-85 Split, 9.63 miles)	13%	29%	42%	50%
I-85A, NB (Camp Creek Parkway to I-75, 4.18 miles)	6%	1%	1%	3%
I-85A, SB (I-75 to Camp Creek Parkway, 4.05 miles)	7%	8%	5%	8%
I-85B, NB (I-75 to Jimmy Carter Boulevard, 14 miles)	22%	49%	19%	23%
I-85B, SB (Jimmy Carter Boulevard to I-75, 13.6 miles)	41%	37%	31%	34%

STRATEGIES TO REDUCE CONGESTION AND IMPROVE RELIABILITY – FOCUS ON OPERATIONS

Transportation engineers and planners have developed a variety of strategies to deal with congestion. These fall into three general categories:

8. **Adding More Base Capacity –** Increasing the number and size of highways and providing more transit and freight rail service. This can include expanding the base capacity (by adding additional lanes or building new highways) as well as redesigning specific bottlenecks such as interchanges and intersections to increase their capacity.
9. **Operating Existing Capacity More Efficiently –** Getting more out of what we have.
10. **Encouraging Travel and Land Use Patterns that Use the System in Less Congestion Producing Ways –** Travel Demand Management (TDM), non-automotive travel modes, and land use management.

All of these strategies can lead to a reduction in congestion, but it is operations strategies that have the most dramatic effect on reliability because they target the sources of unreliable travel directly. Operations strategies focus on the traffic-influencing events that both raise the general level of congestion and increase unreliable travel.

A vast array of strategies are in the transportation professional's "operations toolbox," most of which use advanced technology to identify problems, manage traffic flow, and relay travel conditions to users. Known as Intelligent Transportation Systems (ITS), these technologies enable transportation professionals to implement operations strategies targeted specifically at the causes of unreliable travel:

- **Incident Management –** Identifying incidents more quickly, improving response times, and managing incident scenes more effectively;
- **Work Zone Management –** Reducing the amount of time work zones need to be used and moving traffic more effectively through work zones, particularly at peak times;
- **Road Weather Management –** Prediction of weather events (such as rain, snow, ice, and fog) in specific areas and on specific roadways, allowing for more effective road surface treatment;
- **Planned Special Events Traffic Management –** Pre-event planning and coordination and traffic control plans;
- **Freeway, Arterial, and Corridor Management –** Advanced computerized control of traffic signals, ramp meters, and lane usage (lanes that can be reversible, truck-restricted, or exclusively for high occupancy vehicles);

- **Traveler Information –** Providing travelers with real-time information on roadway conditions, where congestion has formed, how bad it is, and advice on alternative routes; and
- **Value Pricing Strategies –** Proactively managing demand and available highway capacity by dynamically adjusting the toll paid by users.

FHWA has strongly promoted operations for improving congestion for several years in the form of grants, education and outreach, technical tools, and standards development. State and local transportation agencies, who are responsible for implementing transportation improvement projects, have embraced operations as a key part of their solutions. Operations strategies in the above categories have been effectively deployed around the country to decrease congestion and improve reliability. Many deployments include combinations of strategies, or ***congestion relief packages***, which have proven to be more effective than simply deploying individual strategies. Several of the more significant recent deployments include:

- **Arterial Management**. *Road Commission of Oakland County (RCOC) FAST-TRAC Project – Advanced Traffic Signal Coordination.* Oakland County, located just north of Detroit, began implementation of the FAST-TRAC (Faster and Safer Travel through Traffic Routing and Advanced Controls) system in 1992. The key element of FAST-TRAC is the Sydney Coordinated Adaptive Traffic System (SCATS), an advanced adaptive signal system with the capability to adjust signals on an individual intersection, corridor, and areawide basis. The system detects real-time demand on the highways and continuously adjusts signal timing to meet the demand. *The result is that FAST-TRAC reduces congestion by eliminating unnecessary stops and providing green phases where the demand is highest.*
- **Freeway Management and Incident Management.** *Wisconsin District 2 Freeway System Operational Assessment (FSOA) Program – Integrated Congestion Relief Strategies.* During the 1990s Wisconsin DOT's District 2 implemented a freeway management system in Milwaukee. The freeway management center, field equipment, and central computer system are known as the MONITOR system. Expansion continued into the early 2000s until most of the Milwaukee area's major freeways were covered with detectors along 130 miles of freeway, 18 cameras located at major interchanges, 20 Dynamic Message Signs to communicate with motorists, over 80 ramp meters, freeway service patrols, and trailblazer systems to aid in rerouting traffic during traffic incidents, construction, and other emergencies. The program is coordinated with several other related efforts including WisDOT's statewide SmartWays Program and the Gary-Chicago-Milwaukee Corridor Coalition (GCM). *The ramp meters keep the freeway operating at steady flow for longer periods of time than otherwise could be expected. The service patrols and cameras allow for quicker identification of and response to incidents, a major source of unreliable travel.*

- **Incident Management.** *Maryland's Coordinated Highway Action Response Team (CHART) – Statewide Traffic Incident Management.* Maryland developed the Coordinated Highway Action Response Team (CHART) in the mid 1980s as an effort to improve travel to and from the state's coastal area. Years later, this system has evolved into a statewide operations tool that collects, processes and broadcasts traffic information. Data are collected through a communications infrastructure, a closed-circuit television system, and sensor detection system. The information is then used to make real-time traffic management decisions and provide motorists with information through dynamic message signs, radio travel advisories, and a telephone advisory system. Travelers may also access an interactive on-line GIS mapping service for major roads to obtain average speed, traffic conditions, and lane closures due to weather or construction activities. In addition, travelers can view selected road conditions through on-line video links. *By reducing the duration of incidents and providing travelers with advanced warning of their locations, travel reliability is improved.*

- **Corridor Management, Incident Management, and Traveler Information.** *Seattle's Integrated Operations Programs.* The Washington State DOT has been aggressively pursuing operations-oriented improvements for many years. An innovative combination of technology, policies, and resource allocation has provided travelers in Washington with more reliable travel times, reduced collisions and more efficient use of the available funding. Key aspects of the approach include: incident management; ramp metering; short, selected capacity increases; travel conditions and commute time information; high-occupancy vehicle lanes and public transportation facilities; and readily understood performance measures. *As with the Wisconsin and Maryland projects, aggressive incident management practices in Seattle reduce the delay caused by incidents and improve travel reliability.*

- **Work Zone Management, Corridor Management, and Value Pricing.** *Houston's Accelerated Construction of the Katy Freeway – The Systems Approach to Bottleneck Removal.* The Katy Freeway (I-10 West in Houston) expansion project is being constructed using an innovative combination of construction and financing techniques. The project, in broad terms, results in a six-year construction program, (compared to the 12-year original schedule), provides a four-lane tollway in the middle of an expanded freeway, improves the aesthetic and landscaping treatments in the corridor, and rebuilds the existing freeway pavement and bridges.

  Houston's Katy Freeway improvement project highlights an emerging and highly promising operations strategy: ***value pricing of managed lanes***. In this approach, certain travel lanes are set aside for high occupancy vehicles, toll priced for other vehicles, or both. On the Katy Freeway, travelers in buses and carpools, currently restricted to a three-person requirement in the peak hours (2-person requirement during other hours) due to limited capacity in the HOV lane, will be able to travel in the free-flow managed lanes. All travelers will have shorter time periods of congested conditions in the peak, and should have much less stop-and-go traffic in the off-peak. The managed lanes will also provide choices – free, but congested lanes, bus or carpool use of the managed lanes for free or reduced price, and a premium pay-for-travel system that allows travelers to determine the importance of their trip and pay for faster, more reliable travel if they so choose.

PROMISING OPERATIONS STRATEGIES ON THE HORIZON

In addition to innovative projects that have already been implemented, a number of even more advanced technologies and integrated programs are in development. These programs and technologies offer great promise for addressing congestion problems in the near future. A review of several such programs and technologies follows.

***iFlorida:* Testbed for the Next Generation of Operations Strategies.** (Freeway, Arterial, and Corridor Management; Road Weather Management; and Traveler Information). In March 2003, the Florida Department of Transportation (FDOT) was selected to participate in a highly innovative model deployment of operational strategies with FHWA. Named *iFlorida*, this project is based on the idea that advanced operational strategies require highly detailed traffic condition data over a wide area. Therefore, the initial stages of the project are to deploy additional traffic surveillance equipment to augment FDOT's existing information infrastructure. Once in place, the infrastructure will be used to demonstrate the wide variety of advanced operational functions to enhance traffic flow and improve security, including:

- Advanced weather information;
- Security monitoring command and control;
- Variable speed limit trial;
- Roadway diversion information;
- Statewide and central Florida traveler information web sites;
- On-board video surveillance on Orlando City buses; and
- Evacuation operations.

Integrated Corridor Management ITS Initiative. (Freeway, Arterial, and Corridor Management). Recognizing the importance of maximizing the operational effectiveness of an entire corridor, the U.S. DOT's ITS program includes "Integrated Corridor Management" (ICM) Systems as one of nine Major Initiatives. The basic premise behind the ICM initiative is that these independent systems and their cross – network linkages could be operated in a more coordinated and integrated manner resulting in significant improved operations across the corridor. As stated in the ICM vision, "metropolitan areas will realize significant improvements in the efficient movement of people and goods through aggressive and proactive integration and management of major transportation corridors." In essence, integrated corridor management consists of the operational coordination of specific transportation networks and cross-network connections comprising a corridor, and the coordination of institutions responsible for corridor mobility. The goal of the Integrated Corridor Management Initiative is to provide the institutional guidance, operational capabilities, and ITS technology and technical methods needed for effective Integrated Corridor Management Systems. Currently, the ICM initiative consists of the following four phases:

1. Foundational Research;
2. Operations and Systems Development;
3. Model Deployment; and
4. Knowledge and Technology Transfer.

***Clarus* Weather Initiative: Weather Prediction and Monitoring at the Roadway Level.** (Road Weather Management). *Clarus* (which is Latin for "clear") is an initiative to develop and demonstrate an integrated surface transportation weather observation data management system, and to establish a partnership to create a nationwide surface transportation weather observing and forecasting system. The objective of *Clarus* is to enable weather service providers to provide enhanced information to all road, rail and transit managers, and users to reduce the effects of adverse weather (e.g., fatalities, injuries, and delay). The *Clarus* Initiative aims to demonstrate how an open, integrated approach to observational data management can be used to consolidate surface transportation environmental data. Surface transportation environmental data assimilated by the *Clarus* system will include atmospheric data, pavement and subsurface data, as well as hydrologic (water level) data.

Next Steps: Building the Foundation for Effective Transportation Operations

Transportation operations can reduce the growth of congestion and improve the reliability of travel conditions for highway users. By directly targeting the sources of unreliable travel through transportation operations, the chances of unexpected and extreme congestion are greatly reduced, enabling travelers to experience more consistent conditions from day-to-day. Maximizing the potential of transportation operations requires much more than just deploying advanced technology. Meeting customer expectations for safe, reliable, and secure transportation services also requires that planners and system operators coordinate better so that operations can be strategically planned and deployed; so that operations data and system information is routinely shared among system operators, service providers, and transportation planners; and so that performance is continuously monitored to provide the feedback necessary to adapt to changing conditions and properly plan for future demands. These three important aspects of transportation operations are addressed below.

Coordination Between Planning and Operations

The operation of the transportation system and planning for the transportation system are often two detached sets of activities with different requirements and different cultures. Management and operation of the transportation system typically involves a different set of practitioners with a short-term or real-time focus, often with little consideration of how activities relate to a regional transportation systems long-term goals and objectives. Transportation planning has traditionally relied upon long-range travel needs, goals for a region, and funding constraints with little consideration of short-term and ongoing operational issues. Transportation agencies, metropolitan planning organizations (MPOs), and other stakeholders are increasingly recognizing the value of coordination and collaboration among planners and operators. Although they come from differing perspectives, transportation planning and operating agencies generally share the goal of enhancing system performance, and they can benefit from stronger linkages. The major point is that while each group has its own priorities, ***both planners and operators need to be involved in all phases of the project development timeline.***

Sharing Data Effectively: Using Operations Data for Improved Operations

Most major metropolitan areas have advanced technologies deployed to monitor traffic conditions. The data are used in real-time to identify traffic back-ups, retime traffic signals and ramp meters, and for estimating travel times along highway segments. The data is extremely valuable when stored and used to develop historic trends. In fact, the highly detailed nature of the data (typically collected every 20 to 30 seconds at one-half-mile intervals on freeways) allows transportation operators to conduct many types of analyses previously unavailable to the profession. Foremost among these is the estimation of reliability, which requires continuously collected data in order to build a sufficient history of how travel conditions vary over time.[3] The data also provides the basis for

[3] Most of the analyses presented in Chapter 2 (and some in Chapter 3) of the main report use archived operations data.

adjusting operations control strategies such as re-timing signals, deploying additional equipment, and implementing diversion and evacuation plans.

Data sharing may take several forms. For example, operations data could be archived for analysis and used in a number of transportation planning applications, such as calibration of systems planning models, use in micro-simulation models, or for performance monitoring of the transportation system. Effective data sharing can occur in several ways:

- Develop a regional data clearinghouse;
- Coordinate data resources with transit agencies;
- Use special events to initiate new data partnerships;
- Use operations data to develop more effective performance measures and improve planning analysis tools; and
- Use archived data to inform management and operations planning.

Marking Progress Through Performance Measurement

In the last few years, transportation operators have increasingly embraced the concept of performance measurement – tracking the trends of key indicators of how the transportation system is performing. Performance measurement has been widely used in the private sector as a way to improve delivery of goods and services to customers and ultimately, the success of the enterprise. Fundamentally, this is no different from providing improved transportation services to the public – public agencies are businesses "selling" transportation service and travelers are the consumers "buying" them.

Perhaps the most significant lesson from the review of performance measurement activities over the last two decades is that all performance measures and measurement systems have evolved. The changes have been the result of legislative interests, accountability efforts, new data sources, estimation procedures, changes in knowledge about traffic conditions, and perhaps most importantly, growth in demand for the information once reports and data are used. Transportation staff and leaders should experiment with measures, data, and presentation techniques.

Closing

Improved operations are a cornerstone of FHWA's efforts to improve travel conditions for highway travelers. FHWA continues to develop and compile information for transportation agencies and the public on how improved operations can effectively manage congestion. By addressing congestion by its root causes, both overall congestion levels and reliability are targeted. For more information on FHWA's congestion mitigation activities and to access the complete *Traffic Congestion and Reliability Report,* visit the FHWA Office of Operations web site at http://www.ops.fhwa.dot.gov.

1.0 Introduction

This report is the second in an annual series developed by the FHWA's Office of Operations. This series is meant to highlight recent trends in congestion across the Nation and to highlight the activities that Federal, state, and local transportation agencies have initiated to control congestion. The series pays particular attention to the concept of ***travel time reliability*** – how consistent travel conditions are from day-to-day – and strategies aimed at improving reliability.

Mitigating congestion is a high priority for the FHWA, which has established congestion mitigation as a key focus area.[4] This report supports this effort by providing a review of congestion issues and solutions in the United States. The emphasis of the report is on measuring trends in travel time reliability and making travel more reliable through Transportation System Management and Operations (TSM&O) initiatives. The topic of congestion is clearly much broader than this focus. While the broader context of congestion is discussed, the report spends most its effort on defining and measuring travel time reliability, and highlighting TSM&O strategies to address it.

One of the key principles that the FHWA has promoted in congestion measurement is that the metrics used to track congestion should be based on the ***travel time experienced by users of the highway system***. While the transportation profession has used many other types of metrics to measure congestion (such as "level of service"), travel time is a more direct measure of how congestion affects users. Travel time is understood by a wide variety of audiences – both technical and nontechnical – as a way to describe the performance of the highway system. All of the congestion metrics used in the report are based on this concept.

This year's report covers several topics, many of which are recurring themes in the series. However, when the same basic topics as previous years' reports are covered, new information that has come to light is used. The topics covered in this report are:

- **The characteristics of congestion and travel reliability.** Congestion results from the interplay of traffic demand, physical and operational characteristics of highways, and traffic-influencing "events" (such as traffic incidents and bad weather). These ingredients are present in different proportions on different highways. Understanding how they contribute to total congestion is the starting point for crafting congestion strategies. Current efforts to measure congestion are also highlighted.

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[4] Federal Highway Administration, *FY 2004 Performance and Accomplishments Report*.

- **The significance of reliability to travelers.** One of the consequences of the interplay of traffic, highway characteristics, and events is that congestion does not occur in the same way every day. Because traffic demand and events are variable – and can show up at different points on the highway system – congestion also varies from day-to-day. This variability – or "unreliability" – in travel conditions impacts highway users, especially those who must plan around a tight schedule.

- **Recent trends in congestion, especially reliability.** National estimates of congestion trends are reviewed and discussed. These estimates are derived using models that calculate congestion statistics from basic traffic and highway characteristics. On a national basis, we do not yet have a system in place to directly measure congestion everywhere it needs to be monitored. However, data that allow for direct and continuous monitoring of travel conditions are becoming more widespread in metropolitan areas. Sufficient history now exists in several urban areas to allow trend analysis for the last five years.

- **What works in dealing with congestion, particularly approaches that combine several strategies.** Several transportation agencies from around the country have been successful in applying congestion treatments. These success stories are highlighted as a way of showing what aggressive application can do against congestion. Moreover, past experience has taught us that while single strategies can target specific pieces of congestion, combining multiple strategies into "congestion packages" is more effective. The report examines areas where the "package" approach has successfully been used.

- **New tools and initiatives for dealing with congestion.** Information and vehicle technologies are becoming more sophisticated and more available to the average consumer. These offer the promise of greatly improving how we manage our transportation system for both congestion and safety. The report discusses the advances in technology and what FHWA is doing to promote their deployment.

2.0 The Nature of Traffic Congestion and Reliability: Causes, How They Are Measured, and Why They Matter

2.1 What is Congestion?

Congestion is relatively easy to recognize—roads filled with cars, trucks, and buses, sidewalks filled with pedestrians. The definitions of the term *congestion* mention such words as "clog," "impede," and "excessive fullness." For anyone who has ever sat in congested traffic, those words should sound familiar. In the transportation realm, congestion usually relates to an excess of vehicles on a portion of roadway at a particular time resulting in speeds that are slower – sometimes much slower – than normal or "free flow" speeds. Congestion often means stopped or stop-and-go traffic. The rest of this chapter is devoted to describing congestion and how we measure it, as well as its causes and consequences.

2.2 Causes of Congestion and Unreliable Travel

2.2.1 Background: The Seven Sources of Congestion

Previous work has shown that congestion is the result of seven root causes, often interacting with one another.[5] These "seven sources" can be grouped into three broad categories, as shown below:

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[5] *Providing a Highway System with Reliable Travel Times, Future Strategic Highway Research Plan Area 3*, Transportation Research Board, September 2003, http://www4.trb.org/trb/newshrp.nsf/web/progress_reports?OpenDocument.

Category 1 – Traffic-Influencing Events

1. **Traffic Incidents –** Are events that disrupt the normal flow of traffic, usually by physical impedance in the travel lanes. Events such as vehicular crashes, breakdowns, and debris in travel lanes are the most common form of incidents. In addition to blocking travel lanes physically, events that occur on the shoulder or roadside can also influence traffic flow by distracting drivers, leading to changes in driver behavior and ultimately degrading the quality of traffic flow. Even incidents off of the roadway (a fire in a building next to a highway) can be considered traffic incidents if they affect travel in the travel lanes.

2. **Work Zones –** Are construction activities on the roadway that result in physical changes to the highway environment. These changes may include a reduction in the number or width of travel lanes, lane "shifts," lane diversions, reduction, or elimination of shoulders, and even temporary roadway closures. Delays caused by work zones have been cited by travelers as one of the most frustrating conditions they encounter on trips.

3. **Weather –** Environmental conditions can lead to changes in driver behavior that affect traffic flow. Due to reduced visibility, drivers will usually lower their speeds and increase their headways when precipitation, bright sunlight on the horizon, fog, or smoke are present. Wet, snowy, or icy roadway surface conditions will also lead to the same effect even after precipitation has ended.

Category 2 – Traffic Demand

4. **Fluctuations in Normal Traffic –** Day-to-day variability in demand leads to some days with higher traffic volumes than others. Varying demand volumes superimposed on a system with fixed capacity also results in variable (i.e., unreliable) travel times, even without any Category 1 events occurring.

5. **Special Events –** Are a special case of demand fluctuations where traffic flow in the vicinity of the event will be radically different from "typical" patterns. Special events occasionally cause "surges" in traffic demand that overwhelm the system.

Category 3 – Physical Highway Features

6. **Traffic Control Devices –** Intermittent disruption of traffic flow by control devices such as railroad grade crossings and poorly timed signals also contribute to congestion and travel time variability.

7. **Physical Bottlenecks ("Capacity") –** Transportation engineers have long studied and addressed the physical ***capacity*** of roadways – the maximum amount of traffic capable of being handled by a given highway section. Capacity is determined by a number of factors: the number and width of lanes and shoulders; merge areas at interchanges; and roadway alignment (grades and curves). Toll booths may also be thought of as a special case of bottlenecks because they restrict the physical flow of traffic. There is also a wild card in the mix of what determines capacity – driver behavior. Research has shown that drivers familiar with routinely congested roadways space themselves closer together than drivers on less congested roadways. This leads to an increase in the amount of traffic that can be handled.

Highlight Box 1 discusses how the seven sources of congestion are related to the underlying traffic flow characteristics that create a disruption in traffic. We typically think of a bottleneck as a physical restriction on capacity (Category 3 above). However, disorderly vehicle maneuvers caused by events have a similar effect on traffic flow as restricted physical capacity.

Because the traffic flow effects are similar, traffic disruptions of all types can be thought of as producing losses in highway capacity, at least temporarily. In the past, the primary focus of congestion responses was oriented to adding more physical capacity: changing highway alignment, adding more lanes (including turning lanes at signals), and improving merging and weaving areas at interchanges. But addressing the "temporary losses in capacity" from other sources is equally important.

Highlight Box 1 – What Causes Breakdowns in Traffic Flow?

What causes traffic flow to break down to stop-and-go conditions? The layman's definition of congestion as "too many cars trying to use a highway at the same time" is essentially correct. Transportation engineers formalize this idea as capacity – the ability to move vehicles past a point over a given span of time. When the capacity of a highway section is exceeded, traffic flow breaks down, speeds drop, and vehicles crowd together. These actions cause traffic to back up behind the disruption. So, what situations would cause the overload that leads to traffic backups?

Basically, there are three types of traffic flow behavior that will cause traffic flow to break down:

1. ***"Bunching" of vehicles as a result of reduced speed.*** As vehicles are forced to get closer and closer together, abrupt speed changes can cause shock waves to form in the traffic stream, rippling backward and causing even more vehicles to slow down. Several things can cause vehicles to slow down while traveling in their intended lanes:

   - ***Visual Effects on Drivers.*** Driver behavior is a very important part of traffic flow. When traffic volume is high and vehicles are moving at relatively high speeds, it may take only the sudden slowing down of one driver to disrupt traffic flow. Driver behavior in this case is influenced by some sort of a visual cue and can include:

     i. Roadside distractions – unusual or atypical events that cause drivers to become distracted from driving.

     ii. Limited lateral clearance – drivers will usually slow down in areas where barriers get too close to travel lanes or if a vehicle has broken down on the shoulder.

     iii. Traffic incident "rubbernecking" – call it morbid curiosity, but most drivers will slow down just to get a glimpse of a crash scene, even when the crash has occurred in the opposite direction of travel or there is plenty of clearance with the travel lane.

     iv. Inclement weather – poor visibility and slippery road surfaces cause drivers to slow down.

   - ***Abrupt Changes in Highway Alignment.*** Sharp curves and hills can cause drivers to slow down either because of safety concerns or because their vehicles cannot maintain speed on upgrades. Another example of this type of bottleneck is in work zones where lanes may be redirected or "shifted" during construction.

2. ***Intended Interruption to Traffic Flow.*** "Bottlenecks on purpose" are sometimes necessary in order to manage flow. Traffic signals, freeway ramp meters, and tollbooths are all examples of this type of bottleneck.

3. ***Vehicle Merging Maneuvers***. This form of traffic disruption has the most severe effect on traffic flow, with the exception of really bad weather (snow, ice, dense fog). These disruptions in traffic flow are caused by some sort of physical restriction or blockage of the road, which in turn causes vehicles to merge into other lanes of traffic. How severely this type of disruption influences traffic flow is related to *how many vehicles must merge in a given space over a given time*. These disruptions include:

   - Areas where one or more traffic lanes are lost – a "lane-drop" which sometimes occurs at bridge crossings and in work zones.
   - Lane-blocking traffic incidents.
   - Areas where traffic must merge across several lanes to access entry and exit points (called "weaving areas").
   - Freeway on-ramps – merging areas where traffic from local streets can join a freeway.
   - Freeway-to-freeway interchanges – a special case of on-ramps where flow from one freeway is directed to another. These are typically the most severe form of physical bottlenecks because of the high traffic volumes involved.

Influencing all of these disruptions in traffic flow is the level of traffic that attempts to use the roadway. High demand for highway use – such as that caused by special events – can compound the problems caused by disruptions to traffic flow.

2.2.2 How the Seven Sources Cause Congestion

Congestion results from one – or the interaction of several – of the seven sources on the highway system. The interaction can be complex and varies greatly from day-to-day and highway-to-highway. The problem is that with the exception of the physical bottlenecks, the sources of congestion occur with maddening irregularity – nothing is ever the same from one day to the next! One day commuters might face low traffic volumes, no traffic incidents, and good weather; the next day traffic might be heavier than normal, it might be raining, and a severe crash may occur that blocks traffic lanes. An analysis of how the combination of these events conspires to make congestion was done in Washington, D.C. (Table 2.1). The worst traffic days experienced in Washington can be explained by the occurrence ***and*** combination of different events.

Another example of the irregularity in event occurrence can be seen in the frequency and duration of traffic incidents. Figure 2.1 shows how traffic incidents occurred on a 14-mile stretch of Interstate 405 in Seattle, Washington during peak travel periods for the first four months of 2003. Some days are relatively incident-free while others have numerous traffic incidents. Interestingly, at least one traffic incident occurred every day during the peaks on this highway. So, while some days are better than others, traffic incidents are an unavoidable fact on crowded urban freeways.

Another source of variability is traffic demand, which is rarely the same from day-to-day. On routes heavily used for commuting, weekday traffic is typically much higher than weekend traffic. (On routes in recreational, tourist, or shopping-dominated areas, weekend traffic higher.) Figure 2.2 shows this variability in dramatic fashion for Detroit freeways. It also shows that there is some variability on weekdays: Thursdays and Fridays are typically the highest traffic days for this period.

The congestion and travel time variability caused by planned special events are becoming a major concern for transportation agencies. In a recent survey of state Departments of Transportation (DOTs) by the American Association of State Highway and Transportation Officials and the American Highway Users Alliance, special events were cited as significant contributors to noncommuter congestion. These events may be categorized as:

- **Major Sporting Events –** This includes sports events within cities (e.g., major league baseball, professional football games) and college sporting events in relatively small university towns, especially college football. In fact, many college football games are attended by 100,000 spectators or more, and the associated congestion in towns and small cities (e.g., Ann Arbor, Michigan; Knoxville, Tennessee; and Lincoln, Nebraska) can overwhelm the local highway system on game days. The only saving grace is that usually there are no more than seven home games per year; nonetheless, congestion is significant on these days, requiring a lot of planning and active management by transportation and enforcement personnel.

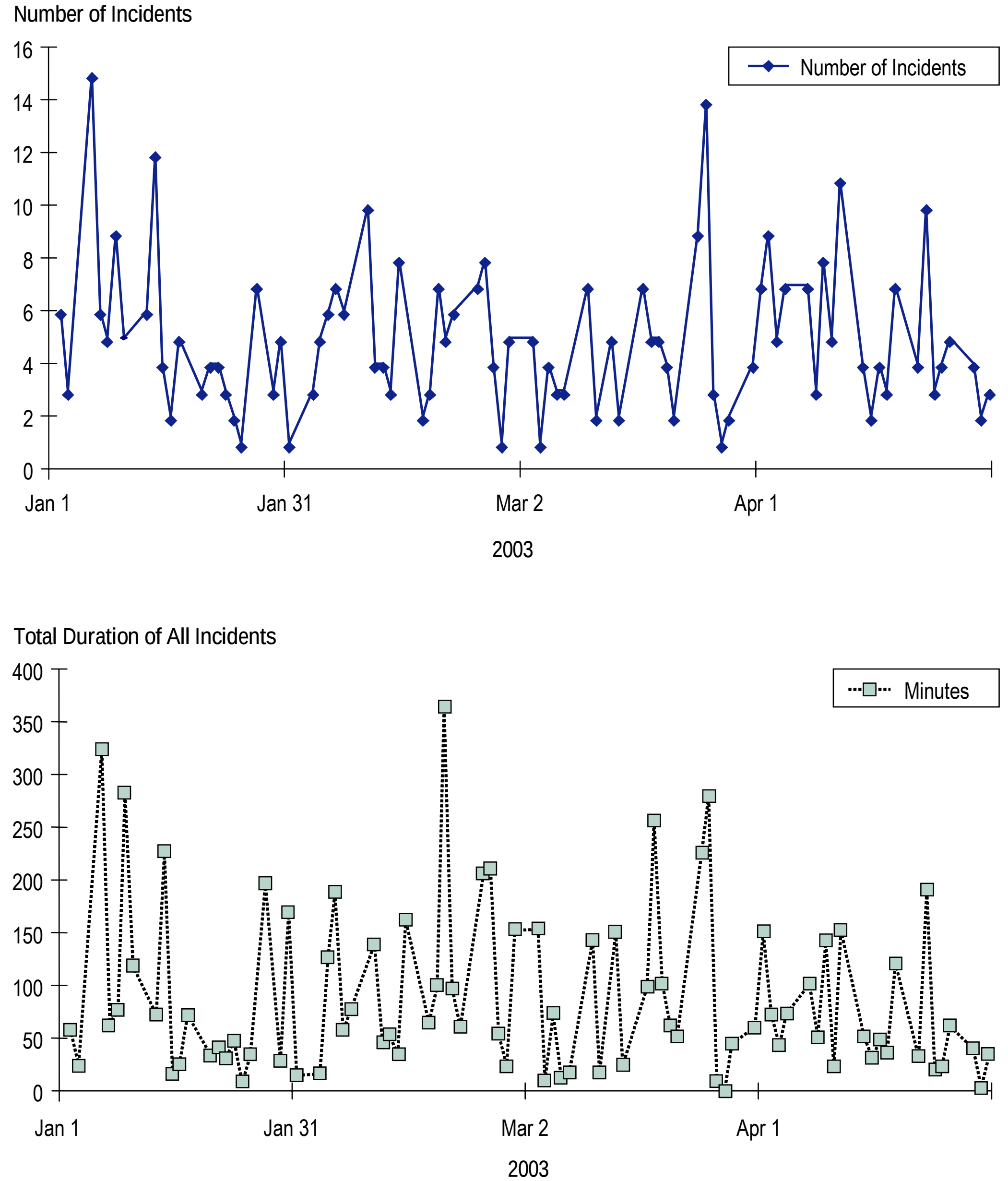
Table 2.1 Factors Contributing to Extreme Congestion
Ten Worst Days of Washington, D.C. Traffic

	Traffic-Influencing Event Present		
	High Demand	Bad Weather	Incident
Day 1		▲	
Day 2	▲	▲	▲
Day 3		▲	
Day 4	▲		
Day 5			▲
Day 6	▲	▲	
Day 7	▲		▲
Day 8	▲		
Day 9		▲	
Day 10	▲		
	6 Days	5 Days	3 Days

Source: Vasudevan, Meenakshy; Wunderlich, Karl E., Shah, Vaisshali; and Larkin, James, Effectiveness of Advanced Traveler Information Systems (ATIS) Under Extreme Congestion: Findings from a Washington, D.C., Case Study, proceedings of ITS America, 2004.

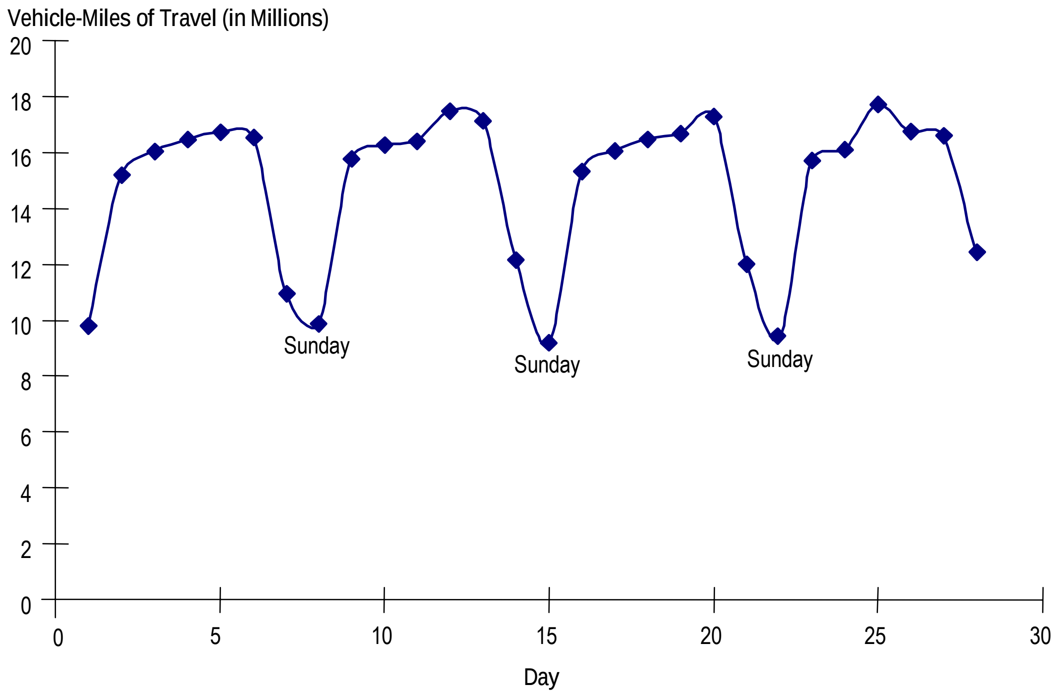
The events that impede traffic flow and cause travel to be unreliable often occur in combination. This diagram shows the number of days when different combinations of events occurred during the study period. For example, there were three days when incidents occurred – on two of these days only incidents occurred and on one day, incidents occurred in combination with high demand and bad weather. As most commuters know, "some days are worse than others." Pile high demand (say, a Friday before a three-day weekend) on top of heavy rain and a lane-blocking crash, and you've got the ingredients for severe congestion.

Figure 2.1 The Number and Duration of Incidents Varies Greatly from Day to Day
I-405 Southbound, Seattle, Washington



Note: Data shown are for the morning and afternoon peak periods (7:00-10:00 a.m. and 4:00-7:00 p.m.) for the period from January 1, 2003 to April 30, 2003. Traffic incidents occur in a fairly erratic pattern from day-to-day. Also, how long they last and how many lanes they block are fairly unpredictable. This erratic behavior contributes significantly to making travel unreliable for travelers.

Figure 2.2 Traffic Levels Vary Substantially over the Course of a Week
Detroit Freeways, 3/11/2001 – 4/7/2001



Note: VMT (or "vehicle-miles of travel") is a common measure of highway usage. It is calculated as the number of vehicles using the system times the distance they travel. For the time period displayed, Sundays are the low points on the graph. Weekday travel can be more than 60 percent higher than Sunday travel. On weekdays, the trend toward highway travel later in the week (Thursdays and Fridays) is common in most urban areas. While commuting trips are relatively stable throughout the week, discretionary trips are higher as the weekend approaches.

