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Supplementary Notes

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Abstract

This handbook provides guidance and recommended practices on managing and controlling traffic on ramps with freeway facilities. The use or application of the guidance and recommendations provided will in time serve to enhance the use and effectiveness of the ramp management and control strategies. This handbook also describes in greater depth the issues and concepts specific to ramp management and control that were presented in Chapter 7 of the *Freeway Management and Operations Handbook*. The *Freeway Management and Operations Handbook* was released by the Federal Highway Administration in September 2003, and has since been updated to summarize the guidance presented in this handbook.

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FOREWORD

Over the last half century, the public's increasing demand for fast, efficient, and convenient means of travel has resulted in greater use and dependency on existing transportation infrastructure, including freeways and their associated ramps, to meet their personal and/or business needs. This increasing demand has largely outpaced efforts to increase supply. Efforts to satisfy public demand for improved travel have, instead shifted from of a philosophy of providing additional capacity to one of improving management and operations of existing transportation infrastructure. Born out of this philosophy was the implementation of policies, strategies and technologies to improve performance of freeway entrance and exit ramps. These policies, strategies, and technologies are better known as Ramp Management.

The over-riding objectives of Ramp Management are to minimize congestion (and its side effects), improve safety, and enhance overall mobility. This handbook provides guidance and recommended practices that help practitioners archive these objectives. The use or application of the guidance and recommendations provided in this handbook will serve to enhance the use and effectiveness of the ramp management and control strategies.

Although more comprehensive in scope, this handbook complements and describes in greater depth the issues and concepts specific to ramp management and control that were presented in Chapter 7 of the *Freeway Management and Operations Handbook*. The *Freeway Management and Operations Handbook* was released by the Federal Highway Administration in September 2003, and has been updated concurrently with this handbook to summarize the guidance presented in this handbook.

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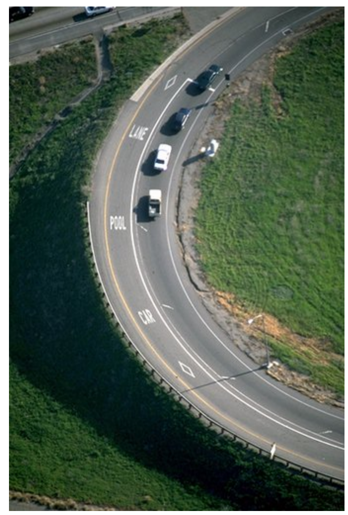
1.1 Ramp Management Introduction and Understanding



The purpose of this handbook is to improve the operation of freeways and their associated ramps by providing support, information, guidance, and recommended practice to practitioners responsible for freeway management and operations. However, before we can discuss the strategies used to manage traffic on ramps, including how we develop, design, implement, operate, maintain, and report their performance, we need to take a step back and describe the need for and importance of ramp management, and the role that it plays with respect to the successful operation of freeways, arterials and, to a broader extent, the entire surface transportation system.

Over the last half century, the public's increasing demand for fast, efficient, and convenient means of travel has resulted in greater use and dependency on existing transportation infrastructure, including freeways and their associated ramps, to meet their personal and/or business needs. This increased demand, in part a result of a growing population and increased auto ownership, has resulted in longer periods of congestion and deterioration of transportation infrastructure. As a result, motorists today must endure longer periods of delay and more safety problems than they have in the past.

As congestion, collisions, and other transportation-related problems continue to increase, improvements to transportation infrastructure in the form of additional lanes and new roadways has lagged behind (see Figure 1-1). For many agencies the cost of making these improvements, both financially and institutionally, are too great. In many cases agencies have considered methods that make better use of existing capacity. These methods include the use of advanced technologies and more efficient procedures. These technologies and procedures are often integrated into the context of freeway management programs that seek to manage, operate, and maintain regional freeways in an efficient and cost-effective manner.

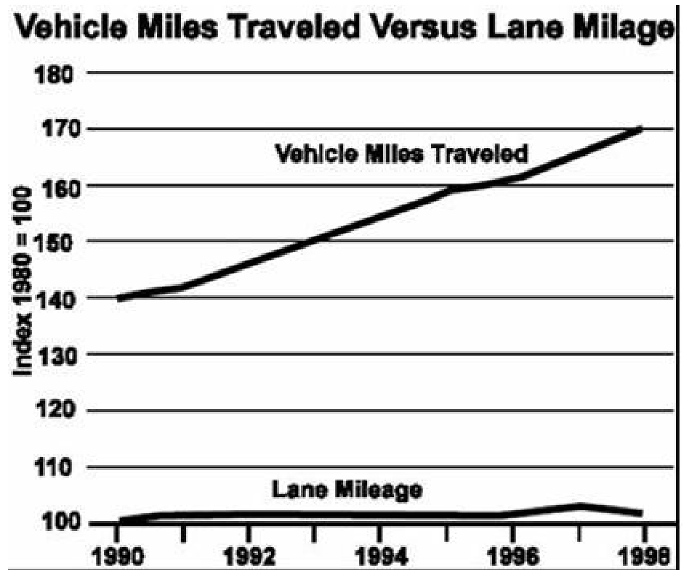


Figure 1-1: Vehicle Miles Traveled versus Lane Mileage[1]

***"Ramp management is the application of control devices, such as traffic signals, signing, and gates to regulate the number of vehicles entering or leaving the freeway, in order to achieve operational objectives."*[1]**

Ramp management is one of several functions performed on a daily basis to fulfill agency-defined objectives of freeway management programs. Ramp management strategies are often integrated with other freeway management program elements to better meet freeway management goals and objectives and to maximize use and benefit of existing transportation investments. The following sub-sections expand on the ramp management discussion provided here, by providing a more comprehensive definition of ramp management including goals and objectives, providing a historical background, identifying observed benefits, and expanding upon the relationship to freeway management briefly described above.

1.1.1 What is Ramp Management?

Managing traffic on freeway entrance and exit ramps, or ramp management, is the "application of control devices, such as traffic signals, signing, and gates to regulate the number of vehicles entering or leaving the freeway, in order to achieve operational objectives".[1] Most ramp management strategies are employed to balance freeway demand and capacity, maintain optimum freeway operation by reducing incidents that produce traffic delays, improve safety on adjacent freeways or arterial streets, or give special treatment to a specific class of vehicles. Ramp management strategies and the systems that support them are often implemented in conjunction with other freeway management programs to create operational efficiencies and to assist in the delivery of overall transportation management goals and objectives.

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

Ramp management may also control the manner in which vehicles enter a freeway. For instance, vehicles that enter the freeway in platoons introduce turbulence, which causes vehicles on both the mainline and ramp to slow down to safely merge. This causes congestion around and upstream of ramp/freeway merge points. Ramp management strategies may be used to control the flow of vehicles entering a freeway, thus smoothing the rate at which vehicles are allowed to enter the freeway.

1.1.2 Why is Ramp Management Important?

Understanding why ramp management is needed begins by defining what ramps are and what purposes they serve. Simply speaking, freeway entrance and exit ramps connect high-speed, limited-access freeways to other high-speed, limited-access freeways or lower-speed, principal arterials/highways, and vice versa. Additionally, ramps are the only facilities motorists may use to legally make connections to and from limited access facilities and as such represent the only locations where traffic entering and exiting a limited access facility can be controlled.

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

Ramp management also serves as an effective medium through which agencies can collaborate to address needs more effectively. Since ramps often join facilities that are operated by different agencies, ramp management can break down barriers that exist between agencies, allowing agencies to work together more effectively to address issues. For instance, a state agency such as the Department of Transportation (DOT) may operate a freeway including adjacent ramps, whereas a local agency such as a city engineering department may be responsible for operating the street or arterial that runs parallel to and connects with the freeway ramp. Using ramp management strategies and techniques, the state and local agency can work together to address traffic problems near the ramp, while remaining cognizant of each others' concerns.

1.1.3 History of Ramp Management in the United States

The rise of freeway congestion and safety problems originated during the economic growth and land development that took place shortly after World War II. In 1956, the need for transportation facilities prompted the U.S. Government to launch the Interstate Highway program. As demand, speed, and congestion increased, collisions became more prevalent and safety became a recognized problem. The response was to study the relationships between capacity and demand on freeways and the impact of the demand-capacity relationship on safety and congestion.

Better understanding of freeway flow led to a variety of methods to manage traffic demand on freeways. Ramp management was one technique born from this investigation.

The early 1960s saw the first successful attempts to manage traffic entering freeways from ramps. In 1963, ramp meters were deployed along Chicago's Eisenhower Expressway and were manually controlled in the field by a traffic enforcement officer.[2,3] Over the next several years, successful ramp metering experiments were conducted in Detroit and Los Angeles. With ramp meter successes came interest in developing new ramp management strategies. In 1967, Los Angeles implemented the first known ramp closure, and in 1972 Minneapolis introduced bus bypass lanes at metered ramps to promote use of transit.[4] Over the last four decades, ramp management strategies such as ramp metering and ramp closure have flourished as effective ramp management strategies and have continued to evolve to meet the additional demands of the public and the constraints inherent in public agency budgets.

Today, ramp management strategies are commonplace in jurisdictions all across the United States. For instance, ramp metering systems have been deployed in 26 metropolitan areas, with 12 having at least one HOV bypass lane. Similarly, at least six agencies have indicated they have temporarily closed ramps that enter or exit freeway facilities. The use of ramp management strategies is also growing. For instance, in 2002, there were approximately 2,160 ramp meters deployed within the United States. By the end of 2005, it is estimated this number will rise to roughly 2,370. Based on this fact, it is critical that practitioners have the tools needed to effectively implement these strategies. A summary of ramp metering activities in Minneapolis, Chicago, Los Angeles, and Detroit is provided below.

Chicago, Illinois

The first ramp meter was installed on Chicago's Eisenhower expressway in 1963.[2] By 2000, a total of 113 ramp meters were in place on regional freeways in the Chicago metropolitan area.[5]

Minneapolis/St. Paul, Minnesota

In 1970, the first two ramp meters were installed on I-35E north of downtown St. Paul. Initially, these meters were operated on a fixed-time basis; however, only two years later they were upgraded to operate on a traffic responsive basis. At this same time, another four meters were activated. In 1974, another 39 meters were activated, bringing the total number of meters to 43. Evaluation of the ramp meter program up to this point indicated that the metering program had been a success. Consequently, more than 300 additional ramp meters were installed before 1995, bringing the total to 368 ramp meters. Today, Minneapolis has one of the largest ramp metering programs in the United States and has been the focus of several evaluations. The results of these evaluations indicate that ramp metering has produced several benefits in terms of safety, improved mobility, and reduced environmental effects.

Detroit, Michigan

Although early experiments with ramp metering were conducted in the Detroit area, no permanent meters were installed until the 1980s. In November 1982, the Michigan Department of Transportation (MDOT) installed six ramp meters on eastbound I-94 (Ford Freeway). The ramp meters were part of MDOT's Surveillance Control and Driver Information (SCANDI) system. During the mid 1980s MDOT increased the number of ramp meters on I-94 to a total of 28. An evaluation of these 28 meters showed a significant increase in vehicle speeds and peak hour volume, as well as a reduction in total and injury accidents on I-94.[6] In 1995, the system was expanded once again, bringing the number of ramp meters deployed along freeways in Detroit to over 60.[7]

1.1.4 Ramp Management Goals, Objectives and Strategies

Ramp management goals, objectives and strategies should be consistent with regional transportation goals and objectives and must support the mission and vision of the agency. Ramp management goals, objectives and strategies should be defined at the regional level and should fit into the context of the broader transportation planning process, including the freeway management program.

"Ramp management goals, objectives and strategies should be consistent with regional transportation goals and objectives and must support the mission and vision of the agency."

Freeway management is defined as "the implementation of policies, strategies and technologies to improve freeway performance."[1] Although the flow of people and goods is a valid concern, it should be expressed that freeways should be operated in a manner that is consistent with the goals and objectives of the overall surface transportation program. In other words, agencies should not implement strategies that improve the flow of people or goods if such strategies do not support local, regional, and statewide surface transportation system goals and objectives. For instance, ramp metering is a strategy that may improve the flow of traffic. However, if policies are not in place and resources are not available to operate and maintain this strategy, deployment may actually result in public contempt for ramp metering. This in turn will impede the agency's ability to effectively manage traffic.

The selection and implementation of ramp management strategies must be based on needs. Ramp management strategies will obviously deliver greater returns if there are needs to address and if the identified needs can be addressed through ramp management approaches.

Although ramp management goals, objectives, and strategies vary from region to region and agency to agency, they are often tied to one or more of the following concerns:

- Safety.
- Mobility.
- Quality of life.
- Environmental effects.
- Motorist perceptions and satisfaction.

Four basic types of strategies are used to manage traffic on ramps:

- Ramp Closure – Ramps may be closed on a temporary, intermittent, or permanent basis. Ramps are often closed due to potential or severe impacts associated with geometric deficiencies on the ramp, or impacts that result from an abnormal mix of vehicles (e.g., high percentage of trucks).
- Ramp Metering – The rate at which vehicles enter a freeway facility may be controlled through the use of traffic signal(s) (i.e., meters) deployed on freeway entrance ramps. Ramp meters may control ramp traffic based on conditions in the field or manually to optimize the release of vehicles entering the freeway facility.
- Special Use Treatments – Preferential treatment may be given to a specific class of vehicle entering or exiting freeway facilities. For instance, a separate lane on a metered ramp may be used by multi-occupant vehicles or transit vehicles to bypass ramp meters and the queues they form. Similarly, an entire ramp may be allocated for use by special vehicle classes like transit and emergency vehicles.
- Ramp Terminal Treatments – Improvements (e.g., signal timing, widening lanes, pavement makings, adding turn lanes, etc.) may be made at the ramp terminal to improve existing conditions, and/or to maximize the benefits of other ramp management strategies like ramp metering.

Although each of these strategies alone can be used to manage traffic on ramps, they are often used in combination with each other to deliver maximum benefits. The specific types of strategies selected for managing ramp traffic depends on the objective of the ramp management program. Additional information pertaining to each strategy can be found in Chapters 2 and 5.

1.1.5 Observed Benefits

Before and after evaluations of ramp management strategies offer strong evidence that operations on ramps, freeways, and even adjacent arterials are improved once these strategies are appropriately implemented and operated. The benefits for some strategies such as ramp metering are widely documented in the literature, but documentation of the benefits of others, such as ramp closure and ramp terminal treatments, are much scarcer. The apparent lack of literature that report the benefits of certain ramp management strategies may be in part related to the frequency in which ramp management strategies are implemented. Full ramp closure, for example, has not been implemented nearly to the extent ramp metering has and, therefore, the logical conclusion can be drawn that less research pertaining to ramp closure will be available. Ramp terminal treatments, on the other hand, are comprised of accepted, low-cost traffic engineering practices that are rarely evaluated exclusively in ramp terminal areas. Despite the lack of research, the existing literature offers a sufficient amount of evidence to determine the impact of strategies and their effectiveness in reducing congestion, improving safety, and addressing other transportation problems.

Safety

Although different in their approach, ramp management strategies can improve safety not only on the ramps in which they are deployed, but also on the freeway and adjacent arterials. Freeway congestion that forms at or immediately upstream of merge areas is often a result of large platoons of vehicles entering the freeway from a ramp. These vehicles must compete for gaps in mainline traffic, limiting motorists' ability to focus on traffic in front of them. Adding to this problem are geometric deficiencies that make weaving operations at the ramp-freeway merge point more complex. Such deficiencies include horizontal and vertical curves, closely spaced ramps, and inadequate acceleration or deceleration distances. As a result, rear-end, sideswipe, and lane change collisions may occur on the freeway or ramp. Similarly, vehicles waiting to enter metered ramps may form queues on the arterial, which consequently increases the chance for collisions (especially rear-end collisions).

"…ramp management strategies can improve safety not only on the ramp in which they were deployed, but also on the freeway and adjacent arterials as well."

To a large extent, collisions attributed to merging problems can be reduced by breaking up platoons so vehicles are not forced to compete for the same gaps in mainline traffic. If repeated on a system-wide basis, the overall operation of the freeway may be stabilized, and crashes that result from stop-and-go driving behavior may be reduced. For instance, a 2001 before and after evaluation of ramp meters in Minneapolis found that the number of peak period crashes on metered freeways and ramps increased 26 percent when meters were turned off.[8] This report seems to verify the findings of a previous study that reported that the average number of peak period crashes decreased 24 percent as a result of ramp metering.[2] Table 1-1 provides a summary of reported safety benefits of other ramp metering programs.