- **Auto and Horse Races –** The rise in the popularity of NASCAR has led to increased congestion around race events.
- **University "Move-in Day" –** Several DOTs indicated that the start of fall term on college campuses create a surge in traffic for two to three days. This seems to be a problem in the smaller towns and cities with large universities, where the local highway network is not well suited to handling large volumes during off-peak periods.
- **Festivals, State Fairs, and Major Concerts –** Many rural areas sponsor these types of events lasting one or more weekends throughout the year. For example, the Bonaroo pop music festival in central Tennessee draws close to 100,000 people one weekend per year. These festival-goers cram onto highways not meant for such traffic, and many arrive several days early and stay a few days late.
- **Seasonal Shopping –** Holiday shopping around major mall areas was indicated as another source of noncommuting congestion, particularly on weekends between Thanksgiving and Christmas.

As if the congestion picture was not complicated enough, consider further that some events can cause others to occur. For example:

- The presence of severe congestion can reduce demand by shifting traffic to other highways or cause travelers to leave later. High congestion levels can also lead to an increase in traffic incidents due to closer vehicle spacing and overheating of vehicles during summer months.
- Bad weather can lead to crashes due to poor visibility and slippery road surfaces.
- The traffic turbulence and distraction to drivers caused by an initial crash can lead to other crashes.[6] They can also lead to overheating, running out of gas and other mechanical failures resulting from begin stuck behind another incident.

All of this suggests the rather complex model of congestion shown in Figures 2.3a and 2.3b. From a practical standpoint, what is important to take away from this model are two notions: 1) the sources of congestion can be tightly interconnected, and 2) because of the interconnectedness, significant pay-offs can be expected by treating the sources. That is, by ***treating one source, you can reduce the impact of that source on congestion plus have a partial impact on others.***

The exact causal relationships among the sources of congestion are not yet well known, but consider the data shown in Figure 2.4. Displayed in this figure is the relationship between delay (both bottleneck- and incident-related) and traffic intensity. Several observations can be made from these data:

- For a roadway with fixed physical capacity, traffic must build sufficiently before either bottleneck delay **or** traffic incident delay occurs. That this is the case for bottleneck delay is obvious. However, for traffic incidents it does show that at low congestion levels, enough excess capacity exists to absorb the effect of most traffic incidents. (During the course of time, a few traffic incidents will block all traffic lanes causing substantial delay, but over a long history, these effects are washed out.)
- At the traffic intensity level where congestion begins (AADT[7]-to-capacity ratio range of 8 to 10), incident-related congestion is a substantial part of total congestion. As the traffic grows on a roadway with fixed capacity, bottleneck-related congestion becomes increasingly dominant.

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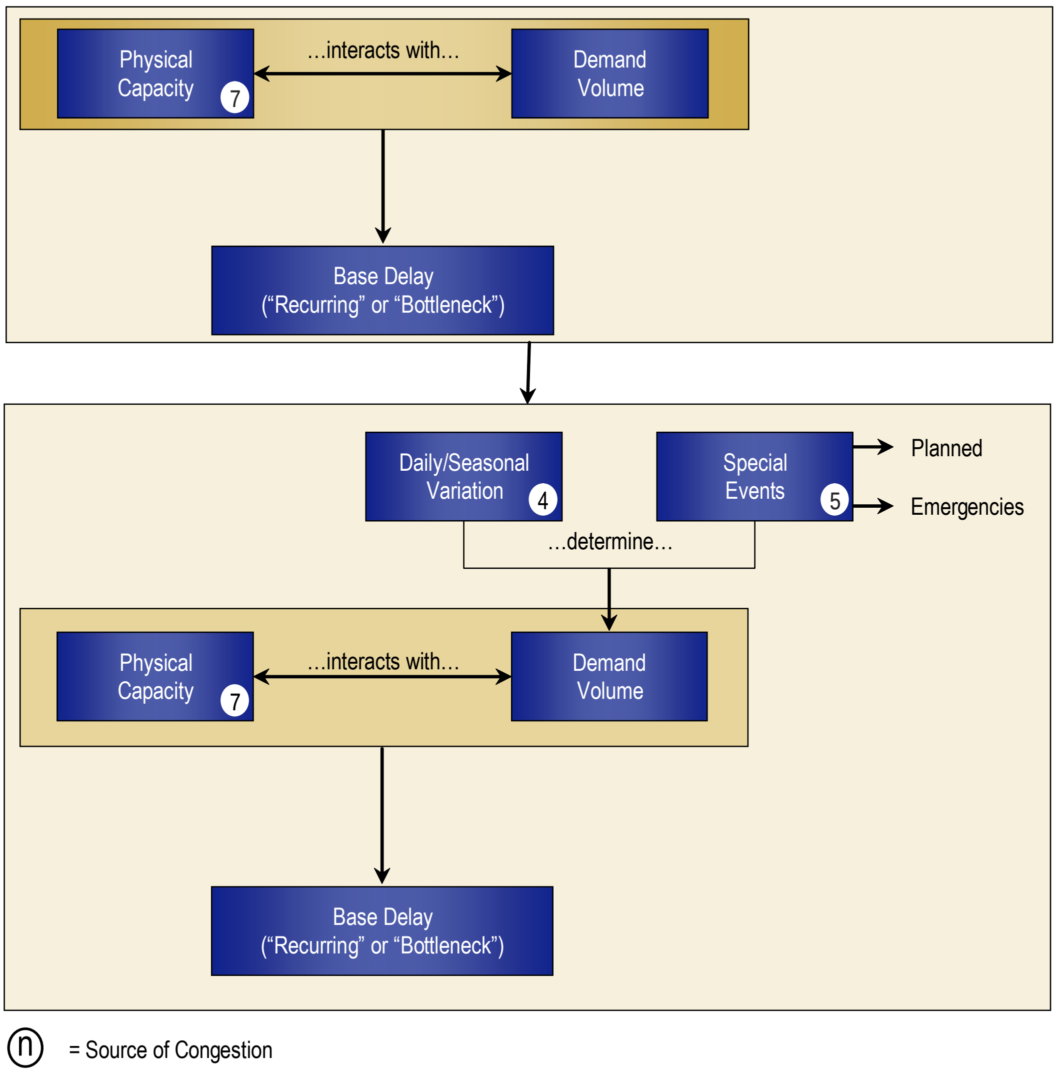
[6] This phenomenon is sometimes referred to as "secondary crashes" – crashes that would not have occurred unless an earlier one in close proximity occurred. Possible causes of secondary crashes include rapidly growing queues caused by the first crash and rubbernecking by motorists.

[7] Average Annual Daily Traffic – the amount of traffic that moves on the average day. Computed as simple average of all 24-hour traffic throughout the year. The AADT-to-capacity ratio is similar to the volume-to-capacity used in many transportation analyses, except the former uses 24-hour total traffic while the later uses hourly traffic.

Figure 2.3 Anatomy of Congestion

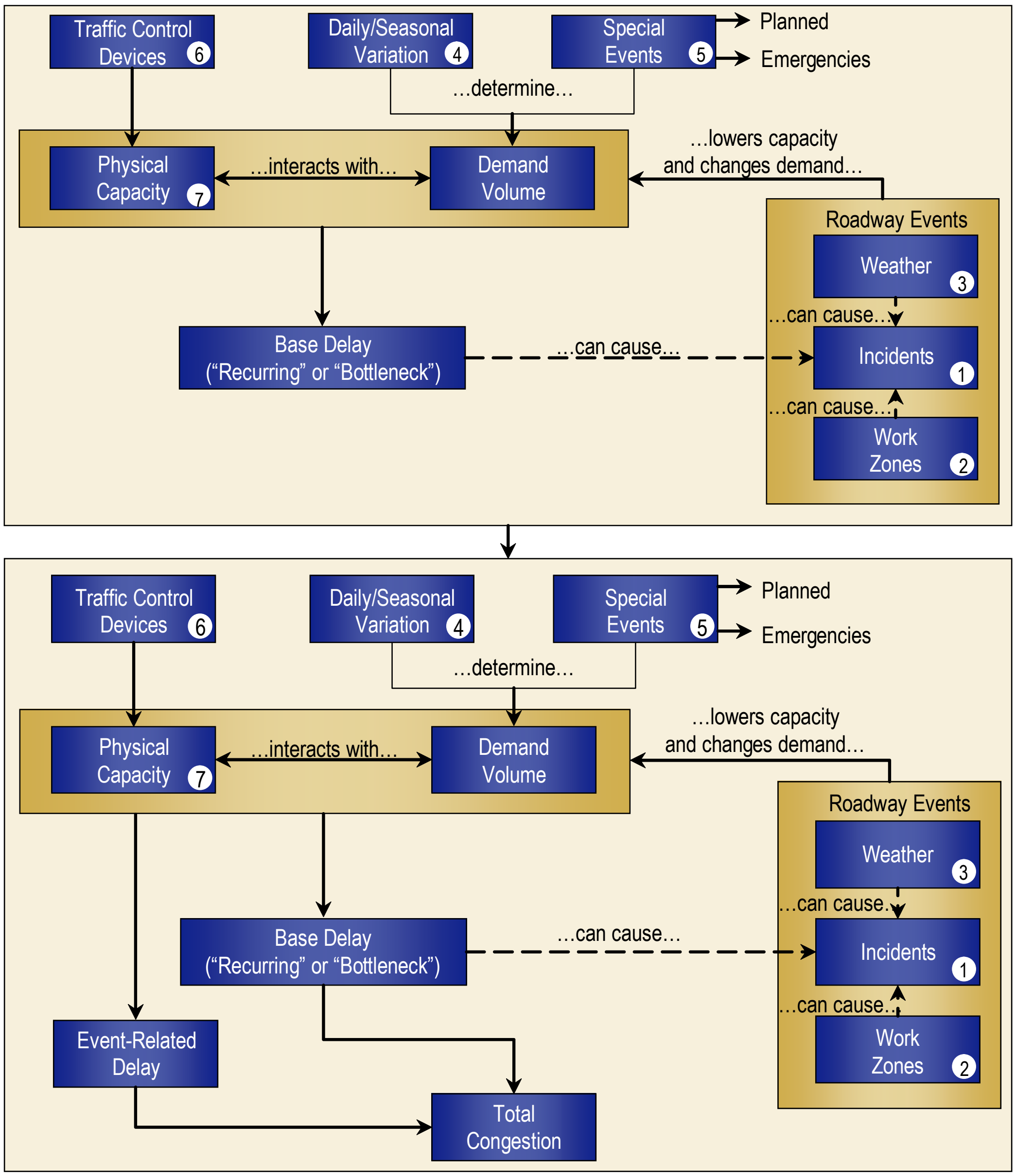
Figure 2.3a Part 1 – Traffic Volumes Interact with Physical Capacity to Produce "Base Delay"



Note: The starting point for congestion on most days is the amount of traffic and the physical restrictions on the highway (bottlenecks). Traffic varies from day-to-day throughout the year and special events may cause surges in traffic at unexpected times. See Figure 2.2 as an example of how much traffic varies even over as short a period as a month.

Figure 2.3 Anatomy of Congestion (continued)

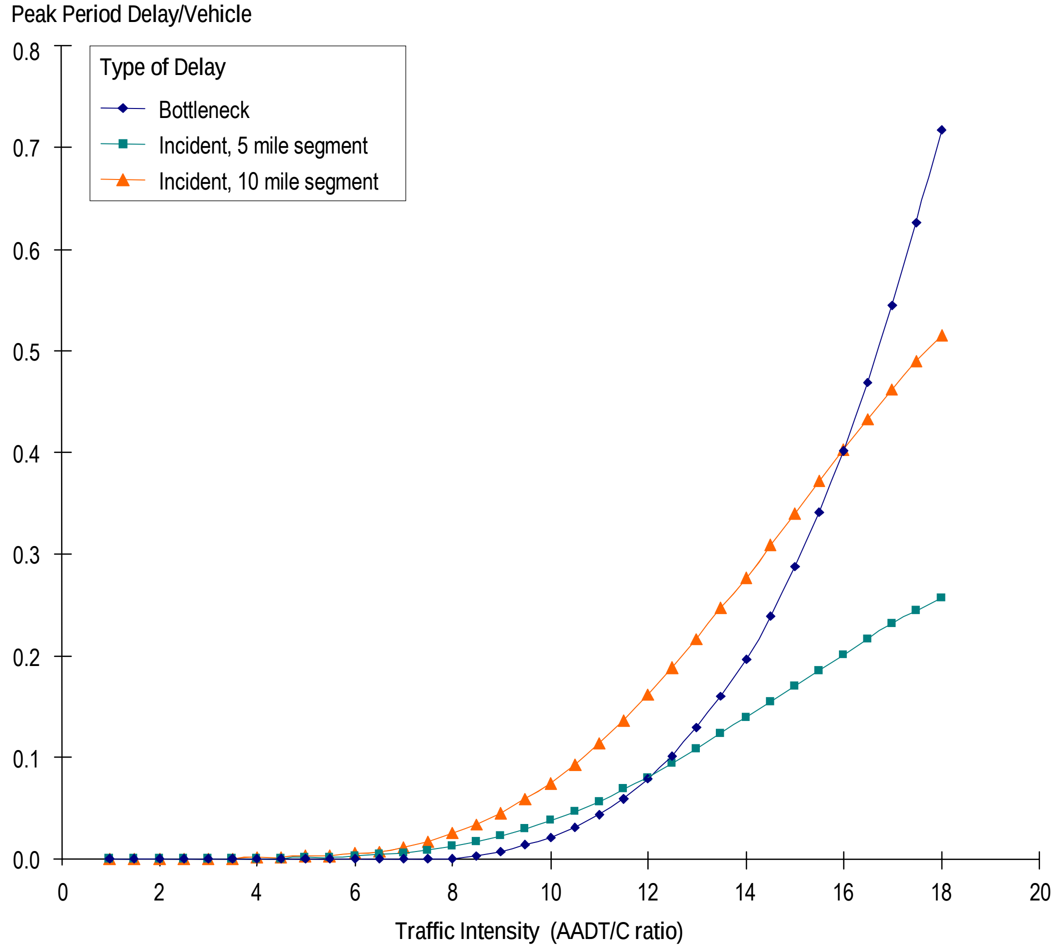
Figure 2.3b Part 2 – Roadway Events Reduce Available Capacity and Add Extra Delay to the System



(n) = Source of Congestion

Note: Just as traffic varies across time periods, so does physical capacity. The operation of traffic signals changes capacity, often minute-to-minute. When roadway events occur, they also cause the physical capacity of the roadway to be lowered. (Traffic incidents and work zones can “steal” lanes, and bad weather causes drivers to space themselves out more.) Base-level congestion caused by bottlenecks can lead to increased traffic incidents due to tighter vehicle spacing and vehicles overheating in summer. Finally, the existence of extreme congestion can cause some drivers to change their routes or to forego trips altogether. Understanding how all these factors interact is the subject of ongoing research.

Figure 2.4 Relationship of Incident and Bottleneck Delay to Traffic Intensity



Note: The AADT/C level is a general indicator of the "intensity" of traffic trying to use a highway with fixed capacity. AADT is Annual Average Daily Traffic (vehicles per day) and C is the two-way capacity of the roadway (vehicles per hour). Bottleneck and traffic incident delay occur differently: bottlenecks cause delay at specific points while traffic incidents may occur anywhere along a highway segment. This is the reason for using 5- and 10-mile segments for the traffic incident delay above. The analysis shows that as traffic grows on a roadway with fixed capacity, traffic incident delay is initially higher than bottleneck delay. As traffic grows, bottleneck delay overtakes traffic incident delay, because it happens fairly regularly while traffic incidents vary in occurrence and characteristics.

This analysis also shows the interrelationship between the sources of delay identified in Figures 2.3a and 2.3b. Even with no changes in traffic incident characteristics, traffic incident delay grows as more traffic is added to a roadway. In other words, as the traffic level grows on a base of fixed capacity, the roadway is more vulnerable to disruptions caused by traffic incidents, or any other traffic-influencing event for that matter.

The exponential growth in bottleneck delay after the onset of congestion is a major reason why it is so difficult for agencies to keep up with congestion: once it starts, things get bad quickly. Introducing an extra vehicle to congested conditions means not only does that vehicle get delayed, it also adds extra delay to any other vehicles that join after it.

- At higher base congestion levels, bottleneck-related congestion grows at an increasingly faster rate. Researchers have long noted that delay increases exponentially (i.e., it goes "ballistic") with traffic level on a fixed capacity base. Why is this? Once a queue has formed and an additional vehicle joins at the back of the queue, you get a double whammy: not only is that vehicle delayed, but the queue is now longer and any new vehicles that join in will also be delayed by the now longer queue. The growth in delay for traffic incidents is more of a straight line, the results of the irregular occurrence of traffic incidents – they do not happen consistently like bottleneck delay does.

The fact that both bottleneck- and incident-related delay increase with base congestion level indicates that if physical capacity is increased, congestion for both sources would be decreased. In other words, Facilities with greater base capacity are less vulnerable to disruptions: a traffic incident that blocks a single lane has a greater impact on a highway with two travel lanes than a highway with three travel lanes. This feature highlights the interdependence of the sources mentioned above. It also reinforces the notion that adding physical capacity is a viable option for improving congestion, especially when made in conjunction with other strategies.

2.2.3 The Reliability of Travel Time and Why It Matters

What Is Travel Time Reliability? By its very nature, roadway performance is at the same time consistent and repetitive, and yet highly variable and unpredictable. It is consistent and repetitive in that peak usage periods occur regularly and can be predicted with a high degree of reliability. (The relative size and timing of "rush hour" is well known in most communities.) At the same time, it is highly variable and unpredictable, in that on any given day, unusual circumstances such as crashes can dramatically change the performance of the roadway, affecting both travel speeds and throughput volumes.

The traveling public experiences these large performance swings, and their expectation or fear of unreliable traffic conditions affects both their view of roadway performance, and how and when they choose to travel. For example, if a road is known to have highly variable traffic conditions, a traveler using that road to catch an airplane routinely leaves lots of "extra" time to get to the airport. In other words, the "reliability" of this traveler's trip is directly related to the variability in the performance of the route she or he takes.

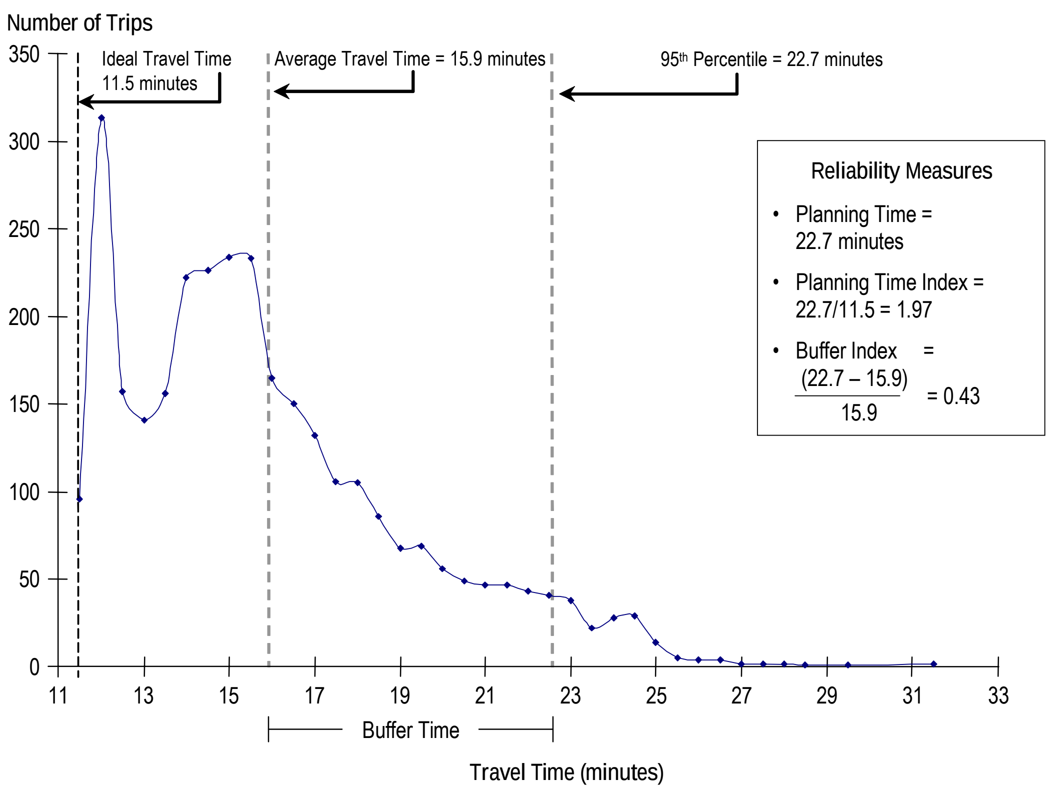
It is becoming clear that we can no longer just define congestion in terms of "average" or "typical" conditions. One of the reasons was identified in Figure 2.4 – as the traffic on a fixed capacity roadway, a highway becomes more susceptible to delay from traffic incidents, and in fact, to all traffic-influencing events. Because reliability indicates how much events influence traffic conditions, it is particularly important when it comes to defining operations strategies, which aim to control the effect of these events.

Highlight Box 2 – Measuring Reliability

Because reliability is defined by how travel times vary over time, it is useful to develop frequency distributions to see how much variability exists. Calculating the average travel time and the size of the "buffer" – the extra time needed by travelers to ensure a high rate of on-time arrival – then helps us to develop a variety of reliability measures. These measures include the Buffer Index, the Planning Time, and the Planning Time Index (see Figure 2.5). They are all based on the same underlying distribution of travel times, but describe reliability in slightly different ways:

- **Planning Time –** The sheer size of the buffer (the 95th percentile travel time).
- **Planning Time Index –** How much larger the buffer is than the "ideal" or "free flow" travel time (the ratio of the 95th percentile to the ideal). In the 11.5-mile long corridor shown, the ideal travel time is 11.5 minutes, assuming that vehicles will travel at 60 mph when no congestion is present.
- **Buffer Index –** The size of the buffer as a percentage of the average (95th percentile minus the average, divided by the average.

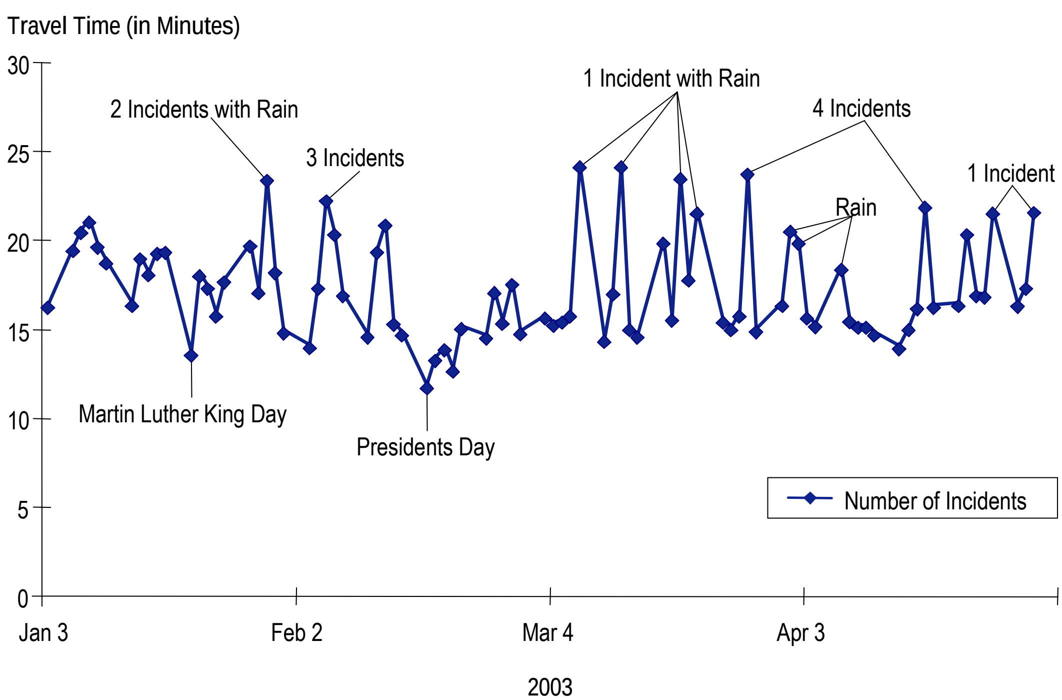
Figure 2.5 Distribution of Travel Times, State Route 520 Seattle, Eastbound, 4:00-7:00 p.m. Weekdays (11.5 Miles Long)



With this discussion in mind, from a practical standpoint, travel time reliability can be defined in terms of how travel times vary over time (e.g., hour-to-hour, day-to-day). Commuters who take congested highways to and from work are well aware of this. When asked about their commutes, they will say things like: "it takes me 45 minutes on a good day, but an hour and 15 minutes on a bad day."

Figure 2.6 typifies this experience with data from State Route (SR) 520, a major commuter route, in Seattle, Washington. If there was no congestion on this 11.5-mile segment, travel times would be around 11 ½ minutes; on President's Day this was the case. On other days, the average travel time was 17.5 minutes, or an average speed of 40 mph. But when events (traffic incidents and weather) are present, it could take nearly 25 minutes, or 37 percent longer. Commuters who take SR 520 corridor must plan for this unpredictable variability if they want to arrive on time – the average just will not do.

Figure 2.6 Weekday Travel Times
5:00-6:00 p.m., on State Route 520 Eastbound, Seattle, Washington



In other words, they have to build in a ***buffer*** to their trip planning to account for the variability. If they build in a buffer, they will arrive early on some days, which is not necessarily a bad thing, but the extra time is still carved out of their day. And this is time they could be using for other pursuits besides commuting.

What Value Does Providing Reliable Travel Times Have? Improving the reliability of travel times is significant for a number of reasons:

- Improvements in reliability are achieved by lessening the overall variability due to the seven sources of congestion, mainly traffic-influencing events. In other words, improvement strategies targeted at reliability decrease the delay due to traffic-influencing events (e.g., traffic incidents, bad weather, and work zones). This produces a double benefit: not only is variability reduced but the ***total congestion delay*** experienced by travelers is also reduced.
- Reducing total congestion saves time and fuel, and leads to decreased vehicle emissions.
- Reducing congestion at international border crossings leads to lower transportation costs and benefits the national economy as a whole. Further, reducing congestion on United States highways for freight moving between Canada and Mexico fosters international trade. Therefore, ***congestion on United States highways has a large influence on the efficiency of international trade.***
- Treating three major components of unreliable travel – traffic incidents, bad weather, and work zones – also leads to safer highways. By reducing the duration of these events, we are reducing how long travelers are exposed to less safe conditions.
- Commuters as well as freight carriers and shippers are all concerned with travel time reliability. Variations in travel time can be highly frustrating and are valued highly by both groups. Previous research[8] indicates that commuters value the variable component of their travel time between one and six times as much as average travel time. And the increase in just-in-time (JIT) manufacturing processes has made a reliable travel time extremely important. Significant variations in travel time will decrease the benefits that come from lower inventory space and the use of efficient transportation networks as "the new warehouse." ***Therefore, in both the passenger and freight realms, evidence suggests that travel time reliability is valued at a significant "premium" by users.***

2.2.4 How Travelers, Operators, and Planners View Reliability

Despite our simple definition of travel time reliability as the variation in travel times over history, different perspectives exist:

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[8] Cohen, Harry, and Southworth, Frank, *On the Measurement and Valuation of Travel Time Variability Due to Incidents on Freeways*, Journal of Transportation Statistics, Volume 2, Number 2, December 1999, http://www.bts.gov/jts/V2N2/vol2_n2_toc.html.

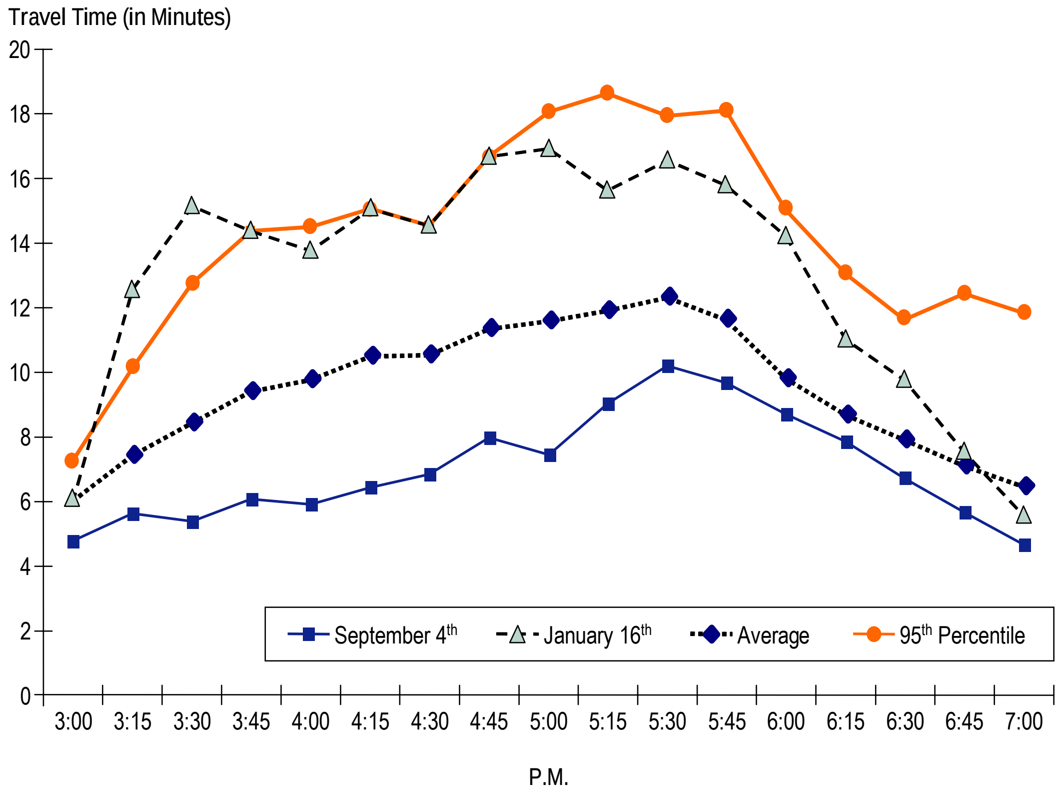
- Travelers want to know information about the specific trip they are about to make and how it compares to their typical or expected trip;
- Similarly, operators want to know how the system is performing now in relation to typical conditions; and
- Planners want to know how the system performed last month or last year in comparison to previous time periods.

As we have already seen, some days are better (or worse) than others in terms of congestion, and there is quite a bit of variation from average or typical conditions on any given day. Figure 2.7 displays this variation from the traveler and operator points of view. Shown are travel times in the heavily congested I-75 corridor in central Atlanta for all Thursdays in 2003. The average and 95th percentile travel times are shown along with the actual travel times from two specific Thursdays. January 16 was clearly a "bad" day in this corridor while September 4 was "better than average." For both travelers and operators, a constantly updated display of travel conditions compared to baselines would be valuable information to have. In fact, at least one traffic management center (Houston TRANSTAR) posts this sort of information on their web site in real-time.[9] It should be noted that currently we do not have the ability to predict what is going to happen – a difficult task given the uncertainty of unpredictable events like incidents or sudden, intense weather. We can only compare what is happening now to historical conditions, but research is currently underway on this topic.

Still, the ability to ***predict with some certainty*** what travel time will be in the near future is of great interest to operators and travelers. Why is this important? If a commuter has a routine activity that must occur every day – such as picking up children from day care – they must plan on an extra amount of trip time just to be sure they do not arrive late. The same goes for local trucking firms engaged in pickup and delivery of goods. Looking again at the data in Figure 2.7, if a traveler starts in the corridor at 5:30 p.m., on the average Thursday the trip will take about 12 minutes. But history has shown that to be safe, they have to plan for about 18 minutes (50 percent more) to have only a small chance of arriving late; they have to build in a ***buffer***. These are not huge numbers – but this is a short corridor (4 miles). The difference is, however, a large percentage. If similar conditions exist over the rest of the commute, then the extra time starts to add up quickly. With this simple approach, an extreme event can cause great problems for an individual trip, but at least we can compute a reasonable probability of arriving on time.

[9] http://traffic.houstontranstar.org/layers/.

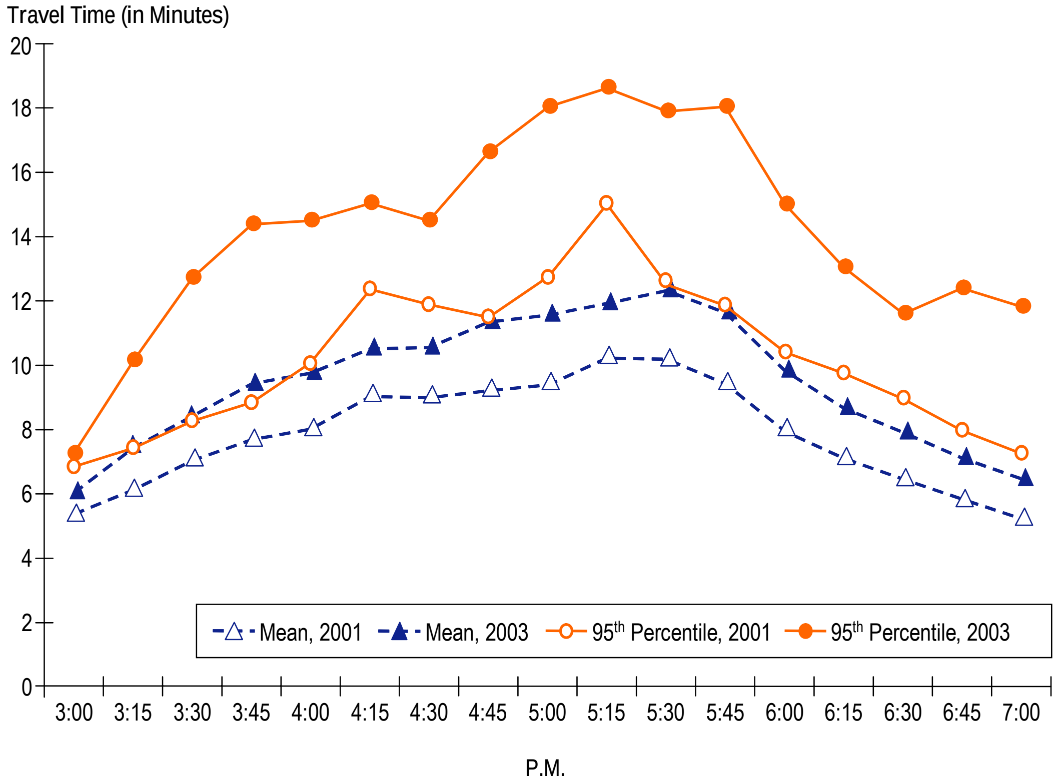
Figure 2.7 Is It a Good Day or Bad Day for Commuting:
Comparing Current Travel Times to Historical Conditions
I-75 Southbound Central Atlanta, Thursdays, 2003



Note: Comparing what is happening on the highway system right now to "typical" (average) and "extreme" (95th percentile) conditions provides both operators and travelers with information that can lead to actions. For example, the afternoon of September 4, travelers could see that congestion was lighter than usual and could schedule additional activities. January 16 on the other hand was a heavy congestion day and as it unfolded, operators could post diversion messages to try to control it.

Planners are most interested in how things change over a longer period of time, though the question of "are things getting better or worse" is of general interest as well. In the I-75 corridor in central Atlanta, travel times in the afternoon peak period have increased and reliability has decreased between 2001 and 2003 (Figure 2.8). Monitoring of performance trends like this is becoming more common at transportation agencies. As discussed in the next section, performance monitoring is a major emphasis in operations and planning.

Figure 2.8 Congestion and Unreliable Travel Have Increased on I-75 Southbound in Central Atlanta, Georgia
Thursdays, 2001 and 2003



Note: By comparing the average travel times in 2001 and 2003 (the blue lines)), it can be seen that average congestion levels have increased in this corridor. At the same time, travel time reliability has decreased, as shown by the increase in the 95th percentile travel times.

2.3 Tracking Congestion

2.3.1 Why Monitor Congestion?

Monitoring congestion is just one of the several aspects of transportation system performance that leads to more effective investment decisions for transportation improvements. Safety, physical condition, environmental quality, economic development, quality of life, and customer satisfaction are among the aspects of performance that also require monitoring.[10] Congestion is intertwined with all of these other categories since higher congestion levels have been associated with their degradation.

[10] More detail on monitoring comprehensive transportation system performance may be found in: *A Guidebook for Performance-Based Transportation Planning,* NCHRP Report 446, Transportation Research Board, Washington, D.C., 2000.

In addition to facilitating better investments, improved monitoring of congestion can lead to several positive outcomes:

- **Improved Performance –** The information from operating systems can be used by the operating agencies to alter hours or methods of operation to improve the system. Performance measures can target, for example, before/after effects of recent programs or the amount of productivity lost from congested conditions.
- **Improved Communication –** Performance measures that include travel time, delay, or other easily understood concepts can provide better ways to communicate system conditions.
- **Program Justification –** Performance measures and a before/after data collection program can be very effective at identifying the effect of a range of freeway and arterial management actions. Many of these actions cannot be easily assessed using models.
- **Funding Enhancements –** In most recent campaigns for funding increases, pricing projects or increased funding flexibility, performance measures have played two key roles. They can be used to demonstrate improved conditions or use of existing funds to show that current agency actions are appropriate and beneficial. The measures and data also can be used in public accountability pledges to demonstrate the effect of the proposed programs.

2.3.2 Congestion Performance Measures

Travel Time as the Basis for Congestion Performance Measures

The performance of the highway system in terms of how efficiently users can traverse it may be described in three basic terms: congestion, mobility, and accessibility. While researchers have different definitions of these terms, we have found it useful to define them as follows:

- **Congestion** – Describes the travel conditions on *facilities*;
- **Mobility –** Describes how well users can complete entire *trips*; and
- **Accessibility –** Describes how close *opportunities* (e.g., jobs, shopping) are spaced in terms of the user's ability to access them through the transportation system.

Congestion and mobility are very closely related and the same metrics and concepts can be used to monitor both. Accessibility is a relatively new concept and requires a different set of metrics. Most the data that are currently available describe facility performance, not trip performance, although new technologies are emerging that will allow for direct monitoring of entire trips.

One of the principles that FHWA has established for monitoring congestion as part of its annual performance plan is that meaningful congestion performance measures must be based on the measurement of travel time. Travel times are easily understood by practitioners and the public, and are applicable to both the user and facility perspectives of performance.

Temporal Aspects of Congestion: Measuring congestion by times of the day and day of week has a long history in transportation. A relatively new twist on this is the definition of a weekday "peak period" – multiple hours rather than the traditional peak hour. In many metropolitan areas, particularly the larger ones, congestion now lasts three or more hours each weekday morning and evening. In other words, over time, congestion has spread into more hours of the day as commuters leave earlier or later to avoid the traditional rush hour. Definition of peak periods is critical in performing comparisons. For example, consider a three-hour peak period. In smaller cities, congestion may usually only last for one hour – better conditions in the remaining two hours will "dilute" the metrics. One way around this is not to establish a fixed time period in which to measure congestion, but rather determine how long congestion exists (e.g., percent of time where operating conditions are below a threshold.)

Spatial Aspects of Congestion: Congestion spreads not only in time but in space as well. Queues from physical bottlenecks and major traffic-influencing events (like traffic incidents) can extend for many miles. Congestion measures need to be sensitive to this by tracking congestion over facilities or corridors, rather than just short highway segments.

Table 2.2 presents a small sample of congestion performance measures (metrics) that can be used by agencies to monitor trends.

Table 2.2 Example Congestion Performance Metrics

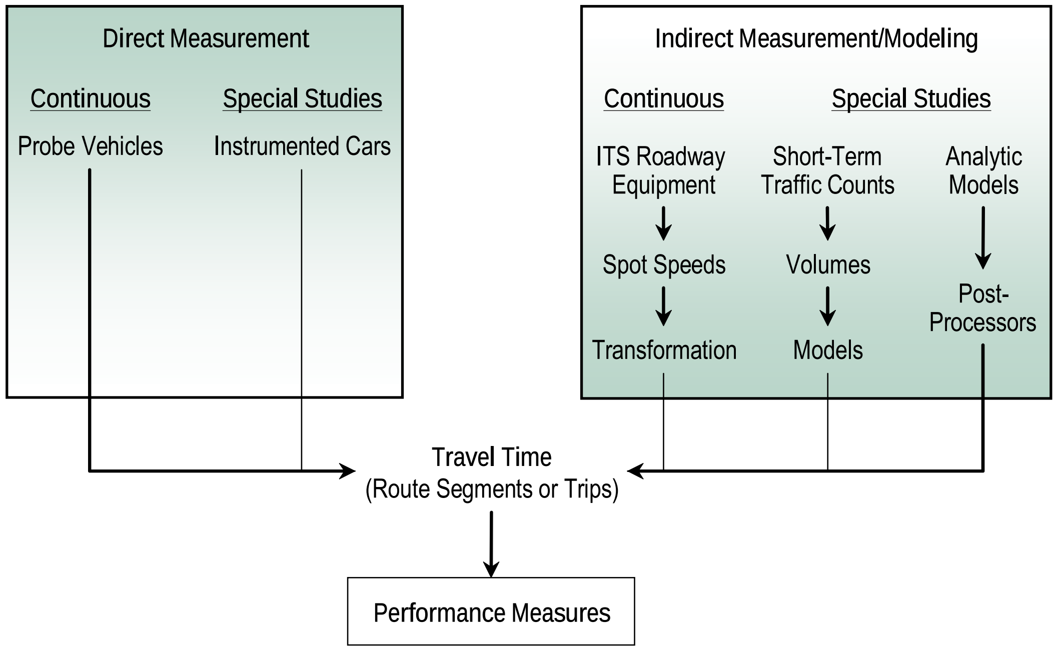
Performance Metric	Definition/Comments
Throughput	
Vehicle-Miles of Travel Truck Vehicle-Miles of Travel Person-Miles of Travel	Vehicle-miles of travel are the number of vehicles on the system times the length of highway they travel. Person-miles of travel is used to adjust for the fact that some vehicles carry more than a driver.
Average Congestion Conditions	
Average Travel Speed	The average speed of vehicles measured between two points.
Travel Time	The time it takes for vehicles to travel between two points. Both travel time and average travel speed are good measures for specific trips or within a corridor.
Number and percent of trips with travel times > (1.5 * average travel time) Number and percent of trips with travel times > (2.0 * average travel time)	Thresholds of 1.5 and 2.0 times the average may be adjusted to local conditions; additional thresholds may also be defined.
Travel Time Index	Ratio of actual travel time to an ideal (free-flow) travel time. Free-flow conditions on freeways are travel times at a speed of 60 mph.
Total Delay (vehicle-hours and person-hours) Bottleneck ("Recurring") Delay (vehicle-hours)	Delay is the number of hours spent in traffic beyond what would normally occur if travel could be done at the ideal speed.

Performance Metric	Definition/Comments
Traffic incident Delay (vehicle-hours)	Determining delay by "source of congestion" requires detailed information on the nature and extent of events (incidents, weather, and work zones) as well as measured travel conditions.
Work Zone Delay (vehicle-hours)	
Weather Delay (vehicle-hours)	
Ramp delay (vehicle-hours and person-hours; where ramp metering exists)	
Delay per Person	Delay per person and delay per vehicle require knowledge of how many vehicles and persons are using the roadway.
Delay per Vehicle	
Percent of VMT with Average Speeds < 45 mph	VMT is vehicle-miles of travel, a common measure of highway usage.
Percent of VMT with Average Speeds < 30 mph	
Percent of Day with Average Speeds < 45 mph	These measures capture the duration of congestion.
Percent of Day with Average Speeds < 30 mph	
Reliability	
Planning Time (computed for actual travel time and the Travel Time Index)	The 95th percentile of a distribution is the number above which only 5 percent of the total distribution remains. That is, only 5 percent of the observations exceed the 95th percentile. For commuters, this means that for 19 out of 20 workdays in a month, their trips will take no more than the Planning Time.
Planning Time Index (computed for actual travel time and the Travel Time Index)	Ratio of the 95th percentile ("Planning Time") to the "ideal" or "free flow" travel time (the travel time that occurs when very light traffic is present, about 60 mph on most freeways).
Buffer Index	Represents the extra time (buffer) most travelers add to their average travel time when planning trips.
For a specific road section and time period:	
Buffer Index (%) =	$\dfrac{\text{95th percentile travel time (minutes)} - \text{average travel time (minutes)}}{\text{average travel time (minutes)}}$

2.3.3 Methods Used to Develop Congestion Performance Measures

Figure 2.9 shows how travel times can be developed from data, analytic methods, or a combination. Clearly, the best methods are based on direct measurement of travel times, either through probe vehicles or the more traditional "floating car" method, in which data collectors drive specific routes. However, both of these have drawbacks: probe vehicles currently are not widely deployed and the floating car method suffers from extremely small samples because it is expensive and time consuming. Further, since many performance measures require traffic volumes as well, additional collection effort is required to develop the full suite of performance measures. Use of ITS roadway equipment addresses these issues, but this equipment does not measure travel time directly; ITS spot speeds must be converted to travel times first. (The Appendix provides a description of the equipment used to collect these data.) Other indirect methods of travel time estimation use traffic volumes as a basis, either those that are directly measured or developed with travel demand forecasting models. Two examples of how FHWA is developing travel times with these methods follow.

Figure 2.9 Measuring Travel Time Is the Basis for Congestion Measures



Monthly Urban Congestion Report

Since 2000, FHWA has been assembling volume and speed data from urban traffic management centers. These data are primarily from ITS roadway equipment, although some cities are exploring the use of probe vehicles to capture travel time. Data from 29 cities are currently obtained annually from participating traffic management centers. Some of these cities are now providing data on a monthly basis, and these monthly data are used to track citywide trends month-by-month. Figure 2.10 shows an example of how these data are presented. As more cities participate – and as surveillance coverage increases in existing cities – these data will provide a way for FHWA to monitor monthly changes in congestion. (Section 3.0 presents additional analysis of the data used in this program.)

Figure 2.10 Example of the Newly Designed Urban Congestion Report Used by FHWA to Track Monthly Changes in Congestion

DRAFT

URBAN CONGESTION REPORT
May-July 2005

Federal Highway Administration

NATIONAL EXECUTIVE SUMMARY

UCR NATIONAL COMPOSITE INDICATORS			
YEAR	Congested Hours ↓ 6.0%	Travel Time Index ↓ 0.3%	Planning Time Index 0.0%
2005	3.85	1.282	1.677
2004	4.09	1.286	1.677

	Congested Hours 6 ↓ Cities DOWN>5%	10 ↑ Cities UP>5%	Travel Time Index 2 ↓ Cities DOWN>5%	1 ↑ Cities UP>5%	Planning Time Index 4 ↓ Cities DOWN>5%	2 ↑ Cities UP>5%	% Usable Data:	Contributing Factors Compared to Previous Year (Peak Period)			
City	This Quarter	(%) Change vs. Year Ago	This Quarter	(%) Change vs. Year Ago	This Quarter	(%) Change vs. Year Ago	96%	Bad Weather	Work Zones	Incidents	VMT Served
Phoenix, AZ	2.2	27.0%	1.16	2.4%	1.39	2.2%	99%	0%	N/A	N/A	9%
R'side-San Bern, CA	0.3	23.0%	1.11	1.1%	1.27	1.5%	99%	0%	N/A	N/A	39%
Seattle, WA	6.3	22.0%	1.42	7.1%	1.91	7.6%	100%	-61%	N/A	-28%	-3%
Philadelphia, PA	5.3	21.0%	1.26	0.6%	1.71	-1.0%	98%	-29%	N/A	39%	0%
Pittsburgh, PA	5.0	15.0%	1.21	2.4%	1.55	5.3%	98%	0%	N/A	-9%	-4%
Portland, OR	3.9	15.0%	1.27	1.2%	1.71	-1.3%	89%	42%	N/A	N/A	-3%
Houston, TX	4.2	13.0%	1.39	1.2%	2.01	-4.3%	99%	-44%	N/A	106%	392%
Salt Lake City, UT	0.6	10.0%	1.10	-0.2%	1.30	-6.4%	97%	70%	N/A	N/A	74%
Minn-St. Paul, MN	3.7	8.0%	1.38	3.2%	1.88	4.5%	100%	19%	N/A	N/A	4%
San Francisco, CA	1.0	8.0%	1.20	2.0%	1.47	2.6%	99%	900%	N/A	N/A	-2%
Los Angeles, CA	5.8	3.0%	1.36	-1.8%	1.78	-1.3%	99%	200%	N/A	-31%	-2%
Chicago, IL	10.3	-4.0%	1.46	-0.8%	2.12	1.5%	84%	-40%	N/A	-21%	20%
Providence, RI	1.7	-4.0%	1.14	-0.5%	1.44	-0.4%	97%	-64%	N/A	N/A	33%
San Diego, CA	2.1	-5.0%	1.28	-0.4%	1.67	-2.3%	99%	0%	N/A	41%	-2%
San Antonio, TX	1.2	-12.0%	1.11	-1.3%	1.32	-3.4%	100%	-88%	N/A	-9%	1%
Detroit, MI	1.6	-18.0%	1.18	-3.3%	1.52	-6.1%	88%	-42%	N/A	N/A	4%
Orange County, CA	2.0	-21.0%	1.24	-1.7%	1.52	-3.6%	99%	0%	N/A	N/A	0%
Sacramento, CA	4.8	-67.0%	1.21	-13.7%	1.49	-12.5%	98%	1500%	N/A	N/A	4%
Hampton Roads, VA	1.7	-69.0%	1.12	-7.6%	1.45	-15.6%	80%	44%	N/A	48%	-9%
Tampa, FL	1.3	N/A	1.16	N/A	1.52	N/A	98%	N/A	N/A	N/A	N/A

Congestion in all three national composite measures declined or remained unchanged the three month period ending in July 2005 compared to the same period in 2004. Composite hours of congestion per day declined 6% to 3.85 hours, led by sharp declines in Hampton Roads and Sacramento. The decline was not broadly based--five cities posted declines of more than 5% in this measure, while 10 cities posted an increase of 5% or more in congested hours. National composite travel time index also fell, but less sharply (0.3%). This measure of peak period congestion intensity was stable across most cities. Seattle posted a 7.1% increase, but this was offset by a 13.7% decline in Sacramento. Composite planning time index remained unchanged from 2004. Data quality was acceptable overall, however, some cities fell below our 90% target (Hampton Roads, Chicago, Detroit, and Portland).

26 August 2005

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Freight Performance Measurement Initiative

The tracking of congestion within cities is dependent on having an intensive system of surveillance to collect vehicle speeds (through roadway detectors) or travel times (using toll-tagged probe vehicles) at closely spaced points on the roadway. Outside of major metropolitan areas, such surveillance does not exist. To complement urban congestion measures and get a better picture of total system performance, FHWA is developing a system to monitor truck travel on intercity corridors that have significant freight volumes. FHWA is partnering with the American Transportation Research Institute and the trucking industry to use existing satellite-based systems that track truck movement for freight and fleet management purposes to support transport system performance measurement. Additionally, FHWA is exploring using similar methods to measure delay at major international border crossings. Figure 2.11 shows an example of how this system has been applied to develop travel times on 10-mile stretches of Interstate 5.

Figure 2.11 Interstate 5 Average Travel Rate for Trucks: 10-Mile Segments
April-June 2004, 3:00-7:00 p.m.

2.4 CONGESTION'S CONSEQUENCES

The nation's local, regional, and national transportation systems play a vital role in creating access to goods and services which sustain and grow our nation's economy. Planners and economic development experts recognize that congestion is an economic development issue because it thwarts business attraction and expansion, and reduces the quality of life for residents.

Transportation system users have developed strategies to deal with increased congestion and reduced reliability. In the short term, we might change our mode or time of travel. Over the longer run, congestion might influence our decisions about where we live and work. The same holds true for businesses. These types of adjustments might reduce the impacts of congestion to us, but they still do not entirely eliminate the economic consequences for a region.

Trucking Impacts. Congestion means longer travel times and less reliable pick-up and delivery times for truck operators. To compensate, motor carriers typically add vehicles and drivers and extend their hours of operation, eventually passing the extra costs along to shippers and consumers. Research on the trucking industry has shown that shippers and carriers value transit time in the range of $25 to $200 per hour, depending on the product being carried. The cost of unexpected delay can add another 20 percent to 250 percent.[11]

Impacts on Businesses. Congestion increases the costs of delivering goods and services, because of the increased travel times and operating costs incurred on the transportation system. Less obviously, there may be are other costs, such as:

- The costs of remaining open for longer hours to process late deliveries;
- Penalties or lost business revenue associated with missed schedules;
- Costs of spoilage for time-sensitive, perishable deliveries;
- Costs of maintaining greater inventory to cover the undependability of deliveries;
- Costs of reverting to less efficient production scheduling processes; and
- The additional costs incurred because of access to reduced markets for labor, customer, and delivery areas.

[11] Federal Highway Administration, *Freight Transportation: Improvements and the Economy;* http://ops.fhwa.dot.gov/freight/freight_analysis/improve_econ/.

The business value of time delay and market access act together to affect the profitability and revenue potential associated with doing business in a state or region. When one area is affected by congestion more than others, the relative competitiveness of these areas also shifts. The result, then, is that businesses tend to stagnate or move out of areas with high operating costs and limited markets, while they locate and expand in areas with lower operating costs and broader market connections. The magnitude of these changes varies by industry, based on how strongly the industry's total operating cost is affected by transportation factors. The evidence seems to indicate that regional economies that are fostered by clusters or "agglomerations" of many interrelated firms are better positioned to counter the higher operating costs due to congestion than economies that are not.

Household Impacts. Households have both financial budgets and what is termed "time budgets" that are both impacted by congestion. Households plan their activities around the available time budget as well as around their financial budgets. As vehicle operating and maintenance costs increase with rising congestion, the budget for some types of activities or expenditures decreases. The perceived "quality of life" of a neighborhood is diminished as well, when the safety, reliability and the convenience of the transportation system decreases.

Regional Impacts. Regional economies are affected by these household and business-specific impacts. Diminished cost competitiveness and market growth opportunities are tantamount to a reduced ability to retain, grow, and attract businesses. Additionally, the redistribution of business and household activity to outlying areas and the direct delay for trips that are not diverted or otherwise changed both lead to decreases in air quality, increases in public infrastructure investment requirements, and potential impacts on health and quality of life factors.[12]

[12] Weisbrod, Glen, Vary, Don, and Treyz, George, *Economic Implications of Congestion*, NCHRP Report 463, Transportation research Board, 2001.

3.0 Recent Trends in Congestion

3.1 Estimating the Sources of Congestion

The previous section emphasized the value of estimating the size of each contributing source to total congestion so that strategies can be tailored to specific conditions. However, teasing out each source from the whole of congestion has proven to be elusive, and we are only beginning to understand the complexities and interactions involved (see Figures 2.3a and 2.3b). Even with continuous measurement of travel times enabled with ITS technologies, some level of modeling is required to assign the contribution of each source.

The results of two studies based purely on modeling are shown in Figure 3.1. These studies used similar data – but different modeling techniques – to provide national estimates of congestion by source. While not directly comparable, these two studies do provide a picture of congestion that is ***highly dependent on traffic-influencing events***, as identified in the last section. Note that the studies are limited in the sense that neither considered all seven sources of congestion. As a result, FHWA has produced the composite estimate of congestion by source shown in Figure 3.2. Until better information is developed, the breakdown in Figure 3.2 is our best estimate of what contributes to congestion nationally.

National estimates of congestion by source are useful to guide FHWA's program and to identify which areas should be emphasized. However, local conditions vary widely and methods for estimating congestion sources on individual highways would be highly useful to transportation engineers "in the trenches" trying to decide how to craft mitigation strategies. A study in Seattle, Washington is currently underway to identify the contribution of congestion sources in three freeway corridors.

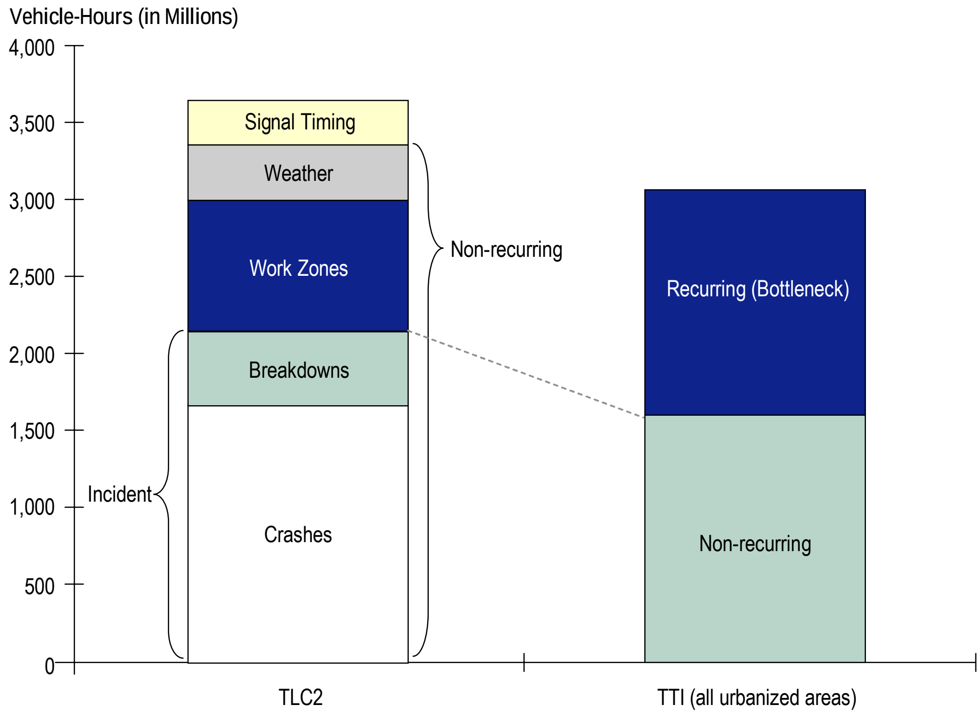
3.2 What Has Been Happening to Congestion Nationally?

3.2.1 What the Roadway-Based Data Are Telling Us

Is congestion getting worse? Yes. The best single source for monitoring congestion trends is produced annually by the Texas Transportation Institute (TTI).[13] In their 2005 report, TTI's researchers found that congestion levels in 85 of the largest metropolitan areas have grown in almost every year in all population groups from 1982 to 2003, as exemplified by the following trends.

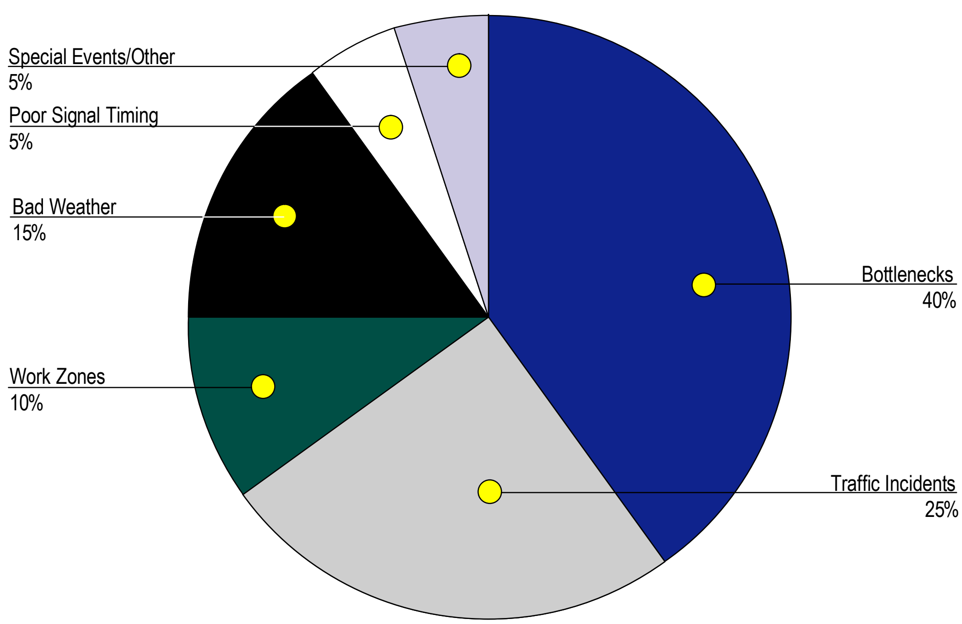
[13]Schrank, D. and Lomax, T., *2005 Urban Mobility Report,* Texas Transportation Institute.

Figure 3.1 Results of Two Modeling Studies to Estimate Congestion by Source



Source: Chin, S.M., Franzese, O., Greene, D.L., Hwang, H.L., and Gibson, R.C., *Temporary Loss of Highway Capacity and Impacts on Performance: Phase 2*, Report No. ORLNL/TM-2004/209, Oak Ridge National Laboratory, November 2004. "TLC2" is the methodology developed for this work; "TTI" are the results from the Texas Transportation Institutes annual Urban Mobility Study for 2004 (http://mobility.tamu.edu).

Figure 3.2 The Sources of Congestion *National Summary*



Ten-Year Average Urban Congestion Trends (1993 to 2003)

- Peak-period trips take an average of about 7 percent longer. (In most metropolitan areas, the idea of "rush hour" is obsolete – congestion happens for multiple hours on both morning and evening weekdays.)
- Travelers spend 47 extra hours per year in travel compared to 40 hours in 1993.
- The percent of urban freeway mileage that is congested has grown from 51 percent to 60 percent.

21-Year Urban Congestion Trends (1982 to 2003)

- Congestion has grown substantially over the past 20 years. While the largest cities are the most congested, congestion occurs – and has grown – in cities of every size (Figure 3.3).
- Congestion extends to more time of the day, more roads, affects more of the travel, and creates more extra travel time than in the past. And congestion levels have risen in all size categories, indicating that even the smaller areas are not able to keep pace with rising demand (Figure 3.4).
- Sixty-seven percent of the peak-period travel is congested compared to 33 percent in 1982. Travelers in the 85 urban areas studied spent an average of 47 hours per year stuck in traffic in 2003, up from 16 hours in 1982.
- Sixty percent of the major road system is congested compared to 35 percent in 1982.
- The number of hours of the day when travelers might encounter congestion has grown from 4.5 hours to 7.1 hours.

Congestion has clearly grown. Congestion used to mean it took longer to get to/from work in the "rush hour." It used to be thought of as a "big city" issue or an element to plan for while traveling to special large events. Sure there was slower traffic in small cities, but it was not much more than a minor inconvenience. The problems that smaller cities faced were about connections to and between cities, manufacturing plants, and markets.

Figure 3.3 Congestion Has Grown Substantially in U.S. Cities over the Past 20 Years

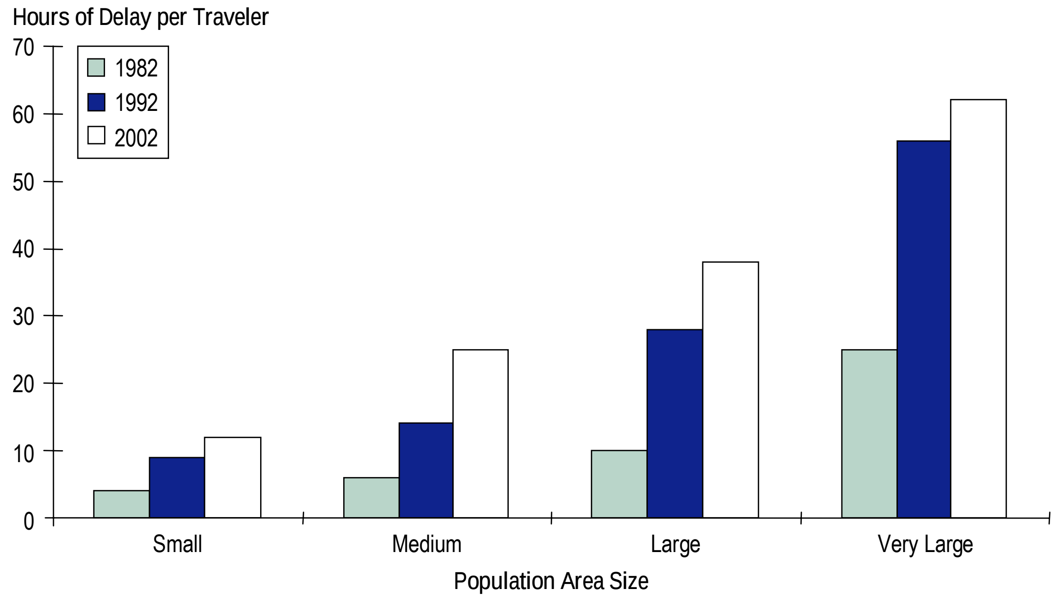
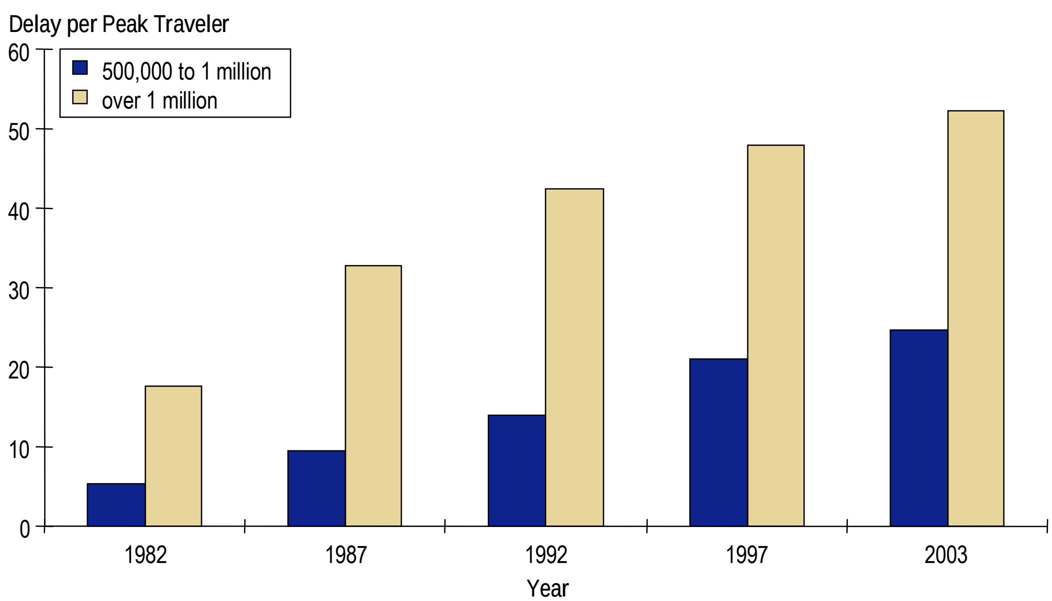


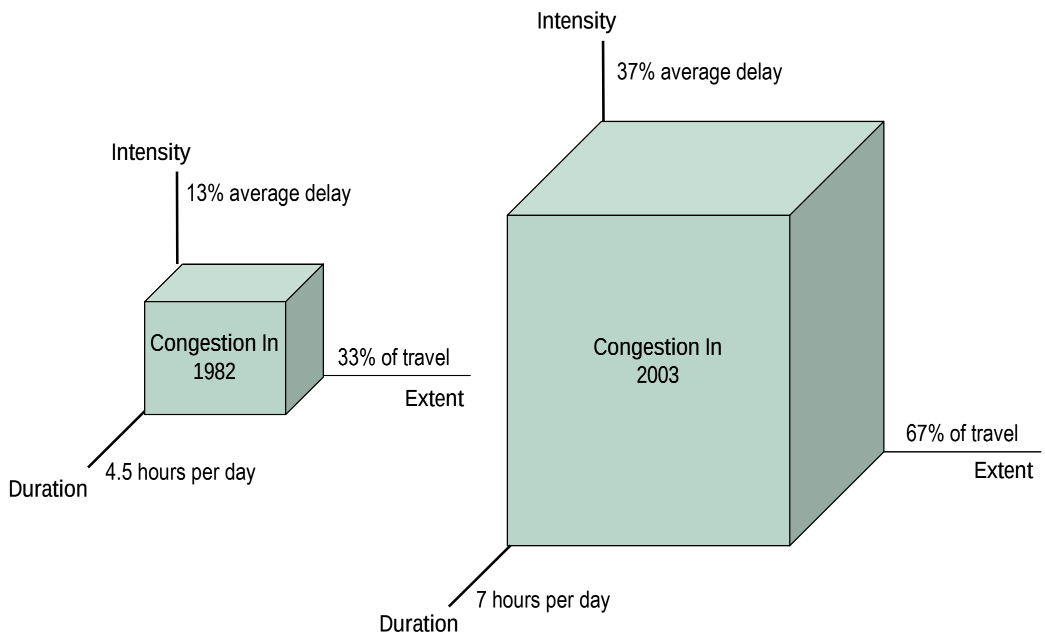
Figure 3.4 Peak-Period Congestion Trends by Urban Area Population Group



Source: Reference (1). Delay per peak traveler is a measure of the amount of extra travel time due to congestion. It is the amount of travel time above that required to complete a trip under ideal conditions

As the economy and lifestyles have changed over the past two decades, congestion is an element that is taken into consideration as we plan our daily travel. Congestion effects are reflected in decisions about business location and expansion, home and job sites, school, doctor visits, recreation, and social events and even who you date.[14] But it also is due to the fact that congestion affects more trips, more hours of the day and more of the transportation system (Figure 3.5). Congestion is affecting not only weekday commuter travel but several other types of travel: weekend travel in suburban shopping areas, travel near major recreational areas, and travel related to special events (such as sporting events).

Figure 3.5 Weekday Peak-Period Congestion Has Grown in Several Ways in the Past 20 Years in Our Largest Cities



Consider the following characteristics of congestion trends:

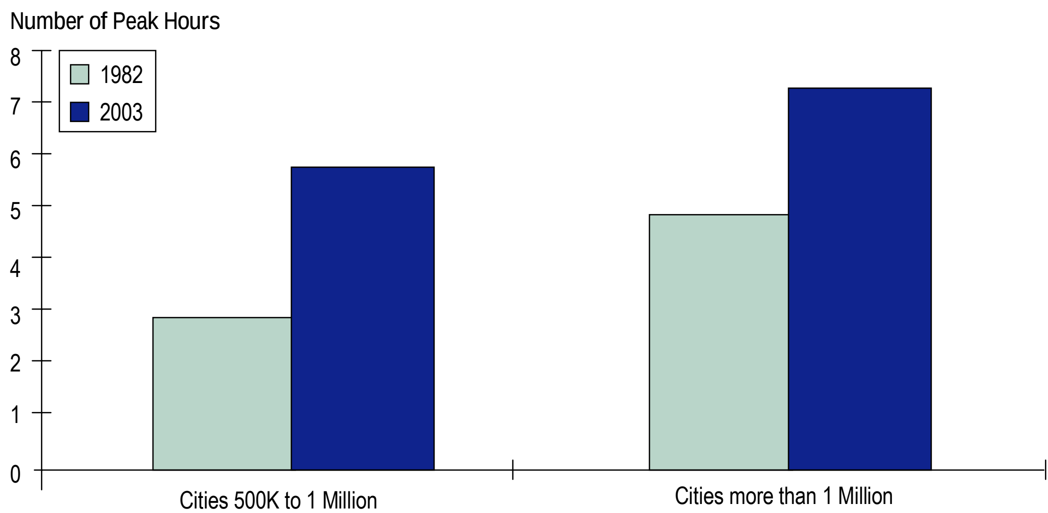
- **Congestion affects more of the system**. You might encounter stop-and-go traffic on any major street or freeway. Congestion effects have spread to neighborhoods, where cities and residents have developed elaborate plans and innovative techniques to make it harder for commuters to use the streets where kids play as bypass routes for gridlocked intersections. These are just the average conditions. Many cities have a few places where any daylight hour might see stop-and-go traffic. Weekend traffic delays have become a problem in recreational areas, near major shopping centers or sports arenas and in some constrained roadways.
- **Congestion affects more time of the day**. We are not just seeing these problems in the "rush hour." Peak periods typically stretch for two or three

[14] Caitlin Liu. Los Angeles Times. *SigAlert on the Roadway to Love; Traffic Sometimes Dictates the Route of Romance in Los Angeles*. February 13, 2004.

hours in the morning and evening in metro areas above one million people (Figure 3.6). Larger areas can see three or four hours of peak conditions.