Table 1-1: Summary of Ramp Metering Safety Benefits[2]

Location	Benefit
Portland, OR	43% reduction in peak period collisions.
Minneapolis, MN	24% reduction in peak period collisions.
Seattle, WA	39% reduction in collision rate.
Denver, CO	50% reduction in rear-end and side-swipe collisions.
Detroit, MI	50% reduction in total collisions and 71% reduction in injury collisions.
Long Island, NY	15% reduction in collision rate.

Mobility and Productivity

Ramp management may significantly improve conditions on the freeway, resulting in benefits to mobility and productivity. By managing the rate at which vehicles are allowed to enter a freeway, practitioners can set limits based on downstream capacity to maintain a pre-determined operational objective. Operational characteristics that may be improved, leading to greater throughput while maintaining freeway operation, include speed, travel time, and delay. Table 1-2 provides a summary of ramp metering mobility and productivity benefits.

Table 1-2: Summary of Ramp Metering Mobility and Productivity Benefits[2]

Location	Benefit
Portland, OR	A 173% increase in average travel speed.
Minneapolis, MN	A 16% increase in average peak hour travel speed and a 25% increase in peak period volume.
Seattle, WA	A 52% reduction in average travel time and a 74% increase in traffic volume.
Denver, CO	A 57% increase in average peak period travel speed and a 37% decrease in average travel time.
Detroit, MI	An 8% increase in average travel speed and a 14% increase in traffic volume.
Long Island, NY	A 9% increase in average travel speed.

Environmental Effects

There is a known direct correlation between improved traffic operations and environmental improvements, as discussed in the previous section. First, and perhaps most important, are reductions in the amount of emissions released into the environment. As the time spent in stop-and-go conditions decreases and average vehicle speeds increase nearer to posted driving speeds, the amount of vehicle pollutants released into the environment decreases. The evaluation of ramp meters in Minneapolis identified a net annual saving of 1,160 tons of emissions.[7] An increase in travel speed also improves fuel efficiency, leading to reduced fuel consumption and cost savings.

Traveler Perception and Satisfaction

Ramp management and improved operations on freeways also have qualitative benefits. Improved traffic flow, decreased travel times, and improved safety all work together to ease motorists' concerns and frustrations. These improvements also help improve motorists' perception of regional transportation officials and agencies, making it easier for these groups to acquire the needed funding to develop, implement, operate, and maintain transportation improvements. The results of the evaluation conducted in Minneapolis indicated that motorists generally thought conditions got worse after meters were turned off compared to when they were operational.[8]

1.1.6 Ramp Management as Part of an Effective Transportation System

An effective transportation system consists of a coordinated, inter-related set of strategies, procedures, and activities intended to meet the goals and objectives articulated in an agency's vision statements and policies. At the most basic level, ramp management efforts must support the vision and mission of the agency that implements them. Ramp management should be considered as an element of the overall transportation management system, not as something that operates in parallel to or separate from it. Ramp management strategies need to be considered as ways to meet the goals and objectives articulated in the agency strategic planning process.

"…ramp management efforts must support the vision and mission of the agency that implements them."

The relationship between ramp management and the freeway management program is similar to the relationship that exists between freeway management and the broader surface transportation program. Ramp management seeks to satisfy freeway management goals and objectives in a similar way that freeway management works to satisfy surface transportation goals and objectives. Ramp management programs must work with other surface transportation programs and freeway management programs, respectively, to ensure that freeways, and in turn the surface transportation system, are optimally operated. In addition, the integration of freeway management strategies and programs with other surface transportation programs is critical for seamless transportation operations.

Freeway Management

Freeway management is one of several functions that comprise the overall surface transportation program. Freeway traffic management is the implementation of policies, strategies and technologies to improve freeway performance. The over-riding objectives of freeway management programs are to minimize congestion (and its side effects), improve safety, enhance overall mobility, and provide support to other agencies during emergencies.[1] Freeway management works with other surface transportation programs, including transit management and arterial management, to satisfy the overall goals and objectives of the surface transportation program. Freeway traffic management entails:

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

The goals and objectives of freeway management are often satisfied through an agency's freeway management system, which is comprised of physically deployed infrastructure elements (e.g., field devices, subsystems, and signs), concepts (e.g., policies and procedures), and personnel. These infrastructure elements, concepts, and personnel work together to satisfy one or more specific objectives. Objectives of a freeway management program may include the following:

- Reduce the impacts and occurrence of recurring congestion on the freeway system.
- Minimize the duration and effects of non-recurring congestion on the freeway system.
- Maximize the operational safety and efficiency of the traveling public while using the freeway system.
- Provide facility users with information necessary to aid them in making effective use of the freeway facilities and to reduce their mental and physical stress.
- Assisting users who have encountered problems (crashes, breakdowns, confusion, etc.) while traveling on the freeway system.

Ramp Management

"Ramp management is one of the many functions that fall under the freeway management 'umbrella'…"

Similar to the relationship between freeway management and the surface transportation program is the relationship between ramp management and the freeway management program. Ramp management is a single function that falls under the freeway management "umbrella" that is performed on a daily basis to fulfill agency-defined objectives of the freeway management program. Ramp management elements work with elements of other freeway management programs to deliver freeway management system goals and objectives. This relationship can be likened to puzzle pieces, with ramp management representing just one of these pieces (see Figure 1-2). The freeway management functions that comprise a freeway management program are identified in Figure 1-2, and their relationship with regard to ramp management is described below.

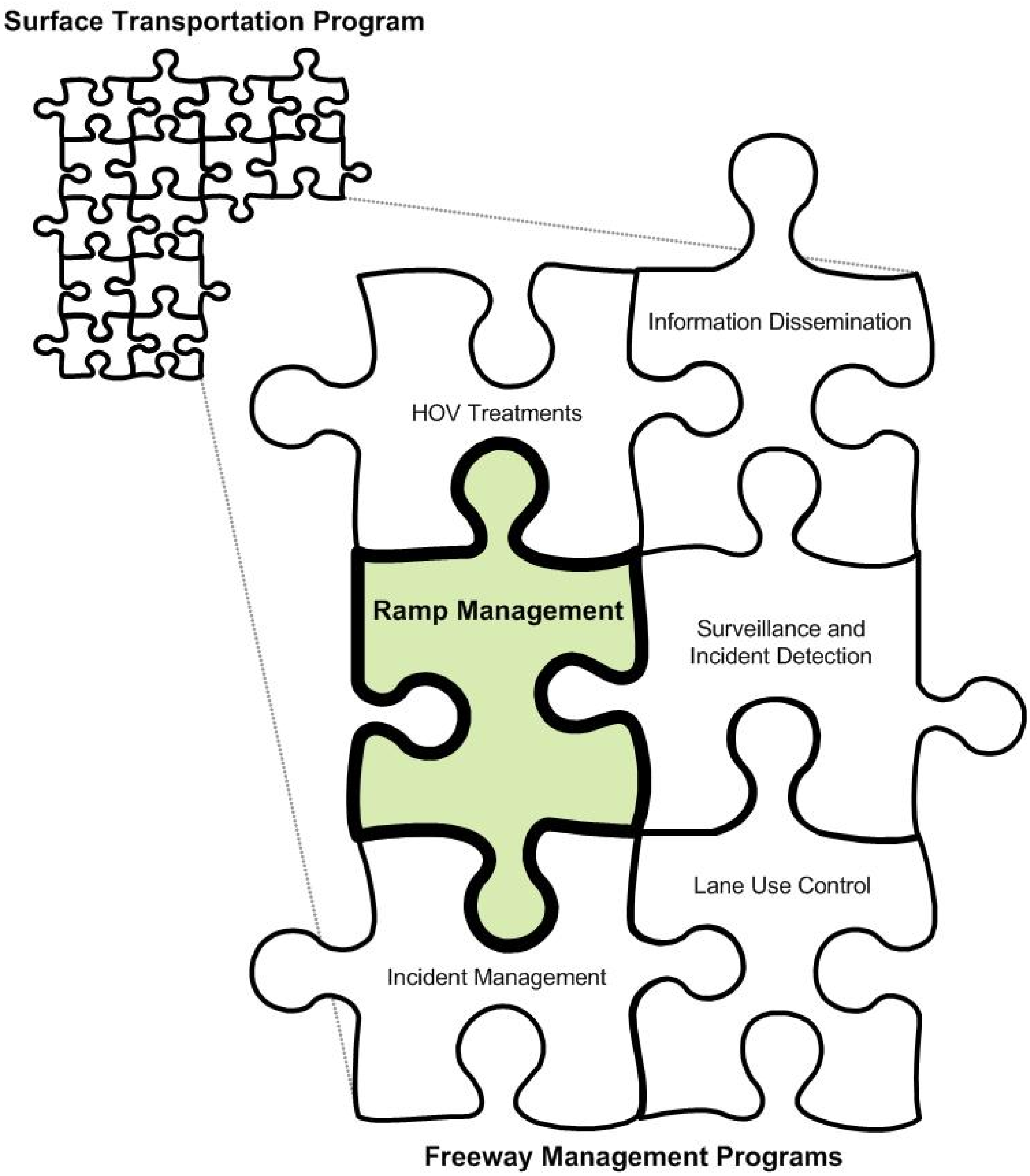


Figure 1-2: Freeway Management Programs and Their Relationship with the Surface Transportation Program

HOV Treatments – Preferential treatment of HOVs and other vehicle classes have been successfully used to bypass single-occupant vehicle (SOV) queues at ramp entrances.

Information Dissemination – Information dissemination techniques employed by other freeway management functions may be used to inform to motorists en-route or pre-trip about the current operational status of ramp meters. Additionally, motorists may be alerted to planned ramp closures as well as construction activities on or near the ramp.

Surveillance and Incident Detection – Surveillance and incident detection systems are used to determine and adjust freeway and ramp operational conditions. Data from detectors installed on either the ramp or mainline can be used to set or adjust ramp metering parameters. Closed circuit television (CCTV) can be used to visually verify that ramp meters are functioning properly or to observe the effects of ramp metering on traffic flow.

Incident Management – Incident management procedures and plans may be integrated with ramp management to improve safety and restore operations on ramps and the mainline in a more timely fashion. Through active management of ramp meters and other devices, operators may monitor freeway operations during emergencies and clear ramp queues to allow a more timely response to emergencies.

Lane Use Control – Lane use controls may be used to direct motorists to use certain lanes and to merge out of other lanes. Lane use controls are usually used either in reversible lane operations or to close lanes because of road work or incidents. Ramp management strategies can be used in conjunction with lane use controls to manage the demand, leading to freeway sections where lane use controls are active.

1.2 Handbook Vision and Development

This handbook was prepared in part to address the need to provide practitioners with a technical reference that offers guidance and recommended practices on managing and controlling traffic on ramps with freeway facilities. The use or application of the comprehensive guidance and recommendations provided here will in time serve to enhance the use and effectiveness of the ramp management and control strategies presented in this handbook. This handbook also describes in greater depth the issues and concepts specific to ramp management and control that were presented in Chapter 7 of the *Freeway Management and Operations Handbook*. The *Freeway Management and Operations Handbook* was released by the Federal Highway Administration in September 2003, and has since been updated to summarize the guidance presented in this handbook.[1]

1.2.1 Purpose and Objectives

The primary purpose of this handbook is to improve the operation of freeways and their associated ramps by providing support, information, guidance, and recommended practice to practitioners responsible for freeway management and operations. The use or application of these recommended practices will, in time, serve to enhance the use and effectiveness of various ramp management and control strategies and techniques. Recommended practices can provide a basis to improve understanding of the dynamics of ramp traffic flow and the influence it has on the operation of the freeway system as a whole. For example, transportation planning must reflect not only the characteristics of mainline freeway flow, but also the impact that ramp-based traffic flows have on the overall operation of the freeway. Improvements should be designed with the operation of the ramp as well as the mainline in mind. The location and geometry of ramp improvements can either facilitate or detract from the ability to control ramp volumes through the use of ramp metering and other management techniques.

Overall Objectives of this Handbook:

Objective 1:	Identify and understand four ramp management strategies and the specific techniques for applying each.
Objective 2:	Understand how ramp management fits into an agency's traffic management program.
Objective 3:	Understand the various issues that need to be considered to develop and select an appropriate ramp management strategy.
Objective 4:	Understand the various issues that need to be considered to implement selected ramp management strategies and plans.
Objective 5:	Understand the strategies and approaches that keep selected ramp management strategies operating effectively over time.
Objective 6:	Identify the importance of performance monitoring, evaluation and reporting, and the steps in applying these tasks so ramp management programs are continuously improved.
Objective 7:	Understand the issues and considerations associated with the design of ramp management strategies.

Intended Audience

This handbook was developed with the specific intent of clearly and precisely presenting information in a way that is both understandable and useful to all those interested in this topic. However, the content contained in this handbook was prepared taking into account the typical needs of transportation professionals charged with the responsibility of implementing, operating, and maintaining ramp management strategies. Although these individuals comprise this handbook's primary audience, consultants, contractors and researchers that have an interest in ramp management will find this handbook, or parts of it, beneficial.

Primary Audience

This handbook will primarily benefit the wide array of practitioners responsible for or affected by the implementation of ramp management strategies and the systems and devices that support them. This group of practitioners includes: traffic managers and decision makers, engineers, planners, designers, and operations staff. Also included are representatives of state DOTs, local agencies, Metropolitan Planning Organizations, and transit agencies who may be involved in the planning, design, monitoring, operation, evaluation, and reporting on the performance and influence of managing traffic at freeway ramps.

Secondary Audience

In addition to the individuals identified in the previous section, consultants, contractors and researchers may also benefit from the discussion and concepts expressed in this handbook. This group of individuals may use this handbook as a resource when completing projects and or addressing concerns on behalf of their clients.

1.2.2 Handbook Development and Organization

The development of this handbook stemmed from the need to deliver guidance to individuals interested in ramp management. Before this handbook was developed, there was no single, comprehensive guidebook dedicated to ramp management and control. Chapter 7 of the *Freeway Management and Operations Handbook* discusses the subject, but not to the level of detail that has been developed here. This handbook synthesizes existing literature, builds on what is being done in current practice, and utilizes the knowledge of technical experts from around the country in its review and content.

This handbook was developed with the understanding that chapters will:

- Provide an overview of ramp management, its associated strategies, organizational and operational considerations in managing ramp traffic, and how to monitor ramp performance and evaluate improvements.
- Enhance the understanding of ramp management strategies and corridor traffic management, how they relate to one another and how they affect the operation of the freeway and the transportation system as a whole.
- Explain the importance of effective planning and design practices of ramp improvements for the operation of the transportation system.

Recently there have been a number of resources developed to enhance the freeway management practitioners' set of tools to address freeway safety and congestion-related issues. These tools include a series of handbooks presenting guidance and effective practice in the broad area of freeway management and operations. These include: the *Freeway Management and Operations Handbook, Incident Management Handbook, Special Events Handbook, Communications Handbook, HOV Systems Manual, Traffic Detector Handbook*, and the Traffic Control Systems Handbook. This *Ramp Management and Control Handbook* will add another critical tool to this set.

This handbook consists of 11 Chapters grouped into four sections and an Introduction (i.e., Chapter 1). Section 1 (Chapters 2-4), titled *Getting Started*, presents all the processes and issues an agency should consider and/or complete before ramp management strategies are developed and implemented. Issues and activities relevant to traffic managers, which they may or may not be able to control, are discussed. Section 2 (Chapters 5-8), titled *Decision Making*, provides all the information that a traffic manager needs to develop, implement, operate and maintain ramp management strategies. Section 3, titled *Visibility* (Chapter 9), provides guidance on how to monitor, evaluate, and report the impacts associated with the implementation of selected ramp management strategies. The last section, titled *Influences* (Chapters 10 and 11), provides design considerations and case studies that may be used by practitioners seeking assistance in implementing ramp management strategies. A chapter-by-chapter summary for each of the four sections is provided in Table 1-3 through 1-6, respectively. A breakdown of chapters contained in each section is shown in Figure 1-3.

Table 1-3: Overview of Section 1 - Getting Started

Chapter	Title	Description
2	Ramp Management and Control Overview	This chapter provides an overview of the ramp management and control issues and activities that are examined in this handbook.
3	Ramp Management and the Traffic Management Program	This chapter describes how ramp management fits into an agency's overall program and structure, including the traffic management program, from the perspective of the individual(s) that will be implementing and operating ramp management strategies (e.g., Traffic Management Center (TMC) supervisors and managers). The focus of this chapter is on how ramp management fits in with the broader agency program, and the issues and activities that are necessary to support ramp management and control that the Traffic Manager can influence, but not control.
4	Preparing for Successful Operations	This chapter continues the discussion of how ramp management fits into an agency's traffic management program but concentrates on the issues and activities that occur at the TMC supervisor level and below. In other words, the issues and activities that can be controlled by the Traffic Manager, as opposed to Chapter 3 which focuses on the issues and activities that the TMC supervisor has influence, but little direct control.