- **The extra travel time penalty has grown**. It just takes longer to get to your destination. Not just work or school, but shopping trips, doctor visits and family outings are planned around the questions "How long do I want to spend in the car, bus or train?" and "Is it worth it?" Peak-period trips required 37 percent more travel time in 2003 than a free flow trip at midday, up from 28 percent 10 years earlier.

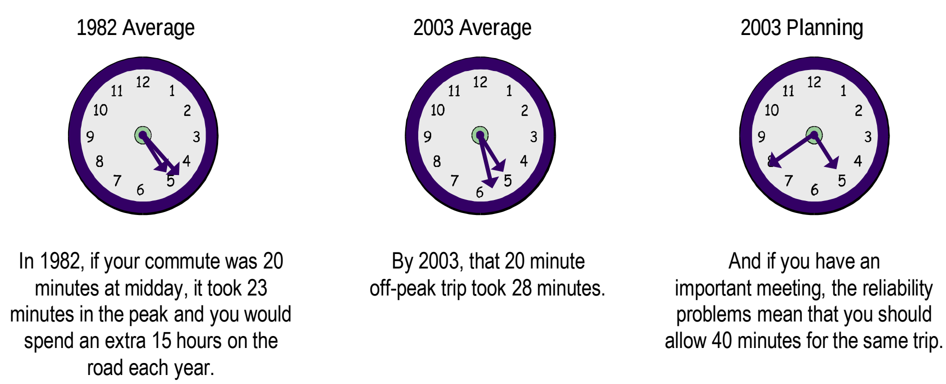
Figure 3.6 How Many Rush Hours in a Day?



Source: Analysis of data used in 2005 Annual Urban Mobility Report, Texas Transportation Institute.

Travel Reliability is getting worse. There really is a fourth characteristic to the congestion problem – Reliability. The extra travel time and amount of the day and system affected by travel delays is not the same every day. It may not even be as it was predicted 10 minutes ago (Figure 3.7).

Figure 3.7 Travel Time Reliability Illustration



Source: Analysis of data used in *2005 Urban Mobility Report*, Texas Transportation Institute.

- **1982 –** If your midday trip took 20 minutes, it would take you 23 minutes in the peak. Although no reliability statistics exist from that long ago, analysis of recent data suggest that you would have to add an additional nine minutes to that trip to guarantee on-time arrival at your destination; a total of 32 minutes might be planned for that trip.
- **2003 –** By 2003, that 20-minute free-flow trip took 28 minutes. And if on-time arrival was important you should allow 40 minutes for the trip.

3.2.2 What the Survey Data Are Telling Us

In addition to the Urban Mobility report and Mobility Monitoring Program, congestion trends are tracked through travel surveys. On the national level, the two primary sources of data that exist are the National Household Travel Survey (NHTS) and the decennial Census. Some metropolitan areas, such as the San Francisco Bay Area, have also conducted their own household travel surveys. In general, all these surveys point to ever increasing congestion for the traveling public.

While the NHTS and Census indicate increasing congestion, the nature of travel behavior is changing as well. This is partially due to the change in family structure and the increase in vehicle ownership. On average, people are also traveling more miles to and from work. However, work trips comprise only a small percentage of all the trips that are taken.[15]

Increasing congestion can be represented by examining a combination of increasing travel time, increasing distance and decreasing speeds for privately owned vehicles (POV; Figures 3.8 to 3.10). Commuters are traveling longer distances at a slower rate. This trend is occurring in metropolitan statistical areas (MSA) of all sizes.

The Metropolitan Transportation Commission (MTC) in the San Francisco Bay Area has also conducted its own household travel survey in 1990 and 2000. Comparison of the results of the two surveys has been documented in the report, "Activities, Time, and Travel: Changes in Women's Travel Time Expenditures, 1990-2000." More people travel for a longer (more than 25 minutes) duration in 2000 than in 1990. The distribution of the travel time duration in Figure 3.11 is derived from data presented in the report.[16]

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[15] *A Walk Through Time: Changes in the American Commute*, http://nhts.ornl.gov/2001/presentations/commuting/index.shtml.

[16] *Activities, Time, and Travel: Changes in Women's Travel Time Expenditures, 1990-2000*, by Rachel Gossen and Charles L. Purvis. http://www.mtc.ca.gov/maps_and_data/datamart/research/Changes-in-Womens-Travel-Time-Expenditures-1990-2000.pdf.

Figure 3.8 The Average Commute Travel Time in a Privately Owned Vehicle (POV) Has Increased

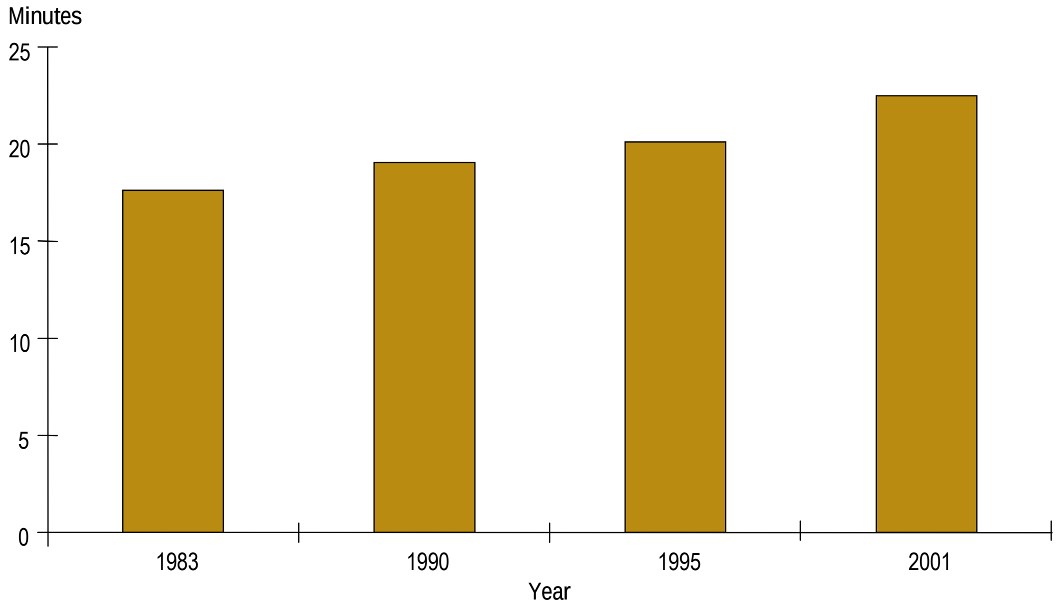


Figure 3.9 The Average Commute Trip Length in a POV Has Increased

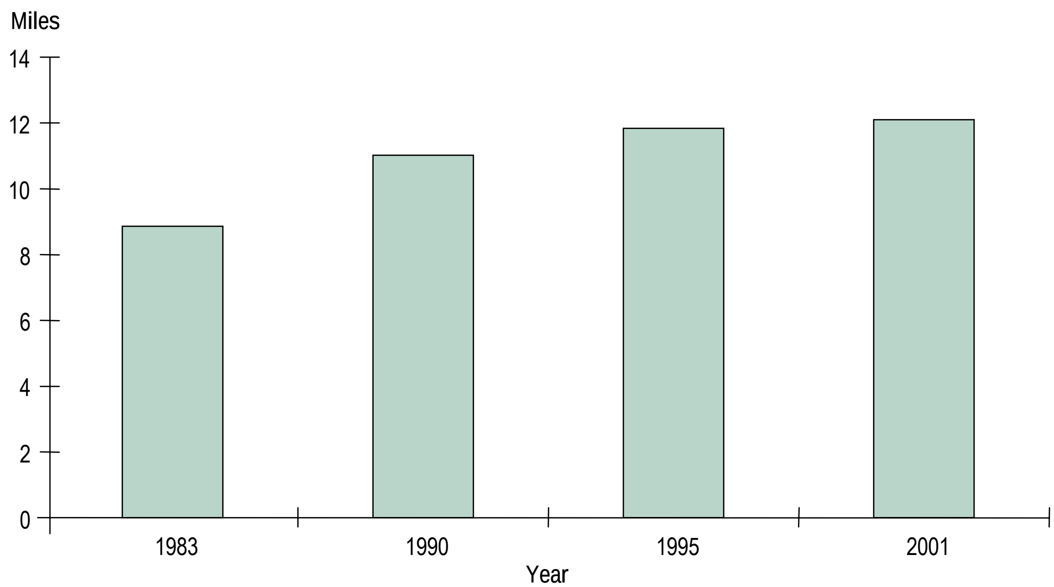


Figure 3.10 After Showing Modest Improvement in the 1990s, Average Commute Speeds Have Begun to Worsen

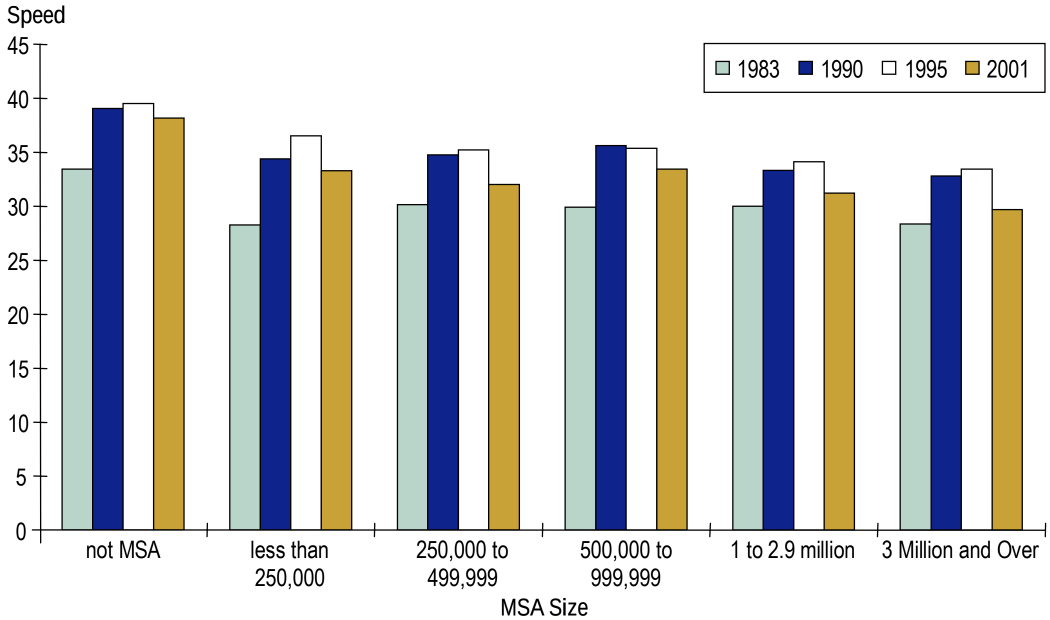
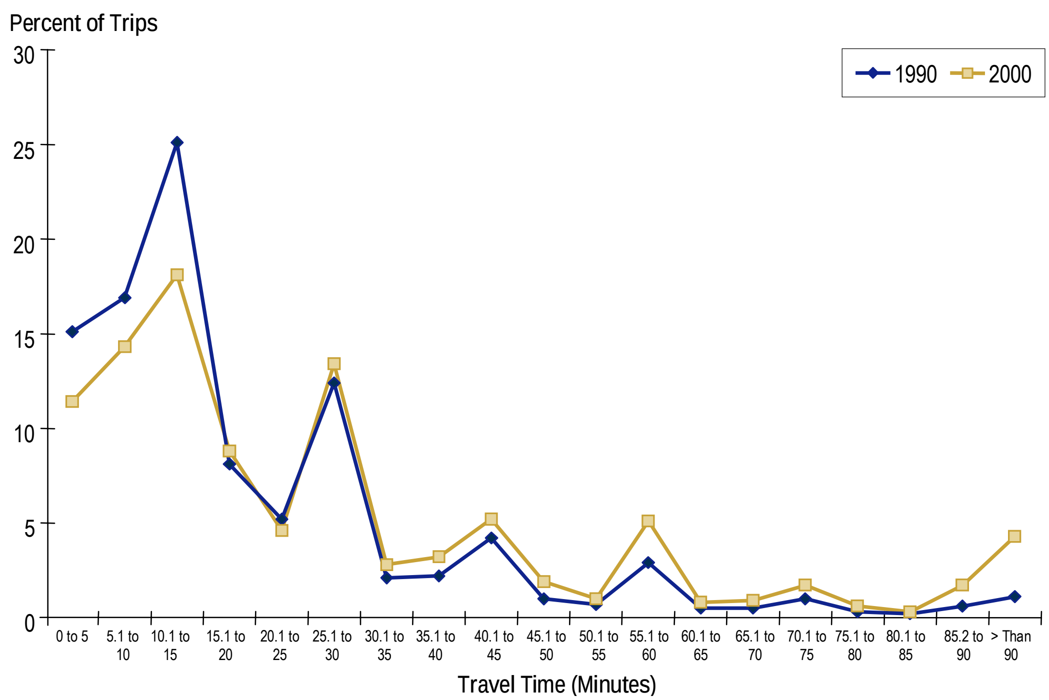


Figure 3.11 Trips in San Francisco Are Now Taking Longer to Complete



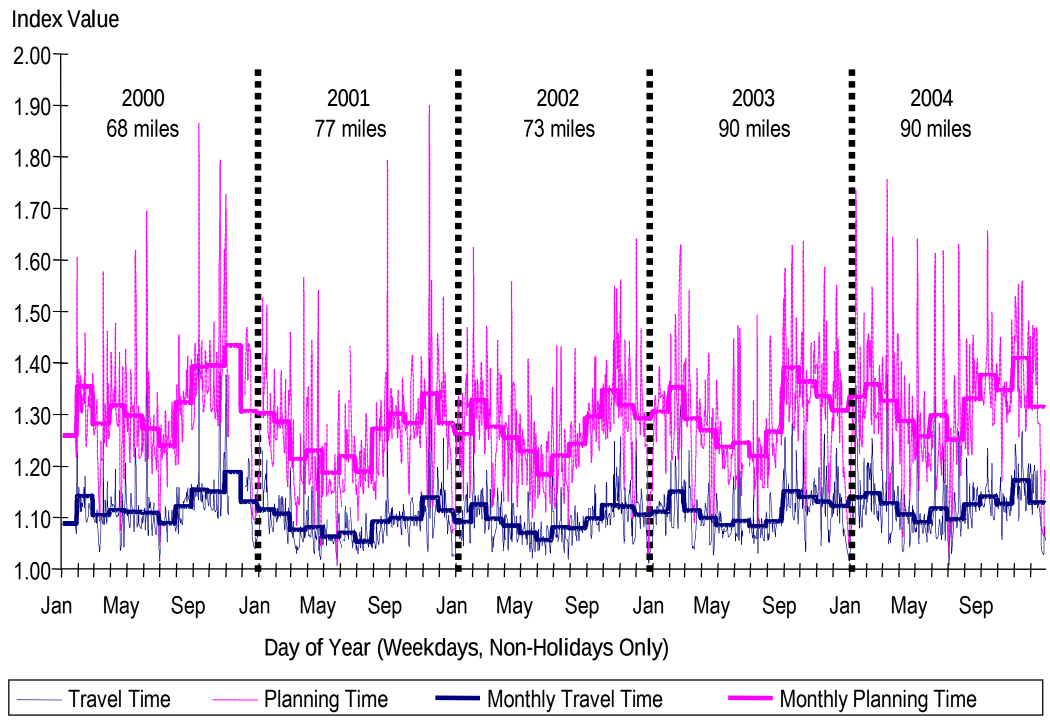
3.3 A Closer Look at Congestion Trends

3.3.1 Cities with Detailed Traffic Monitoring Systems

FHWA has been compiling traffic monitoring data in major metropolitan areas since 2000. The program started with 10 cities and has added new cities every year. Additionally, some cities add traffic monitoring to new highways every year. The Appendix provides a description of the technologies used and the data collected from these systems. These data can be summarized at the areawide level or at the individual corridor level. Data from three cities whose participation began in 2000 follows.

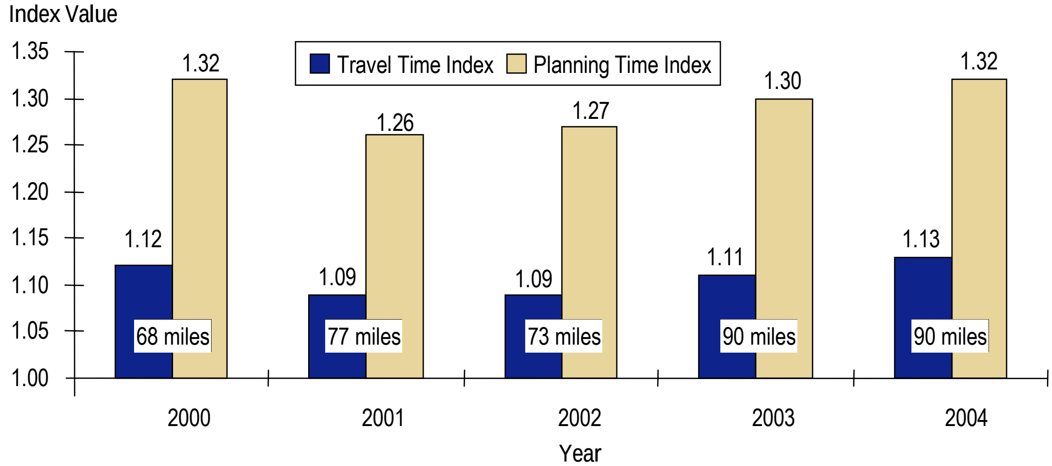
Figures 3.12 and 3.13 summarize data from San Antonio for the 2000-2004 period. Congestion trends over the five years appear to relatively stable, with a slight increase overall in both congestion level and unreliable travel.

Figure 3.12 Daily and Monthly Trends in Congestion
San Antonio, Texas, 2000-2004



Source: Analysis of data from FHWA's *Mobility Monitoring Program*. The Travel Time Index (TTI) is a measure of total congestion. It is the ratio of the peak-period travel time to the travel time under ideal conditions. A TTI value of 1.2 indicates that peak-period travel takes 20 percent longer than under ideal conditions. All are shown for individual days. The "-Month" indices are monthly averages and are shown to smooth out the trends. Although weekends and holidays are excluded, days next to holidays show light peak-period traffic characteristics (e.g., July 5). Note the upturn in peak-period delay and unreliability in the Autumn months as vacationing travelers return to work and school. Note also that as the Travel Time Index increases, so does unreliable travel.

Figure 3.13 Annual Trends in Congestion
San Antonio, Texas, 2000-2004



Note: The number of miles indicated on the chart is the amount of highways directly monitored by TXDOT in the San Antonio area in each year.

The dip in congestion in 2001 and 2002 can be due to two possible reasons: a decrease in economic activity and/or changes in the amount of roadway monitored. Another trend displayed in San Antonio that is also observed in many other cities is that as average congestion level increases, so does the amount of unreliable travel. This provides some empirical evidence for the theoretical relationships between bottleneck delay and traffic incident delay previously identified in Figure 2.4.

Examining trends in individual corridors removes the problem of changing traffic surveillance coverage from year to year. Table 3.1 shows corridor-level trends in the Seattle, Washington and Atlanta, Georgia areas. As with the San Antonio data, both cities exhibit the upturn in congestion level in 2001, followed in most corridors by a decrease in 2002, followed by a slight upturn in 2003. The fact that congestion is influenced by the general state of the economy has been noted anecdotally for many years, and these data provide some empirical evidence of the relationship. Also, the positive correlation between average congestion level (Travel Time Index) and reliability level (Buffer Index) is demonstrated very well in these data (Figure 3.14).

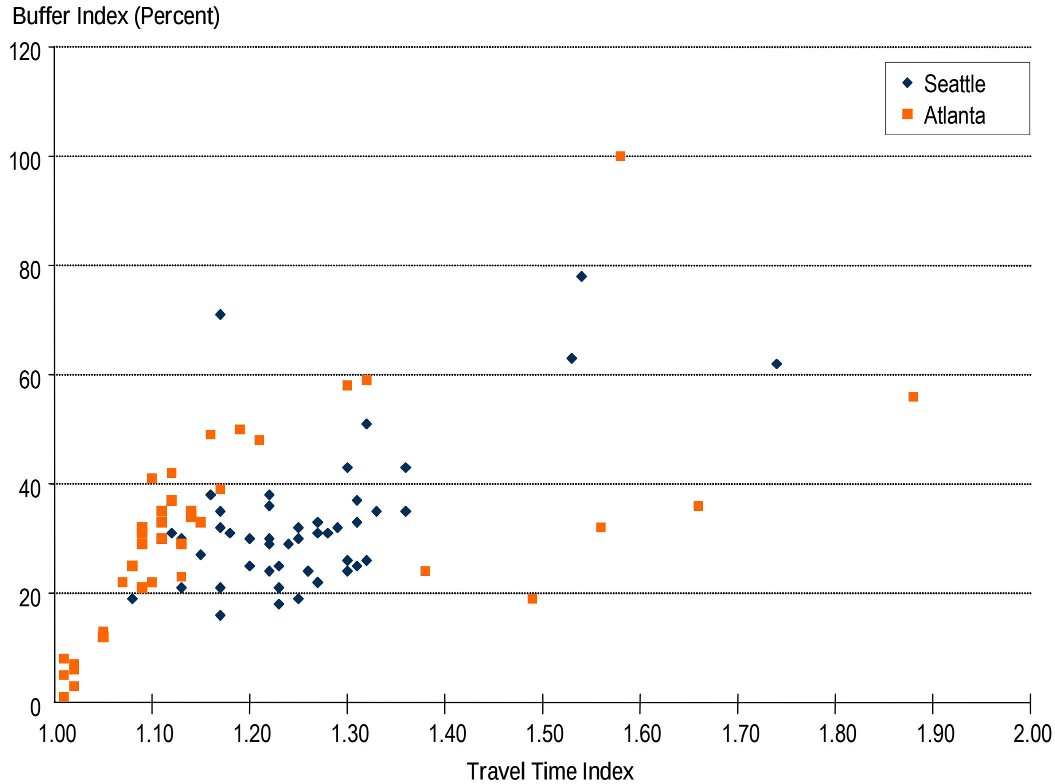
Table 3.1 Most Freeway Corridors in Seattle, Washington and Atlanta, Georgia Have Experienced a Growth in Congestion and Unreliable Travel

	Travel Time Index			
Corridor	2000	2001	2002	2003
SEATTLE				
I-5A, NB (I-405 to I-90 11.13 mi)	1.20	1.32	1.22	1.22
I-5A, SB (I-90 to I-405 11.13 mi)	1.13	1.25	1.17	1.17
I-5B, NB (I-90 to SR 520 2.69 mi)	1.25	1.74	1.53	1.54
I-5B, SB (SR 520 to I-90 2.69 mi)	1.22	1.31	1.24	1.23
I-5C, NB (SR 520 to SR 526 21.39 mi)	1.17	1.33	1.29	1.31
I-5C, SB (SR 526 to SR 520 21.39 mi)	1.22	1.27	1.30	1.36
I-90, EB (S Norman Street (I-5) to Front Street 14.06 mi)	1.08	1.17	1.13	1.12
I-90, WB (Front Street to 12th Avenue (I-5) 14.32 mi)	1.18	1.15	1.16	1.13
I-405A, NB (I-5 S to I-90 9.01 mi)	1.32	1.36	1.30	1.26
I-405A, SB (I-90 to I-5 S 9.01 mi)	1.20	1.30	1.31	1.23
I-405B, NB (I-90 to I-5 N 15.44 mi)	1.23	1.27	1.25	1.17
I-405B, SB (I-5 N to I-90 15.44 mi)	1.26	1.27	1.28	1.22
	Buffer Index			
	2000	2001	2002	2003
I-5A, NB (I-405 to I-90 11.13 mi)	30%	51%	29%	30%
I-5A, SB (I-90 to I-405 11.13 mi)	21%	30%	32%	35%
I-5B, NB (I-90 to SR 520 2.69 mi)	32%	62%	63%	78%
I-5B, SB (SR 520 to I-90 2.69 mi)	36%	37%	29%	25%
I-5C, NB (SR 520 to SR 526 21.39 mi)	21%	35%	32%	33%
I-5C, SB (SR 526 to SR 520 21.39 mi)	38%	33%	43%	43%
I-90, EB (S Norman Street (I-5) to Front Street 14.06 mi)	19%	71%	29%	31%
I-90, WB (Front Street to 12th Avenue (I-5) 14.32 mi)	31%	27%	38%	30%
I-405A, NB (I-5 S to I-90 9.01 mi)	26%	35%	24%	24%
I-405A, SB (I-90 to I-5 S 9.01 mi)	25%	26%	25%	21%
I-405B, NB (I-90 to I-5 N 15.44 mi)	18%	31%	19%	16%
I-405B, SB (I-5 N to I-90 15.44 mi)	24%	22%	31%	24%

Table 3.1 Most Freeway Corridors in Seattle, Washington and Atlanta, Georgia Have Experienced a Growth in Congestion and Unreliable Travel (continued)

	Travel Time Index			
Corridor	2000	2001	2002	2003
ATLANTA				
I-75A, NB (I-285 to I-20 7.72 mi)	1.09	1.13	1.11	1.14
I-75A, SB (I-20 to I-285 7.36 mi)	1.05	1.10	1.08	1.15
I-75B, NB (I-20 to I-85 Split 3.73 mi)	1.21	1.32	1.30	1.58
I-75B, SB (I-85 Split to I-20 4.04 mi)	1.38	1.66	1.56	1.88
I-75C, NB (I-85 Split to I-285 8.95 mi)	1.11	1.17	1.09	1.11
I-75C, SB (I-285 to I-85 Split 9.63 mi)	1.05	1.09	1.12	1.19
I-85A, NB (Camp Creek Parkway to I-75 4.18 mi)	1.02	1.01	1.01	1.02
I-85A, SB (I-75 to Camp Creek Parkway 4.05 mi)	1.02	1.01	1.01	1.01
I-85B, NB (I-75 to Jimmy Carter Boulevard 14 mi)	1.07	1.16	1.49	1.13
I-85B, SB (Jimmy Carter Boulevard to I-75 13.6 mi)	1.10	1.12	1.09	1.14
	Buffer Index			
	2000	2001	2002	2003
I-75A, NB (I-285 to I-20 7.72 mi)	21%	29%	33%	35%
I-75A, SB (I-20 to I-285 7.36 mi)	12%	22%	25%	33%
I-75B, NB (I-20 to I-85 Split 3.73 mi)	48%	59%	58%	100%
I-75B, SB (I-85 Split to I-20 4.04 mi)	24%	36%	32%	56%
I-75C, NB (I-85 Split to I-285 8.95 mi)	30%	39%	32%	35%
I-75C, SB (I-285 to I-85 Split 9.63 mi)	13%	29%	42%	50%
I-85A, NB (Camp Creek Parkway to I-75 4.18 mi)	6%	1%	1%	3%
I-85A, SB (I-75 to Camp Creek Parkway 4.05 mi)	7%	8%	5%	8%
I-85B, NB (I-75 to Jimmy Carter Boulevard 14 mi)	22%	49%	19%	23%
I-85B, SB (Jimmy Carter Boulevard to I-75 13.6 mi)	41%	37%	31%	34%

Figure 3.14 Corridor Statistics for Seattle and Atlanta
2000-2003



Source: Analysis of data from FHWA's *Mobility Monitoring Program*. The Travel Time Index (TTI) is a measure of total congestion. It is the ratio of the peak period travel time to the travel time under ideal conditions. A TTI value of 1.2 indicates that peak period travel takes 20 percent longer than under ideal conditions. The Buffer Index is a measure of reliability; as it increases, travel times become increasingly unreliable. (See Table 2.2 for definitions.)

3.3.2 The Nation's Major Traffic Bottlenecks

Physical bottlenecks have been the focus of transportation improvements – and of travelers' concerns – for many years. On much of the urban highway system, there are specific points that are notorious for causing congestion on a daily basis. These locations – which can be a single interchange (usually freeway-to-freeway), a series of closely spaced interchanges, or lane-drops – are focal points for congestion in corridors; major bottlenecks tend to dominate congestion in corridors where they exist. Many acquire nicknames from local motorists such as:

- "Spaghetti Bowl" in Las Vegas;
- "Hillside Strangler" in Chicago; and
- "Mixmaster" in Dallas.

How bad congestion becomes at a bottleneck is related to its physical design. Some bottlenecks were originally constructed many years ago using designs that were appropriate when there were built, but are now considered antiquated. Others have been built to extremely high design specifications and are simply overwhelmed by traffic. A recent examination of national bottlenecks identified the worst physical bottlenecks in the country and examined the positive effects that improving them could have on travel times, safety, emissions, and fuel consumption. Table 3.2 provides a ranking of these bottlenecks.

Table 3.2 The Worst Physical Bottlenecks in the United States
2002

Rank	City	Freeway	Location	Annual Hours of Delay (Hours in Thousands)
1	Los Angeles	U.S. 101	U.S. 101 (Ventura Freeway) at I-405 Interchange	27,144
2	Houston	I-610	I-610 at I-10 Interchange (West)	25,181
3	Chicago	I-90	I-90/94 at I-290 Interchange (“Circle Interchange”)	25,068
4	Phoenix	I-10	I-10 at SR 51/SR 202 Interchange (“Mini-Stack”)	22,805
5	Los Angeles	I-405	I-405 (San Diego Freeway) at I-10 Interchange	22,792
6	Atlanta	I-75	I-75 south of the I-85 Interchange	21,045
7	Washington (D.C.-Maryland-Virginia)	I-495	I-495 at I-270 Interchange	19,429
8	Los Angeles	I-10	I-10 (Santa Monica Freeway) at I-5 Interchange	18,606
9	Los Angeles	I-405	I-405 (San Diego Freeway) at I-605 Interchange	18,606
10	Atlanta	I-285	I-285 at I-85 Interchange (“Spaghetti Junction”)	17,072
11	Chicago	I-94	I-94 (Dan Ryan Expressway) at I-90 Skyway Split (Southside)	16,713
12	Phoenix	I-17	I-17 (Black Canyon Freeway) at I-10 Interchange (the “Stack”) to Cactus Road	16,310
13	Los Angeles	I-5	I-5 (Santa Ana Freeway) at SR 22/SR 57 Interchange (“Orange Crush”)	16,304
14	Providence	I-95	I-95 at I-195 Interchange	15,340
15	Washington (D.C.-Maryland-Virginia)	I-495	I-495 at I-95 Interchange	15,035
16	Tampa	I-275	I-275 at I-4 Interchange (“Malfunction Junction”)	14,371
17	Atlanta	I-285	I-285 at I-75 Interchange	14,333
18	Seattle	I-5	I-5 at I-90 Interchange	14,306

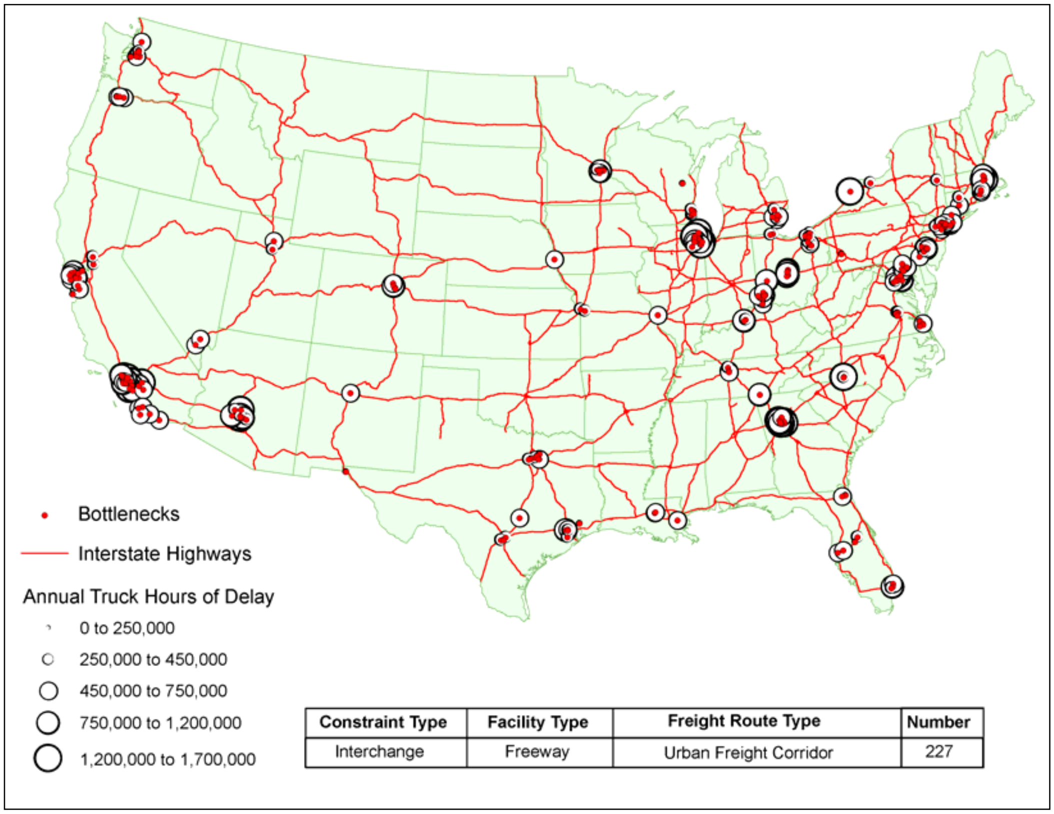
Rank	City	Freeway	Location	Annual Hours of Delay (Hours in Thousands)
19	Chicago	I-290	I-290 (Eisenhower Expressway) Between Exits 17b and 23a	14,009
20	Houston	I-45	I-45 (Gulf Freeway) at U.S. 59 Interchange	13,944
21	San Jose	U.S. 101	U.S. 101 at I-880 Interchange	12,249
22	Las Vegas	U.S. 95	U.S. 95 west of the I-15 Interchange ("Spaghetti Bowl")	11,152
23	San Diego	I-805	I-805 at I-15 Interchange	10,992
24	Cincinnati	I-75	I-75, from Ohio River Bridge to I-71 Interchange	10,088

Source: *Unclogging America's Arteries: Effective Relief for Highway Bottlenecks*, American Highway Users Alliance (AHUA), February 2004. Delay is the extra time it would take to travel through the bottlenecks compared to completely uncongested conditions. The report did not consider many severe bottlenecks from the New York City area. As most travelers know, congestion in and around the boroughs of New York can be significant. However, a very large amount of delay in the New York area is related to bridge and tunnel crossings into Manhattan, most of which are toll facilities. Also, while the New York metropolitan area is laced with Interstates, parkways, and expressways, they seldom reach the proportions seen in other major areas, except where multiple highways converge on bridge of tunnel crossings. (A typical lane configuration for a New York area freeway is six lanes, three in each direction. But there are many of these.) Toll facilities were excluded from the study because toll facilities are fundamentally different from other physical bottlenecks (such as freeway-to-freeway interchanges) that are prevalent around the country. Delay comparisons between toll facilities and other types of bottlenecks might not be consistent since different modeling techniques would be used. If objective field measurements of delay could be made at all locations around the country, several river crossings into Manhattan would no doubt be included in a list of the nation's worst bottlenecks.

A current FHWA study is identifying the location of bottlenecks specific to truck traffic.[17] Not surprisingly, when total truck delay is considered, urban locations dominate the bottleneck rankings (Figure 3.15). In fact, many of the same locations identified in the AHUA study as commuting bottlenecks also appear as truck bottlenecks, though the rankings shift due to higher truck volumes at some locations. The fact that trucks get caught in congestion at urban bottlenecks (resulting in productivity losses and increased transportation costs) only increases the significance of these bottlenecks as major transportation problems. Conversely, alleviating congestion at specific bottleneck locations will result in substantial benefits to commuters and truckers alike, and these benefits will be passed onto the economy at-large.

[17] Cambridge Systematics and Battelle Memorial Institute, *Freight Bottlenecks*, unpublished white paper for FHWA Office of Policy, March 2005.

Figure 3.15 Interchange Capacity Bottlenecks on Freeways Used as Urban Truck Corridors



Source: Cambridge Systematics and Battelle Memorial Institute, *Freight Bottlenecks*, unpublished white paper for FHWA Office of Policy, March 2005.

3.3.3 Expected Congestion in the Future: *Not Just for Metropolitan Areas Anymore*

Figure 3.16 depicts congestion at the national level for 1998. As shown, congestion is confined to metropolitan areas. In contrast, Figure 3.17 shows the expected growth in congestion by 2020, assuming no additional increases in physical and operational highway capacity. In addition to more metropolitan areas experiencing congestion, Figure 3.17 shows that congestion will spread into formerly rural areas, the urban fringe, and intercity corridors. Much of this congestion will affect intercity truck traffic, which is expected to grow by 75 percent between 2000 and 2020.[18]

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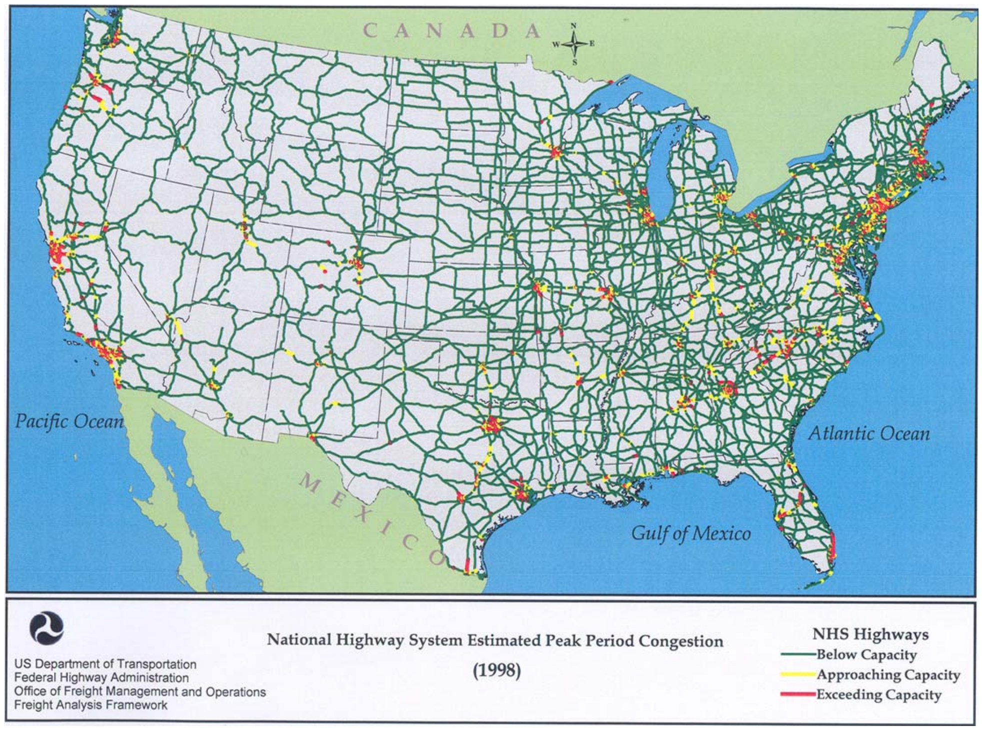
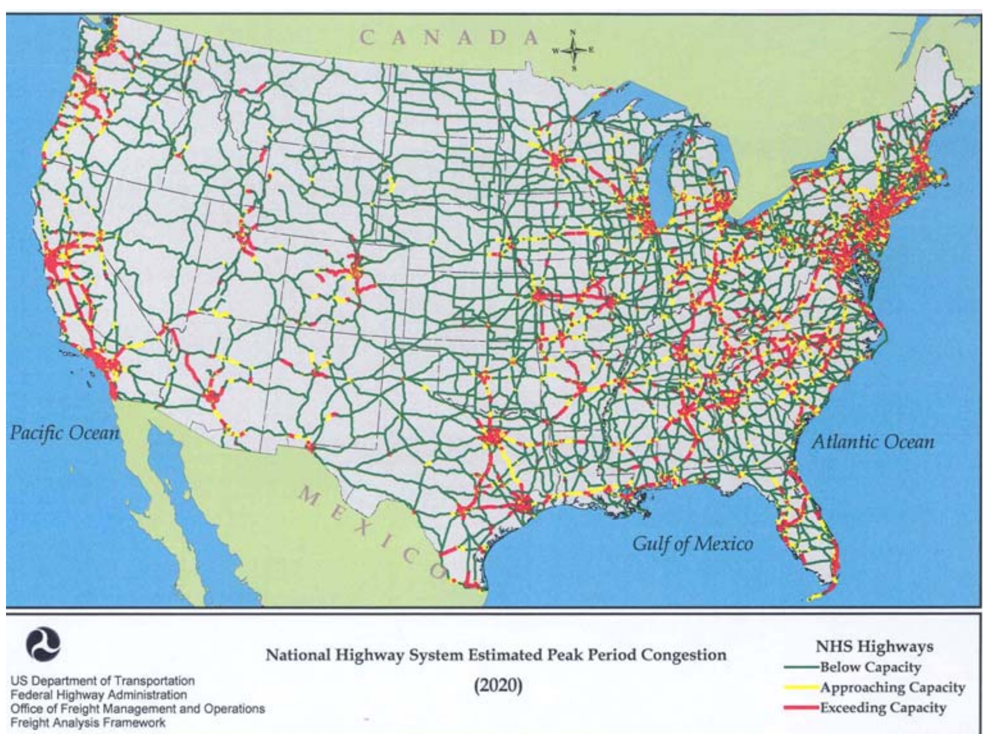
[18] FHWA Freight Analysis Framework, http://www.ops.fhwa.dot.gov/freight/freight_news/FAF/talkingfreight_faf.htm.

Figure 3.16 Congested Highways (1998)



Source: Federal Highway Administration Freight Analysis Framework.

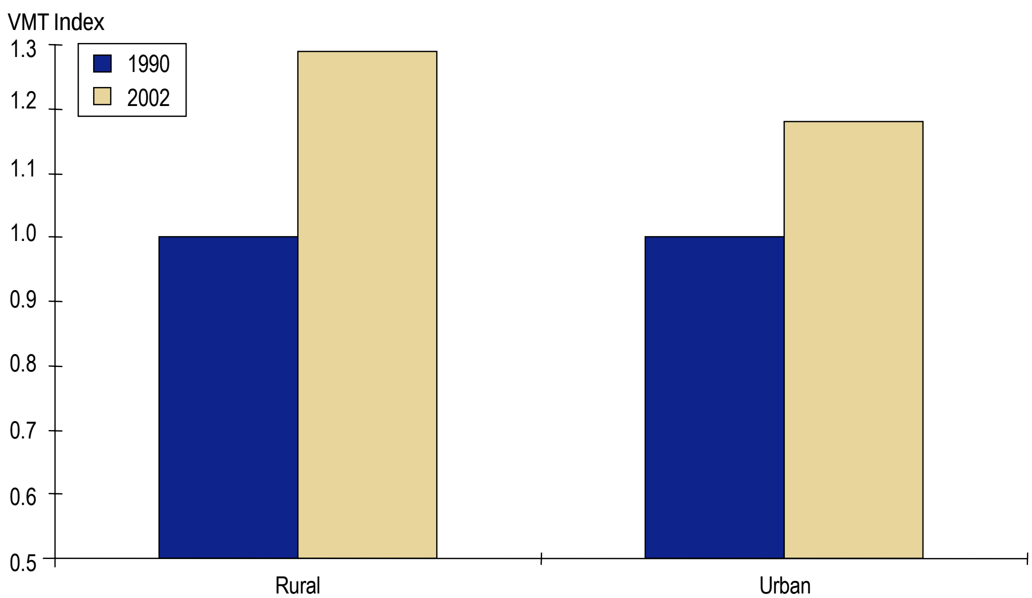
Figure 3.17 Potentially Congested Highways (2020)



Source: Federal Highway Administration Freight Analysis Framework.

In addition to the long-range modeling used to produce the data in Figure 3.17, examination of trends over the past decade, reinforce the idea that congestion is spreading out of cities. Figure 3.18 shows that vehicle-miles of travel are growing faster in rural areas than in urban areas. While there is currently enough excess capacity in most rural areas to absorb this increase, it will be eventually overtaken by traffic growth. Moreover, the first indications of non-metropolitan congestion are beginning to manifest themselves. A recent study by transportation interest groups identified several rural recreational and tourist destinations that routinely experience congestion during the summertime peaks.[19] While congestion at these locations is far less than in urban areas – the bottleneck restrictions are not as severe and delay is incurred usually only on peak-season weekends – the growth in rural traffic of all kinds means that congestion in nonmetropolitan areas will continue to increase.

Figure 3.18 Vehicle-Miles of Travel on Major Rural and Urban Roads Increased Between 1990 to 2002



Note: For the VMT Index, 1.0 = 1990 level

Source: American Highway Users Alliance, AAA, and TRIP, *Are We There Yet? A Report on Summer Traffic Bottlenecks and Steps Needed to Ensure that Our Favorite Vacation Destinations Remain Accessible*, June 30, 2005. http://www.highways.org/pdfs/travel_study2005.pdf.

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[19] American Highway Users Alliance, AAA, and TRIP, *Are We There Yet? A Report on Summer Traffic Bottlenecks and Steps Needed to Ensure that Our Favorite Vacation Destinations Remain Accessible*, June 30, 2005. http://www.highways.org/pdfs/travel_study2005.pdf.

4.0 Congestion Strategies: What Works?

4.1 The Toolbox for Congestion Relief: What Can We Do about Traffic Congestion?

Transportation engineers and planners have developed a variety of strategies to deal with congestion (Figure 4.1). These fall into three general categories:

1. **Adding More Capacity – Increasing the Number and Size of Highways and Providing More Transit and Freight Rail Service.** Adding more lanes to existing highways and building new ones has been the traditional response to congestion. In some metropolitan areas, however, it is becoming increasingly difficult to undertake major highway expansions because of funding constraints, increased right-of-way and construction costs, and opposition from local and national groups. However, it is clear that adding new physical capacity for highways, transit, and railroads is an important strategy for alleviating congestion.

   In those locations where the lack of physical capacity is the greatest contributor to congestion, addition of new capacity is critical. In such locations, the addition of new capacity is critical. Further, the addition of new capacity presents an excellent opportunity to combine it with other types of strategies. This often means that highway designers must think "outside the box" and find creative ways to incorporate new designs and travel alternatives that accommodate the concerns of diverse groups and a variety of system users. Since the worst highway bottlenecks tend to be freeway-to-freeway interchanges, advanced design treatments that spread out turning movements and remove traffic volumes from key merge areas have been developed, often by using multilevel structures that minimize the footprint of the improvement on the surrounding landscape.

   Adding new freeways or additional lanes to existing freeways will add large amounts of capacity to the roadway network. However there are other improvements to the transportation system that can reduce or manage congestion, albeit in a more localized area. Widening arterial roads, providing street connectivity, provide grade separations at congested intersections and providing high-occupancy vehicle (HOV) lanes all will help to mitigate congestion. Also, adding capacity to the transit system, whether it is to the bus system, urban rail system or commuter rail system will assist in relieving congestion on the roadway network.

Figure 4.1 A Variety of Strategies, When Used in Combination, Can Effectively Deal with Congestion

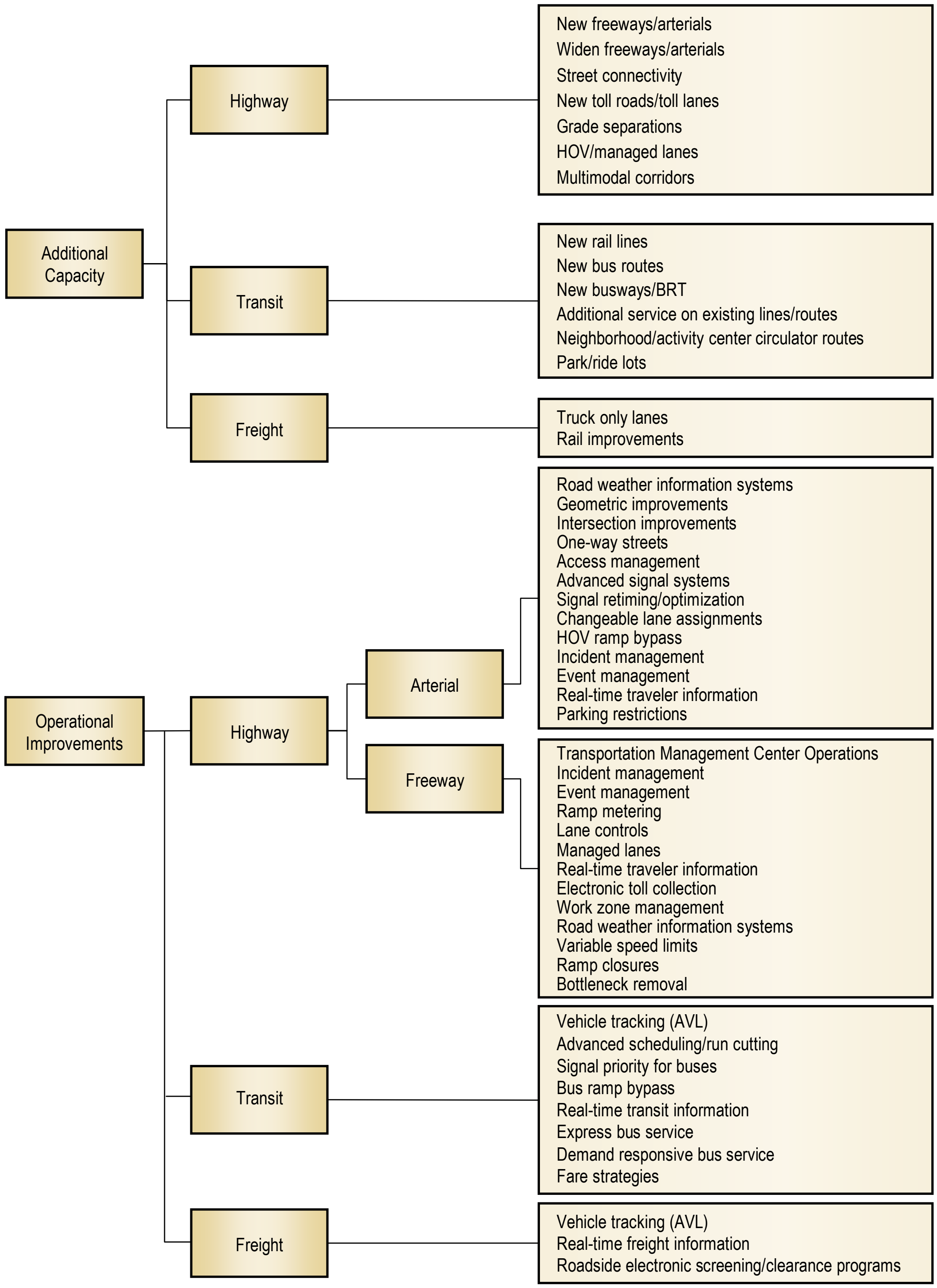
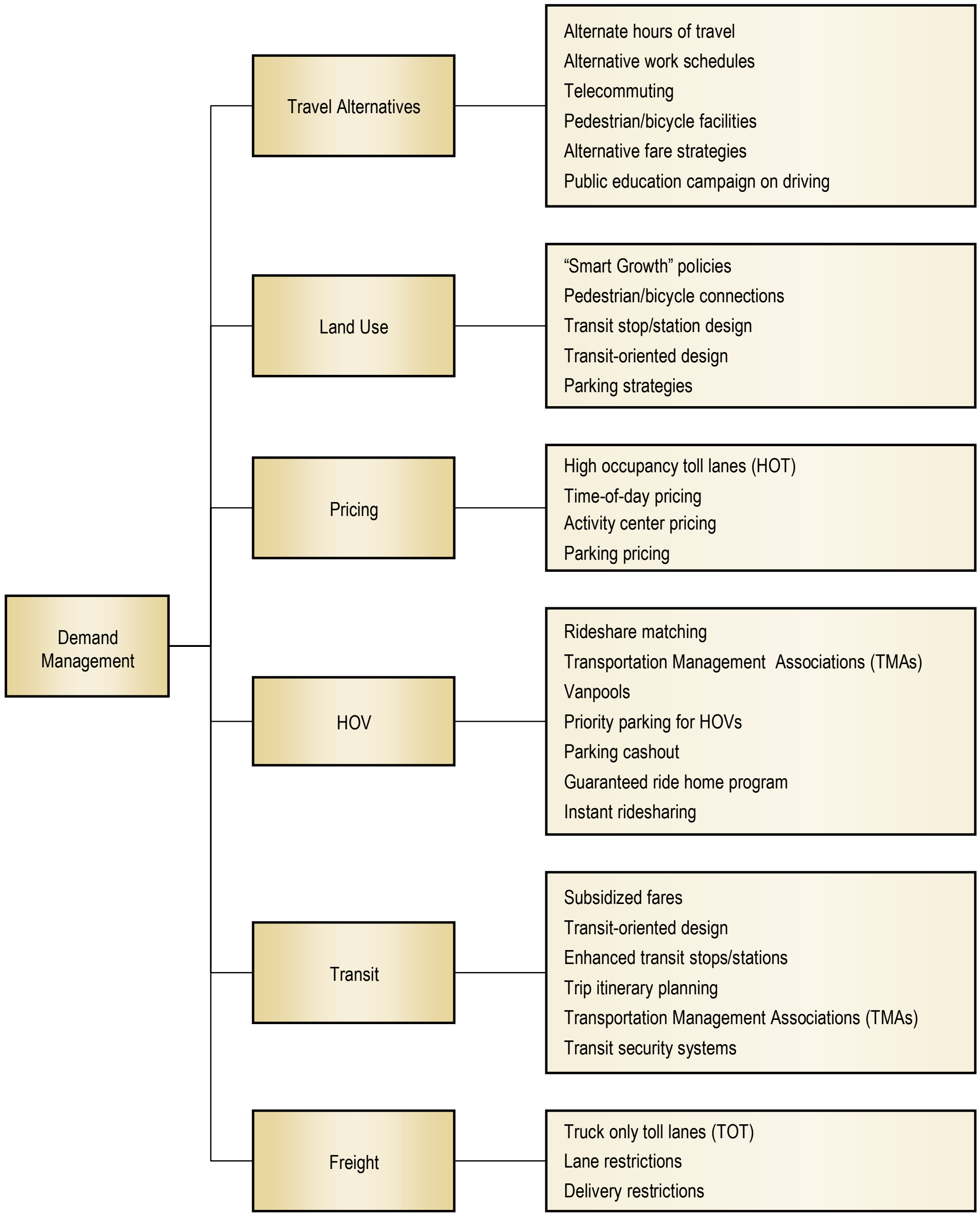


Figure 4.1 A Variety of Strategies, When Used in Combination, Can Effectively Deal with Congestion (continued)



Note: Improvements in italics are those enabled by Intelligent Transportation Systems technology.

2. **Operating Existing Capacity More Efficiently – Getting More Out of What We Have.** ("Operational Improvements" in Figure 4.1). In recent years, transportation engineers and planners have increasingly embraced strategies that deal with the *operation* of existing highways, rather than just building new infrastructure. The philosophy behind Transportation System Management and Operations (TSM&O) is to mitigate the effects of a wide variety of roadway events and to manage short-term demand for existing roadway capacity.

   TSM&O includes the application of advanced technologies using real-time information about highway conditions to implement control strategies. Collectively referred to as ITS, real-time control of highway operations through a transportation management center (TMC) has become a major activity undertaken by transportation agencies. ITS control strategies take many forms: metering flow onto freeways, dynamically retiming traffic signals, managing traffic flow during incidents, monitoring transit vehicles in real-time, electronic screening of trucks, and providing travelers with information about travel conditions, alternative routes, and other modes.

   In addition to ITS, other TSM&O strategies to improve the efficiency of the existing road system have been implemented, including reversible commuter lanes, movable median barriers to add capacity during peak periods, and restricting turns at key intersections. There are numerous congestion mitigation strategies that are enhanced by the use of advanced technologies or ITS. These strategies are highlighted in italics in Figure 4.1. There are several other effective strategies that do not rely on advanced technology, including geometric improvements to roads and intersections, converting streets to one-way operations and access management.

   The idea behind TSM&O strategies is to increase the efficiency of the *existing* transportation infrastructure. That is, roadway events essentially "steal" roadway capacity and TSM&O seeks to get it back. The deployment of TSM&O strategies and technologies is increasing and evaluations have shown their impact to be highly cost-effective. However, relying on TSM&O alone is a limited approach to addressing the congestion problem. A sound base infrastructure already must exist before TSM&O can be used or TSM&O strategies can be added along with capacity improvements. Also, only so much extra efficiency can be squeezed out of an already stressed highway system.

   Improving the efficiency and reliability of the freeway, street, transit, and freight systems is an aspect of the transportation program that in many cases can be accomplished in shorter time, with more public support and at a lower cost than some other strategies. The size of the benefits from any single project may not be of the magnitude of a new freeway lane or rail transit line, but the cost and implementation time also are not as high. One key to understanding the benefits from operational projects is to think of these strategies as enhancing the return on investment in the infrastructure projects.

3. **Encouraging Travel and Land Use Patterns that Use the System in Less Congestion Producing Ways – Travel Demand Management (TDM), Non-Automotive Travel Modes, and Land Use Management.** ("Demand Management" in Figure 4.1.) Other approaches to the problem of congestion involve managing the demand for highway travel. These strategies include putting more people into fewer vehicles (through ridesharing, increased public transportation ridership, or dedicated highway lanes for high-occupancy vehicles), shifting the time of travel (e.g., through staggered work hours), and eliminating the need for travel altogether (e.g., through telecommuting). The major barrier to the success of TDM strategies is that they require an adjustment in the lifestyles of travelers and the requirements of employers. Flexible scheduling is not simple for many American workers their employers and families, which limits the effectiveness of TDM strategies. Investing in non-automotive modes of travel – such as rail and bus transit systems and bikeways – is another strategy for reducing the number of personal use vehicles on the highway system. These approaches can be an excellent supplement to the highway system, particularly for commuter trips. However, in most metropolitan areas, the level of investment required to meet transportation demand solely through these means is massive and infeasible.

   Another approach that is being recently considered in many urban areas is managing demand through pricing schemes. Pricing strategies include charging for the use of HOV lanes either by the number of persons in the vehicle, by time of day, or both. This strategy is known most commonly as "value pricing," but has also been called "congestion pricing" and "peak-period pricing." Value pricing is a way of harnessing the power of the market to reduce congestion and the economic and environmental costs that congestion imposes. For example, since February 2003 the City of London, U.K. has charged a fee for driving private automobiles in its central area during weekdays as a way to reduce traffic congestion and raise revenues to fund transport improvements. This has significantly reduced traffic congestion, improved bus and taxi service, and generates substantial revenues. Public acceptance has grown and there is now support to expand the program to other parts of London and other cities in the U.K.

   In the United States, experience with the variably tolled Express Lanes on SR 91 in Orange County, California has clearly demonstrated the ability of pricing to maximize freeway efficiency. The Express Lanes became operational in December 1995. By 1997, congestion had increased on the free lanes as demand increased due to development growth in Riverside County. Analysts have noted that the SR 91 Express Lanes represent only 33 percent of the highway's capacity (i.e., two out of six lanes in each direction), but are carrying 40 percent of the traffic in the busiest peak hours, at speeds of 65 mph versus 10 to 20 mph in the adjacent free lanes. This is due to the fact that congestion results in reduced throughput on the regular lanes, accounting for the higher relative throughput on the free flowing Express Lanes in peak hours.

Land use management is another type of strategy that can influence congestion. The historical cycle of suburban growth has led to an ever-increasing demand for travel. Suburban growth was originally fueled by downtown workers who moved from city centers to the urban fringe to take advantage of lower land prices and greater social amenities. In the past 20 years, businesses also have moved to the suburbs to be closer to their employees and to take advantage of lower rents. This in turn allows workers to live even further away from city centers, thereby perpetuating suburban expansion. To influence these processes, strategies that attempt to manage and direct urban growth have been used in several metropolitan areas. These include land use controls (zoning), growth management restrictions (urban growth boundaries and higher development densities), development policies (transit-oriented design, which provides land use densities and forms to favor transit use) and taxation policy (incentives for high-density development). The main problem with many of these strategies is that they often are contrary to market trends, increasing consumer costs and dampening economic efficiency, at least in the short term. Unless a truly regional approach is followed – with cooperation of all jurisdictions within the region – sprawl may simply be pushed into areas not conforming to growth policies.

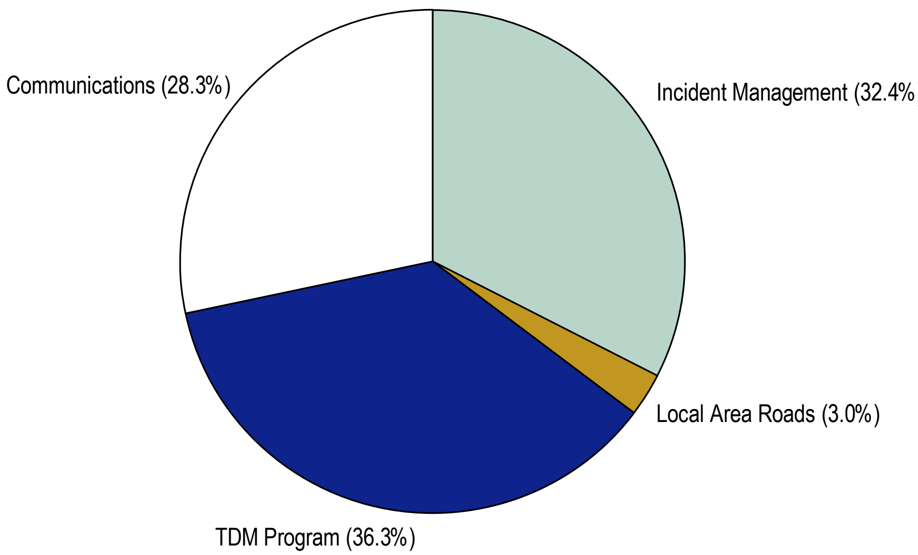
4.2 Examples of Recent Efforts to Address Congestion

Virginia's Springfield Interchange: Multimodal Approach to Bottleneck Removal. One of the examples of congestion relief performed on a large scale is the approach taken at the Springfield Interchange in northern Virginia. Three different roadways, I-95, I-395, and I-495, come together at the Springfield Interchange. 430,000 vehicles pass through this area daily. A two-year study showed that 179 crashes occurred during that time.[20] This improvement project – which will add more than 50 new bridges, add new flyover ramps, and widen Interstate 95 to 24 lanes around the interchange – is expected to take eight years to complete and has a budget of $585 million (although recent cost estimates are closer to $700 million). The construction is currently in its sixth year. In order to alleviate congestion caused by one of the largest construction projects in this nation, $28 million is devoted to the Congestion Management Plans (CMP).

[20]Springfield Interchange Improvement Project web site: http://www.springfieldinterchange.com/pb.asp.

Figure 4.2 shows the budget of the CMP divided by the different components.[21] The goals of the CMP included removing vehicles from the corridor, responding quickly to traffic incidents, and improving flow on local area roads. Additionally, the CMP aims to enhance alternative commute options and provide information for better traveler decision-making.[22] To that end, the CMP is comprised of several demand-side strategies, traffic incident management strategies, local road improvement strategies, and strategies to inform the general traveling public.

Figure 4.2 Springfield Interchange Congestion Management Plan Budget Breakdown



The demand-side strategies for the Springfield Interchange Improvement Project consist of several investments to give travelers alternatives to driving. These strategies were preceded by a commuter research study, conducted using 6 focus groups and 1,500 telephone interviews. Transit options include an expanded commuter rail service, OmniRide bus enhancements, telework centers, and fare discounts for bus and rail service. Some of the rail services have expanded capacity on their trains. Bus service near the interchange is free of charge. Travelers can also take advantage of the promotion of vanpools, carpools, and private buspools of more than 30 passengers. A 10 percent increase of Park and Ride space encourage travelers to use transit. Moreover, CMP also promotes the use of the reversible HOV lanes on I-395 and I-95, which run north and south of the

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[21] Springfield Interchange Improvement Project Presentation to 2001 VASITE and ITSVA Joint Annual Meeting – June 28, 2001.

[22] Presentation to Northern Virginia Transportation Commission: Potomac and Rappahannock Transportation Commission – Joint Meeting, May 6, 1999.

interchange. Furthermore, the Springfield Interchange web site encourages travelers to consider biking or joining the "Guaranteed Ride Home" program.

A traffic incident management component exists in the CMP. A state-of-the–art police mobile command vehicle is located near the interchange. This allows the police to coordinate communication and respond quickly to major traffic incidents. A fire department has a state-of-the-art foam truck available to assist in HAZMAT situations. In addition, the VDOT safety service patrols and state and county police routinely patrol the corridor.

In order to inform the traveling public of how they may be affected by the construction, information is disseminated through the project web site, an information phone line, and other types of media. The two-prong approach to communications consists of a grassroots outreach and advertising. The grassroots outreach involved employers. VDOT informed employers of the partnerships with regional rideshare agencies that could help them implement on-site transportation programs. Speakers bureau and community briefings were also used as mechanisms for informing the traveling public about the impacts of the Springfield Interchange. In addition, communication through advertising includes newspaper, radio, outdoor billboards, periodic newsletters, informational videos, and other collateral materials. Moreover, VDOT has opened a sophisticated Information Center. This is located in a nearby mall and helps to disseminate project information. The storefront station is equipped with cameras monitoring the progress of the project. The store provides information on alternative means of travel, such as ridesharing or transit timetables, and upcoming roadway operational improvements.

Other improvements have been made to local operations and infrastructure around the Springfield Interchange. Adjustments were made to the signals near to the interchange. In addition, turn lanes were added and intersections were improved. The sequence of other maintenance and construction activities in the Springfield Interchange area has been coordinated.

Even though the project has not been completed, some lessons can already be learned about congestion management during major highway improvements. First, budgeting decisions require appropriate expertise at decision-making level to make sure that traffic management and traveler information are incorporated into all phases of the construction. Building trust is essential among the stakeholders of this project. Moreover, the CMP should be planned and budgeted in the design phase. Finally, proactive communication should be included in the CMP.

Road Commission of Oakland County (RCOC) FAST-TRAC Project: Advanced Traffic Signal Coordination. Oakland County, located just north of Detroit, is one the largest and most affluent metropolitan counties in the United States. Although its population exceeds 1.2 million Oakland County has a limited freeway system and relies on major arterials, generally spaced a mile apart, for much of its roadway capacity. Opportunities for expanding freeway capacity are very limited due to both financial and environmental considerations. Starting in 1992, RCOC began implementation of the FAST-TRAC (Faster and Safer Travel through Traffic Routing and Advanced Controls) system. The key element of FAST-TRAC is the Sydney Coordinated Adaptive Traffic System (SCATS), an advanced adaptive signal system with the capability to adjust signals on an individual intersection, corridor, and areawide basis. Other key elements are Autoscope™ video detection cameras installed at each FAST-TRAC intersection and a Traffic Operations Center. Incorporated into the TOC is the Traffic Information Management System (TIMS), which is FAST-TRAC's comprehensive information processing tool. The TOC is able to share data and videos with Michigan DOT's regional ITS center in Detroit. About 600 of Oakland County's 1,300 signalized intersections are currently part of FAST-TRAC. Oakland County also participates in a consortium with other jurisdictions in the area to improve signal coordination for those intersections that are not part of FAST-TRAC.

Real-time traffic information is displayed on the RCOC web site and information on freeway conditions and major traffic incidents in the region is exchanged with MDOT's ITS Center. The RCOC web site is unusual in that it provides information on arterial congestion levels. Since describing arterial congestion levels in terms of speed and/or travel time is very difficult, RCOC uses general description (heavy, moderate, light, no congestion) as noted by color. As shown in Figure 4.3, the web site combines local arterial information with MDOT's freeway data. Camera images and DMS messages, both of which are provided by MDOT, can be called up on the RCOC screen. Even though the arterial information is general in nature, this is one of the few web sites in the United States that can be effectively used to plan and assess alternative arterial routes that can be used to avoid freeway incidents and/or congestion.

Figure 4.3 Road Commission of Oakland County Road Condition Web Site Map

Source: http://www2.rcocweb.org/.

The RCOC generates data that can be used to evaluate system impacts. Since intersections are added to the system on a regular basis, before-and-after studies are feasible. These studies have been limited, however, by lack of funding and available staff time. Several studies have been conducted by academic institutions in Michigan to assess SCATS impacts.

Michigan State University (MSU) conducted a before-and-after study of six intersections in the outlying community of South Lyon. Four approaches were evaluated in detail and showed an overall reduction in afternoon peak-period total stopped delay from 12.6 hours to 10.1 hours.