Table 1-4: Overview of Section 2 - Decision-Making

Chapter	Title	Description
5	Ramp Management Strategies	This chapter introduces and describes commonly used strategies that may be implemented to better manage traffic on and adjacent to freeway ramps.
6	Developing and Selecting Strategies and Plans	This chapter builds upon the high-level discussion of ramp management strategies presented in Chapter 5, and furthers it by discussing the various issues that agencies should take into consideration when developing and selecting an appropriate ramp management strategy.
7	Implementing Strategies and Plans	This chapter builds off the previous two steps discussed in depth in Chapters 5 and 6, and furthers this discussion by addressing the various issues and activities associated with the implementation of ramp management strategies and plans.
8	Operation and Maintenance of Ramp Management Strategies	This chapter discusses considerations to keep the ramp management strategies operating effectively.

Table 1-5: Overview of Section 3 - Visibility

Chapter	Title	Description
9	Ramp Performance Monitoring, Evaluation and Reporting	This chapter describes the process of monitoring, evaluating, and reporting the performance of ramp operations and the ramp management strategies selected and implemented in Chapters 6 and 7, respectively.

Table 1-6: Overview of Section 4 - Influences

Chapter	Title	Description
10	Planning and Design Considerations	This chapter supplements Chapter 7 by addressing issues and activities that need to be considered when implementing individual capital projects that have already been approved and funded, and support the overall ramp management strategy implemented in Chapter 7.
11	Case Studies	This chapter provides practical examples and experience that illustrates various aspects of planning, deploying, and operating ramp metering systems by providing overviews of the experiences of various agencies that have implemented ramp metering and other ramp management strategies in their cities.

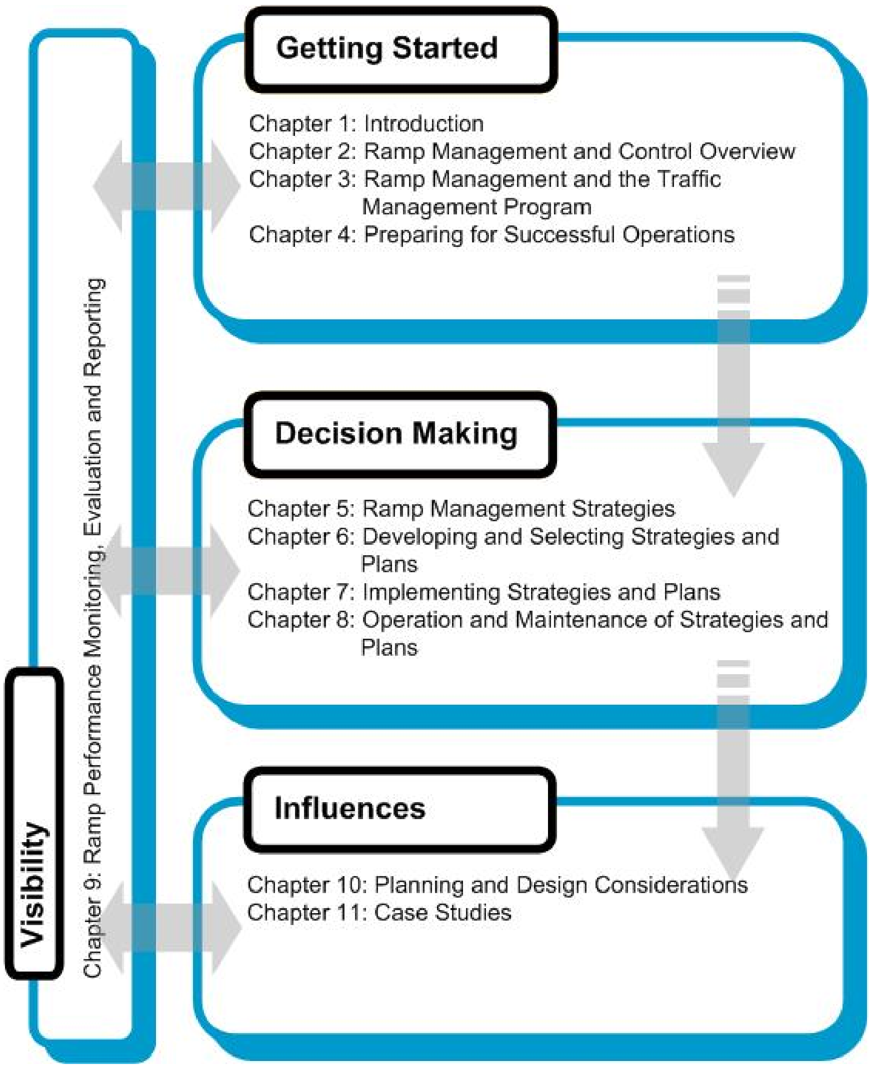


Figure 1-3: Document Organization by Main Section

1.2.3 How to Use this Document

The use or application of guidance provided in this handbook serves to enhance the use and effectiveness of ramp management and control strategies. It is believed that agencies including state DOTs, local agencies, Metropolitan Planning Organizations, and transit agencies will use the concepts and guidance expressed in this handbook to further develop effective practices to plan, design, operate, monitor, evaluate, and report on the performance and influence of managing traffic on and near freeway ramps.

The organization and content of this handbook is intended to meet the needs of the intended audiences by:

- Meeting challenges.
- Showing interdependence between other programs and initiatives.
- Identifying gaps in the state-of-the-practice and advancing it forward.
- Meeting agency needs.
- Identifying issues that cut-across the different transportation management program areas.

Specifically, the intended use of this document varies by the type of audience that will use it. Three groups fall under the primary intended audience first identified in Section 1.2.2:

- Agency decision-makers.
- TMC or traffic managers.
- First line supervisors and technical staff.

Ways each group can effectively use this handbook are described below.

Agency Decision Makers

At a minimum, agency decision makers should review Chapters 1 and 2 to obtain a high-level view of ramp management, including the strategies used to address issues and the considerations to think about when implementing strategies. These chapters will give agency decision makers the most comprehensive understanding of ramp management strategies and issues, without having to invest the time needed to read the entire handbook. The remaining chapters of the handbook can be referenced on an as-needed basis to obtain more detailed information.

TMC or Traffic Managers

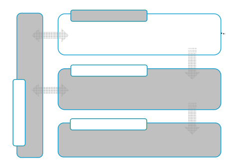
It is recommended that TMC or traffic managers read and understand this entire handbook. Initial focus should be on the first four chapters. As ramp management projects move into the project development stages, Chapters 5 through 8 should be reviewed. Chapter 9 is important to review in on-going situations; especially as new elements are implemented and new capabilities to collect performance measures are developed. Chapter 10 should be reviewed at the beginning of any new capital improvement project that affects ramp management. Chapter 11 should be reviewed when the manager wants to gain deeper understanding of how others have implemented ramp management.

First Line Supervisors and Technical Staff

First line supervisors and technical staff have different roles and responsibilities and are therefore likely to benefit differently from the information and concepts expressed in this handbook. Regardless of their roles and responsibilities, all first line supervisors and technical staff should review Chapters 1, 2 and 5 to gain a basic understanding of ramp management and ramp management strategies. In addition to these three chapters, operations staff should review Chapters 7 and 8 to understand on-going implementation, operation and maintenance issues. Traffic analysts and engineers on the other hand should focus on Chapter 9 to gain understanding of the role and methods of performance monitoring. Designers and design support staff should review Chapter 10 at the beginning of each capital improvements project that involves ramp management.

2

RAMP MANAGEMENT AND CONTROL: OVERVIEW



Getting Started

2.1 Chapter Overview

This chapter provides an overview of ramp management and control issues and activities that are examined within the remaining chapters of this handbook.

The topic of ramp management and control is introduced and the key points that practitioners need to understand and consider in successfully developing, selecting, implementing, and maintaining ramp management and control techniques and strategies are discussed. This chapter provides an overview of ramp management and control and a high-level understanding of the entire handbook. Thus, this chapter can be used by practitioners to navigate to the sections within it to obtain additional information.

A ramp management and control element of an agency's traffic management program offers several techniques and strategies to manage traffic on freeway ramps. The intended use and application of these techniques and strategies vary depending on the goals and objectives of an agency's traffic management program as well as the conditions in the field. Ramp management techniques and strategies can improve safety and mobility while reducing the environmental effects associated with traffic congestion and delay.

Chapter Organization

The key issues of this chapter deal with developing a high-level understanding of ramp management and how ramp management may fit with other traffic management efforts. This chapter also covers how to take advantage of opportunities throughout the life cycle of the freeway facility and explore ways to improve freeway and ramp performance and safety. The chapter follows the logical progression of implementing a ramp management and control program and introduces ramp management and control concepts in the same order that they are presented in the remaining chapters of this handbook.

Initiating ramp management and control techniques and strategies requires close analysis of agency program goals and objectives to determine if and how a ramp management strategy may fit into an agency's traffic management program (Chapters 3 and 4). The relationship of ramp management to other elements of the traffic management program must be closely analyzed to determine if a given ramp management strategy will support other traffic management elements. Only after the analysis of an agency's traffic management program shows that ramp management fits and is supportive of agency goals and objectives should agencies begin to make decisions about how to develop, select and implement ramp management techniques and strategies (Chapters 5, 6, and 7). After implementing a ramp management strategy or set of strategies, agencies must take steps to successfully operate and maintain (Chapter 8) and measure the performance (Chapter 9) of the selected strategy(ies). Once the strategies are selected, the physical elements of the strategy are normally deployed through capital or operational improvement projects. Planning for and designing those elements are discussed in Chapter 10.

Chapter 2 Objectives:

Objective 1:	Develop a high-level understanding of what ramp management is and how it can benefit agencies.
Objective 2:	Understand how ramp management fits within a larger traffic management program and how to prepare for successful ramp management operations.
Objective 3:	Become familiar with the each step of the ramp management life cycle, from developing strategies to operations and maintenance.
Objective 4:	Identify typical transportation improvements and how ramp management strategies can be considered within these improvements.

2.2 Introduction to Ramp Management and Control

As previously discussed in Chapter 1, attempts to manage ramp-based traffic were first conducted over a half-century ago in metropolitan areas such as Chicago, Los Angeles, and Detroit. These attempts, although slightly different than those deployed today, were successful and bred additional attempts to manage traffic entering freeways from ramps. Over the last four decades, strategies such as ramp metering and ramp closure have flourished as effective traffic management strategies and have continued to evolve to meet the additional demands of the public and the constraints inherent to public agency budgets.

If performed effectively, ramp management and control strategies can significantly improve the operation of not only ramps but also the facilities they connect (i.e., freeways and arterials). This conclusion is based in part on the fact that ramps are the only facilities that motorists may use to legally make connections between these facilities and, as such, represent the only locations where traffic entering and exiting these facilities can be controlled. As conditions on ramps, freeways, and arterials continue to worsen due to an increasing gap between roadway capacity and traffic demand, ramp management strategies can be employed as a cost-effective approach to manage traffic that use these facilities.

2.2.1 What is Ramp Management?

As stated in Chapter 1, ramp management can be defined as "the application of control devices such as traffic signals, signing, and gates to regulate the number of vehicles entering or leaving the freeway, in order to achieve operational objectives".[1] Those objectives usually are stated similarly to the following:

- Balance freeway demand and capacity.
- Maintain optimum freeway operation by reducing incidents that produce traffic delays.
- Improve safety.

Ramp management is one of several freeway management elements. Ramp management should seek to satisfy freeway management goals and objectives in a similar way that freeway management works to satisfy surface transportation goals and objectives.

2.2.2 Ramp Management and Control Benefits

Before and after evaluations of ramp management strategies offer strong evidence that ramps, freeways, and even adjacent arterials operate better once these strategies are implemented. Typical benefits of ramp management strategies are briefly outlined in the following sections.

Safety

According to evaluations from across the country, ramp metering reduces collisions on freeways and ramps from 15 to 50 percent.[1,2] Ramp metering reduces stop-and-go driving behavior, resulting in fewer rear-end collisions. It also breaks up platoons entering the freeway, resulting in fewer side-swipe and merge-related collisions.

Mobility and Productivity

Ramp management strategies often increase travel speeds while reducing travel time and delay. Freeways that have metered entrance ramps usually carry more traffic than they did before metering began, while attaining the improvements mentioned previously. A ramp metering study in Minneapolis showed a 25-percent increase in peak period traffic volumes while increasing average speeds by 5 km/h (3 mi/h).[1,2]

Environmental Effects

The improved speeds, reduced stop-and-go traffic, and reduced delays that result from ramp management strategies also result in reduced emissions and fuel consumption.

Traveler Perception and Satisfaction

Ramp management and improved operations on freeways demonstrate to the public that agencies responsible for transportation facilities are doing something about congestion and safety problems. As a result, travelers and the public in general will be more satisfied with transportation agencies and the job they are doing. Higher public satisfaction makes it easier for agencies to acquire the needed resources to develop, implement, operate and maintain transportation improvements.

2.3 Ramp Management and the Traffic Management Program

At the most basic level, ramp management efforts must support the vision and mission of the agency. Ramp management should be considered as an element of the overall traffic management program versus a program that operates parallel to or separate from it. Ramp management strategies need to be considered as a means of meeting the goals and objectives articulated in the agency strategic planning process.

Ramp management strategies require funding to be implemented, operated and maintained, and therefore must compete for funding with other agency actions. Transportation decision-making follows a tiered government structure starting at the national level, filtering through state and regional levels, and culminating at the agency level. The authority for transportation decision-making spans all these tiers and may also involve several agencies within the same level. Decisions to fund ramp management are primarily at the state, regional, and agency levels, however the overall funding levels and policy direction at the national level affects these decisions.

In order to successfully compete for funding, ramp management strategies not only need to support the goals and objectives of the agency and region, but must also be included in agency and regional long-range transportation plans and shorter-term business plans. The manager responsible for ramp management needs to understand the transportation and business planning processes in his or her agency and region in order to provide input into these processes. In turn, the manager develops specific actions to reflect the decisions made in these processes.

The plans are implemented through annual or multi-year program plans. The program plan lays out the specific projects that will receive funding as incremental steps toward meeting the long-range transportation plan.

It is vital that agency staff understand how the program plans are developed so that they can provide input into their development and advocate for projects of interest, such as ramp management projects. The Traffic Manager or the manager responsible for ramp management activities must understand that there are different funding mechanisms. Knowledge of the funding structure is what allows agency staff to determine how their program can be funded.

Ramp management strategies need to address, and usually conform to, existing regulations and policies. At the same time, regulations and policies should be reviewed to make sure ramp management activities are consistent and to determine if any updates or amendments in regulations and policies are needed. The key is for the manager responsible for ramp management to ensure that there is an appropriate support structure for accepted ramp management activities.

In addition to regulatory and policy support, organizational support is needed in order for ramp management activities to be successful. Agency management should be updated and their support is needed in order for ramp management to be successfully implemented. Once agency management supports the concept, the organizational structure should be assessed to make sure the structure will support ramp management activities. There is no single structure that is better than another and reorganization is rarely required. It is more a matter of determining where in the existing structure ramp management activities best fit.

2.4 Preparing for Successful Operations

There are several institutional and operational considerations that are vital to the success of ramp management. These include:

- Coordination.
- Staffing.
- Resources to support successful operations.

2.4.1 Coordination

Coordination includes internal (intra-agency) and external (inter-agency) activities. Inter-agency coordination covers a broad set of agencies and stakeholders. The key is to break down barriers between agencies and institutionalize working together as a way of doing business among transportation agencies, public safety officials, and other public and private sector interests within a metropolitan region. The agencies and disciplines that are critical to ramp management include:

- Enforcement agencies.
- Local traffic engineering or public works departments.
- Transit agencies.
- Metropolitan Planning Organizations and congestion management agencies.
- Media organizations.

Internally, ramp management needs to be coordinated with the broader traffic management program. As mentioned throughout this handbook, ramp management is one element of the traffic management program and needs to further the goals and objectives of that program. However, internal coordination goes beyond the traffic management program. Personnel responsible for ramp management activities must also coordinate with the following set of internal staff:

- Planning staff, to make sure ramp management needs are incorporated into the agency plans.
- Design staff, to make sure that ramp management needs are incorporated in project designs.
- Maintenance staff responsible for maintaining ramp management equipment.
- Public information staff who are responsible for informing the public of activities related to ramp management.
- Senior management, so they are aware of any issues arising from ramp management activities.