The percentage of vehicles stopped was reduced significantly at three of the four approaches but increased slightly at the other.[23]

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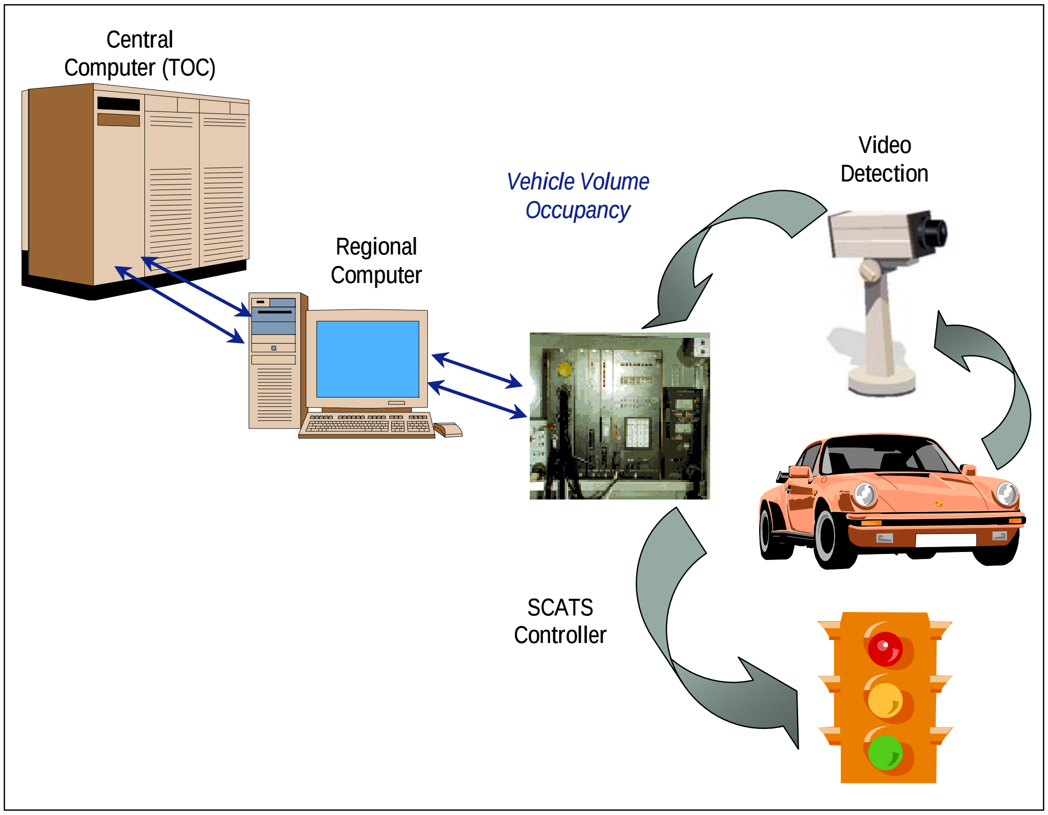
[23] *Final Report on the Analysis on the Impact of Installing SCATS in South Lyon – FAST TRAC Phase III Deliverables*, Underwood and Demski, University of Michigan).

Highlight Box 3 – How Advanced Traffic Signal Control Works

Starting in 1992, the Road Commission of Oakland County began implementing a program to improve traffic flow along arterial roadways. The key element of this program is the Sydney Coordinated Adaptive Traffic System (SCATS). About 600 of Oakland County's 1,300 signalized intersections are now on the SCATS system. SCATS takes advantage of several different technologies to ease the commute for Oakland County residents through improved timing of traffic signals.

SCATS intersections are outfitted with video detection cameras. These cameras include computer software that enables them to count the number of cars stopped at intersection, the number of cars going through on green signals and vehicle speeds. This information is sent to a central computer, which compares current traffic flows to trends over the past few years and to traffic conditions at other intersections along the same street. The SCATS computer can then calculate the mix of green and red signal time that will minimize the total time for all drivers on the system.

Figure 4.4 SCATS Hardware Structure



RCOC's traffic engineers can intervene if necessary. The SCATS central computer is located in a traffic operations center, where engineers can review system and data and observe traffic on Closed Circuit Television (CCTV) cameras. If, for example, a hazardous material spill occurs closing a major street, engineers can intervene to re-route traffic and change signal timing.

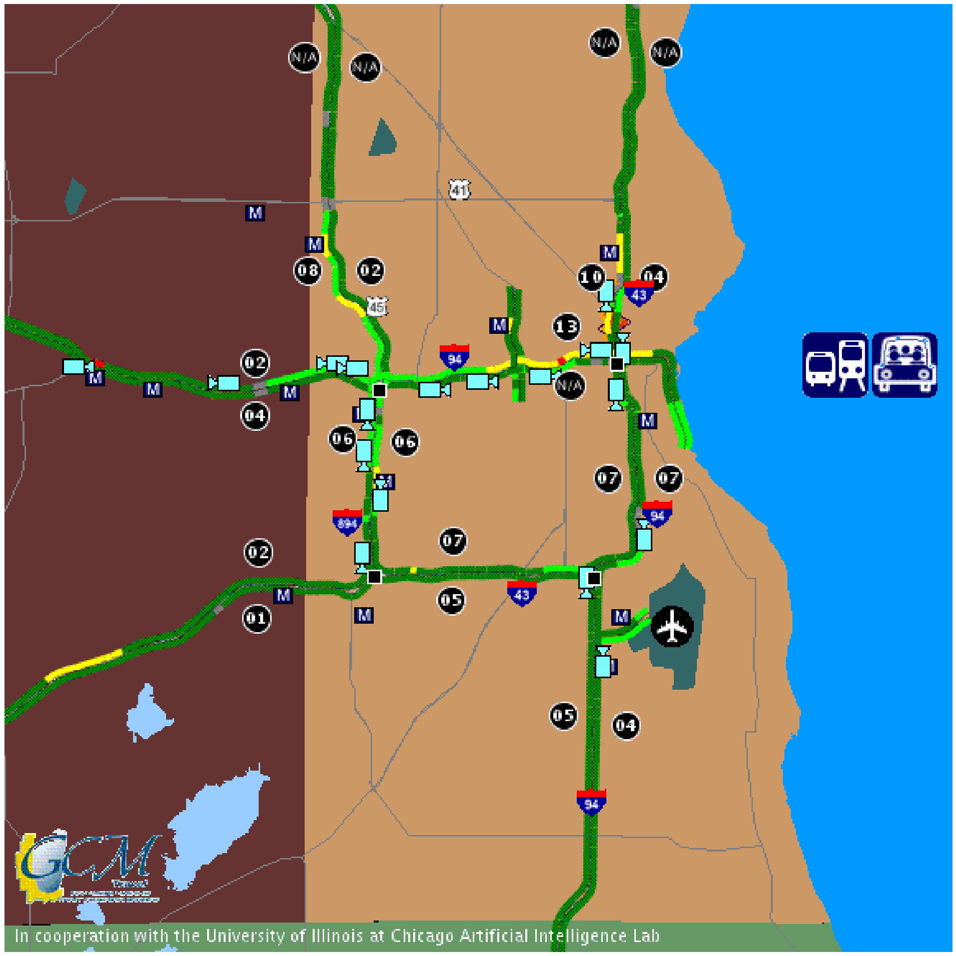
Studies have shown that the SCATS system in Oakland County reduces overall travel time, the number of red lights where motorists must stop and the length of time they are stopped. In some corridors travel times have been reduced by up to 30 percent during nonpeak hours and up to 15 percent during peak hour. Crash rates were also reduced and those crashes that did occur were less severe in nature. RCOC plans to continue adding intersections to the system. Additional information is available from FHWA arterial management web site: http://ops.fhwa.dot.gov/arterial_mgmt/index.htm.

An impact study was also conducted on a 3-mile corridor along Orchard Lake Road, one of Oakland County's most heavily traveled and densely developed arterial corridors. This study focused on travel time and intersection delay impacts along the primary corridor and found significant improvements as a result of SCATS implementation. The corridor provided a good location for a before-and-after study since no geometric or physical improvements were made to the intersections. Travel time reductions along the corridor ranged from 7 percent to 32 percent with the greatest improvements coming in the off-peak periods. By allocating green time more effectively, SCATS-related delay reductions along the main corridor were greater than corresponding increases on the cross streets. Both speeds and travel times for through traffic on Orchard Lake Road improved by 7 percent to 9 percent in peak direction. Off-peak direction travel times improved by 7 percent to 20 percent during peak periods and non-peak travel times improved by 15 percent to 32 percent. Speed improvements showed a similar pattern.

RCOC continues to expand the FAST-TRAC program. While no evaluation studies have been conducted in the past few years, the RCOC has confidence that the program is helping to move traffic more efficiently. A demonstration project currently under design will involve joint management of traffic on the I-75 freeway and Opdyke Road, a parallel arterial. These facilities serve several major traffic generators in Oakland County including Daimler-Chrysler headquarters, the Palace at Auburn Hills (home of the NBA Detroit Pistons) and the Great Lakes Mall. This project will enable RCOC and MDOT to test different operating strategies and measure the impacts.

Wisconsin District 2 Freeway System Operational Assessment (FSOA) Program: Integrated Congestion Relief Strategies. Wisconsin DOT District 2 covers the southeastern portion of the State including the Milwaukee metropolitan area. During the 1990s WisDOT implemented a freeway management system. The freeway management center, field equipment, and central computer system are known as the MONITOR system. Expansion continued into the early 2000s until most of the Milwaukee area's major freeways were covered. The system includes detectors along 130 miles of freeway, 18 cameras located at major interchanges, 20 Dynamic Message Signs, over 80 ramp meters, freeway service patrols, and trailblazer systems to aid in rerouting traffic during traffic incidents, construction, and other emergencies. Figure 4.5 shows a snapshot of the Milwaukee area freeway system traveler information map. The program is coordinated with several other related efforts including WisDOT's statewide SmartWays Program and the Gary-Chicago-Milwaukee Corridor Coalition (GCM).

Figure 4.5 Milwaukee Area Freeway Web Site Map



Source: http://www.gcmtravel.com/gcm/maps_milwaukee.jsp.

The most recent coordination effort involves the Marquette Interchange project, a major reconstruction of the largest and busiest freeway interchange in Wisconsin. WisDOT built upon its existing traveler information system to develop a new web site showing detailed traffic conditions and traveler information through the interchange area.

The FSOA program has also been integrated with two freeway-arterial management projects. One is the Integrated Corridor Operations Project (ICOP) a demonstration project involving joint management of parallel east-west freeway (I-94) and arterial facilities (Layton Avenue) near the Milwaukee Airport. The other was an innovative trailblazer system implemented along the U.S. 45 corridor in the northeast portion of Milwaukee County. Trailblazers were used for real-time diversion of traffic between parallel facilities during a period of major freeway construction.

The FSOA Program was initiated in 1999 in response to increased freeway congestion and a recognition that operational strategies needed to become a permanent part of the District 2 program. In initiating the program WisDOT noted increased breakdown of the system caused by left-hand ramps, increasing demand for access and a financial emphasis on rehabilitation rather than capacity expansion. Capacity expansion projects are generally limited to spot, segment and bottleneck improvements. WisDOT noted two major gaps in switching to this strategy:

- In evaluating the impacts of improvements, systemwide impacts were not being adequately considered. Bottleneck and spot improvements were being evaluated on a case-by-case basis without considering what impacts may occur in other portions of the system. An improvement to one bottleneck, for example, may end up moving the problem to a nearby location with limited or no improvement to the entire system.
- One of the best opportunities to implement operational/ITS strategies is by incorporating them into larger capital projects. Installing ITS equipment such as detectors, cameras, and dynamic message signs is more cost-effectively accomplished while a roadway is under construction. The processes and technical tools to follow through on this strategy did not exist, however.

The FSOA program was implemented to address these gaps by supplying both a process and technical tools for evaluating operational/ITS strategies. In addition to supporting expansion of operational/ITS strategies, FSOA also provides tools to improve existing operational strategies such as ramp metering, construction traffic mitigation and service patrol deployment. Consistent performance measures and detailed technical tools are key elements of the FSOA.

A variety of tools have been used to develop these measures including microsimulation, highway capacity analysis, ramp origin-destination inventory, geographic information systems, and geometric analysis. Microsimulation models have been a major focus of the FSOA effort. A regionwide model using Paramics™ software is currently being used for evaluation of both operational policies and physical improvements. These models are refined for each application; for example WisDOT is currently updating the model for use in a major improvement study for the I-94 corridor south of Milwaukee.

A recent application of the FSOA tools and data was a WisDOT research project conducted by the University of Wisconsin-Milwaukee and Marquette University. This study evaluated expansion of an existing ramp metering system in the U.S. 45 corridor in northeast Milwaukee County. The purpose of the research was to determine the benefits of ramp meters in the Milwaukee area freeway system, to determine underlying relationships that permit evaluation of new ramp meters or ramp meter systems elsewhere, and to develop a coherent framework for performing evaluation of ramp meter effectiveness on a whole system.

The findings of the study showed that the ramp metering system accomplished its overall objective of improving mobility and safety in the corridor. Some of the conclusions reached by the researchers were:

- Diversion – Drivers react to recurrent delays at ramp meters and along freeway mainlines when choosing between alternate routes. When faced with a long queue at an on-ramp, some drivers divert to another on-ramp while some others avoid the freeway entirely. The U.S. 45 experience suggests that average trip length on the freeway increases when meters are deployed, thereby resulting in less entering or exiting for a given level of traffic on the mainline.
- During the period with new ramp meters in operation the most congested southern part of the analysis corridor experienced an improvement in traffic operations measures of effectiveness, during the most congested afternoon peak period: a substantial reduction in vehicle-hours of travel and increases in travel speeds, under minimal volume changes (a 0 to 2 percent increase) in one of the most congested segments. Speeds increased in this area by 6 percent to 13 percent, and overall by 4 percent during the afternoon peak.
- New ramp meter operation, in conjunction with geometric improvements in ramp merging areas and mainline resurfacing resulted in a 21 percent crash rate reduction for the analyzed corridor during ramp metering hours.

Maryland's Coordinated Highway Action Response Team (CHART): Statewide Traffic Incident Management. Maryland developed the Coordinated Highway Action Response Team (CHART) in the mid 1980s as an effort to improve travel to and from the State's coastal area. Years later, this system has evolved into a statewide operations tool that collects, processes and broadcasts traffic information. Data are collected through a communications infrastructure, a closed-circuit television system, and sensor detection system. The information is then used to make real-time traffic management decisions and provide motorist with information through dynamic message signs, radio travel advisories, and a telephone advisory system. Travelers may also access an interactive on-line GIS mapping service for higher functional classes to obtain average speed, traffic conditions, and lane closures due to weather or construction activities (see Figure 4.6 and 4.7). In addition, travelers can view selected road conditions through on-line video links.

Figure 4.6 CHART's Traffic incident Mapping Interface

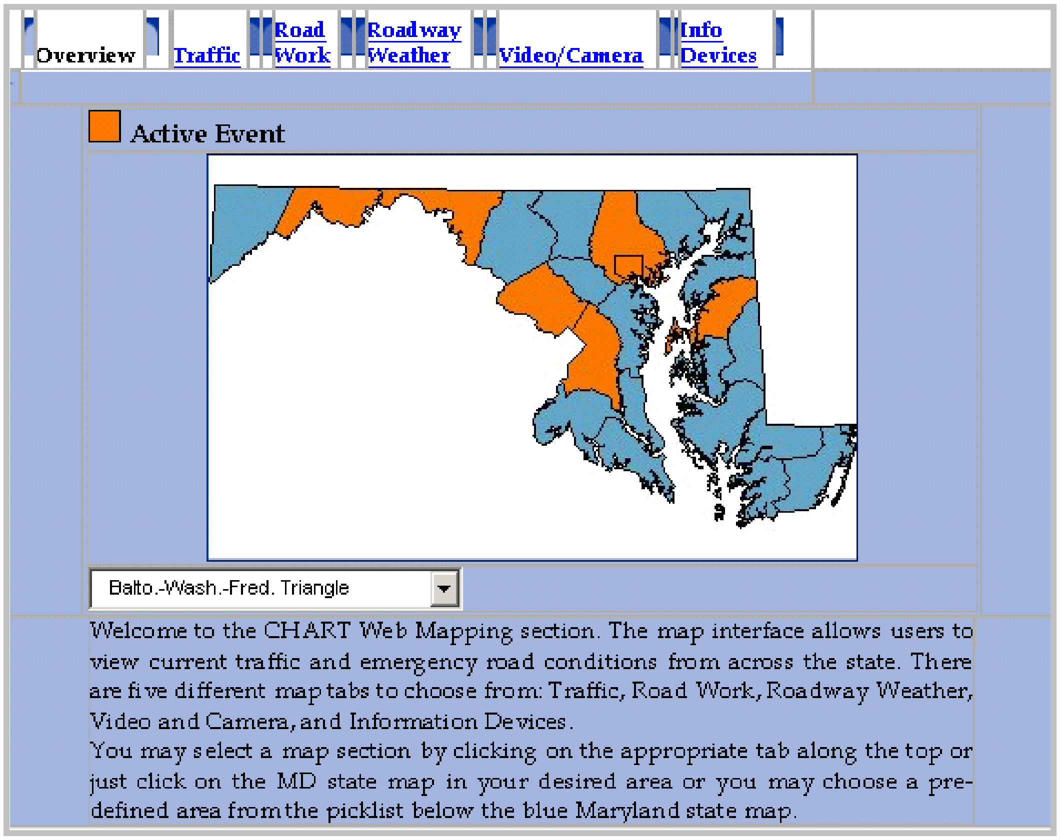
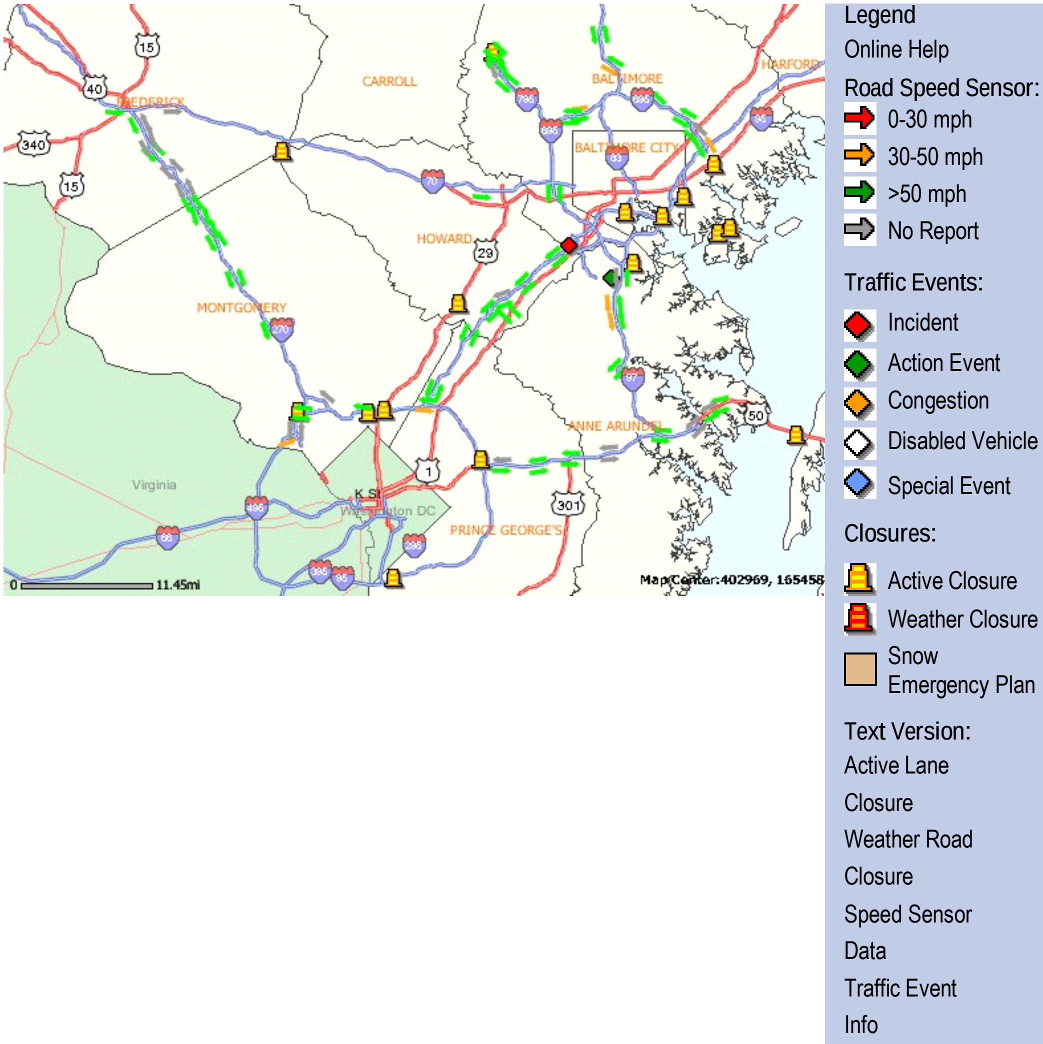


Figure 4.7 Sample Drilldown Map from CHART



CHART's ability to detect and manage traffic incidents on major freeways is annually reviewed by the Civil Engineering Department of The University of Maryland at College Park and Maryland State Highway Administration (SHA) staff.[24] In 2002, the most recently available performance evaluation report, the CHART/SHA operations responded to 13,752 lane blockage incidents, and provided assistance to 19,062 highway drivers which resulted in a potential reduction of 377 secondary incidents. In addition, CHART patrol units' removal of stationary vehicles and debris prevented 343 potential lane-changing-related collisions and other delays due to rubbernecking.

[24] Chang, Gang-Len, Ying Liu, Pei Wei Lin, Nan Zou, and Jean Yves Point-Du-Jour (2003). *Performance Evaluation of Chart: Year 2002.*

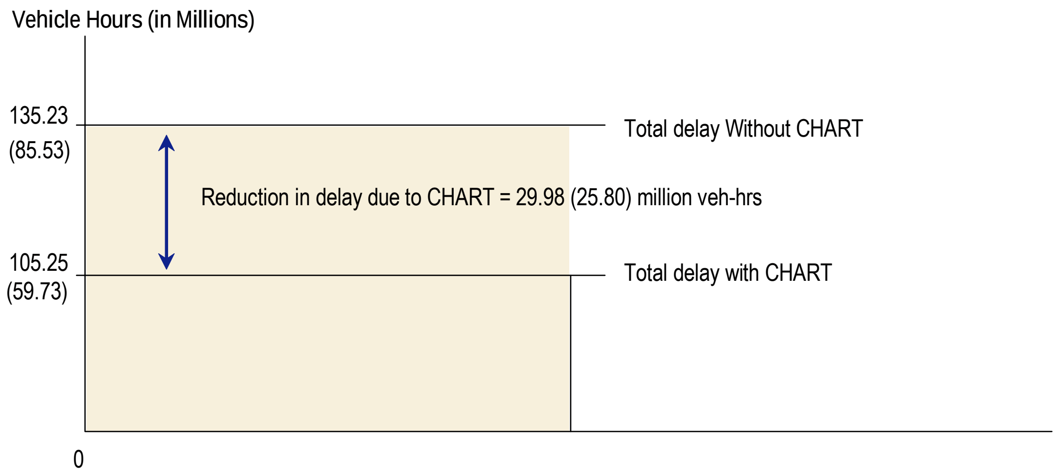
The result of CHART operational strategies has been a decrease in average traffic incident duration. As Table 4.1 shows, CHART has consistently decreased the average traffic incident duration since 1999. The average duration of traffic incidents with CHART are also notably lower in comparison to traffic incidents without the CHART response program (*e.g.*, CHART resulted in a 27 percent lower average traffic incident duration time in 2002).

Table 4.1 The Effectiveness of CHART's Traffic incident Management on Average Incident Duration

Year	With CHART (Minutes)	Without CHART (Minutes)
1999	42	93
2000	33	77
2001	29	51
2002	28	39

A shorter incident duration in turn decreases driver delay, fuel consumption, and emissions. Figure 4.8 illustrates the 29.97 million vehicle-hours "saved" as a result of the 2002 CHART program.

Figure 4.8 Reduction in Delays Due to CHART Operations



Note: Numbers in parentheses show 2001 results.

Source: Chang, Gang-Len, Ying Liu, Pei Wei Lin, Nan Zou, and Jean Yves Point-Du-Jour (2003). *Performance Evaluation of Chart: Year 2002.*

The benefits of the CHART program can also be expressed as monetary savings. Table 4.2 tabulates the total direct benefits from reduction in driver delay, fuel consumption, and emissions. In summary, CHART enabled Maryland to manage its existing infrastructure more efficiently resulting in approximately $468 million in benefits to the traveling public.

Table 4.2 Total Direct Benefits to Maryland Highway Users in Year 2002

Reduction Due to CHART		Amount	Unit Rate	Dollars (Millions)
Delay (Million Vehicle-Hours)		29.98 (25.80)	$14.34/hour	$429.87 ($369.97)
Fuel Consumption (Million Gallons)		5.06 (4.35)	$1/gallon	$5.06 ($4.35)
Emissions (Million Tons)	HC	391.89 (337.3)	$6,700/ton	$33.04 ($28.43)
	CO	4,402 (3,788)	$6,360/ton	
	NO	187.69 (161.5)	$12,875/ton	
Total (Million Dollars)				$467.97 ($402.75)

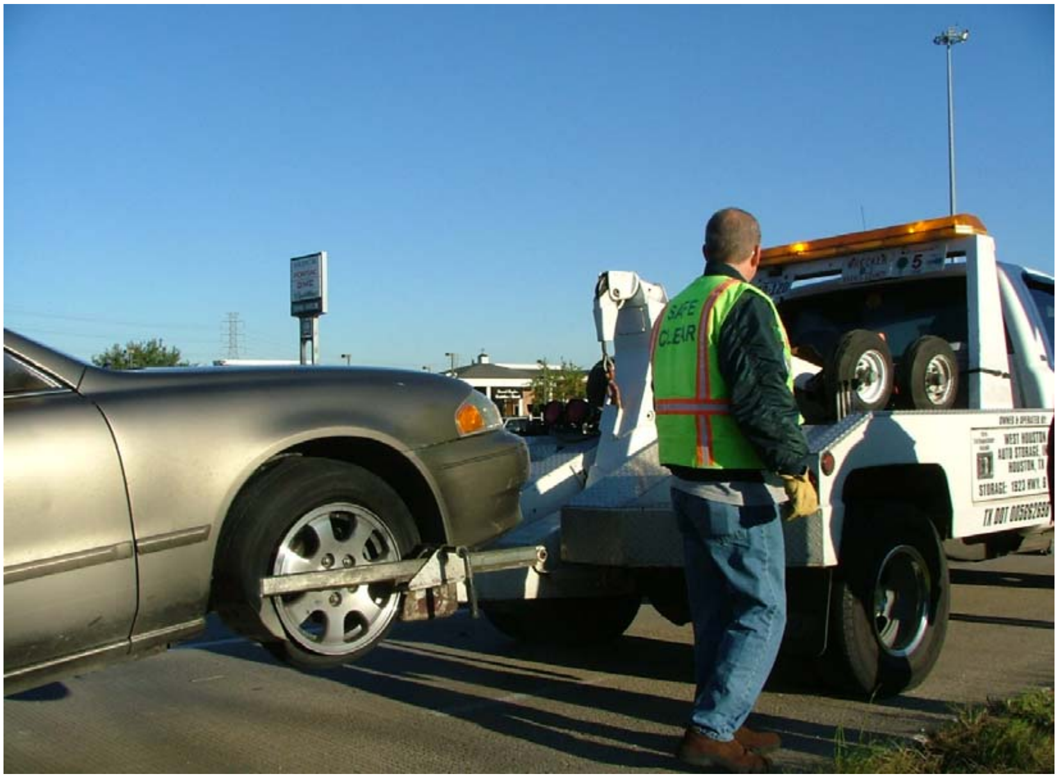
Source: Chang, Gang-Len, Ying Liu, Pei Wei Lin, Nan Zou, and Jean Yves Point-Du-Jour (2003). *Performance Evaluation of Chart: Year 2002*.

Note: The numbers in parentheses show the result in Year 2001.

Houston's SAFEclear Program: Advanced Traffic Incident Management at the Local Level. Traffic incident management programs that rapidly remove vehicles with mechanical breakdowns or those that have been involved in a collision are an important element of congestion relief programs across the country. Whether the disabled vehicles are on the emergency shoulder or in the travel lanes, they reduce the number of vehicles that can use the freeways. This causes an increase in congestion, travel time and fuel consumed and also increases the possibility of other collisions. These negative effects occur on the roadway where the traffic incident occurred, but also in the other travel direction as drivers slow down to examine the problem area. Incident-related problems are typically identified as peak-period issues, but during off-peak hours, the unexpected congestion not only delays and frustrates travelers, it can also lead to other collisions caused by the unexpected slowdowns. Emergency medical services, fire, police, and other responders are partnering with transportation agencies in many major metropolitan areas to improve safety and reduce congestion using traffic incident management programs.

The City of Houston has taken a particularly aggressive stance in removing disabled vehicles with their SAFEclear Program. The program is an enhanced version of the long-running Motorists Assistance Program (MAP) coordinated by the Transtar Transportation Management Center. SAFEclear uses contracted towing companies to patrol the freeways, identify incidents or respond when called upon, and rapidly remove them to a location off of the freeway (Figure 4.9). Houston Police officers use Transtar's closed-circuit camera network to authorize the tows from a central location rather than the previous on-the-scene requirement. Where MAP used nine trucks to provide services, there are about 60 tow trucks patrolling the 190 miles of freeway in Houston.

Figure 4.9 Houston's SAFEclear Program Has Improved Incident Response Times



Some of the program costs are offset by the fees paid by the tow companies to enroll in the program, and additional funds are being provided by the Metropolitan Transportation Authority as part of its broad transportation operations mission. Tows from the shoulder are free to motorists and the tow companies are provided with a rebate of their initial franchise fee for the service. Long-distance tows or tows of vehicles in travel lanes are paid for by the motorist. The net cost of the program in 2005 is projected to be $2.1 million.

Over the first three months of the program, the tow trucks responded to more than 14,000 stalls and collisions. The response and clearance times for SAFEclear are well under the initial targets for response. Tow trucks responded to more than 89 percent of incidents in less than the 6-minute target. The events were cleared in less than 20 minutes 77 percent of the time. Less than 2 percent of the incidents took longer than 90 minutes to clear. Although the program is relatively new, over the first four months of the program there was a 10 percent reduction in the number of collisions on the freeways compared to the same four months in 2003 and 2004. Comparisons of travel time data from Transtar indicate that travel delay will be 1.8 million hours lower in 2005 than expected given the traffic growth rate. Travel time reliability, as measured by the amount of extra travel time to accomplish a trip during the worst day of the month, also stabilized in 2005 after being 16 percent worse in 2004 than in 2003. Not all of these improvements can be traced to SAFEclear but the improvements in congestion and collisions represent more than $70 million in savings to Houstonians. In addition, vehicle repair and collision paperwork activities are being conducted in places well away from flowing traffic.[25]

WSDOT's Integrated Operations Programs in the Puget Sound region and Seattle. Managing the transportation system to provide the best service and most efficient use of the limited space is a growing trend in major urban areas. But the Washington State DOT has been aggressively pursuing these kind of improvements for many years. An innovative combination of technology, policies, and resource allocation has provided travelers in Washington with more reliable travel times, fewer collisions, and more efficient use of the available funding.

Key aspects of the approach include:

- Incident management;
- Ramp metering;
- Signal Synchronization/retiming;
- Removing capacity bottlenecks;
- Travel conditions and commute time information;
- High-occupancy vehicle lanes and public transportation facilities; and
- Readily understood performance measures.

The approach concentrates on addressing everyday congestion problems, as well as the weather, collisions or vehicle breakdowns that cause the frustrating variations in travel times as well as safety, environmental and other negative effects. The management approach includes projects and programs, but starts with aggressive action and performance measurement. The improvements in travel time reliability and decline in congestion in some areas of Puget Sound, begin with the adage "Do Something and Measure It." The attitude is reflected in the equipment and personnel assigned to incident response, the technology and attention to adjusting the ramp meters and the incorporation of performance evaluation into operating practices and public communication.

The incident response program was doubled in 2002 and a formal partnership was established between WSDOT, the Washington State Patrol, private tow companies, and a media-sponsored motorist assistance van. This equipment patrols the freeway system in a roving mode and additional vehicles can be dispatched. The reduction in travel times and incident-related congestion is important, but the top priority is safety. Reducing the time that vehicles are stalled in lanes or on the emergency shoulder reduces the possibility of another

[25] Program Evaluation. Preliminary Data Analysis, Rice University and Texas Transportation Institute, May 2005.

collision. Evaluations of the incident response program's efforts in removing disabled vehicles indicate a savings of $5,800 in fuel and other operating costs for each incident involving a one-lane blockage and a $7,000 savings in traveler time savings for each incident.[26]

Freeway ramp meters have been in use in the Puget Sound system for two decades. By providing a regular flow of traffic and lower entering volumes at busy entrance ramps, the meters allow the freeway mainlanes to carry more volume and at higher speeds. The short entrance ramp wait time (average of 2 minutes) is made up for with the shorter freeway travel times. In addition, the greater spacing between entering vehicles has resulted in 30 percent fewer rear-end and sideswipe collisions and lower travel delay. The advanced controllers in the metering system monitor traffic congestion and entering volumes and adjust the metering timing accordingly. The Traffic Systems Management Center operators provide oversight on the system and can adjust the computer systems if necessary.[27]

I-405 and SR 167 are major commuter routes in the south Puget Sound area. A $10 million project to add a new exit ramp from I-405 to southbound SR 167 reduced the stop-and-go traffic from a nearly 2-mile backup to less than half a mile and increased the traffic volumes handled on the ramp by 8 percent and the mainlanes by 13 percent. Heavy congestion has also been eliminated on the weekends. The total value of travel time savings were estimated at $4.3 million per year indicating that the travel time benefits exceeded the cost of the project in less than 2.5 years.[28]

Other minor capacity improvements have also been key to maximizing the returns from the roadway investments. The addition of a "weaving" lane between an entrance ramp and exit ramp allows merging and exiting traffic to move more smoothly to their destinations. Where traffic patterns have changed since the initial road construction, a short section of additional travel lane can allow a bottleneck to be relieved and provide a technique that uses road capacity more efficiently. These improvements do not usually eliminate congestion, but

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[26] *Measures, Markers and Mileposts*. The Gray notebook for the quarter ending March 31, 2003. Washington State Department of Transportation's quarterly report to the Washington State Transportation Commission: http://www.wsdot.wa.gov/accountability/Archives/GrayNotebookMar-03.pdf.

[27] *Measures, Markers and Mileposts*. The Gray notebook for the quarter ending September 30, 2004. Washington State Department of Transportation's quarterly report to the Washington State Transportation Commission on Transportation Programs and Department Management: http://www.wsdot.wa.gov/accountability/Archives/graynotebookSept-04.pdf.

[28] Bremmer, D., Cotton, K.C., Cotey, D., Prestrud, C.E., and Wesby, G. Measuring Congestion: Learning from Operational Data. Paper prepared for Transportation Research Board, March 2004.

they can remove a constriction that causes stop-and-go traffic to begin in one section and spread to others well before most of the roadway has more traffic than it can handle. This is similar to a narrow driveway at the exit from a parking lot. There may be plenty of space on the major street serving the lot, but only a few cars per minute can exit through the one lane leaving the parking area.[29]

The combination of improved operational treatments and relatively minor capacity expansions are attacking the problem that WSDOT has dubbed "lost productivity." Freeways, for example, carry the highest volume of traffic when speeds are 45 to 50 mph. The lanes are "full" – operating with around 2,000 vehicles per hour per lane – without having so much traffic that drivers feel uncomfortable and slow down. The slow down is what causes stop-and-go traffic to develop and results in traffic volumes less than 1,500 vehicles per hour in each lane at speeds closer to 20 to 30 mph. "WSDOT's goal is to stay on top of the <speed-volume> curve, working toward improving productivity of the system by investing in opportunities that provide optimal throughput."[30]

Houston's Accelerated Construction of the Katy Freeway: The Systems Approach to Bottleneck Removal. The Katy Freeway (I-10 West in Houston) expansion project is being constructed using an innovative combination of construction and financing techniques. The project, in broad terms, results in a 6-year construction program, (compared to the 12-year original schedule), provides a four-lane tollway in the middle of an expanded freeway, improves the aesthetic and landscaping treatments in the corridor, and rebuilds the existing freeway pavement and bridges.[31]

The Katy Freeway extends 40 miles from the Central Business District of Houston west to the Brazos River. Constructed from 1960 to 1968 with 6 to 10 lanes, it was designed to carry 80,000 to 120,000 vehicles per day and to have a pavement life of 20 years before major reconstruction would be required. A single-direction HOV lane has since been added in some portions of the corridor for buses, vanpools, and carpools.