2.4.2 Staffing

Successful ramp management requires skilled, well-trained staff in sufficient numbers to operate and maintain the strategies at effective levels. Staff who operate and maintain ramp management strategies should have knowledge, skills, and abilities (KSAs) similar to staff who operate and maintain other traffic management elements. The needed KSAs will differ based on the functions that staff are intended to perform – planning/design, operations, or maintenance. Chapter 4 provides specific KSAs needed for each of these functions.

Staff assigned to ramp management must be properly trained in the knowledge areas identified above. Training is available from in-house sources, national transportation organizations (e.g., the National Highway Institute), and educational institutions.

The appropriate staffing level will depend on a number of factors including the size of the system, the system complexity, the hours of operation and the specific ramp management strategies chosen. For example, ramp metering will usually require more operations staff in a traffic management center, whereas time-of-day ramp closure will take more field staff.

2.4.3 Resources to Support Successful Operations

Operations staff should be provided with the tools and resources they need to effectively and efficiently carry out their job duties. These tools and resources include:

- Operating procedures.
- Operations, training, and maintenance manuals.
- Operations and maintenance tools.

Operating Procedures

Developing and following standard operating procedures is critical to the success of ramp management activities. Procedures are needed to provide staff with the information needed to do their job – which includes both technical and human resources or personnel procedures. Procedures should be developed for operating, monitoring, and maintaining all ramp management strategies employed. Ramp metering, because metering rates and traffic conditions can change frequently throughout a single peak period, requires the largest set of procedures dealing with operations. Some of the topics to be considered for standard operating procedures include:

- Basic ramp meter operations.
- Ramp meter timing and adjustment.
- When to adjust ramp meter timing based on performance and need.
- How to monitor ramps and their effect on both mainline and arterial traffic flow.
- Performance measures.

For ramp closures, step-by-step procedures are needed to assure that a ramp is closed properly and safety is taken into consideration. These procedures include how to operate any electronic and mechanical equipment that is used for closure, and where and how to place any barriers and signs that are needed for the closure.

Maintenance procedures are needed for maintaining field equipment, such as ramp meters and detectors. Maintenance procedures cover preventive and response maintenance actions and diagnostics.

Operations, Training, and Maintenance Manuals

Training information can either be incorporated into the Standard Operating Procedures (SOP) or reside in a stand-alone document. For ramp management, training manuals should include the information noted above as being part of the SOP as well as detail on the theory behind the strategy, under what conditions the strategy is effective, how to operate the strategy, and how to track performance.

For maintenance personnel, their training manual should include the above information as well as equipment manuals, installation and maintenance instructions, maintenance schedules, and troubleshooting guides.

Operations and Maintenance Tools

Practitioners responsible for ramp management must provide their staff with the tools needed to effectively operate, maintain and troubleshoot ramp management strategies. These tools include software to help staff do their jobs more efficiently or effectively and diagnostic equipment for maintenance personnel so they can more quickly determine the cause of failures to equipment.

2.5 Ramp Management Strategies

As briefly discussed throughout the earlier sections of this handbook, there are four commonly accepted and proven strategies to manage traffic on freeway ramps:

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

These strategies are not all mutually exclusive and may be combined to maximize their potential advantages. For example, high-occupancy vehicle (HOV) ramps or bypass lanes, a special use treatment strategy, are often implemented with ramp metering. Ramp terminal treatments are often combined with any one or combination of the other three. However, the unique advantages and disadvantages of each ramp management strategy differ, thereby requiring practitioners to closely analyze each to determine their appropriateness for satisfying existing problems and conditions. The four ramp management strategies that comprise much of the discussion contained in this handbook are introduced and briefly described in the following sections. Chapter 5 of this handbook closely examines each strategy and their related techniques, and provides practitioners with the knowledge needed to narrow the list of appropriate strategies to those that best address existing conditions and problems. The comprehensive analysis of strategies provided in Chapter 5 will also prove useful to practitioners seeking to implement, operate and maintain selected strategies.

2.5.1 Ramp Closure

Ramp closure has the greatest potential impact on existing traffic patterns and is rarely implemented as a long-term strategy. The potential for significant impact is especially true for full or permanent ramp closures, where access to the ramp is no longer provided, requiring traffic to seek alternative routes to access the freeway. In many cases, full ramp closure involves the physical removal of the ramp roadway so as not to give the false impression that the ramp will be re-opened. Other types of ramp closures that affect traffic to a lesser degree include temporary and scheduled closures. These types of closures usually involve deploying automatic gates or manually placing barriers at the ramp entrance to prevent access to the ramp. Due to the relatively high impact on existing traffic patterns, ramp closures are seldom considered for deployment if other viable options are available. Full ramp closure is best applied as a last resort for severe safety problems. Temporary or scheduled closures may be applicable for reducing potential vehicle conflicts that may result from construction, major incidents, emergencies, or special events.

"Ramp metering is the use of a traffic signal(s) deployed on a ramp to control the rate by which vehicles enter a freeway facility."

2.5.2 Ramp Metering

Ramp metering has been deployed and used successfully for roughly a half century in several metropolitan areas. Ramp metering is the use of a traffic signal(s) deployed on a ramp to control the rate at which vehicles enter a freeway facility. By controlling the rate at which vehicles are allowed to enter a freeway, the flow of traffic onto the freeway facility becomes more consistent, smoothing the flow of traffic on the mainline and allowing more efficient use of existing freeway capacity. Although controversial at times, if deployed correctly, ramp metering can be an effective tool to address congestion and safety concerns that occur at a specific point or along a stretch of freeway.

Ramp metering offers the potential to reduce congestion and its direct effects through the optimal use of freeway capacity. Metering can significantly improve freeway safety by reducing stop-and-go driving behavior and smoothing the flow of traffic entering freeway facilities. Ramp metering can also improve overall system performance by increasing average freeway throughput and travel speed, thereby decreasing travel delay. Finally, ramp metering can lead to a reduction in fuel consumption and vehicle emissions. Specific benefits documented in past literature are described in Chapter 5.

There are several aspects associated with ramp meter operation that practitioners should be aware of prior to deciding whether to implement ramp metering. These aspects affect how a ramp meter or the system of ramp meters control traffic, based on agency goals and objectives and local conditions. Aspects of ramp metering that need to be considered are listed below. Each aspect is described in greater detail in Chapter 5.

- Metering strategy.
- Geographic extent.
- Metering approaches.
- Metering algorithms.
- Queue management.
- Flow control.
- Signing.

2.5.3 Special Use Treatments

Special use treatments for ramp management give "special" consideration to a vehicle class or classes to improve safety, improve traffic conditions, and/or encourage specific types of driving behavior. Treatments include HOV bypass lanes, exclusive HOV ramps, and ramps dedicated for the sole use of construction, delivery, or emergency vehicles. Special use treatments require that the necessary policies (e.g., HOV, special events) be in place before strategies are implemented and funding requirements can be met.

2.5.4 Ramp Terminal Treatments

Ramp terminal treatments are solutions to specific problems that occur at the ramp/arterial intersection or have the potential to affect operations on the ramp, adjacent arterial, or freeway. Typically, ramp terminal treatments focus on managing queues that form on the ramp that spill back onto an adjacent arterial or the freeway facility. Ramp terminal strategies implemented at entrance ramps will provide better flow of arterial traffic not destined for the freeway and will improve the flow and handling of traffic on the ramp. Ramp terminal treatments implemented at exit ramps may reduce queue spillback from the ramp terminal signal, reducing the potential for collisions on the freeway at the back of the queue.

There are at least four different strategies that can be implemented at ramp terminals that can improve traffic conditions (e.g., traffic flow and safety) on or near ramp facilities:

- Adjustments to signal timing and phasing.
- Ramp widening.
- Additional or changes to turning movements and storage lanes.
- Additional or improvements to signing and pavement markings.

These ramp terminal treatments are described in detail in Chapter 5.

2.6 Developing and Selecting Ramp Management Strategies

Due to the abundance of ramp management strategies, the process of selecting and developing a strategy that best addresses an existing problem or situation can be difficult. It is often helpful to narrow the list of available strategies before selecting the preferred strategy. As part of this process, the impacts of each available strategy should be analyzed more closely to ensure that strategies do not result in new problems or shift existing problems from one location to another. Additionally, the indicators (current conditions or problems that are present that may be corrected through ramp management) for ramp management strategies should be analyzed and the strategies that best satisfy observed indicators should be selected.

The process of selecting ramp management strategies should begin by revisiting transportation management program goals and objectives. Further clarification and understanding of program goals and objectives will help practitioners identify the ramp management strategies that best fit within an agency's transportation management program.

Just because a ramp management strategy is deemed feasible does not necessarily make it the most appropriate strategy based on situations and problems observed in the field. Ramp management strategies may also unintentionally shift problems from one location to another, reducing the overall benefits. Impacts that have the potential to affect the selection of an appropriate ramp management strategy are listed below and discussed in greater detail in Chapter 6:

- Traffic diversion.
- Equity issues.
- Vehicle emissions.
- Arterial impacts.
- Public perception.
- Shifts in land values.
- Ramp geometry and spacing.

Practitioners who consider implementing ramp management strategies should analyze traffic operations on ramps, the freeway mainline and adjacent arterials. There are several indicators that may be used to justify implementing a strategy. Indicators that may warrant ramp management strategies are listed below:

- Safety.
- Congestion.
- Convenience.
- Access.
- Ramp capacity and queues.
- Adjacent facility operations.

Besides taking into account the impacts of strategies and the indicators that may warrant ramp management strategies, agencies must also consider the fact that, although ramp management strategies may provide additional benefits, existing conditions on the freeway, ramp or arterial may be satisfactory and ramp management may not be necessary. Additionally, agencies considering ramp management strategies may not have the policies in place to support their implementation. However, if it appears that operations on the ramp or nearby freeway or arterial facilities are not satisfactory, and policies are in place, ramp management strategies may be needed and applicable. In this case, the selection of the strategies deemed acceptable needs to be more thoroughly analyzed in order to determine the strategies or set of strategies that are most beneficial for existing conditions. The recommended processes for selecting specific ramp management strategies are provided in Chapter 6.

2.7 Implementation Issues

Ramp management strategy implementation is a delicate process that begins well before strategies are physically deployed, and concludes only when deployed strategies have been successfully tested and initially operated. Before ramp management strategy implementation is seriously considered and systems or equipment are purchased, practitioners must coordinate internally with upper management to determine the feasibility of and support for ramp management strategy implementation. This includes close examination of the minimum requirements to successfully deploy and operate ramp management strategies, such as staffing levels and needs, hardware and software needs, budgetary constraints and resources, and policy directives.

Assuming that the necessary requirements for successful ramp management strategy implementation can be secured and that upper management support has been obtained, practitioners must actively market the benefits of ramp management strategies. As part of this effort, practitioners must solicit and report information to the public and to the various agencies directly and indirectly affected by implementation. In doing so, practitioners must develop methods and tools to successfully collect and distribute information to these groups. Agencies that may be directly affected by the implementation of ramp management strategies include both municipal and county traffic departments, state and local law enforcement, emergency services, and local transit. Coordination with the media as well as neighborhood and community groups is needed to encourage their support so they act as advocates for the implementation of ramp management strategies.

2.8 Operations and Maintenance Issues

Upon implementation, ramp management strategies must be actively operated and maintained to maximize benefits, and to reduce the negative impacts that result from malfunctioning or broken equipment. Failure to operate and maintain systems and equipment in an effective manner will result in inefficiencies that in turn result in decreased performance and safety. Operations and maintenance personnel need to be trained to effectively operate and maintain the ramp management strategies that are implemented. Operators need to be aware of all the internal and external dependencies that may either positively or negatively affect ramp, freeway, and adjacent arterial operations. Operators also need to understand that their actions directly influence the success of ramp management strategies, and as such they must remain cognizant of the policies and procedures that dictate how ramp management strategies are to be operated and maintained.

2.8.1 Operations

Ramp management is one of many elements of a freeway management program. Ramp management operations should not conflict with, but should rather support the overall performance of the transportation management program. All staff responsible for the operation of ramp management strategies should be familiar with established transportation management and ramp management policies and procedures and should be able to reference the operational policies and procedures resources when needed. Operational policies and procedures with respect to the four ramp management strategies outlined in this handbook are provided in Chapter 8.

2.8.2 Maintenance

Regular and timely maintenance of systems helps to extend their useful life spans.

Systems, software, and other devices that support ramp management strategies must be routinely maintained to ensure adequate performance and operational stability. This involves replacing defective parts, cleaning components, updating software, logging repairs, and testing equipment. When systems or devices fail, staff must be available to fix problems in a timely manner to reduce the impact on and exposure to the public. Any delay in fixing problems will result in greater public skepticism of the effectiveness of ramp management strategies. In short, timely maintenance of ramp management strategies ensures the effectiveness of those strategies and furthers the basic goals and objectives of those strategies, such as improving safety and reducing congestion, vehicle emissions, and fuel consumption.

Systems that are maintained according to vendor requirements will last longer than those that are minimally maintained or not maintained at all. Regularly scheduled maintenance activities will allow agencies to use systems up to (or perhaps even beyond) their designed life cycle and obtain maximum benefits from their investments. However, even the best maintained systems will have unexpected component failures. When failures occur, systems need to be repaired as soon as possible. In emergency situations, systems should be repaired immediately so operations can be restored. Therefore, agencies must also define responsive and emergency maintenance procedures, so operations of failed equipment can be restored in a timely manner.

2.9 Performance Monitoring, Evaluation, and Reporting

The goal of performance monitoring is to determine if selected strategies are achieving their intended objectives. Chapter 9 provides a detailed structure for practitioners to carry out the tasks needed to monitor, evaluate, and report performance of ramp operations and ramp management strategies.

More specifically, there are three key components to this process. First, performance monitoring involves collecting performance statistics using manual or automated means. The data collected are used to evaluate or assess the measures of effectiveness (MOEs) of the ramp management strategies. Second, the evaluation presents the data analysis and provides feedback on system performance. Third, reporting is the documentation of the evaluation in a format that is suitable for agency personnel and management, decision makers, or the public.

Determining the type of analysis is the first step of an evaluation. This is dependent upon the objectives of the evaluation and the type of feedback that is desired. Some of the different types of analyses include pre-deployment studies, system impact studies, benefit/cost analysis, and ongoing system monitoring and analysis. A critical element of the analysis is the definition of an appropriate study area, of which there are three broad categories: localized, corridor, or region-wide. Each has a particular application that can be based on the selected performance measures, proposed analysis tools, and available evaluation resources.

Performance measures are the foundation for identifying the severity and location of problems and for evaluating the selected strategy's effectiveness. Selection of good performance measures includes consideration of goals and objectives, data needs, decision-making processes, and stakeholder involvement. Though there are many categories of performance measures, those that are common deal with safety, mobility, travel time reliability, environmental effects, throughput, and public acceptance.

In addition, for the data collection effort, performance measures must be limited in number, easy to measure, simple, understandable, and geographically appropriate. A variety of data collection methods and tools are discussed in detail in Section 9.3.

After determining the type of analysis, the evaluation has six steps: 1) form the evaluation team, 2) develop the evaluation strategy, 3) develop the evaluation plan, 4) develop detailed test plans, 5) collect and analyze data and 6) document the results. Most evaluation efforts are conducted with a variety of analysis techniques. These can either be analysis tools or models to enhance field measurement or to be used in place of field measurement when data is unavailable. Traffic analysis tools can be grouped according to the following categories: sketch-planning tools; travel demand models; analytical/deterministic tools (*Highway Capacity Manual*-based); traffic signal optimization tools; and macroscopic, mesoscopic, and microscopic simulation models.

Reporting is the link between performance monitoring and strategy refinement. It is also instrumental in showing the benefits of ramp management and building support for ramp management activities. Formats vary based on the needs of the evaluation and the audience.

2.10 Planning and Design Considerations

There are a variety of considerations for the planning and design of the systems and field elements within any capital improvement project that supports a ramp management strategy. Planning and design considerations are discussed in detail in Chapter 10 of this handbook. Every project must be reviewed to ensure that it is consistent with the operational objectives and that all pieces of the project are consistent with one another.

2.10.1 Planning Considerations

To be effective, ramp management strategies often need to take into consideration aspects of ramp management strategy implementation that indirectly affect overall outcomes. For instance, ramp management implementation and operation may be perfect, but if ramp management strategies are not enforced, the overall objectives of strategies may not be achieved. Similarly, if issues affecting equity are ignored, strategies may viewed unfavorably by certain groups of individuals, ultimately limiting the positive impacts that strategies offer. Last but not least, maintenance of strategies must be taken into consideration during the planning process to ensure that strategies can be actively maintained and that malfunctioning equipment does not confuse motorists. Issues related to maintenance, enforcement and equity are discussed further in the following paragraphs.