The reconstruction program encompasses the middle 20-mile section from near its intersection with I-610 West Loop to the City of Katy. The freeway will have

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[29] Bremmer, D., Cotton, K.C., Cotey, D., Prestrud, C.E., and Wesby, G. Measuring Congestion: Learning from Operational Data. Paper prepared for Transportation Research Board, March 2004.

[30] *Measures, Markers and Mileposts*. The Gray notebook for the quarter ending September 30, 2004. Washington State Department of Transportation's quarterly report to the Washington State Transportation Commission on Transportation Programs and Department Management: http://www.wsdot.wa.gov/accountability/Archives/graynotebookSept-04.pdf.

[31] http://www.katyfreeway.org/index.asp.

14 lanes: 4 managed toll lanes, 8 general-purpose freeway lanes and 2 auxiliary lanes. The toll lanes will be separated on each side from the other lanes by a 2-foot buffer and managed with a variable toll to provide high-speed operations. The toll lanes will have 5 access points including the western and eastern ends. The lanes will operate exclusively with an automated toll system. Buses and carpools will use the managed toll lanes with either a discounted toll or at no cost.

The FHWA approved a proposal in 2002 for tolled managed-use lanes in the center of the reconstructed Katy Freeway as part of the Value Pricing Pilot Program currently in operation on the Katy Freeway HOV lane. In March 2003, an agreement was signed to implement the tolled managed-use lanes in the center of the freeway. In exchange the Harris County Toll Road Authority (HCTRA) would purchase the operating franchise for the four tolled lanes for $237 million and another $250 million in in-kind service should they be needed. This funding accelerated the construction time – cutting in half (from 12 to six years) the expected schedule. Without this unique funding arrangement the project, begun in 2003, would have been completed in 2015. With the participation of these entities and acceleration in available funds, the project will be substantially completed in early 2009.

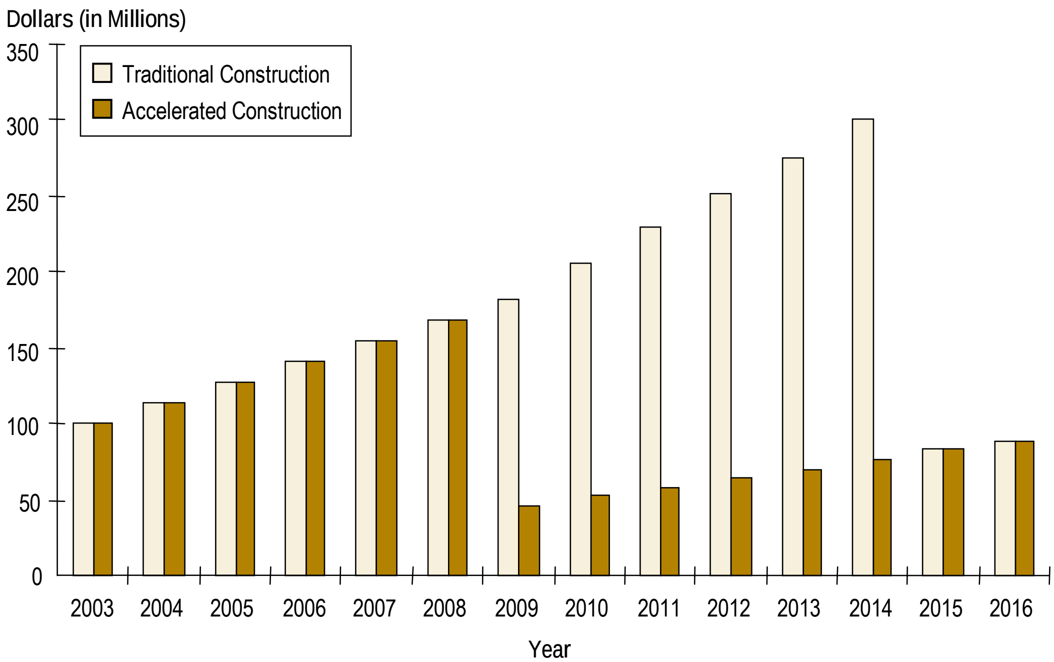
The construction contract has incentive-disincentive clauses that result in few lane or roadway closures and maintain the previously existing number of through-lanes during peak periods. In most cases, the lane and roadway closures are caused by overhead or underground construction that is required by the final road design, not the method or timing of construction.

A significant financial benefit of the accelerated project completion is that the Harris County Tollroad Authority will be able to collect tolls on the four managed lanes in 2009 rather than 2015. Travelers in buses and carpools, currently restricted to a 3-person requirement in the peak hours (2-person requirement during other hours) due to limited capacity in the HOV lane, will be able to travel toll free in the free-flow managed lanes. All travelers will have shorter time periods of congested conditions in the peak, and should have much less stop-and-go traffic in the off-peak. The managed lanes will also provide choices – free, but congested mainlanes, bus or carpool use of the managed lanes for free or reduced price, and a premium pay-for-travel system that allows travelers to determine the importance of their trip and pay for faster, more reliable travel if they wish.

Annual travel delay in 2003, as the project was started, was estimated at 5.1 million person-hours of delay on the Katy Freeway mainlanes and HOV lane. As illustrated in Figure 4.10, the value of that delay and the fuel wasted sitting in congested traffic amounted to just over $100 million. By 2009, without the freeway improvements and with the traffic growth, it is estimated that there will be 9.3 million person-hours of delay and with a time and fuel value of $181 million annually. With the freeway improvements, it is estimated that annual delay in 2009 will be reduced to 2.5 million person-hours with an estimated value of

$46 million – an annual savings of $135 million and 6.8 million fewer person-hours stuck in congestion as a result of completion of the project. If the Katy Freeway project were built on the traditional schedule (i.e., with completion in 2015), by the time the project was completed there would be an estimated 16.8 million person-hours of delay and with a time and fuel value of almost $327 million annually. Once the project was completed in 2015, the number of person-hours of delay would be reduced to 4.5 million with a time and fuel value estimated at $84 million. The total value of the fuel and time wasted in congestion over just the six years of early completion is estimated at $1.1 billion.[32]

Figure 4.10 Cost of Wasted Fuel and Time on Katy Freeway under Alternative Construction Scenarios



Another benefit of the project is its effect on improving the business climate by providing lower travel times for raw and finished good shipments, lower service and delivery costs, and more efficient use of personnel. An FHWA-sponsored study by Nadir and Ammines estimated the value of these benefits as a 16 percent annual return on an initial transportation capacity investment.[33] For the Katy Freeway project, a more conservative 12 percent return was used. The benefit

[32] *Texas' Roadways – Texas' Future. A Look at the Next 25 Years of Roadway Supply, Demand, Cost and Benefits*. Governor's Business Council, Updated 2005.

[33] Nadiri, M.I., and Mamuneas, T.P. *Contribution of Highway Capital to Output and Productivity Growth in the U.S. Economy and Industries*. Federal Highway Administration, August 1998. Available at: http://www.fhwa.dot.gov/policy/gro98cvr.htm.

associated with the six-year acceleration is estimated to be between $1.2 billion and $1.8 billion over the 2009 to 2015 period.

The cost premium to obtain the accelerated construction schedule included several components. Right-of-way and utility relocation costs have exceeded initial estimates due to the more rapid schedule. The cost of contractor incentives are also included in the cost premium. Reducing the construction schedule also has cost benefits, however, as the typical construction cost inflation will not be seen in the construction bids. The net cost increases are estimated at between $80 million and $265 million.[25]

In sum, the benefits of accelerating construction, reducing construction effects on travelers and businesses and improving the transportation system in west Houston are between $2.2 billion and $2.9 billion for the six-year period from 2009 to 2015. This represents a benefit/cost ratio of between 8:1 and 36:1 if only the six-year accelerated period is analyzed and only the differential construction costs are used. The accelerated construction schedule reduces the effects of construction activity, but it also significantly improves the quality of life and the viability of businesses. In this case, an innovative financing scheme has created a better transportation product, faster.

The Katy Freeway expansion project combines an innovative financing strategy, attention to traffic problems during construction and an accelerated construction schedule to improve the west Houston transportation network. The Harris County Tollroad Authority is essentially purchasing the new four-lane toll and high-occupancy vehicle facility from the Texas DOT. The $237 million HCTRA purchase price provides more funds early in the construction period than the typical state DOT project allowing the project to be completed sooner, mobility to be improved earlier and the frustration of driving through, and living with construction reduced.

4.3 PROMISING CONGESTION RELIEF STRATEGIES ON THE HORIZON

In addition to innovative projects that have already been implemented, a number of even more advanced technologies and integrated programs are in development. These programs and technologies offer great promise for addressing congestion problems in the near future. A review of several such programs and technologies follows.

***iFlorida:* Tested for the Next Generation of Operations Strategies.**[34] In March 2003, the Florida Department of Transportation (FDOT) was selected to participate in a highly innovative model deployment of operational strategies

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[34] http://www.iflorida.net/.

with FHWA. Named *iFlorida*, this project is based on the idea that advanced operational strategies require highly detailed traffic condition data over a wide area. Therefore, the initial stages of the project are to deploy additional traffic surveillance equipment to augment Florida's existing information infrastructure. Once in place, the infrastructure will be used to demonstrate the wide variety of advanced operational functions to enhance traffic flow and improve security, including:

- **Advanced Weather Information –** Numerous sources of weather information, current and forecasted, are available and will be increased through *iFlorida*. This project takes these multiple sources as input and develops very specific current conditions and forecasts for ***individual roadway segments for major Florida highways***; these are time-sliced forecasts (15-30 minutes) of weather and road surface conditions for each segment.

- **Security Monitoring Command and Control –** This element will provide a monitoring capability for sensors and video at two high-priority bridges in Florida: 1) the Fuller Warren Bridge on I-95, which serves as a bypass route for Jacksonville and 2) the St. Johns River Bridge serves as a major I-4 route between Daytona Beach and Orlando. Each of these facilities will have a 24/7 operations and monitoring capability.

- **Variable Speed Limit Trial –** Twenty-two static speed limit signs on I-4 will be replaced with variable speed limit signs, giving FDOT the capability to adjust speed limits to match current conditions. One likely application will be during the reconstruction of the I-4 and SR 408 interchange, which will begin in 2005. Other applications, such as reducing speed limits during adverse weather or when an incident occurs, have also been discussed.

- **Roadway Diversion Information –** In Orlando, the expansion of roadway surveillance to include not just freeways but signalized highways as well opens up expanded possibilities for providing traveler information. FDOT plans to use existing DMS to provide travelers with comparative travel time estimates from the *iFlorida* deployment at locations where alternate route choices are available.

- **Statewide and Central Florida Traveler Information Web Sites –** Likewise, expanded surveillance coverage of traffic conditions statewide allows richer data to be passed onto the traveling public.

- **On-Board Video Surveillance on Orlando City Buses –** Real-time feeds from operating buses allow increased security for passengers.

- **Evacuation Operations –** The expanded surveillance and communications backbones of *iFlorida* will be used to support evacuations. This will include decision support on where and when to implement contraflow traffic operations and to identify major problems along evacuation routes, and to provide information to travelers on current conditions and alternative routes. *iFlorida* information will be used to enhance the functioning Florida's Emergency

Operations Center, especially the Hurricane Evacuation and Decision Support Utility Program (HEADS UP) being developed by the Florida Division of Emergency Management.

Integrated Corridor Management ITS Initiative. Recognizing the importance of maximizing the operational effectiveness of an entire corridor, the U.S. DOT's ITS program includes "Integrated Corridor Management" (ICM) Systems as one of nine Major Initiatives. The basic premise behind the ICM initiative is that these independent systems and their cross-network linkages could be operated in a more coordinated and integrated manner resulting in significant improved operations across the corridor. As stated in the ICM vision, "metropolitan areas will realize significant improvements in the efficient movement of people and goods through aggressive and proactive integration and management of major transportation corridors." In essence, integrated corridor management consists of the operational coordination of specific transportation networks and cross-network connections comprising a corridor, and the coordination of institutions responsible for corridor mobility.

The goal of the Integrated Corridor Management Initiative is to provide the institutional guidance, operational capabilities, and ITS technology and technical methods needed for effective Integrated Corridor Management Systems. Currently, the ICM initiative consists of the following four phases:

1. **Foundational Research –** Working with multimodal stakeholders, develop an understanding of the institutional, operational, and technical integration needs and issues of developing and deploying an integrated corridor management system. Phase 1 activities include developing definitions; identifying corridor types, operational approaches and strategies, and the associated integration requirements; reviewing existing and simulated corridor operations; and developing initial guidance for "ICM Planning and Implementation," including a Concept of Operations for a generic corridor.

2. **Operations and Systems Development –** Based on the Phase 1 findings, structure the development phase to address the corridor ITS integration issues that may include alternative shared operations management schemes and cross network operations strategies. Modify or develop analytical tools and methods that will enable the development and evaluation of integrated corridor management strategies. This phase also includes laboratory and limited field-testing of component integration interfaces and component operations of an integrated corridor management system.

3. **Model Deployment –** Candidate model deployment sites will be selected with a "request for application" process. These candidate model deployment sites will become key members of the ICM Stakeholder group and be provided funding and support to develop a site-specific Concept of Operations for their proposed corridor. The final model deployment site will be chosen from the candidate sites at a later date. The selection will take into account each site's ability to demonstrate the ICM concept and successful implementation

of an ICM system. The model deployment will demonstrate the application of institutional, operational, and technical integration approaches in the field, and document implementation issues and operational benefits. An independent evaluation will be conducted to document the results.

4. **Knowledge and Technology Transfer –** Formal technology transfer efforts will be initiated to disseminate the knowledge gained from Phase 1 and Phase 2. Towards the end of the model deployment effort, those outreach activities will provide guidance and transfer the tools and technologies needed to support successful integrated corridor management strategies.

U.S. DOT is currently working with stakeholders to identify the ICM institutional, operational, and technical integration issues; and revise the program to address these issue and support stakeholder implementation needs. U.S. DOT is also developing a Model Deployment/ICM Demonstration approach. The innovative approach provides for the joint development of Model Deployment/ICM Demonstrations. The U.S. DOT will work with stakeholders to collectively craft what can be done to effectively demonstrate how ICM can be implemented and its operational benefits.

***Clarus* Initiative: Roadway Weather Information**. *Clarus* (which is Latin for "clear") is an initiative to develop and demonstrate an integrated surface transportation weather observation data management system, and to establish a partnership to create a nationwide surface transportation weather observing and forecasting system. The objective of *Clarus* is to enable weather service providers to provide enhanced information to all road, rail and transit managers and users to reduce the effects of adverse weather (e.g., fatalities, injuries, and delay). The *Clarus* Initiative aims to demonstrate how an open, integrated approach to observational data management can be used to consolidate surface transportation environmental data. Surface transportation environmental data assimilated by the *Clarus* system will include atmospheric data, pavement and subsurface data, as well as hydrologic (water level) data. All of these types of data and information are referred to as "environmental data" and "environmental information" in this paper.

Clarus is a joint effort of the U.S. DOT ITS Joint Program Office and the FHWA Road Weather Management Program, which resides in the Office of Transportation Operations. The *Clarus* Initiative has four primary motivations:

1. Provide a North American resource to collect, quality control, and make available surface transportation environmental observations so that state and local transportation agencies can be more productive in maintaining safety and mobility;

2. Support real-time operational responses to weather events and weather impacts through the collection of surface transportation environmental observations;

3. Enhance and extend the existing weather data sources that support general purpose weather forecasting for the protection of life and property; and

4. Integrate surface transportation environmental observations with existing observation data to support the enhancement and creation of models that make better predictions in the atmospheric boundary layer and near the Earth's surface to support more accurate forecasts.

The *Clarus* Initiative consists of two development components. The first component is the *Clarus* system – a network for assimilating and exchanging quality-controlled environmental data related to surface transportation. The second component is the creation of tailored tools (e.g., decision support systems, route-specific forecasts) that make effective use of *Clarus* system data. Such tools will illustrate the utility of these data sets and provide the genesis for new and enhanced environmental information products for the surface transportation community.

Goal-Oriented Planning Processes: Expanding on the Traditional Planning Process. Long-range regional transportation plans are visions of the future. Current Federal planning regulations require that the plans identify funding sources for all projects, programs, or strategies within the plan. All urban regions have other projects that they would like to pursue if funding were available. The major metropolitan areas in Texas and Atlanta, Georgia have developed a more extensive process for quantifying the need for other projects and estimating the costs and the benefits of action. While the efforts differ in several ways, they point to an expansion in the role of planning and a more active discussion about the role and importance of transportation in urban America.

The discussion about the projects that should be pursued, how those should be implemented and benefits of additional funding will require more than a single plan, funding amount or set of ideas. The public and decision-makers must be engaged in the dialogue so that the amount of funding and the potential for additional user fees, changes to policies or additional services can be discussed along with the benefits of those programs.

The Texas Metropolitan Mobility Plan has a goal of eliminating serious congestion from all travel corridors in the eight largest population centers. The long-range transportation planning models in each area were used to estimate the capacity improvements required to accomplish this goal. The capacity costs were estimated using roadway construction costs, but the actual combination of projects, programs, and policies will not be identified until the corridors are studied in more detail. What the TMMP did accomplish, however, is to provide additional information to the decision-makers and public about the beneficial effect of additional transportation spending and allow a more informed discussion about the choices faced by residents.

The goals set in the Texas Metropolitan Mobility Plan are an important element of the plan. A measurable goal provides a clear way to identify progress and needs beyond current financial capability. Goals might include congestion and reliability performance goals that can be used to evaluate current systems as well as the longer-term scenarios. Access to jobs and other destinations are also relevant and can be identified using the long-range travel model output. The goals may also need to be related to other areawide targets such as population and employment growth, home prices, education quality, etc.

Atlanta's Aspirations Plan, one component of the Mobility 2030 process, the region's long-range plan efforts used a more detailed planning approach that included several factors – congestion relief among them – to select projects that were beyond the ability of the currently identified funding sources. The long-range planning model was modified to include estimates of the effect of operational improvements for roadways and public transportation in the performance measures to provide a comprehensive view of system characteristics. A prioritization process was used to select the important projects and programs beyond the regional plan and a preliminary cost estimate was developed for each. The Aspirations Plan included several sets of land use and transportation system options. The investment "portfolios" included more road and public transportation capacity, improved operations, demand management, land use pattern changes and pricing projects.

The Atlanta Aspirations Plan and the Texas Metropolitan Mobility Plan allow consideration of a broad set of transportation and land use choices. Analyzing a range of project costs and the congestion resulting from those solutions provides more information for public discussion. The projects, programs, and strategies,, the methods to finance the strategies and the path to achieving desired outcomes are more explicitly identified. Using the long-range transportation models to analyze the effect of land use options and transportation strategies allows the community to see the effect of those choices. The techniques being developed in these evolving efforts are providing the basis for a very robust analytical and communication process.

5.0 Building the Foundation for Effective Transportation Operations

5.1 Using Data Effectively: Archived Operations Data for Improved Operations

5.1.1 Marking Progress Through Performance Measurement

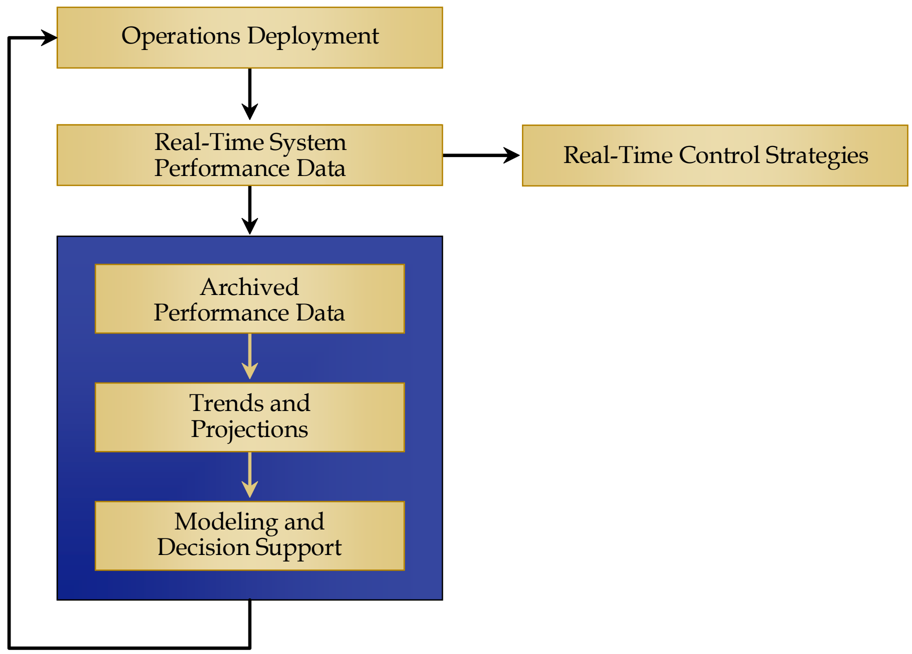
In the last few years, transportation operators have increasingly embraced the concepts of performance measurement – tracking the trends of key indicators of how the transportation system is performing. Performance measurement has been widely used in the private sector as a way to improve delivery of goods and services to customers and ultimately, the success of the enterprise. Fundamentally, this is no different from providing improved transportation services to the public – public agencies are businesses "selling" transportation service and travelers are the consumers "buying" them.

Perhaps the most significant lesson from the review of performance measurement activities over the last two decades is that all performance measures and measurement systems have evolved. The changes have been the result of legislative interests, accountability efforts, new data sources, estimation procedures, changes in knowledge about traffic conditions and perhaps most importantly, growth in demand for the information once reports and data are used. Transportation staff and leaders should experiment with measures, data, and presentation techniques.

5.1.2 Reusing Operations Data for Performance Measurement

Most major metropolitan areas have advanced technologies deployed to monitor traffic conditions. (See the Appendix for a description of the technologies.) The data are used in real-time to identify traffic back-ups, re-time traffic signals and ramp meters, and for estimating travel times along highway segments. These data are also extremely valuable when stored and used to develop historic trends (Figure 5.1). In fact, the highly detailed nature of these data (typically collected every 20 to 30 seconds at one-half-mile intervals on freeways) allows transportation analysts to conduct many types of analyses previously unavailable to the profession. Foremost among these is the estimation of reliability, which requires continuously collected data in order to build a sufficient history of how travel conditions vary over time.[35]

Figure 5.1 Reusing Real-Time Operations Data, Used Initially in Control Strategies, Is an Effective Way of Monitoring Performance and Providing Data for Future Assessments



Data sharing may take several forms. For example, operations data could be archived for analysis and used in a number of transportation planning applications, such as calibration of systems planning models, use in micro-simulation models, or for performance monitoring of the transportation system. Effective data sharing can occur in several ways:

- Develop a regional data clearinghouse;
- Coordinate data resources with transit agencies;
- Use special events to initiate new data partnerships;
- Use operations data to develop more effective performance measures and improve planning analysis tools; and
- Use archived data to inform management and operations planning.

Some current examples of what state DOTs are doing with these data to produce performance statistics follows.

[35] Most of the analyses presented in Section 2.0 (and some in Section 3.0) use archived operations data.

Maryland DOT Annual Attainment Report on Transportation System Performance

The Maryland Department of Transportation (MDOT) is required to submit to the state legislature an annual performance measures report (called the "Attainment Report") to evaluate the Department's progress in meeting the goals and objectives of the Maryland Transportation Plan (MTP). Each modal administration identifies performance measures and targets (where feasible) related to one of the four MTP goals: Efficiency, Mobility, Safety, and Productivity/ Quality. All four goals are impacted by congestion making it a key concern in Maryland. Therefore, several performance measures convey information about congestion in Maryland including:

Reduction in Incident Congestion Delay: the number of driving hours saved due to the Coordinated Highway Action Response Team (CHART) traffic incident management system. The State Highway Administration (SHA) developed this measure to track improvements in the operation of Maryland's existing transportation system. CHART traffic incident management program resulted in 26.8 million vehicle hours saved in 2003. SHA's short-term performance target is to save 30.0 million vehicle hours per year.

Percentage of lane-miles with average annual volumes below congested levels: the percentage of freeway lane-miles with an average annual density less than 20,000 vehicles per lane per day (vplpd) and percentage of arterials with an average annual density less than 10,000 vplpd. Facilities with densities greater than these vplpd levels will generally result in congested conditions. Figure 5.2 shows that from 1995-2003 the percentage of "congestion-free" miles has decreased. Although the vplpd measure provides useful information, it does not directly address the traveling experience of the system user. MDOT is working with SHA to identify metrics based on travel time for future attainment reports.

In the most recent Attainment Report, the modal administrations were also asked to identify the programs and projects that contributed to changes in performance and describe future performance strategies. For example, to reach the traffic incident congestion reduction target, SHA proposed to expand the number of service patrols. MDOT seeks to control or reverse the growth of lane-miles with high vplpd through capacity expansion, express toll lanes, and using technology to expand the capacity of existing infrastructure.[36] Although the performance measures are not directly used in decision-making, the report demonstrates MDOT efforts to implement performance-based planning. In addition, the Annual Attainment Report serves as an important communication tool with the public and elected officials.

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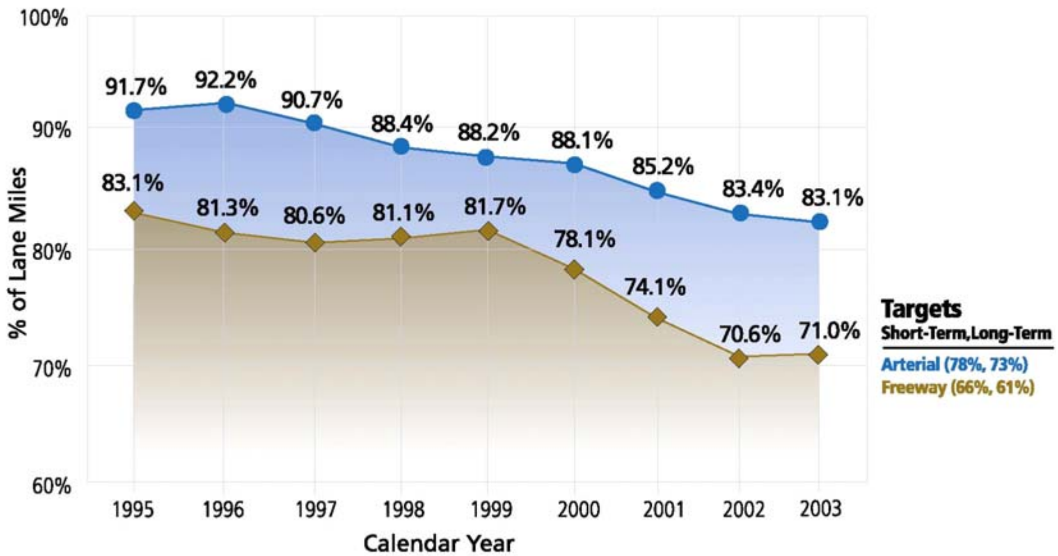
[36] Maryland Department of Transportation (2005). *Annual Attainment Report of Transportation System Performance.*

Figure 5.2 Percentage of Maryland Lane-Miles with Average Annual Volumes Below Congested Levels



Percentage of Arterial Lane Miles with Volumes < 10,000 vehicles per lane, per day
Percentage of Freeway Lane Miles with Volumes < 20,000 vehicles per lane, per day

Washington Department of Transportation

The Washington Department of Transportation (WSDOT) quarterly performance report, the Gray Notebook, is one of the nation's leading examples of effective statewide performance monitoring. WSDOT continually improves the Gray Notebook to better communicate how it is addressing state transportation issues. In 2002, WSDOT introduced the concept of travel time reliability and recent efforts to distinguish between recurring and nonrecurring congestion. WSDOT acknowledges that travel time reliability is one of the traveling public's most important concerns.[37] WSDOT uses archived freeway operations data to develop several congestion measures (including reliability) for the Seattle region. Examples of the metrics reported by WSDOT include the following, reported as current conditions and changes in annual trends.

- For specific commuter route segments (7 to 24 miles in length):
  - The time of day (e.g., 5:20 p.m.) that experiences the worst congestion;
  - Travel time on the segment during the peak time;
  - "95 percent Reliable Time" (the 95th percentile of travel time);

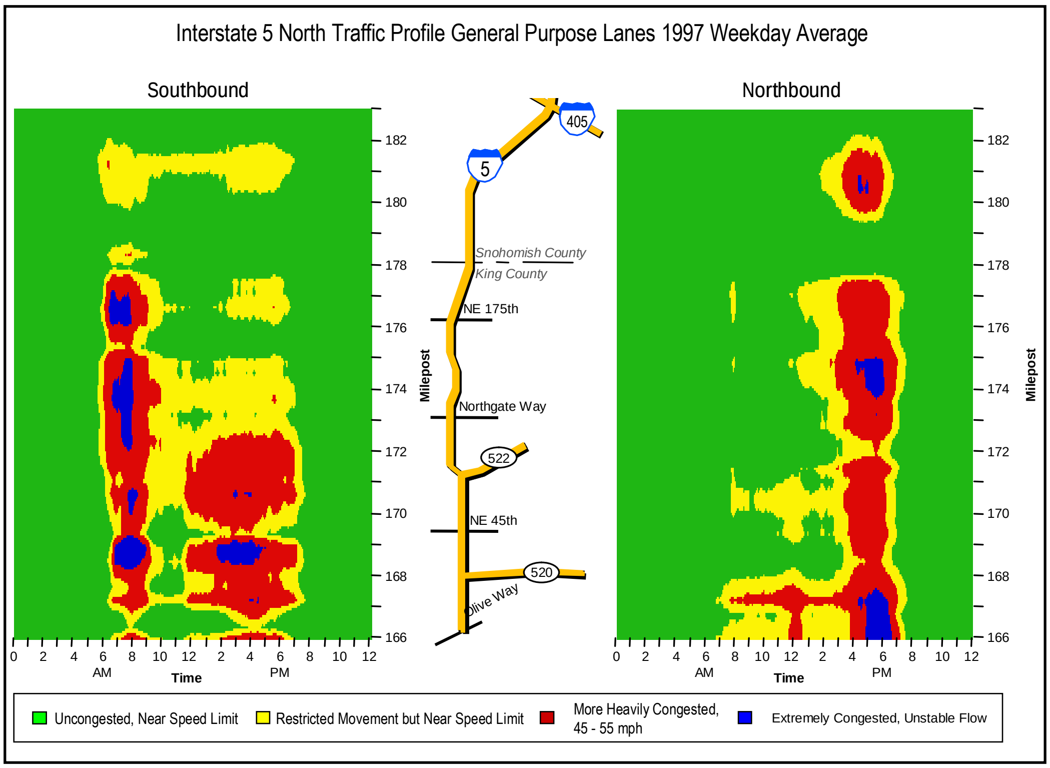
[37] Bremmer, Daniela, Keith Cotton, Dan Cotey, Charles Prestrud, and Gary Westby (2004). *Measuring Congestion: Learning from Operational Data*. Presented at the Transportation Research Board Annual Meeting, January 2004.

- Number of days when travel time exceeded twice the free flow travel time; and
- Percent of days where average route speed was less than 35 mph.

- For entire named freeways in the region:
  - Vehicle-hours of delay per day;
  - Vehicle-hours of delay per highway mile; and
  - Vehicle-miles traveled.
- Case studies documenting before/after congestion conditions.

WSDOT also uses geo-isometric graphs to visually locate and express the severity of delay on Washington freeways (Figure 5.3).

Figure 5.3 Example of Seattle's Portrayal of Historic Congestion Patterns

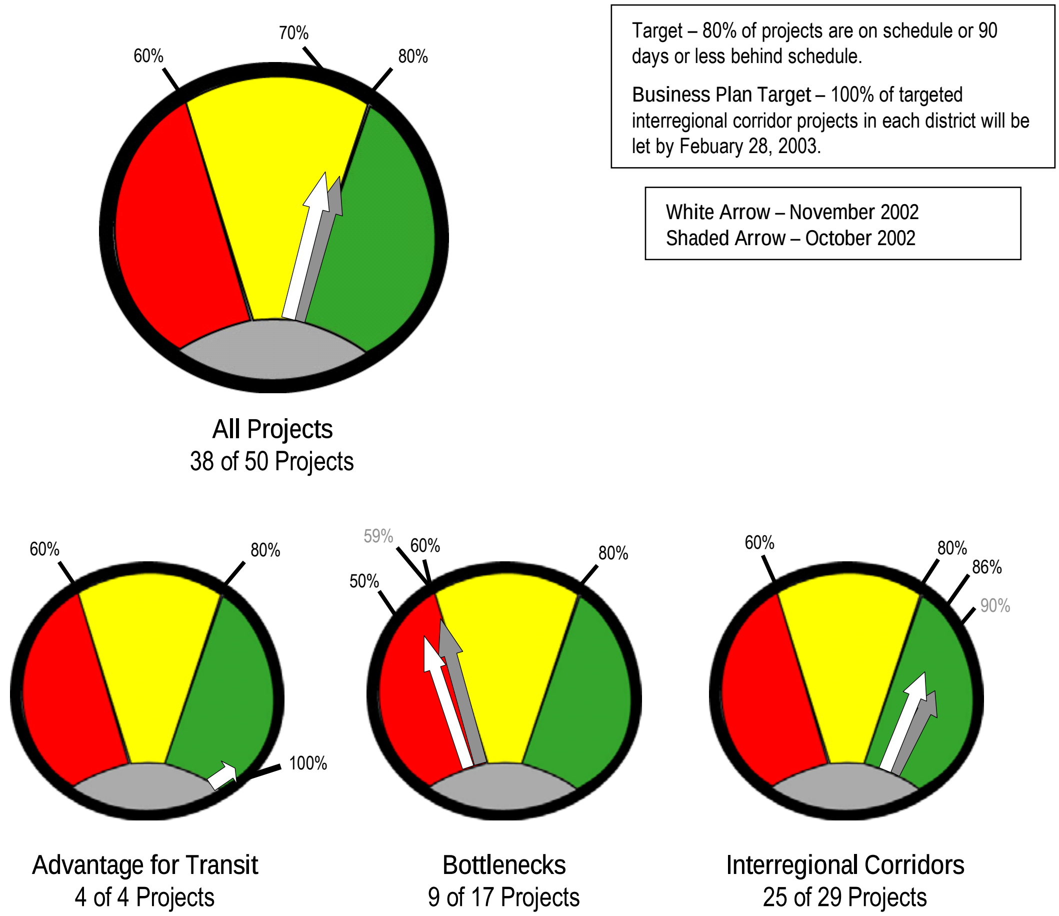


Minnesota DOT Dashboards

Operations data plays a key role in Minnesota DOT (Mn/DOT) performance-based planning approach. Mn/DOT's 2003-2023 Statewide Transportation Plan established 41 performance measures and 6-, 10- and 20- year targets to guide the agency towards its 10 policy goals. The performance measures from the Plan are translated into shorter-term business plans with 2-year targets. One of the operations-based measures, "percent of Interregional Transportation Corridors

(IRC) miles meeting target speeds," is used to assess Mn/DOT's attainment of its policy goal "enhance mobility in IRCs linking regional trade centers." Performance data is internally reported using a red-yellow-green dashboards for weekly, monthly, or quarterly monitoring (Figure 5.4). The information the measures, targets and dashboard reports provide guide budget and operational decisions.[38]

Figure 5.4 Example Minnesota Dashboard
Projects on Schedule (Status Report: November 2002)



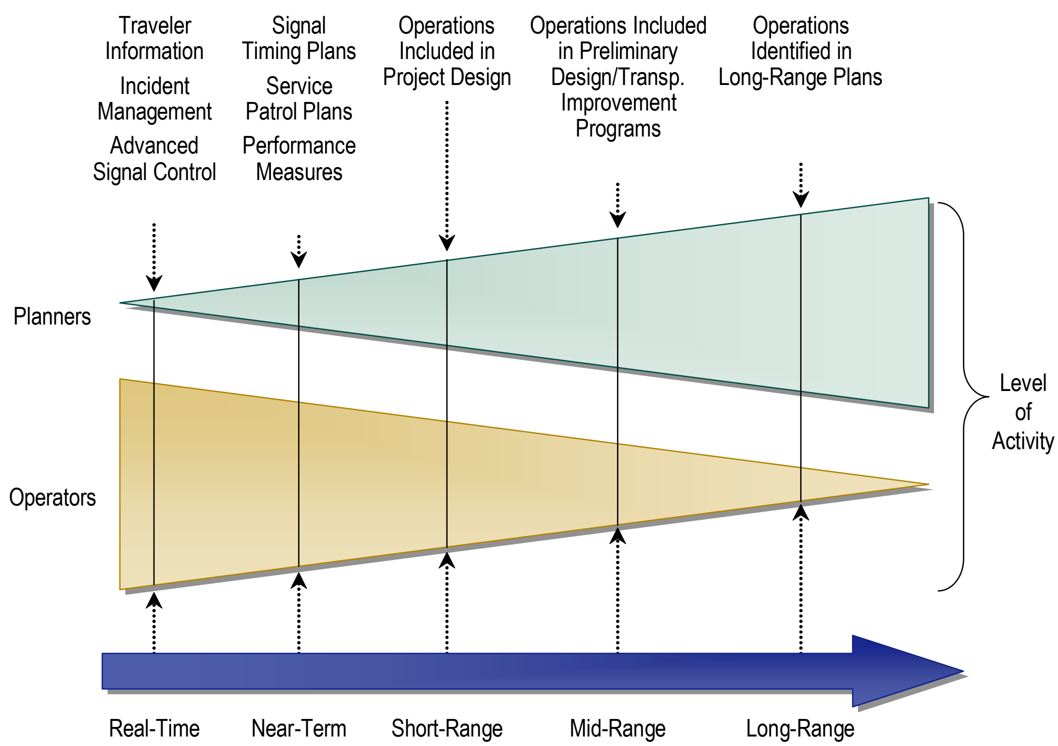
[38] http://www.dot.state.mn.us/dashboards/.