Enforcement is one key to effective ramp management and control. This is especially true for ramp metering because compliance is critical to its operational success. Therefore, enforcement issues associated with ramp management strategies must be taken into consideration during the planning process so appropriate actions are taken to ensure that ramp management strategies are enforceable. This includes a coordinated effort with law enforcement to ensure that issues such as an appropriate enforcement strategy, safe enforcement areas, adequate staff, and support by the courts are addressed.

Similar to enforcement, equity and environmental justice issues are also a key consideration for ramp management projects. The direct involvement of diverse cultural and economic communities in the development of transportation projects will help to ensure that projects fit harmoniously within their communities without sacrificing safety and mobility.

Performance measurement should be examined in the planning stages of the project. Various types of equipment can be installed to conduct performance monitoring and streamline the data collection process.

Planning is also required for maintenance, especially if new systems are implemented. Therefore, it is important to include the maintenance staff in the planning stages of a project, as they will have recommendations on the types and manufacturers of equipment to procure, equipment location, and other issues that are an integral part of their jobs.

2.10.2 Design Considerations

The *American Association of State Highway and Transportation Officials* (AASHTO) *Design Guidebook* and the *Manual on Uniform Traffic Control Devices* (MUTCD) provide design guidelines for freeway facilities. Some agencies also have their own design guides. Sections 10.6 through 10.9 address the design considerations for ramp closures, special-use ramps, ramp terminal treatments, and ramp metering. The types of equipment, signing, and pavement markings needed are outlined for each.

With many ramp control strategies, ITS elements are typically required. Section 10.8 offers guidance in following a systems engineering approach, whereby the agency can guide their ITS procurement through a step-by-step process from the Concept of Operations and detailed requirements and design to implementation and system acceptance.

2.11 Ramp Management and Other Transportation Improvements

As mentioned earlier in this chapter, ramp management strategies represent one approach to meeting an agency's or region's transportation goals and objectives. However, ramp management strategies should not be viewed in isolation and are often most effective when implemented in conjunction with other transportation improvements. When planning or implementing these other improvements, consideration should be given to ramp management. This section describes some of the possible transportation improvements that are often considered and how they relate to ramp management.

2.11.1 Corridor Planning and Investment

At the heart of any transportation system or program is the efficient operation of the existing or planned facilities. Corridor studies and plans generally look at over-arching needs to improve mobility and increase the people-moving capacity in a transportation corridor. Ramp management activities enhance the efficiency of freeway facilities and could reduce the needs for more costly capital improvements. Ramp management should be considered in corridor investment decisions. The definition of the ramp management component of alternative investment strategies should support the overall character of the investment strategy itself and the transportation goals and objectives of the agencies involved.

Usually, ramp management is not a competing strategy to alternative investments, but is considered as a supporting element of many, if not all, corridor investment strategies. Ramp management strategies can be linked with roadway improvements to improve overall operation for the funding available. Alternative ramp management approaches can be considered, but there is often insufficient detail in the analysis techniques at the corridor level to select from among alternative ramp management strategies. At this level, selection of ramp management approaches to be carried forward is often a matter of policy.

2.11.2 New Highways

The construction of new highways provides additional freeway capacity and travel routes for motorists. It is relatively rare that new highways are constructed in totally new corridors. It is more rare that new highways in urban areas operate in an uncongested state very long after opening. Ramp management, along with the full spectrum of traffic management tools, should be considered in the planning and design of new highways in urban and suburban areas. Geometric decisions, such as ramp spacing and the design of ramp tapers and merge areas, should be made considering ramp management concepts. Accommodations for electrical and communication components of ramp management should be made in the design and construction of new facilities.

2.11.3 Additional Lanes

The addition of more freeway lanes is one of the most basic ways to increase roadway capacity. Ramp management should be analyzed when considering the addition of new lanes, both as a complementary improvement and as an alternative to adding new lanes. As in new construction, consideration should be given to ramp management concepts, including ramp geometrics, ramp spacing, and accommodation of electronic and communication components of ramp management.

2.11.4 Geometric Improvements

There are a variety of other geometric improvements that can be made to a freeway facility. Eliminating geometric deficiencies such as narrow shoulders, narrow lane widths, or substandard acceleration and deceleration lanes are just a few examples of improvements that can complement ramp management strategies. In particular, it is important to consider the merge distance and queuing storage area requirements if ramp metering is a current strategy employed or a likely strategy to be implemented in the future.

2.11.5 Reconstruction and Traffic Management

Ramp metering can sometimes be a “hard sell” to the locals. As an alternative, ramp metering could initially be installed as a temporary solution during a reconstruction project to provide better traffic flow through the work zone. If deemed successful, it can be used afterwards as a permanent installation. Other ramp management strategies, such as ramp closure and special use treatments, can also be effective during construction to improve merge areas in and upstream of work zones.

2.11.6 Incident Detection and Verification

Detecting, verifying, and clearing incidents quickly and effectively reduces resultant congestion and delay and helps to restore roadway capacity in a timely fashion. Ramp management, both metering and closure, can help limit the demand through incident scenes, making it easier for emergency response vehicles to arrive at the incident. Limiting traffic demand through incident scenes also helps to restore free-flow conditions as quickly as possible.

2.11.7 Traveler Information Systems

Traveler information systems assist motorists in making informed decisions about their trips. There are a variety of pre-trip and en-route traveler information sources available – all of which require accurate data to be of value. Ramp management systems also need accurate data to operate properly. Data collected for ramp management purposes can also be used by traveler information systems. For example, most ramp metering algorithms require real-time data on freeway mainline traffic conditions. This information is also of interest to motorists. Further, ramp conditions may be an important element of the traveler information system. Motorists could be alerted to congested areas, queues and incident locations from the data that is collected for the ramp metering system.

2.11.8 Corridor Traffic Management

The greatest concentration of congestion occurs along the principal routes in major metropolitan areas.[9] These routes are often "critical corridors" that link activity centers (e.g., business centers, sports arenas, and shopping areas) with residential areas and carry the highest volumes of people and goods. Ramp management strategies can be coordinated with other corridor traffic management activities to reduce impacts and improve overall mainline traffic flow. For instance, metering may help corridor traffic flow by smoothing the flow of vehicles entering the mainline, but also by encouraging a portion of traffic to use adjacent routes that parallel the mainline. Unused corridor capacity often exists on parallel routes, especially in the non-peak direction on freeways and arterials.

2.11.9 Operational Improvements

Ramp management strategies can improve operations on freeways and arterials and the ramps that connect them. When implementing these strategies, however, special consideration should be taken to ensure that existing signing, pavement markings, and lighting are adequate for the changes in traffic patterns these strategies may cause. For instance, lighting in and around metered ramps should be reviewed to determine if it is sufficient for the queues that may develop. Similarly, geometric improvements to the ramp may need to be implemented if a nearby ramp is closed and the percentage of trucks that use the ramp greatly increases.

2.11.10 High-Occupancy Vehicle Facilities

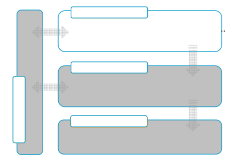
Providing incentives (e.g., less delay) for high-occupancy vehicles (HOVs) can reduce demand by converting single-occupant vehicle trips to HOV trips. Ramp management strategies can support policies to encourage HOV trips. HOV bypass lanes or HOV-only ramps allow motorists to avoid queues formed at metered locations. HOV ramp management treatments are especially important around park-and-ride facilities to provide unencumbered freeway access for buses, vanpools, or carpools originating at the park-and-ride facility.

2.11.11 Special Event Management

A special event is "a public attended activity or series of activities, with a scheduled time and location that may increase or disrupt the normal flow of traffic on affected streets or highways."[1] A special event represents a trip generator; thus the impact an event has on transportation system operations as a whole must be examined. This includes operations on freeways, arterials and ramps. Ramp management can improve operations on these facilities when special events occur, helping to minimize the impacts that special event traffic has on neighborhoods and non-special event-related traffic near the special event. Ramp management may be applied to reduce the length of queues on ramps, allowing queues to be fully contained to the ramp instead of flowing back onto the freeway and adjacent arterial. This not only improves safety on these facilities, but also improves the flow of traffic that use them. Ramp management may also be used to minimize the impacts on neighborhoods near the special event by restricting assess to ramps in the areas, requiring special event traffic to use upstream and downstream ramps, where traffic will have less of an impact.

3

RAMP MANAGEMENT AND THE TRAFFIC MANAGEMENT PROGRAM



Getting Started

Chapter 1: Introduction

Chapter 2: Ramp Management and Control Overview

Chapter 3: Ramp Management and the Traffic Management Program

Chapter 4: Preparing for Successful Operations

3.1 Chapter Overview

Ramp management should not be viewed as a program separate from an agency's traffic or freeway management program. In reality, ramp management strategies should be derived directly from a traffic or freeway management program and, as such, should be consistent with overall agency and regional policies, goals, objectives and strategies. Typically, a ramp management strategy represents just one of several elements that work together to comprise a traffic management program, which in turn supports the larger goals and objectives of an agency. Therefore, the ramp management and control techniques and strategies should support a traffic management program. Techniques and strategies that are not supportive should not be considered for implementation.

The overview of ramp management and control concepts and strategies presented in Chapter 2 provides the foundation needed to understand how or if ramp management fits into an agency's traffic management program. Based on this understanding, practitioners may elect to follow the recommended process for selecting, developing, implementing, and maintaining ramp management techniques and strategies outlined in this handbook.

Chapter Organization

This chapter, together with Chapter 4, describes how ramp management fits into an agency's overall program and structure, including the traffic management program, from the perspective of the individual(s) that will be implementing and operating ramp management strategies (e.g., Traffic Supervisors and Managers). Chapter 4 focuses on the issues and activities that are necessary to support ramp management and control, and that the manager can control. This chapter, on the other hand, focuses on how ramp management fits in with the broader agency program and the issues and activities that are necessary to support ramp management and control that the manager can influence, but not control. In other words, this chapter focuses on the issues and policies that relate to the manager's supervisor, upper management, and other regional officials, who are responsible for setting policies and procedures for agency and regional programs, including the traffic management program. The topics discussed in this chapter will likely affect the selection of ramp management techniques and strategies, and therefore elements described in this handbook need to tie back to this chapter to determine if elements of a ramp management strategy support broader agency and other traffic management goals and objectives.

Chapter 3 begins with a discussion of the activities that comprise traffic management program development, an element of which will be ramp management. Subsequent issues covered in this chapter include:

- Strategic and business planning.
- Regional and departmental transportation planning.
- The multi-year transportation program plan.
- Differences in the roles and responsibilities between ramp management and the overall traffic management program.
- Organizational support needed to effectively support ramp management activities.

Chapter 3 Objectives:

Objective 1:	Understand how ramp management can fit into an agency's overall program, including the traffic management program – from the perspective of the Traffic Manager.
Objective 2:	Understand the issues, activities and policies that are needed to support ramp management and control.
Objective 3:	Understand the activities that comprise traffic management program development.
Objective 4:	Understand how various organizational structures can support ramp management.

3.2 Traffic Management Program Development

A 'program' is a coordinated, inter-related set of strategies, procedures and activities (such as projects), all intended to meet the goals and objectives articulated in vision statements and policies.[1] At the most basic level, ramp management efforts must support the vision and mission of the agency. Ramp management should be considered as an element of the overall traffic management program, not as something that operates in parallel to or separate from it. The strategies developed for ramp management need to be considered as ways to meet the goals and objectives articulated in the agency strategic planning process.

Figure 3-1 shows the activities that should be conducted when developing or enhancing a traffic management program, of which ramp management is a part. This funnel diagram depicts the traffic management program within the context of the broader transportation planning process and the institutional environment as represented by the stakeholders. The process begins with the development of the vision, policies and goals and definition of required services. This is followed by the development of the Concept of Operations and establishment of performance measures. From this stems decisions regarding improvements, management systems, and staffing requirements. These actions lead to results and performance measurement, which ultimately comes full circle and flows back to the top of the funnel – which influences the policies, goals, and objectives and starts the process all over again. These activities are discussed in detail in Sections 3.2.1 through 3.2.9 of the Federal Highway Administration (FHWA)'s *Freeway Management and Operations Handbook.*

3.2.1 Roles and Responsibilities

As mentioned previously, ramp management does not operate as a separate entity. When developing ramp management activities, one should look at how ramp management fits in with overall agency goals and objectives. Effective ramp management is an on-going process.

The Traffic Manager needs to:

- Make sure new projects are proposed.
- Advocate for sufficient resources to operate and maintain these projects.
- Act as a proponent for the adoption of other important capital projects in future plan updates.

To achieve this, the Traffic Manager must provide input into the strategic and business planning and the transportation planning and programming processes. This is an iterative two-way process where one must advocate for the ramp management projects and strategies that are needed and that reflect the agency strategies, goals, and objectives. Knowing where to interface in the process so that these goals and strategies can be furthered requires an understanding of the program and process.

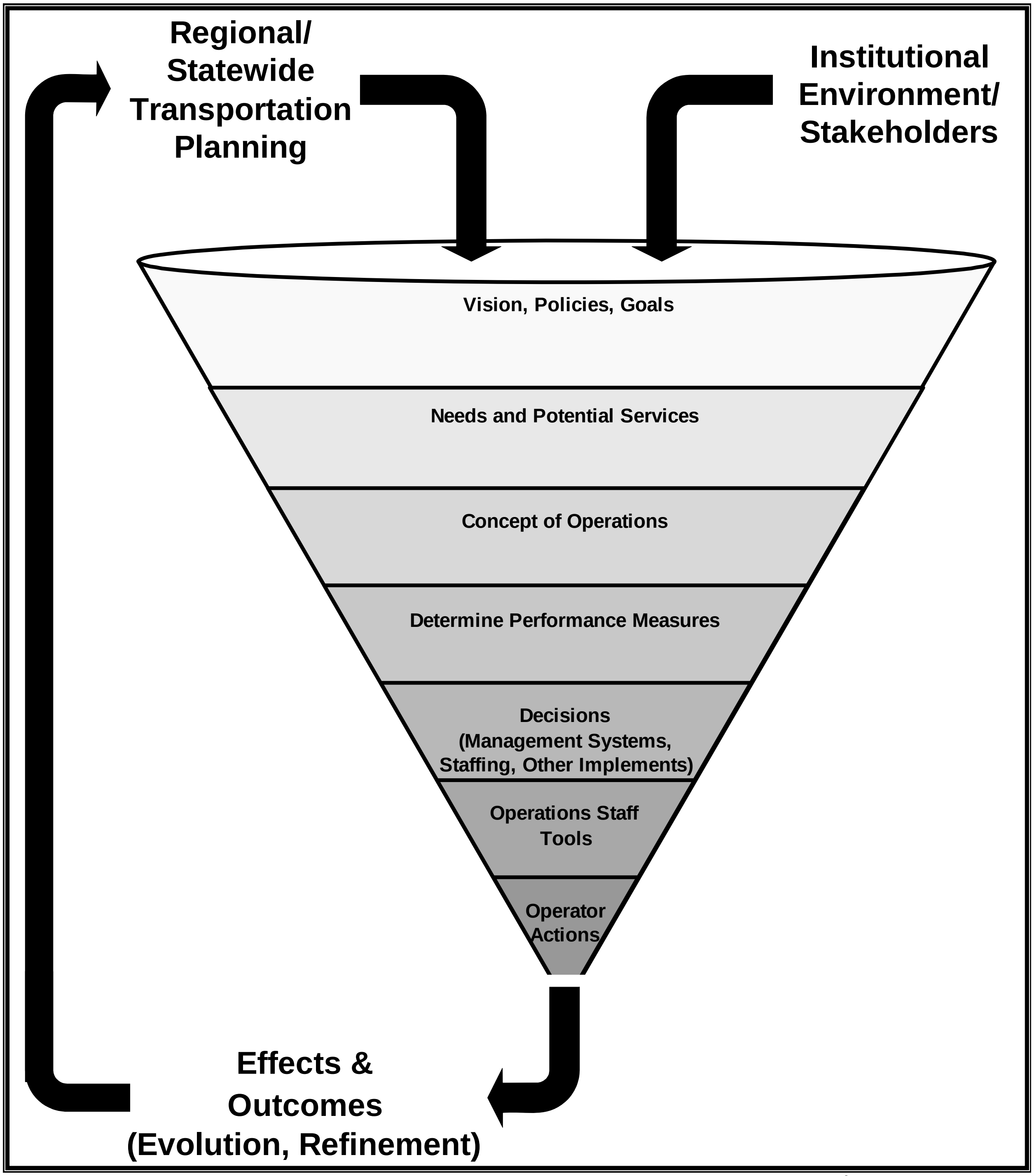


Figure 3-1: Traffic Management Development Program Process[1]

Ramp management is an element of the freeway management program, which in turn is an element of the overall traffic operations program. As such, the roles and responsibilities of the people who are implementing ramp management actions are included in these other two, higher-level programs. The people who will manage and operate the ramp management elements of the program will either operate other elements of the program, such as surveillance, incident monitoring, and Dynamic Message Signs (DMS) operation, or work hand-in-hand with those who do. However, it depends on the agency as to how those specific roles and responsibilities are defined. See related information regarding organizational structure in Section 3.3.1 of this chapter.

Many ramp management strategies are implemented through individual capital improvement projects. A key to the successful advancement of new ramp management projects and services is to understand how projects are selected for funding. Developing ways to champion the project within and outside of the agency positions the new ramp management project in such a way that it is more likely to be funded. A champion at the management level would best serve the project because of his or her stature within the agency and knowledge of the benefits of the new project. In addition, a management-level champion can ensure that the project remains in the overall plan and program if budget cuts are required.

The manager responsible for ramp management activities has a similar role to any other manager in the traffic operations arena in providing efficient traffic management. There is not a large difference in the roles and responsibilities for ramp management and control and other elements of the traffic operations program, except that ramp management activities are often more visible and may be more controversial than other elements of the program. Therefore, one needs to be more focused on the institutional, political, and public involvement impacts associated specifically with ramp management.

When adding ramp management capabilities and elements, there will be new issues that have not been dealt with previously. In many cases, ramp management contains ramp metering, which is generally controlled in the Transportation Management Center (TMC). Ramp management strategies are usually initially implemented through capital projects, and ramp management personnel must be involved in the design and construction role. However, responsibility for the overall design of a ramp management project could be handled at the TMC itself, or at the Traffic Operations, Intelligent Transportation Systems (ITS), or Traffic Design divisions. The actual construction is almost always managed in the construction group with support from experts in the TMC and Traffic Operations or Design divisions to assist with inspection. The addition of new ramp metering equipment also requires more intensive maintenance efforts. The Traffic Manager must build a strong relationship with the Maintenance Division so additional devices can be properly maintained.

3.2.2 Planning and Decision-Making

The state and federal planning and decision-making process for implementing a transportation project is complex. Transportation decision-making follows a tiered government structure starting at the national level, filtering through state and regional levels, and culminating at the agency level. The authority for transportation decision-making spans all these tiers and may involve several agencies within the same level. There are also several planning horizons involved in the investment decision-making process. These range from strategic long-range planning (20+ years) and program and system planning (3-20 years) to day-to-day operations planning (1-3 years) and day-to-day operations (real-time to 1 year). A graphical representation of this is shown in Figure 3-2. One of the most critical elements of getting strategies implemented is for the Traffic Manager to have a thorough understanding of this planning and decision-making process. Without it, he lacks the proper tools to see projects come to fruition. Further discussion regarding the decision-making process can be found in Section 2.3 of the Freeway Management and Operations Handbook, and is summarized briefly below.[1]

National Level

At the national level, decisions are made regarding national transportation policy and legislation is developed that provides a high-level commitment to programs, policies and research in transportation. The federal programs provide the impetus for advancing the state-of-the-art with new and innovative technologies and practices. For instance, the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA) was the beginning of major federal funding for ITS projects. From 1992 to 1997, it was the U.S. Department of Transportation (USDOT)'s charge to foster the deployment of ITS products and services nationwide. ISTEA's successors, the 1998 Transportation Equity Act for the 21st Century (TEA-21) and the 2005 Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU) reinforced the federal commitment to manage and operate the nation's transportation system.[10] TEA-21 and SAFETEA-LU further advanced ITS applications and deployment through mainstream funding under the federal aid program.

There are other functions that occur at the national level. For example, Section 5206 of TEA-21 mandated the development of a National Architecture whose standards and protocols would provide continuity and interoperability in the use of ITS technology across the United States. Another function of the national tier is technology transfer. For example, FHWA is not only responsible for creating the planning, design and implementation requirements, but also orchestrate the development and distribution of handbooks like this one and training courses for local agencies around the country. Guidance and training materials developed at the national level can be invaluable. The Traffic Manager must be aware that these resources exist and are available for use.

State and Regional Level

At the state and regional level, a short- and long-term mechanism exists for planning and funding. This tier focuses on strategic transportation planning that may include projects that focus on the long-term. The agencies involved at the state and regional level include state government, Metropolitan Planning Organizations (MPOs), municipalities, and other operating agencies that develop short- and long-term transportation plans.

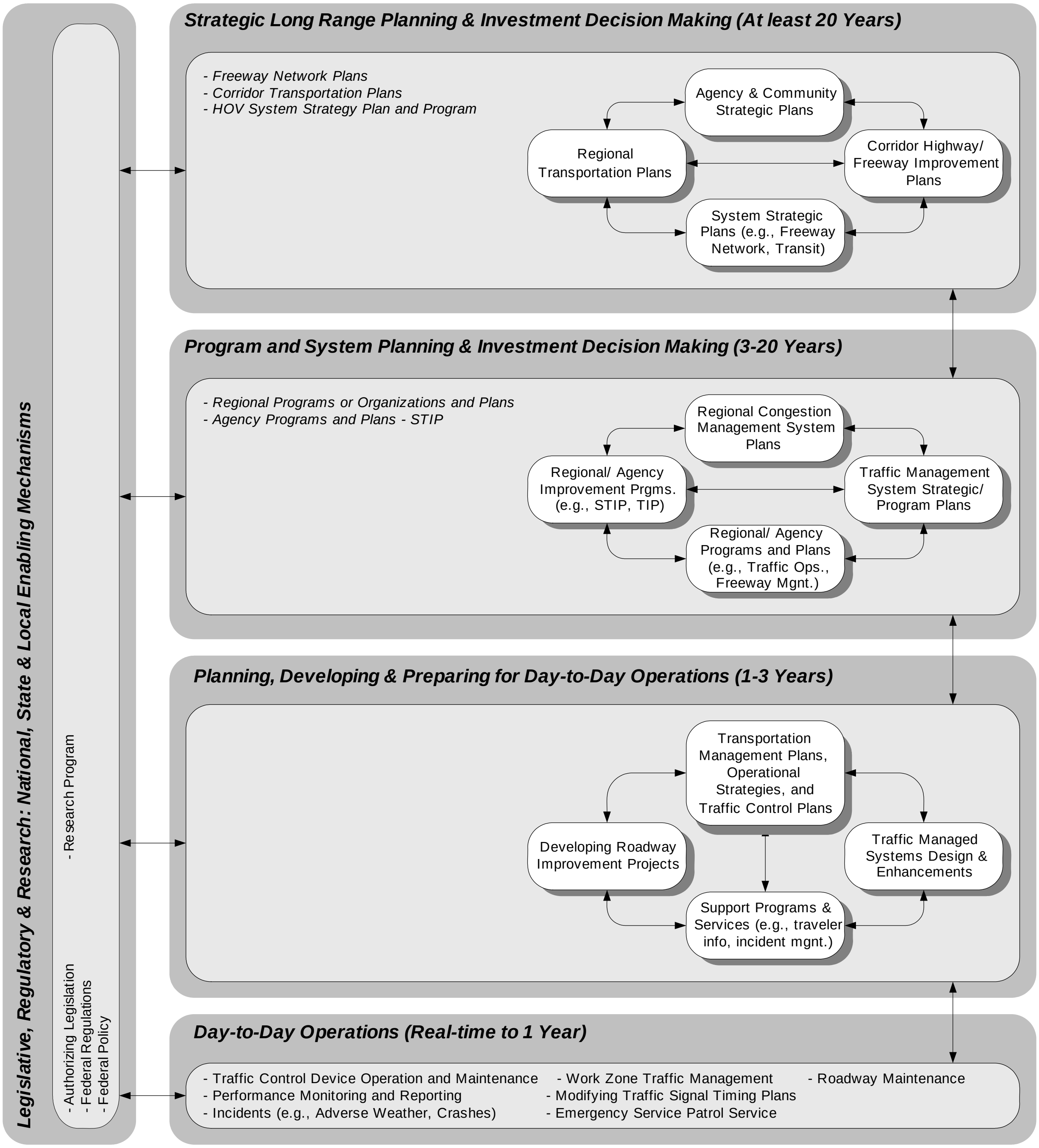


Figure 3-2: Transportation Tier Diagram[1]

[1] This figure was adapted from Figure 2-1 of the *Freeway Management and Operations Handbook*.

Agencies at the local level are responsible for programming, design, and operation of their facilities. The process varies by state because there is a range of ways that agencies obtain project funding. It is at this level where the specific roadway improvement projects are developed that will be implemented according to the overall transportation goals. The process to obtain funding and support for ramp management projects, services, and activities requires that the Traffic Manager be prepared to have a proactive involvement in and across each tier. Knowledge about the decision-making process and the ability to assess how well the projects will meet the agency's needs is a critical skill that the Traffic Manager should have. Key questions that should be raised include:

- How do we address the deficiencies in our system?
- What ramp management projects will achieve this?
- How does this specific project fit into our overall plan and address our agency goals?
- What ramp management projects can we afford to include?

The complete list of projects will be prioritized based on cost effectiveness. This includes a financial constraint analysis based on what projects cost and how much funding is anticipated. The recommendation process can be highly competitive given that the costs of needed projects typically exceed the available funding. For example, achieving consensus on how to distribute the funding is one of the primary responsibilities of the Puget Sound Regional Council (PSRC). Each of the projects selected for funding will help to implement their long-range regional plan for the future.[11] Funding for PSRC's selected projects are derived from three federal sources: Surface Transportation Program (STP), Congestion Mitigation and Air Quality (CMAQ), and Federal Transit Administration (FTA) funds.

The Sacramento Area Council of Governments (SACOG) defines the "life of a transportation project" as follows.[12] This example demonstrates the various steps of SACOG's process to obtain project funding.

- Process starts with an idea (transportation need that has been identified). This first-step action can be by a citizen, private business, community group, or public agency.
- Then the idea must become adopted by a local agency. The idea should be refined and formed into a defined project with clear specifications.
- After local review, it may be financed at the local level. If state or federal funds are required, there needs to be a county review and incorporation into the Long-Range Transportation Plan (LRTP) and the Transportation Improvement Program (TIP).
- If approved for state funding, the project then gets incorporated into the regional TIP and is then considered for inclusion in the state TIP.
- The project can then move up for consideration for federal funding. These projects can provide for any mode (e.g., bus, rail, highway).
- Projects listed in the STIP and federal program are reviewed for requirement compliance. Approved projects are forwarded to state or federal authorities for final award of funds.

3.2.3 Strategic and Business Planning

An agency's Strategic Plan is a blueprint for achieving the agency's strategic objectives (second tier of Figure 3-2). For example, some strategic objectives may include safety, mobility, global connectivity, environmental stewardship, or security. An example of a mobility strategic objective would be to "advance accessible, efficient, inter-modal transportation for the movement of people and goods" and an outcome may be to reduce congestion in all modes. Implementing a ramp management strategy may help to support and achieve this strategic objective, but specific ramp management strategies are not yet identified at this stage.

A business plan outlines and documents a planned multi-year effort to sustain operations using sound and universally accepted practices and techniques. By understanding the business plan, the Traffic Manager is aware of the entire realm of possible alternatives and the management and operational implications of those alternatives.[13] Ramp management strategies need to be developed in the context of business planning efforts and should be coordinated with all appropriate business plans.

"Ramp management strategies need to be developed in the context of business panning efforts…"

The Traffic Manager provides input into these processes and develops actions and recommended projects based on their outcome. For example, a Traffic Manager can develop standard operating procedures so that the ramp management operation will better meet a goal or strategy. He may also develop a list of recommended projects that are considered in the planning and programming process. It should be noted that the direct actions that the Traffic Manager can take are the subject of Chapter 4 of this handbook.

Conversely, ramp management actions should not be undertaken in isolation or outside the strategic and business planning process. The formulation of ramp management strategies must be needs-based. Often, the strategic and business planning efforts consider needs at a high level. A needs assessment process for ramp management will often need to be performed at the program level. (Note: a needs assessment is always required at the Concept of Operations and project levels.)

Case studies on strategic and business planning are provided in Chapters 11 through 15 of the *TMC Business Planning and Plans Handbook*.[14]

3.2.4 Regional or Departmental Transportation Planning

Programming is the formal inclusion of a funded transportation project into a document to give it official standing with the state and federal agencies. There are two types of program plans at the regional level: long-range and short-term. Long-range plans (typically 20-year plans) identify general types of projects. These projects do not include a high level of detail because the actual funding has not been determined. The short-term program defines projects that are typically in the one to six-year timeframe.

The regional program may include a wide variety of transportation projects, including road construction, road maintenance, transit capital (including light rail transit (LRT) and bus purchases), and the funds to operate transit services, bike and pedestrian programs, air quality improvement programs, traffic management projects and programs, and transportation enhancement projects. Funding sources are identified so as to develop a constrained and unconstrained list of capital projects. These funding sources can be public or private.

In order to develop ramp management activities, input must be provided to guide the development of the long-range plan. From the large list of projects in the long-range plan, a short-term program is developed. The Traffic Manager then uses the short-term program to figure out what funding may be available. Primarily, capital expenditures must be included in the regional or departmental transportation planning process. However, operational aspects of ramp management fit in to these planning processes if they consider operational programs. This process is vital in order to make decisions regarding staffing and operations as well as capital expenditures. The Traffic Manager must also be involved with the regional planning process at the MPO level to get CMAQ or STP (surface transportation) funding. In some circumstances, ramp management may provide a more effective means of meeting transportation goals and objectives than any other investment. As such, ramp management should be considered in the alternatives analysis of the planning process.

The Traffic Manager's involvement in the planning process must be ongoing. The plans are updated at regular intervals (e.g., every one to three years) to reflect changing conditions and new planning priorities, based on growth and travel demand projections coupled with financial assumptions.

3.2.5 Multi-Year Program Plan

Multi-year program plans developed at the agency level can be for the short-term or mid-term. Both types of program plans provide agency personnel with information regarding what funding levels they can expect for their projects.

It is vital that the Traffic Manager understand how the multi-year programs are developed so that he can provide input into their development. This will ensure that projects of interest (i.e. ramp management projects) are going to receive funding. For example, many states use the annual or biennial program to document the guaranteed types of funding in the short-term. They also use the six-year program plan to show the vision for the near-term, but this may be subject to modification due to changes in priority or availability of funding sources.

The Traffic Manager or the manager responsible for ramp management activities must understand that there are different funding categories, such as safety, mobility, rehabilitation, capacity improvements, and preservation. Knowledge of this funding structure allows agency staff to determine how their program will be funded. Though the specific project-level details have not yet been developed, the Traffic Manager must understand which funding category would be appropriate. He must ask the question – "Where do my activities fit into the agency funding structure?".

It is also an opportunity to look for cost-effective ways to tag onto other funded projects. For example, if the Traffic Manager would like to re-stripe the on-ramp for a new dual-lane ramp metering system, it would be advantageous to "piggyback" with a resurfacing project that is already funded. With adequate knowledge of the funding structure, there may be more than one way to fund ramp management elements. The success of ramp management efforts partially depends on how savvy and creative the Traffic Manager is in obtaining needed funding.

Ramp management projects, especially ramp closures and ramp metering, are different than other types of projects. These types of projects require more extensive involvement with the public. It extends beyond the typical design and includes the operational facets of the project. These elements may include informing the public of strategies, obtaining support from the media and public officials as well as other local agencies, and establishing proper laws or regulations for enforcement. Agencies must be prepared to deal with and fund the public outreach efforts. Outreach activities are discussed in detail in Chapter 7 of this handbook.

3.2.6 Regulations and Policies

Ramp management strategies need to address, and usually conform to, existing regulations and policies. However, at times, policies and regulations may conflict with one another or may not be consistent with higher-level goals and objectives. Regulations and policies should be reviewed to make sure ramp management activities are consistent and to determine if any updates or amendments in regulations and policies are needed. The key is for the Traffic Manager to ensure that there is an appropriate support structure for accepted ramp management activities.

Reviewing current regulations for potential conflicts with ramp metering is vital and necessary. For example, some states have laws that require that all traffic signals have three signal heads. As some agencies do not use the yellow head for their ramp meter signals, this must be verified to ensure that there are no conflicts. Another example is that some states require traffic signals to go through a yellow change interval. This regulation must be amended for ramp meter signals because it conflicts with effective ramp meter operation.

Similar to laws and regulations, the agency’s policies (how it conducts business) must also be reviewed as they pertain to ramp management operations. For example, when operating a TMC, one needs to assess how to handle the hours of operation. Are there any provisions in the human resources policies relating to staffing of split shifts? Would this be in violation of any union rules?