5.2 Linking Planning and Operations

5.2.1 "Planning for Operations"

Transportation planning is a long-established tradition in state and local transportation agencies. Its aim is to identify near-term and long-term deficiencies in the transportation system and to identify projects that can be implemented to alleviate them. Regional transportation planning and investment decision-making require a great deal of inter-jurisdictional coordination. Similarly, effective regional transportation systems management and operations require collaboration and coordination among operating agencies across jurisdictions and between transportation and public safety agencies. The focus of linking planning and operations is to provide stronger connections between these two processes and activities as shown in Figure 5.5. The major point is that while each group has its own priorities, ***both planners and operators need to be involved in all phases of the project development timeline.***

Figure 5.5 Planning for Operations
Roles and Activities for Planners and Operators



Note: Operations and planning need to be integrated in order to provide a seamless transition from real-time strategies up to long-range identification of future investments. While the roles shift according to the timeline, *both planners and operators need to be involved to some degree at all points of the project development horizon.*

Specifically:

- Planners need to have a greater understanding of the role of operations projects and programs in the context of meeting regional goals and objectives, and a greater understanding of to advance these activities.
- Operators need to have a greater understanding of how the long-range planning process can support management and operations activities, and how these activities fit into the context of regional goals and objectives in the planning process.

5.2.2 Developing Regional Collaborations to Foster Operations

Implementing operations strategies cannot be done in isolation – multiple agencies and entire regions are affected. To be more successful at solving regional transportation problems, FHWA is promoting the concept of regional transportation operations collaboration and coordination: 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. To achieve this, agencies within a region can cooperatively develop a ***Regional Transportation Concept of Operations*** (RTCO) for how regional operations collaborations should work. Examples of what can be achieved by regional collaboration – and documented in an RTCO – include:

- During traffic incidents and emergencies, transportation system operators and public safety officials improve response times and decision-making by effectively coordinating and communicating with each other;
- During a major highway reconstruction project, public transit services and traffic operations successfully work together to manage demand;
- For special events, public transit services, traffic operations, and public safety services move goods and people and minimize negative effects on the community by coordinating transportation operations and travel demand management;
- Freeway ramp meters work together with arterial signal systems to balance demand throughout the regional network;
- Traffic signals coordinated across multiple jurisdictions manage mobility and demand to meet community needs;
- Road users hear reliable, timely, and relevant news about weather conditions and traffic situations thanks to a regional traveler information service that seamlessly delivers information across jurisdictions, agencies, and modes;
- Customers move easily between travel modes and across jurisdictions because of a multijurisdictional and multi-agency electronic payment service strategy for transit, parking, and tolls;

- Hazardous materials moving through an urban area are electronically identified, monitored, tracked, and coordinated by regional traffic management and public safety agencies to ensure safe, secure, and efficient intermodal movement; and
- Regionally accepted system performance standards and performance measures drive transportation resource investment decisions.

Nationally, we are just beginning to see formation of regional collaborations. However, several regions have already taken the initiative and formed regional collaborations. Examples of products that have emerged from regional collaboration and coordination are:

- In the New York City Metro Area, TRANSCOM's Concept of Operations is important to governing how the member agencies, as well as other agencies involved, interact with each other and share information. TRANSCOM maintains planning documents such as a multiyear strategic plan, an annual business plan and budget, an information and communication systems plan, and a technology programs development plan.
- The Southern California ITS Priority Corridor management Concept of Operations calls for decentralized information sharing and an open system architecture that supports technical information sharing and the integration of different systems. This concept lies behind the strategy to "develop once, deploy many times," thus allowing for cost sharing among the agencies.
- Maricopa Association of Governments (Phoenix, AZ) developed a Regional Concept of Transportation Operations to provide the "big picture" of the region's desired state of transportation operations and management and the institutional commitment to get there.
- Metropolitan Transportation Commission (MTC) in the San Francisco Bay Area's Regional Concept of Operation focuses on freeway management in this multijurisdictional region where congestion and long daily commute trips through multiple jurisdictions are common and freeway expansion is unlikely.

Ultimately, greater coordination and collaboration among planners and operators improves transportation decision-making and benefits the traveling public, businesses, and communities in several ways:

- **Improved Ability to Address Short- and Long-Term Transportation Needs –** Improved traffic operations information and understanding can help planners better predict future conditions and system improvements. It can also bring attention to operational improvements that can be implemented in a shorter timeframe than traditional infrastructure investments. This will lead to a more effective mix of operational, capital, safety, maintenance, and preservation investments.

- **Improved Reliability –** Stronger connections between planners and operators help planners consider programs and strategies to improve reliability, such as deployment of technologies to rapidly detect incidents; variable message signs and other approaches for providing quick, reliable traffic information to the public and media outlets; and use of roving incident response teams to quickly clear accidents to open up a roadways for full operation.
- **Improved Emergency Preparedness –** Regional operations planning and flexibility is a critical element of a secure transportation system. Coordination between planning and operations reinforces efforts to ensure emergency preparedness and transportation security. States and regions that advance operational flexibility in their planning and investment prioritization are building their capacity to address the myriad of emergency and security situations that could arise.

6.0 Concluding Thoughts: Where Do We Go from Here?

6.1 How Can Everyone Pitch in Against Congestion?

Success against congestion requires not only attacking it on multiple fronts with strategies from the Congestion Relief Tool Box (Section 4.0). It also requires cooperation between transportation agencies, public safety agencies, businesses, and the public. Since we are all affected by congestion, it is important that we all work together to address the congestion problem. Here are some ways that transportation agencies, businesses, and the public can collaborate to mitigate congestion.

Take Ownership

The first step is for all parties to recognize they have a stake in the congestion problem. Public agencies are in the business of serving customers the same way that any private firm is – except that the customers (the public and businesses) are buying efficient and safe travel. The public, elected officials, and businesses are more than just consumers – they are shareholders too. These consumers also should examine their own decisions and policies to identify changes that can improve their quality of life while recognizing that the agencies cannot solve the problem by themselves. The ongoing transportation planning process, which has been successfully used in major metropolitan areas for at least the past 40 years to address transportation problems, provides an excellent framework for promoting ownership of congestion problems. A major part of the transportation planning process is establishing a Vision that outlines what the future transportation system should look like. The Vision leads to more specific statements of desired actions to achieve these states or characteristics. The Vision is also an opportunity to educate all stakeholders on the nature of congestion in your area and the importance of mitigating it.

Identify Where the Congestion Problems and Opportunities Are

Both technical analyses and anecdotal information from the public are useful in identifying where the major congestion problems currently are and what causes them. Discuss where the problems are likely to occur in the next five, 10, and 20 years. The existing transportation planning process in metropolitan areas can be tapped as a resource for this purpose. Provide realistic assessments on what can reasonably be done in each case, and what the expected improvements might be. FHWA supports a wealth of information on expected improvements from operational strategies, such as the ITS Benefits and Cost Database.[39] The process should include considering:

- **Strategies –** What types of treatments should be considered?
- **Coverage –** How much area does the treatment cover?
- **Density –** How well is congestion treated?
- **Congestion Target –** What aspect of congestion is treated?
- **Effect –** What is the delay reduction effect? Are there secondary effects, such as on safety? What are the spillover effects on other facilities and neighborhoods?

Develop Plans, Programs, Policies, and Projects

Solutions that effectively address congestion can take a variety of forms, as shown in the Congestion Relief Tool Box (Section 4.0). Think broadly – no single tool will be highly effective against the congestion problem. But when used in combination – and tailored to specific circumstances – congestion mitigation strategies can be successful. The strategies should be action-based – things we can actually accomplish in a reasonable timeframe and at a reasonable cost. Consider all types of strategies including adding new highway and rail capacity, improved operations, and better demand management and land use planning. For congestion, both immediate and long-term actions should be developed. Recognize that many transportation and community plans already exist and should be tapped as mechanisms for carrying out the Vision. In fact, acting on a list of "things we can do now" will help galvanize support for congestion mitigation over the long term.

Operate the Transportation System Proactively and Regionally

Focus on addressing system reliability by targeting capital and operations strategies to specific conditions. Anticipate problems and take corrective actions early. Also, regional and multimodal cooperation is key to the success of deploying effective operations – many different agencies have a stake in the congestion problem. Therefore, a broad perspective should be taken in applying capital and operations strategies – avoid a narrow, facility-oriented view.

Use Performance Measures to Track Progress

One of the main actions that transportation agencies can contribute to the process is the tracking of congestion trends over time. Trends provide a basis for determining how well actions are working and can identify changes in the underlying congestion problem (e.g., traffic incidents may become more important in your

[39] http://www.mitretek.org/its/benecost/BC_Update_2003/index.html.

area). Use of performance measures also brings an element of **accountability** to the process – what we are really getting for our investments – just as private firms do. The performance measures should track progress toward achieving program goals and objectives. Several principles may be followed in establishing a performance monitoring program:

- ***Sound Information Leads to Sound Decisions***. By their nature, operational strategies require continuous involvement in the day-to-day, hour-to-hour activities of the transportation system. Continuous involvement in the transportation system requires feedback at a detailed level so that strategies can be adjusted. In the era of TSM&O, we can no longer afford to be "flying blind."
- ***When You Measure, Measure Like You Mean It.*** Production of congestion trends is a valuable tool for self-assessment and public relations. However, to realize its full potential, performance measurement must be taken to the next level: active use in decision-making. Once performance measurement is embedded in agency culture and procedures, increased attention will be focused on the data, yielding higher quality and greater coverage. Evaluate projects you've done using your measurement process. Determine if the project produced the expected improvements in congestion and if not, why not? Identify aspects of the project that could be improved next time.
- ***Measure Where You Can, Model Everything Else.*** Performance measurements based on real-time operations data represent the best combination of accuracy and detail, but they do not cover all major roads in urban areas. However, transportation agencies have many other data and modeling resources that could be used in performance monitoring. Do not wait for perfect data – start performance monitoring now and improve data as you go.

6.2 Operations-Related Congestion Mitigation Activities at the FHWA

Future Reports on Congestion Trends

This report is the second in a series of planned annual reports on congestion trends, effects, and solutions. Several years ago, FHWA embarked on a support and outreach program to address the many causes of congestion and to improve highway safety through increased use of operational strategies. We are constantly learning more about the basic nature of congestion, where it is going, its impacts, and what can be done about it. As we learn more, additional information will be woven into future reports. Some of what we are learning will come from programs as outlined below.

Congestion Monitoring Activities

Part of the effort to improve support and outreach for operations was establishing national-level performance programs. The programs started small and have built to the point that enough data exists for enough cities to report trends; this report has presented some of these data. Future reports in this series will continue to use these sources.

Congestion Resources and Research

FHWA continues to develop and compile information for transportation agencies and the public on how improved operations can effectively manage congestion. Table 6.1 provides an overview of these activities, which are organized around the components of congestion as identified in this report. By addressing congestion by its root causes, both overall congestion levels and reliability are targeted. For further information, visit the FHWA Office of Operations web site: http://www.ops.fhwa.dot.gov/.

Table 6.1 Selected FHWA Operations Congestion Mitigation Resources

Congestion Strategy	Action	Example Resources
Reducing Nonrecurring Congestion	Traffic Incident Management	• NCHRP – Synthesis – Safe and Quick Clearance of Traffic Incidents • Quick Clearance and "Move-It" Best Practices – I-95 Corridor Coalition • Traffic Incident Management Self Assessment Tool • Model Procedures Guide for Highway Incidents • Integrated Computer-Aided Dispatch-TMC Field Operational Test
	Work Zone Management	• QuickZone (Traffic Impact Analysis) Tool and Training • Work Zone Self-Assessment Tool • Work Zone Best Practices Guidebook • Accelerated Construction Technology Transfer • ITS in Work Zones: A Cross-Cutting Study
	Road Weather Management	• Clarus Initiative (integrated surface transportation weather observing, forecasting and data management system) • Maintenance Decision-Support System Project • Best Practices for Road Weather Management • Fundamentals of Road Weather Management Training Course • Weather Responsive Traffic Management Analysis and System Development • Work Zone Communications and Outreach Activities
	Special Events Traffic Management	• Training Course on Managing Travel for Planned Special Events • Managing Travel for Planned Special Events Handbook
Reducing Recurring Congestion	Freeway Management	• Configuration Management for Transportation Management Systems • Freeway Management and Operations Handbook • Freeway Management and Traffic Operations Training Course • Managed Lanes Case Studies
	Arterial Management	• Access Management, Location and Design Training Course • Adaptive Urban Signal Control and Integration (AUSCI) Final Evaluation Report • Cross Jurisdictional Signal Coordination Case Studies • National Traffic Signal Report Card (w/NTOC)
	Corridor Traffic Management	• Brochure, primer and handbook on managing and controlling traffic between freeways and surface streets • Integrated Corridor Management (ICM) Initiative

Congestion Strategy	Action	Example Resources
	Travel Demand Management	• HOV Systems Training Course • ITS Professional Capacity Building Program • Travel Demand Management Toolbox • Brochure on Managing Demand Through Traveler Information
Improving Day-to-Day Operations	Operations Asset Management Real-Time Traveler Information Traffic Analysis Tools	• Changeable Message Sign O&M Handbook • Deploy 511 Web Site • Portable Changeable Message Sign Handbook • Displaying Travel Times on DMS Technical Guidance • National Traffic and Road Closure Information Web Site
Creating a Foundation for 21st Century Operations	Planning for Operations	• Guidance on Regional Collaboration and Coordination • Guidance on Linking Planning and Operations • Advancing TSM&O Executive Session and Training Course • Advancing TSO&M Course • Guidance on Regional Concept for Transportation Operations
	Performance Measurement	• Technical Guidance and Case Studies in Performance Measurement
	Facilitating Integrated ITS Deployment	• Standards Development • Architecture Development, Maintenance, and Use
Improving Global Connectivity by Enhanced Freight Management and Operations	Freight Analysis	• Freight Analysis Framework
	Freight Professional Development	• Integrating Freight in the Transportation Planning Process
	Intermodal Freight Technology Truck Size and Weight	• Cargo*Mate Logistics Information Management • Electronic Intermodal Supply Chain Manifest – Freight Operational Test Evaluation Final Report • Border Wizard
Improving Mobility and Security through Better Emergency Management	Emergency Transportation Operations (internal)	• Public Safety and Security Program Brochure
	Emergency Transportation Operations (external)	• FHWA Order 5181.1, Emergency Notification and Reporting Procedures

Source: http://ops.fhwa.dot.gov/.

A. Technologies for Advanced Traffic Monitoring

[Note: This Appendix was contributed by Mark Hallenbeck, Director, Washington State Transportation Center at the University of Washington.]

A.1 DATA SOURCES

Reporting and using performance measures requires the collection of data that can be used to compute performance measures. In general, three different categories of data collection are required; data regarding

- Facility use and performance;
- Staff activities and resource use; and
- Events and incidents that disrupt "normal" freeway conditions.

Facility use and performance data provide an understanding of the mobility benefits provided by a freeway system. Staff activities and resource use data describe how available resources are being expended. Event and incident data describe the external forces that influence how a freeway operates. When combined, these three categories of data provide insight into what is happening on the freeway system, and what types of changes in mobility are occurring as a result of the combination of "events" and the application of various resources and policies to provide mobility in the face of those "events." Each of these subject areas is described below.

Facility Use and Performance

Facility use and performance can be collected either continuously (usually by capturing surveillance or control system data), or using samples, usually as part of special data collection studies.

Continuous Data Collection

A wide variety of technologies can be permanently mounted and used to provide continuous facility performance information. The available options can be broadly categorized as:

- Point detection;
- Beacon-based probe vehicle data; and
- Nontraditional probe vehicle performance.

Point detection involves placing surveillance equipment at a specific location and using the measures of traffic performance at that location to estimate traffic performance over a segment of roadway. The "roadway segment" described by a single point detector is normally between one-third to one mile long in most United States freeway surveillance systems.

Point detectors generally report data on vehicle volume and lane occupancy (which when combined can be used to estimate vehicle speed), and when deployed in a "dual loop" configuration can also directly measure and report vehicle speed and vehicle classification (by length.) These basic measures serve as the basis for a wide variety of the mobility (outcome) performance measures described elsewhere in this report. Vehicle volume estimates at different points on the roadway describe how heavily the roadway is being used. When combined with vehicle speed information, vehicle volume statistics describe how efficiently the roadway is operating. (That is, during what time periods does congestion effect vehicle throughput, and how far below "optimal throughput" is the freeway operating during those congestion periods?)

Speed measurements at consecutive points along a roadway segment can usually be converted into reasonable measures of travel time along freeway segments, thus providing performance measures describing the delays being experienced by travelers using that roadway.

The fact that data are collected continuously means that analysis of these data allow a review of the time-of-day, day-of-week, and geographic trends present in travel patterns. This allows agencies to understand when, where, and how frequently problems are occurring on their roadways, and how those trends change as new counter measures are implemented.

Continuous data collection means that "unusual" conditions are also measured, and the effect these conditions have on freeway performance can be determined and compared against "routine" congestion. This allows agencies to understand the relative importance of different "unusual" events, and gage the relative value of spending resources on responding more effectively to these events versus spending those resources on improving "routine" conditions. That is, how reliable is the freeway system? When and where does the freeway become unreliable? And how significant are the delays of these "unreliable" times compared to routine commute period congestion?

A wide variety of sensors can be used to provide these point statistics, with the most common being

- Inductance loops;
- Video detection (most commonly used to simulate inductance loops); and
- Microwave radar.

However, a number of other technologies, including infrared, sonic, and acoustic sensors can provide these same data inputs.

Selection of the data collection technology to be used is usually a function of conditions under which the system will operate. Each technology has strengths and weaknesses which lead different agencies to select different technologies.

Inductance loops are inexpensive to purchase, and are generally considered a robust, well known, reliable technology. However, inductance loops require lane closures for installation and for maintenance of the wire loop itself. In freeze/thaw climates, in pavements in poor condition, and if installation is poorly done, the wire can break, meaning that additional lane closures are required to replace the failed loop. In addition, because loops are physically "cut" into the pavement, they are not moveable, and thus must be replaced if lane lines are moved as a result of new construction activities or other geometric and operational changes.

Video image detection technology was designed in part to deal directly with the limitations in loop technology. Because cameras are above ground, in many (but not all) instances, traffic lanes need not be closed to place, repair, maintain, or adjust the data collection devices. If lane lines are changed, detection zones in the camera image can often be "redrawn" without physically moving the camera system, thus allowing continued data collection without roadway closures or other significant disruptions to the facility or data collection system. Camera-based systems are thus generally considered a better choice than loops for point data collection on roadways where construction activities are expected to result in changing lane configurations or where pavement conditions make loop life problematic.

However, video image detection techniques also have limitations. Most of these problems stem from the fact that video systems can only measure "what they see." Thus video systems tend to work poorly in low-visibility weather conditions (e.g., heavy snow and thick fog.) Thus, they are often not recommended for implementation in climates where these conditions occur frequently.

In addition, video detection from beside the roadway can suffer from "occlusion"[40] which degrades the accuracy of traffic volume counts. Cameras placed over top of roadways generally have less problem with occlusion, but often require lane closures when being installed, repaired, or maintained, because of safety rules governing work above active roadway lanes. Finally, cameras frequently require more routine maintenance than loop detectors, as dirt and water can reduce image clarity, thus degrading system performance.

Microwave radar technology was developed, in part, in response to the limitations in loop and video technology. The characteristics of microwave radar

[40] Occlusion occurs when one vehicle "hides" another vehicle within the video image. This commonly happens when a truck passes a camera placed beside the roadway. A car on the far side of the truck from the camera can not be seen by the camera, and is thus not counted by the video detection software.

signals means that these systems are not affected by the weather problems experienced by video detection. Microwave radar does, however, have other minor limitations that generally result in slightly less accurate volume count information than obtained with loops and/or video detection. Like video detection, microwave radar can work from sensor positions either above the traffic lanes, or from beside the roadway. And also like video, the "above" locations provide more accurate data (less chance of occlusion) than the "side-fired" positions. Unfortunately, the "side fired" positions are usually less expensive to install, maintain, and repair because they do not require working within the constraints of moving traffic.

The primary limitation of point detectors is that they provide information about the performance about a single location, and that location may not be an accurate representation of the performance of the rest of the roadway segment to which those data are associated. This problem becomes less of a concern, the more closely spaced the point detectors. (That is, it is not much of an issue if the detectors are 400 feet apart, but it can be a problem if a single detector is used to represent traffic conditions along a mile-long roadway segment.)

Similarly, the fewer the geometric disruptions within a roadway segment, the better a single point detector is at estimating conditions within that segment. (For example, a single detector location will do a better job estimating conditions within a 1-mile roadway segment if there are no interchanges or major geometric features within that 1-mile segment than if there are interchanges or major geometric changes.) Even with fairly closely spaced detectors, the location of the detectors near specific traffic disruptions can effect how "representative" the data they produce are relative to the roadway segment they represent. For example, a detector placed just upstream of a ramp merge may underestimate roadway segment speed, as that specific section of road may see slightly slower speeds than the segment as a whole, as vehicles slow to allow vehicles entering the freeway from the ramp to merge. Such a sensor placement might also measure more "congestion" than the roadway segment as a whole experiences, because the merge point is likely to be the location within the segment which experiences congestion first (and stays congested longest) as a result of that merge.

As a result of these considerations, there is relatively little "simple" guidance on the deployment of point detectors. Instead, engineers designing point detection-based surveillance systems must tradeoff the cost, accuracy, and functionality of different sensor spacings and placements against the available budget and system requirements in order to settle on an appropriate design, and that final design effects how the resulting sensor data are converted into performance measures.

Beacon-based probe vehicle data collection is most commonly associated with electronic toll data collection systems. In these systems, a device (beacon) that uses Dedicated Short-Range Communication (DSRC) standards interrogates electronic vehicle tags as vehicles pass that reader location. The result is a data record that indicates when individual tag-equipped vehicles pass particular points on the roadway. (For toll collection systems, this allows automated billing of the owner of that vehicle, without forcing that vehicle to stop.)

By matching the time and location data associated with each vehicle as it passes from one beacon location to the next, it is possible to determine the travel time for that vehicle between two consecutive beacon locations. The result is an excellent data set that describe travel times for roadway segments defined by the location of the data collection beacons.

For toll roads with electronic toll collection systems, these data are essentially "free" for performance monitoring, since they exist for billing purposes. In cities where electronic tolling exists on some roads, it is also common (and fairly inexpensive) for agencies to place some additional readers on "free" roadways in order to capture vehicle time and location data on those facilities. In these cases, these data are not used for toll collection, but they do produce excellent travel time information on those selected road segments.

The result of these beacon-based systems is a very robust measurement system of travel times between tag readers. These data can then be aggregated and summarized to produce all of the travel time, delay, and trip reliability measures discussed elsewhere in this report. Travel times collected in this manner are more accurate than those estimated from point detectors, but they do not provide information about the geographic distribution of delays within the road segment being monitored.

For toll roads with closely spaced electronic toll collection points, the lack of spatial detail is not an issue. However, where tag reader spacings are fairly large, the lack of geographic detail can be a drawback, as the data collection system does not describe the location of any delays that are occurring. This can be a significant limitation on "free" roadways where multiple congestion locations (e.g., interchanges) lie within the measured roadway segment, as no data are gathered on the relative size and frequency of congestion caused by each of those locations.

Another limitation is that most toll tag-based data collection systems do not provide a measure of total facility use. Unless all vehicles using the facility must carry toll tags (this is the case on some roadways), the toll tag readers only monitor the performance of a sample of all vehicles. While this is generally good enough to provide an excellent measure of travel time, it does not provide an excellent measure of vehicle use on the facility. Thus, only half of the basic mobility performance information is available from most toll tag-based data collection systems.

As a result, vehicle volume use must be collected from other sources. For toll facilities, it can be obtained from the toll collection statistics. For "free" roadways taking advantage of the prior existence of tag-equipped vehicle fleets, additional data collection efforts are needed. These frequently involve a limited deployment of point detectors. The advantage of this "combined" approach to data collection is that the tag reader system provides very accurate and robust travel time information, and the point detectors can provide both vehicle volume information and estimates of the geographic distribution of delays. The downside of these systems is that they require two sets of data collection hardware and software.

Nontraditional probe vehicle performance systems are designed to provide travel time, speed and delay information without the beacon-based communications system. This allows these systems to cover much larger geographic areas (i.e., entire urban roadway networks) without the cost of building beacon-based communications infrastructure throughout those networks. None of these systems are actively used on a continuous basis in the United States, but they are in use in some parts of the world, and considerable effort is underway to complete testing and development of them in the United States.

While there are multiple companies/agencies working on this basic data collection approach, most of these efforts can be broken down into two general concepts.

- Cell phone tracking; and
- GPS-equipped vehicles with wireless data transmission.

A variety of different techniques are being promoted within each of these general approaches. Ongoing research is expected to provide more details in the near future about the costs and accuracy of estimates from these different approaches. Because the development process in this area is still underway, this subsection only introduces these data collection topics, and does not attempt to judge their relative merits.

Cell phone tracking techniques take advantage of the fact that it is possible to determine the approximate location of all cellular phones. By tracking the movement of cell phones it is possible to determine the speed of the cell phone. By restricting the analysis to those phones located on roadways, cell phone tracking provides a means to measure vehicle speeds on those roads.

Federal legislation intended to improve emergency response to cell phone users (E-911 requirements), and the commercial potential for “location-based services” associated with the location of cell phones have resulted in considerable effort to improve the accuracy and decrease the cost of collecting cell phone location information. Research is currently underway to determine the accuracy and cost of converting that information into roadway performance information.

The advantage of this technique is that the number of cell phone-equipped vehicles is quite high, and increasing. Thus, any road on which a cell phones is currently located becomes a data point on which vehicle speed can be obtained. This means that (potentially) entire roadway systems can be monitored without the need to install costly “roadway monitoring infrastructure.” That is, the infrastructure will exist to meet E-911 needs, and roadway performance data can be obtained at the marginal cost of processing the existing cell phone data into roadway performance measures. Exactly what those “marginal costs” will be, and how accurate those performance statistics are (given the need to correctly assign specific cell phones to specific roads, and to remove from the data sets those phones not in vehicles without biasing the data being collected from very slow moving vehicles), is the subject of various ongoing field operational tests. However, significant potential exists for this technique.

The second technique takes advantage of the significant reductions in the cost of Global Positioning Satellite (GPS) technology. GPS devices report current location, heading, and speed information with a high degree of accuracy. When placed in vehicles and combined with electronic map information, GPS devices are the primary component of excellent vehicle location systems. Storage and analysis of the GPS location data allow for very accurate roadway performance measurement. The difficulty with GPS data is that it is the **vehicle** carrying the GPS device that has this performance information. To convert data from GPS-equipped vehicles into roadway performance information usable by a freeway operations agency, it is necessary to provide some communication mechanism to/from GPS-equipped vehicles in order to obtain that vehicle location and performance data. In addition, to provide reliable roadway performance estimates, a large enough number of vehicles must be equipped with GPS to provide an unbiased measure of roadway performance, and to provide the temporal and geographic diversity desired by the performance measurement system.

Cellular phone tracking has the advantage that a very large number of drivers/ passengers in vehicles now carry cellular phones. Thus, a large number of potential probes exist. GPS technology requires that GPS devices be installed in vehicles. While the number of GPS-equipped vehicles is increasing slowly (for example, all On-Star-equipped vehicles have GPS devices, even if the vehicle owner does not subscribe to the On-Star service) the number of GPS-equipped vehicles is still relatively small, and the majority of those vehicles do not provide for routine communication of their GPS data to outside sources.

Several ongoing research efforts are working to resolve the cost and device distribution issues associated with GPS technology. Dramatic changes in wireless communications technology have significantly lowered the cost of wireless communications, allowing more cost effective retrieval of data collected by vehicle probes. Significant private and governmental efforts are underway to promote both the Intelligent Vehicle Initiative and the Vehicle-Infrastructure Integration (VII) programs, which encourage adding technology like GPS to vehicles, and are aimed at providing the infrastructure necessary to communicate key pieces of information from that technology to the roadside to improve safety and operations.

As with cell phone tracking, a number of operational field tests are currently underway that are testing new developments in these areas and that have the potential for providing new, robust, data sets that can be used for roadway performance monitoring. For example, efforts are currently underway in Germany to incorporate GPS and cellular phone technology into heavy vehicle tax/fee collection systems. Adoption of similar systems in the United States would provide another source of vehicle (and thus roadway) performance information.

One significant drawback to probe vehicle-based performance monitoring (whether cell phone- or GPS-based) is that, like toll tag tracking, it does not provide information about the level of roadway use (vehicle volume.) It only provides information about the speeds and travel times being experienced. Thus, if probe vehicles are the primary source of performance information used, some supplemental data collection will be needed to supply the performance measures related to the level of use freeways are experiencing.

Special Study Data Collection

The previous discussion of data collection technologies focused on the types of technologies that operate continuously. That is, once placed in the field, they provide data regularly for reasonably long periods of time. Where these systems do not exist and agencies can not afford to implement them (or where supplemental data sets are required), special, short duration studies are often performed.

These special studies have the advantage of generally having lower costs. They have the disadvantage of (normally) being noncontinuous, and are thus less likely to be able to accurately collect performance data on the number, frequency, and severity of "unusual" events.

Special studies are generally focused on collecting specific pieces of information, not available through existing sources. Since these sources differ from region to region, the special studies needed in one region are different than needed in others.

In a region with significant freeway surveillance and incident response systems, special studies may only be needed to provide the vehicle occupancy and transit ridership information needed to convert vehicle volume information into estimates of person throughput, person hours of delay, and other performance measures that relate to key policy initiatives.

In other areas where continuous data collection systems do not exist, special floating car travel time runs may be performed in order to provide the baseline travel time statistics needed to judge routine freeway performance. Similarly, special traffic volume counts are often performed to provide key statistics on freeway use.

As with continuous data collection, a wide variety of data collection techniques exist for collecting freeway performance information on a "special study" basis. The following discussion describes only a few of the more common techniques.

Traffic volume counts on high-volume freeways can be very difficult to perform, as traditional axle sensor-based traffic counters can not be safely deployed on high-volume roadways. The result is that many state agencies have been working with vendors of non-intrusive data collection technologies to develop portable versions of these devices.[41] Most commonly, these devices (usually using microwave radar, video, or acoustic sensor technologies) are placed, along with a power source such as a solar panel or batteries) on an extendable pole attached to a trailer. The trailer is then placed beside the roadway, behind a guardrail or concrete barrier, and the data collection device views traffic from a "side-fired" orientation.

The other common approach is for an agency to place convention road tube-based counters on all ramps within a corridor and use those ramp counts to estimate volumes on the freeway mainline.

Travel time and delay information is most commonly collected using floating car studies. However, as with other data collection efforts, a wide variety of other techniques can be used to collect this information.[42] The floating cars themselves can be paid data collection consultants, or volunteers recruited for the task. Travel times can also be collected using various license plate (or other vehicle) matching techniques.

In general, floating car studies provide better geographic information relative to the trip being monitored (i.e., where are the delays taking place and how big are those delays) than license plate matching approaches, but the license plate matching techniques provide a much bigger sample of the travel times being experienced by different vehicles using that roadway during the study time period.

All short-duration travel time studies have limitations in collecting data relative to temporal differences in travel time (whether those are time-of-day or day-to-day temporal differences), simply because of the cost of collecting those data. Thus, short-duration travel time studies usually only collect data for a sample of days and time periods. If the sample design is done well, a special study will produce an unbiased estimate of the mean condition and a reasonable estimate of trip reliability. However, limitations in the number of hours of travel being monitored make it difficult for short-duration studies to provide accurate measures of travel reliability relative to both time-of-day and day-to-day variations in traffic conditions.

Other congestion measures, especially the geographic extent of congestion, have been collected by a number of regions using aerial surveillance. The most

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[41] More on these efforts can be learned by visiting the National Detector Clearinghouse at http://www.nmsu.edu/~traffic/. Another good resource is Summary of Vehicle Detection and Surveillance Technologies, http://www.fhwa.dot.gov/ohim/tvtw/vdstits.htm.

[42] A good resource for learning more about travel time data collection is the Travel Time Data Collection Handbook available on-line at http://www.fhwa.dot.gov/ohim/timedata.htm.

common form of this is when agencies hire consultants who fly planes[43] and take photographs of traffic conditions of specific roadway segments over multiple hours and/or days. The photographic images are then analyzed to provide estimates of volume, delays, and the geographic distribution of congestion by time of day for the roadways being studied.

Estimating **person use** of freeways corridors almost always involves short-duration data collection efforts to collect the vehicle occupancy data needed to estimate average vehicle occupancy (AVO). Vehicle occupancy counts may include transit ridership estimates, although in many cases transit ridership can be obtained directly from transit authorities (who perform this task with some combination of manual counts and automated passenger counters located on buses).[44]

Most vehicle occupancy counts are done manually, although, some vendors of image detection software are starting to market systems that they claim can count passengers in vehicles. Vehicle occupancy counting on freeways is quite difficult, and can only be done when lighting is good, from locations where the viewing angle into the passing vehicles allows a clear view into the passenger compartment, and where the data collection personnel can stand (or sit) safely. These limitations, along with the cost of manual data collection generally limit AVO counts to a few sample locations, on a few sample days, along each freeway corridor of interest. These AVO estimates are then applied throughout the corridor.

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[43] Other techniques exist to perform this same basic data collection task.

[44] If transit ridership can be collected directly from the transit authority, AVO counts are normally restricted to non-transit vehicles. Person volume is then computed as (AVO * volume) for non-transit vehicles + transit ridership.