Other specific issues to address include: Can you close a ramp part-time? What is the process to close a ramp temporarily? What enforcement policies need to be developed to support the overall operation of the ramp management program? Do existing regulations and policies allow for use of a ramp exclusively for special use vehicles, such as HOV or construction-related vehicles?

3.2.7 Concept of Operations

The Concept of Operations (Con Ops) is a key document that outlines the overall ramp management concept and explains the environment in which the system operates and how it will work once it is in operation. It is developed with all stakeholders during the needs assessment process and is based on the vision, mission, goals and objectives for the agency. Specifically, it explains the primary reason for implementing the ramp management project(s). It also documents the agency's responsibilities for operating the system and expectations for its performance and life cycle. The Con Ops describes the system's operational characteristics, facilitates an understanding of the goals, forms a basis for long-range planning, and presents an integrated view of the stakeholder organization and mission.

Ramp management activities…should be included as one element of a regional level Con Ops."

The Con Ops should be conducted at the regional or agency system level, such as for the entire freeway management or TMC system. Ramp management activities, including their relationship to other traffic management activities and elements, should be included as one element of a regional level Con Ops. The Con Ops should state the actions that will flow back into the program development process.

It is the agency's responsibility to develop a Con Ops. If ramp management elements are being added to an existing freeway management and operations program, it is necessary to make sure that the original Con Ops is updated to reflect the new ramp management strategies. Likewise, the interaction of how ramp management projects may affect other operational strategies, such as HOV lanes, must also be included as this relates to the existing conditions. Ramp management strategies such as terminal treatments or ramp closures may not need to be discussed in the Con Ops if they do not utilize ITS components.

There are many steps in the development of a Con Ops document. In general terms, this involves identifying the user needs, developing owner's policies, providing procedures and responsibilities, defining the interagency working relationship and agreements, defining the physical environment, and setting performance measures. For specific guidelines on how to prepare a Con Ops, please refer to the IEEE *Guide for Information Technology – Systems Definition - Concept of Operations (ConOps) Document*, IEEE Std. 1362-1998.[15] *The TMC Concept of Operations* report is another resource.[16]

3.2.8 Performance Monitoring, Evaluation, and Reporting

Performance monitoring has a continuous and integral role in supporting ramp management activities. Performance measures need to demonstrate how well the ramp management strategies contribute to meeting the goals and objectives of the program (see Figure 3-1). The results should feed back into strategic and business planning, transportation planning and programming processes. Performance monitoring should also feed into day-to-day operation, operational planning, and decision-making, and thus signifies the importance of real-time performance data to gauge how ramps are performing as compared to the "norm". In general, performance monitoring helps to provide "checks and balances" on the system and ensures continuous operational improvement.

Performance monitoring, evaluation, and reporting should be performed and continuously supported by operating agencies. It must occur throughout the life cycle of the facility, to identify ramps and adjacent arterial streets with sub-optimal performance, analyze corrective solutions, estimate associated costs and benefits, and determine actual improvement in performance and overall cost effectiveness.

Some key considerations in providing effective ramp management performance monitoring are to:

- Use Measures of Effectiveness (MOEs) that focus beyond freeway mainline traffic.
- Consider feedback from the system users as part of the evaluation, so as not to rely solely on the technical results.
- Limit the number of MOEs, particularly when initiating a new program.
- Select MOEs that are easy to measure and simple to understand.

Detailed information on how to conduct performance monitoring, evaluation, and reporting can be found in Chapter 9 of this handbook as well as in Chapter 4 of the *Freeway Management and Operations Handbook*.

3.3 Organizational Support

Agency upper management support for ramp management strategies is primarily derived from the actions discussed earlier in this chapter. Upper management must understand the reasons for managing ramps and how ramp management upholds the agency's overall goals and objectives before they will support it. This includes understanding legislation, policies and rules, the transportation planning process and products, strategic plans, and much more.

"Funding mechanisms must be understood in order to position ramp management projects..."

Funding mechanisms must be understood in order to position ramp management projects for inclusion and positive consideration. Budgets are required for staffing, training, and equipment maintenance. A key to remember is that the budget process flows two ways. Budgets are established through the agency programming effort. However, budget requirements need to be established at the operational level and fed back into strategic and business planning efforts as well as the agency programming efforts. This helps to ensure that not only the capital projects receive funding, but also that the required staff, training, and other resources needed to operate it are funded.

Additional considerations are discussed in Section 2.4.1 to 2.5.5 of the *Freeway Management and Operations Handbook.*

3.3.1 Organizational Structure

The organizational structure within the agency needs to be assessed to ensure that it serves ramp management activities. There are many possible organizational structures. The exact structure should be devised to fit within the agency and regional organizational structure, given the selected ramp management strategies. One key is to provide an organizational structure that will not impede ramp management activities. The responsibilities for ramp management must be designated at the right level and in the right group.

Typically, the responsibility for the overall ramp management program will be shared among the planning, design, operations and maintenance staff within the organizational structure. This relationship is key to the success of the program. For example, the responsibility for ramp management and control typically falls in the agency's Traffic Operations or ITS Division. While it may be appropriate for the maintenance staff to be placed in the agency's Maintenance Division, there must be accountability by their supervisors for the operation of the ramp management program. Other agencies structure their organization such that both operations and maintenance staff responsible for ramp management elements fall under the same division. This helps to eliminate artificial barriers and conflicts in priorities because all functions are united under the same set of goals and objectives.

The organizational structures will vary from agency to agency. If there are separate divisions for each of the functions, then it is important to concentrate on the relationships among each division to ensure that they work well. This will help to minimize conflicts. Section 2.6 of *Freeway Management and Operations Handbook* discusses human relations. The Handbook states that "most of the institutional challenges and barriers are really about human relations."

The following are a few examples of how the organizational structure of ramp management is handled across the country:

- Houston's TRANSTAR consortium is a partnership of four government agencies that are responsible for providing Transportation Management and Emergency Management services to the greater Houston region. Ramp metering activities are operated out of the TRANSTAR center and there is one person who oversees the ramp management activities during the peak periods. Additional information about TRANSTAR can be found on their website at http://www.houstontranstar.org
- The Regional Transportation Commission of Southern Nevada (RTC) together with the Nevada State Department of Transportation (NDOT) has ramp meters along US 95 to help mitigate congestion, improve air quality and increase mobility. Freeway and Arterial System of Transportation (FAST) operators work out of RTC's control center to operate NDOT's ramp meters. In this case, a regional body under agreement to the state is operating the ramp meters. More information on this partnership can be found at RTC's website at http://www.rtcsouthernnevada.com/rampmeters
- In Seattle, the freeway operations group in the Washington State Department of Transportation (WSDOT)'s Northwest Region has the responsibility to operate the ramp metering system. They typically have one operator that monitors and operates the ramp meters during the peak periods. An engineer is also available to assist with operational decisions. This is an example of operating ramp meters from a DOT's district or regional office. More information on the WSDOT ramp metering system can be found at: http://www.wsdot.wa.gov/regions/northwest/traffic/tsmc/RampMeters
- A fourth example is operating the ramp management activities at a DOT headquarters. In Utah, the operations staff at the Salt Lake City Traffic Operations Center (TOC) are part of the central office organizational structure. Further information about Utah Department of Transportation's Traffic Management Division can be found at http://www.udot.utah.gov/index.php/m+c/tid=191

3.4 Chapter Summary

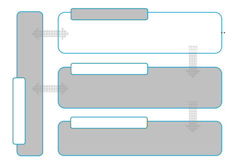
It is now clear that ramp management fits into the larger traffic management program and functions as an element of the freeway management program. Understanding that ramp management activities do not operate as a separate entity is a key factor. The Traffic Manager has a great level of responsibility in that he must be savvy in topic areas ranging from issues and policies to funding mechanisms to strategic and business planning. He must also understand how ramp management can affect current regulations and policies.

Within the agency organization, the Traffic Manager must work with upper management to increase their understanding and support for the strategies. Meeting the agency's overall goals and objectives is paramount. It is also vital to ensure that ramp management activities are operated within the appropriate organizational structure.

By following the guidance that is outlined in this chapter, the Traffic Manager will learn about the skills needed to influence and, hopefully in turn, advance their ramp management strategies. Though he will not have control over many of the areas (e.g., funding mechanisms), the knowledge gained from this chapter will make him better prepared. Chapter 4 discusses the issues that the Traffic Manager can control, such as staffing and interagency coordination.

4

PREPARING FOR SUCCESSFUL OPERATIONS



Getting Started

4.1 Chapter Overview

Chapter 4 represents the last step within the Getting Started module. Building on Chapter 3, this chapter continues the discussion of how ramp management fits into an agency's traffic management program, but concentrates on the issues and activities that can be controlled by the individual responsible for ramp management. In contrast, Chapter 3 focused primarily on the issues and activities over which this individual has influence, but little direct control.

By reading this chapter, readers will begin to understand the importance of obtaining both inter- and intra-agency support before developing ramp management techniques and strategies. Coordination is needed to gain support for ramp management activities and to maximize their effectiveness within the overall traffic management program.

Readers will also take away from this chapter an understanding of the day-to-day issues, operations, and procedures aimed specifically at the manager of the unit that will be implementing and operating ramp management strategies, referred to in this handbook as the *Traffic Manager* (depending on the organizational structure of the agency, the Traffic Manager could be the manager of the Transportation Management Center (TMC) or the Traffic Operations, Intelligent Transportation Systems (ITS), or Traffic Design divisions within the agency). A discussion on staffing, including levels, skills, and training as it pertains to ramp management and control, is provided. Finally, there is a discussion of the re-

Chapter Organization

sources that may support the operation of ramp management and control activities.

Chapter 4 Objectives:

Objective 1:	Understand the organizational support that is required for a successful ramp management effort.
Objective 2:	Understand the staffing considerations for ramp management, including the skills, training, and staffing levels needed, and the resources needed to support each activity.
Objective 3:	Understand the types of multi-agency support that is required to support ramp management.

4.2 Understanding the Bigger "Operations" Picture

Successful ramp management operations require that practitioners responsible for the day-to-day operation of ramp management strategies understand how ramp management fits into an agency's traffic management program. Practitioners need to keep in mind that ramp management is not an independent function, but rather one that supports the overall mission of the freeway management program. Ramp management strategies need to fit with and be integrated into other freeway management functions. Integration includes coordinating with individuals inside and outside their respective agencies to determine if ramp management is appropriate and practical for the situation faced.

In coordinating ramp management with other freeway management programs, the ramp management practitioner must assess how coordination can be used to improve freeway operations, not only operations on the ramp. As such, the ramp management practitioner should identify how resources such as staff, equipment, and funding can be shared across different freeway management programs in an effort to reduce costs and maximize benefits.

Practitioners responsible for the day-to-day operation of ramp management strategies also need to remain cognizant of internal and external processes and products that may either positively or negatively affect ramp management operations. This includes the processes and products currently in place and those that are planned. Such processes include legislation, agency policies and directives, inter-agency agreements, and availability of supporting resources. Products that influence ramp management may include regional transportation plans, agency business plans, and operations/design plans. The ramp management practitioner should ensure that ramp management strategies do not conflict with existing processes or products, and can be successfully implemented, operated, and maintained.

4.2.1 Performance Monitoring

Effective ramp management relies on the ability to monitor the effects of any action taken to manage the movement of vehicles on ramps, regardless of whether it is on an exit or entrance ramp. Along with the ability to monitor is the ability to implement actions to change the conditions under which the ramp is operating, such as varying the ramp meter timing, adjusting the time of day a ramp is closed, or adjusting signal timing at the ramp-arterial intersection.

The success of a ramp management strategy can be measured by how well the strategy furthers the region's transportation goals. The benefits must be measurable – it is important to determine which measures of effectiveness (MOEs) best represent the goals.

"The success of a ramp management strategy can be measured by how well the strategy furthers the region's transportation goals."

The performance of the ramp metering strategy used should be monitored to ensure that the strategy is operating effectively. Feedback on system performance is critical to evaluate and adjust the day-to-day operation of the strategy. Active performance monitoring provides a necessary foundation for active system management. The public will be more confident in the operation of the strategy and supportive of ramp management overall if the system is actively managed and monitored, with performance reported periodically. A full assessment of ramp management strategies should be performed periodically. Recommended assessment periods include: (1) prior to a change, (2) soon after a change, and (3) at regular periodic intervals. This self-assessment will provide detailed performance results that help identify where improvements are needed and measure employed strategy benefits.

Details on the process of selecting MOEs, obtaining the necessary data, and monitoring performance can be found in Chapter 9 of this handbook. Chapter 9 focuses on the importance of practitioners being aware of the ongoing monitoring program that is used to improve the operation of the strategies employed.

4.3 Inter- and Intra-Agency Coordination

Practitioners responsible for ramp management must coordinate with individuals inside and outside their respective agencies, first to ensure that ramp management strategies can be supported and secondly, to develop effective procedures to implement and operate these strategies. The key is to break down barriers that exist within and between agencies and institutionalize working together as a way of doing business among transportation agencies, public safety officials, and other public and private sector interests within a metropolitan region.

Practitioners responsible for ramp management may choose to use inter- and intra-agency coordination as a means to obtain consensus on how ramp management will operate and how it fits into the overall traffic management program. Development of a regional traffic management program Concept of Operations (Con Ops) presents a good opportunity for inter- and intra-agency coordination in defining how ramp management fits into the larger traffic management program. In short, the process of developing a Con Ops should involve all stakeholders and serve to build consensus in defining the mission, goals, and objectives of ramp management. It should also provide an initial definitive expression of how functions are performed (thereby supporting resource planning), and identify interactions between organizations.[1] Refer to Section 3.2.8 of this handbook for more information on developing a Con Ops.

4.3.1 Human Relations

Good human relations can help practitioners form solid relationships with individuals within and outside their respective agencies, fostering a seamless environment where information exchange can frequently occur. This helps to lay the groundwork for ongoing, regional collaboration that can be exploited to help satisfy ramp management goals and objectives. For instance, day-to-day technical and operational issues can be more easily overcome through interaction and support of other department managers and individuals responsible for managing systems that interact with ramp management systems or strategies. Good human relations may also play a critical role in quickly resolving queues at metered ramps that affect operations on the adjacent arterial. In this case, a good relationship between the individual responsible for ramp management and the individual responsible for signal operations at the ramp/arterial intersection may benefit operations.

Practitioners responsible for ramp management and other freeway management activities should exercise the following principles to promote and maintain good human relations:

- Engage in face-to-face communications, where possible.
- View problems as others do.
- Clearly present the facts and be honest.
- Approach people as individuals and not as stereotypes.
- Show respect for the opinions and talents of others.
- Confidently promote business concepts and ramp management strategies.
- Recognize that circumstances change and openly accept new ideas.

4.3.2 Inter-agency Coordination

Practitioners with day-to-day responsibilities for ramp management should coordinate with other regional stakeholders, including but not limited to law enforcement, local traffic engineering departments, and public transportation officials. This will help build sustained relationships and create strategies to improve transportation system performance. Inter-agency coordination will help the ramp management practitioner identify and exploit possibilities for improving day-to-day operations, as briefly described earlier in this chapter. At first, coordination may be in the form of simple information exchange. However, the goal is to combine knowledge, expertise, and information to more efficiently and effectively manage ramps. The continual coordination between these individuals may foster the development of strong relationships and tactics that, over time, equate to measurable improvements in the safety, efficiency, and quality of service associated with regional transportation facilities, including ramps.

Inter-agency coordination, however, is not an easy process. The ramp management practitioner should expect to make several attempts to obtain the level of inter-agency coordination needed to support ramp management activities, especially if this is a first attempt to coordinate with individuals from these outside agencies. Adding to this difficulty are institutional barriers, such as resource constraints, internal stovepipes in large agencies, and the often narrow jurisdictional perspective of governing boards. As such, initial attempts to coordinate with outside agencies should begin early in the planning process to allow enough time to ensure that coordination can occur.

Ramp management coordination among the partner agencies must follow the same processes as the region's overall freeway or transportation management activities. Ramp management is but one element of that process. The process should consist of formal activities (written policies and guidelines) as well as informal human relationships. Both are focused on improving the performance of the transportation network. The ramp management activities must be integrated with the region's transportation program and must support the region's other initiatives without competing against them. Ramp management activities must also be compatible with the region's ITS architecture.

Enforcement

It is critical that the ramp management practitioner work with law enforcement personnel early in the planning process to gain their support for ramp management strategies. The practitioner must convey to law enforcement the reasons for, and benefits of, ramp management while helping to define the role enforcement plays in successful ramp management operations. This can be accomplished through one-on-one meetings, group workshops, or a combination of the two. Information on ramp management activities should be tailored to law enforcement personnel, and at a minimum ramp management strategies must:

- Make sense.
- Comply with existing laws and regulations (and/or revise laws to uphold proposed strategies).
- Provide a safe enforcement area.

Assuming that practitioners have acquired the support of law enforcement, these two parties must then work together to promote voluntary driver compliance of ramp management strategies and establish policies and procedures for enforcing them. First, efforts should be made to increase awareness of ramp management strategies. This awareness should include the reasons for and benefits of ramp management strategies, and the consequences for non-compliance. Motorists generally will adhere to the strategy if there are real consequences for non-compliance. However, despite these efforts, it is unlikely that all motorists will comply with ramp management strategies. Therefore, law enforcement must physically enforce ramp management strategies on a periodic basis. Practitioners should work with law enforcement to determine good non-intrusive enforcement techniques, areas safe for citing violators, and the number of enforcement staff needed. Ramp management practitioners should also be open to recommendations of law enforcement on the enforceability of the ramp management strategies that are under consideration.

During the project planning phase, a specific exercise identifying the legalities of implementing the ramp management program should be explored. Local agency legal departments and state attorneys should be involved in this exercise. If current laws support the strategy, these laws and ordinances should be compiled into a concise document. If it is discovered that new laws are needed, then the process for developing these new laws, including sponsorship of legislation, must begin.

Local Traffic Engineering/Public Works Engineering Staff

As is the case with enforcement personnel, ramp management practitioners should also work with local traffic engineering/public works engineering staff responsible for local street system operations, including traffic signals. This coordination must occur, due in part to the fact that there may be a separation of jurisdiction at the ramp/arterial intersection. In other words, the individual responsible for ramp management is typically not the same individual responsible for operations along the arterial. Therefore, differences may arise in the manner in which these two types of facilities are operated. These two individuals should collectively decide the most effective approach for implementing selected ramp management strategies so they do not affect operations on either the ramp or arterial.

Local Transit Authority Staff

Inter-agency coordination should extend to local transit authority staff. Coordination between the individuals responsible for ramp management and transit management needs to occur to identify how ramp management can satisfy regional transit needs and determine whether or not these approaches are feasible. For instance, ramp management strategies such as dedicated HOV/transit lanes can be used to promote and improve transit operations. However, conditions on ramps (e.g., narrow ramps, ramps with inadequate turning radii, etc.) may prohibit these strategies from being implemented. If preliminary analysis proves that ramp management strategies are feasible, ramp management and transit management practitioners must work together to further define the intricate details of a ramp improvement.

Regional Transportation Planning Agencies

Practitioners should coordinate with regional transportation planning agencies, such as metropolitan planning organizations (MPOs) to incorporate regional transportation data into the ramp management decision-making process and to program ramp management projects as needed. Regional transportation planning data such as traffic counts, crash data, and congestion data are valuable in the selection and implementation of ramp management strategies. Practitioners should coordinate with regional transportation planning agencies early in the planning process to ensure that these types of data are available and recent. Additionally, practitioners need to ensure that selected ramp management strategies can be funded. Therefore, they should work with regional transportation planning staff to program projects into the regional transportation planning program. Chapter 3 discusses this topic in greater detail.

4.3.3 Intra-agency Coordination

Practitioners responsible for ramp management should coordinate ramp management activities with an agency's broader traffic management program. As mentioned throughout this handbook, ramp management is one element of the traffic management program and needs to further the goals and objectives of that program. However, internal coordination goes beyond the traffic management program. Personnel responsible for ramp management activities must also coordinate with the following set of internal staff.

- Planning staff, to make sure ramp management needs are incorporated into the agency plans.
- Design staff, to make sure that ramp management needs are incorporated in project designs.
- Maintenance staff responsible for maintaining ramp management equipment.
- Operations staff responsible for operating the ramp management system. The Traffic Manager has the most influence over this group, as they are his or her assigned staff and primarily responsible for ramp management.
- Public information staff responsible for informing the public of activities such as ramp management.
- Upper management responsible for setting ramp management policy and directives, so they are aware of any issues arising from ramp management activities.

Agency department heads or managers responsible for day-to-day operations, which include those individuals responsible for ramp management, should work together to solve operational problems, improve system performance, and communicate successfully with one another through deliberate collaboration and coordination. The Traffic Manager is the link between advising upper management of issues and concerns associated with ramp management and carrying out, through staff, the policies adopted by upper management. The Traffic Manager must be involved in a multitude of efforts, which include:

- Planning the ramp management activities.
- Developing coalitions and coordinating with his or her counterparts at partner agencies to identify and resolve issues between agencies, including enforcement issues.
- Managing the staff designated to plan, design, operate, and maintain the ramp management elements.
- Carrying out all inter- and intra-agency agreements.
- Identifying any issues associated with funding the ramp management activities.

More specifically, this would mean that the Traffic Manager continuously coordinates and collaborates with other managers who are directly responsible for operating elements of the transportation system on a day-to-day basis. They should aim to reach agreement on a shared operations vision and a concept for how regional activities should be operated over time. This translates into determining what measures to use to assess effectiveness and how to make improvements to achieve desired expectations in operating performance.

4.4 Staffing

When ramp management and control activities are added to the traffic management capabilities of an organization, it is possible that staffing changes will need to be made. Prior to the inclusion of ramp management, it is likely that staffing levels and skills met the needs, perhaps at a minimum level, of the existing traffic management program. Therefore, new staff may need to be hired, or existing staff may need to be trained, when ramp management and control activities are added to the traffic management program.

The ramp management practitioner must determine the impacts that ramp management and control activities have on existing staff levels. Practitioners must also assess the effect that changes to staffing have on current funding allocations. Budgeting for training usually falls into an agency's overhead budget and is 100-percent agency-funded. This is often overlooked during the planning stage, yet can be costly if training new staff is required or inadequate training is provided.

Staffing can be grouped in four basic categories: planning, design, operations and maintenance. These four categories correspond to the general engineering departments of most agencies, specifically Departments of Transportation. Generally, although agencies have dedicated staff in each of these departments, at the ramp management or traffic management level, staff may perform functions that cross categories. This is especially true for planning and design. In this case, the same person(s) may be responsible for ramp management planning and design.

Staffing for ramp management is similar to staffing for a traffic management program. Staffing should be based on three primary areas:

- The skill level required to think logically, do multiple tasks, and dedicate themselves to the completion of tasks.[17]
- The knowledge required to fulfill the functions and corresponding tasks of the system.
- The number and type of personnel needed.

4.4.1 Staff Skills

Staff must have the knowledge, skills, and abilities (KSAs) needed to effectively plan, design, operate, and maintain ramp management strategies and activities. Staff assigned to ramp management must have a certain level of knowledge in several planning, design, operations, and maintenance areas. For example, in operations, there are primarily two different skill levels needed for a TMC Operator. The first entails executing a pre-defined set of plans to manage traffic. The second skill level is more advanced and requires engineering judgment to adjust ramp strategies (e.g., ramp metering rates or operation) "on the fly" in response to an incident or other change in conditions. Table 4-1 identifies the knowledge level for the key KSA areas.

Staffing needs and skill sets should be traced back to the overall Con Ops. With a good understanding (concept) of how the system should work (operate), the ramp management practitioner will be able to adequately determine which staff skills and numbers of staff are needed to plan, design, operate, and maintain the ramp management strategies and activities.

The staffing skills and levels correspond with the life cycle of project: planning, design, operations and maintenance. The skill sets needed to plan and design ramp management activities are similar and the same person can be used for both planning and designing the system. To some extent, the ramp management designer will be involved in operations and maintenance. However, generally the designer will not be heavily involved in the operations and maintenance aspects of the program.

4.4.2 Staff Training

Staff assigned to ramp management must be properly trained in the knowledge areas identified in Section 4.4.1. Numerous training programs are available through the National Highway Institute (NHI), Institute of Transportation Engineers (ITE), American Society of Civil Engineers (ASCE), and other organizations. Also, some agencies have internal training programs. All of these organizations have courses available to suit staff with differing levels of knowledge. Training must include technical training (details of how the hardware and software work) and functional concepts training (how to plan, design, operate, and maintain the system). Another form of internal training is “on-the-job” training or apprenticeships. This can be a valuable and important form of in-house training for younger or less experienced staff, conducted by co-workers or supervisors who have a high level of technical ability.

Training Issues

The key factors contributing to the successful operation of any traffic system are training and practice.[17] Training can be categorized in two forms: technical and operations.

Technical training covers how the equipment, communications network and software work and includes how to design, install, troubleshoot, and repair the system.

Operations training is directed toward understanding the concept behind the strategy or system chosen, and using the strategy to achieve the operational goals and objectives. Operations training should also include a course on Systems Engineering. Designing, building, operating and maintaining systems is different than designing and building roads. Staff, at all levels, must become comfortable with the process.

Practitioners must identify training needs as part of the planning process. This is a key factor because the process of identifying qualifications and hiring staff is time consuming. In addition, the needs are ongoing as staff turns over and the system expands. There should be a training program to provide opportunities for training on an ongoing basis.

Table 4-1: Recommended Knowledge, Skills, and Abilities Levels for Ramp Management Staff

KSA Area	Staff Type		
	Planning/Design*	Operations**	Maintenance***
Traffic Management/ Engineering Concepts	Thorough^^^	Working^	Working^
Traffic Flow Theory	Thorough^^^	Working^	Working^
Freeway Traffic Operations	Thorough^^^	Thorough^^^	Considerable^^
ITS Planning	Thorough^^^	Working^	Working^
ITS Design	Thorough^^^	Working^	Considerable^^
Telecommunications	Thorough^^^	Working^	Thorough^^^
Systems Engineering	Thorough^^^	Considerable^^	Working^
Traffic Signal Systems Design	Thorough^^^	Considerable^^	Thorough^^^
Traffic Signal Maintenance	Working^	Working^	Thorough^^^
Roadway Geometric Design	Thorough^^^	Working^	Working^
HOV Planning/Design	Thorough^^^	Working^	Working^
HOV Operations	Considerable^^	Considerable^^	Working^
Public Information/Public Speaking	Considerable^^	Considerable^^	Working^

* "Planning/Design" refers to staff involved in the development of the initial concept/layout through the detailed design of the ramp management elements.

** "Operations" refers to staff involved in monitoring and operating the ramp management strategies.

*** "Maintenance" refers to staff involved in maintaining and repairing the ramp management equipment.

^ "Working" implies a basic knowledge and understanding of basic ramp management concepts and traffic management program.

^^ "Considerable" implies a sufficient knowledge and understanding of more detailed ramp management concepts, an understanding of the traffic management program, and the ability to identify performance levels and make suggestions for changing/modifying strategies.

^^^ "Thorough" implies an in-depth knowledge of all elements of the ramp management arena and all interrelated traffic management areas.

4.4.3 Staffing Levels

The number of staff will depend on a number of factors, including the size of the system, the system complexity, the hours of operation, and the specific ramp management strategies chosen. For example, in the Seattle area, the Washington State Department of Transportation (WSDOT) operates 120 ramp meters. WSDOT has one operator who focuses on the ramp meters during the peak periods. During the non-peak periods, this person performs other duties when the ramp metering is off. In Salt Lake City, the Utah Department of Transportation (UDOT) has one operator who takes traffic signal trouble calls and operates and monitors the 24 ramp meters during the peak periods.[18]

In addition to these factors, staff levels may be influenced by the personal choices of the individual responsible for ramp management. For instance, the amount of staffing may be driven by how aggressive the ramp management practitioner plans, designs, installs, operates, and maintains ramp management strategies.

Several issues are of concern when determining the type and amount of staff:

- Service level.
- Using in-house staff or outsourcing.
- Funding.

Service Level Issues

In order to be able to determine the appropriate service level, the Traffic Manager needs to figure out what activities the agency is going to support and how much effort this will require. Once these activities have been prioritized, the appropriate number of staff can be assessed and hired.

In-House versus Outsourcing

There are three basic methods of staffing for ramp management strategies: in-house, outsourcing, and hybrid.

In-House

In-house staffing refers to developing ramp management staff within the agency. Staff assigned to ramp management would provide services from planning through maintenance. For example, with maintenance, if the practitioner decides to develop in-house expertise, two options are available. The first option is to organize a full-time traffic management maintenance staff who are part of the traffic management organization. The advantage of this option is that the staff is dedicated to the traffic management devices and infrastructure. The disadvantage for most agencies is that this scheme requires additional (and in some cases, duplicated) staff, which can be difficult to obtain.

The second option is to utilize existing agency maintenance staff who maintain similar types of systems or equipment, such as traffic signals. The advantage of this option is the ability to utilize staff who are already trained and familiar with the agency's procedures. The disadvantage is that the traffic signal maintenance technician may be more comfortable responding to a traffic signal trouble call than to a ramp meter trouble call. Priorities must be set in advance to avoid any issues when there are competing maintenance needs.

The practitioner should be aware that sometimes employee skills that are specific to ramp management do not always neatly fit into the agency's employee classification system. The manager must work with the agency's human resource department to develop the appropriate job classifications.

Outsourcing
A problem for many government agencies is obtaining a budget to increase staffing needs. Also at issue is the agency's ability to recruit and retain qualified personnel with the skill sets necessary to design, operate, and maintain systems. Outside contractors and consultants have been used successfully for planning, designing, operating, and maintaining systems. Another form of outsourcing is working with partner agencies and utilizing their staff to support ramp management efforts.

Hybrid
A hybrid staffing program is a combination of the in-house and outsourcing options. The agency may have the ability to obtain some additional staff, but not all that are needed. The agency then has the ability to perform some aspects while managing outside contractors for the remaining elements. This form of staffing plan allows the responsible manager to target the skills needed for in-house staff, thereby targeting the skills needed for outside contracting.

Funding

Staffing levels and methods are in part based on the amount of funding an agency has available. It is recommended that practitioners first identify current funding levels and estimate future funding, and then make ramp management decisions. Failure to follow this process may result in agencies implementing strategies that cannot be supported by current or anticipated future staffing levels. For instance, if a decision is made to manually close ramps, additional funding will be needed to hire additional staff to perform these duties. The exact amount of funding needed however, depends on several factors, one of which is the number of ramps that need to be manually closed. This also assumes that current staff workloads are not flexible and do not allow additional duties beyond the ones they currently perform. Therefore, based on funding levels the ramp management practitioner must ultimately make decisions regarding the implementation of ramp management strategies. This decision indirectly influences staffing levels and approaches.

4.5 Resources to Support Successful Operations

This section explores the operational issues that affect the success of day-to-day operations and management of ramp management strategies. Individuals responsible for ramp management need to provide their staff with the tools needed to efficiently and effectively do their jobs. They should also be aware of the tools available to operators that promote efficiencies and reduce operator workload. In summary, this section discusses the importance of having the correct programs in place to support successful operations. For more information on the specific needs for ramp management actions, refer to Chapter 8 which focuses on the operations and maintenance of ramp management strategies.

The required resources for effective ramp operations and management include many of the elements common to today's traffic management systems. They include properly trained personnel as well as:

- Operating procedures.
- Operations, training, and maintenance manuals.
- Operations and maintenance tools.

4.5.1 Operating Procedures

Standard operating procedures (SOP) are needed to provide staff with the information needed to do their jobs – which includes both technical and human resources or personnel procedures. Procedures should be developed for operating, monitoring, and maintaining all ramp management strategies employed. Ramp metering, because metering rates and traffic conditions can change frequently throughout a single peak period, requires the largest set of procedures dealing with operations. Some of the topics to be considered for standard operating procedures include:

- Basic ramp meter operations.
- Ramp meter timing and adjustment.
- When to adjust ramp meter timing based on performance and need.
- How to monitor ramps and their effect on both mainline and arterial traffic flow.
- Performance measures.

Part of basic ramp operations is monitoring the conditions on ramps and the freeway section associated with the ramps. Ramps can be monitored:

- From a centralized location (such as a Traffic Management Center) through the use of field-located closed-circuit television (CCTV) cameras.
- Through sensors located at the ramp and along the freeway.
- Through direct observation in the field.

Being able to monitor the effect of a particular ramp control strategy is critical to success. This allows the operating agency to make adjustments as needed depending on conditions, traffic volumes on the ramp or mainline, incidents, or special events.

Constant monitoring of each interchange using CCTV is difficult to do, both because of the staffing it would require and because an operator cannot be expected to keep attentive while simply watching CCTV images. However, the ability to observe the effects of a particular ramp management strategy in real-time is necessary. With proper detection equipment placed at critical locations, operators determine when adverse conditions occur and begin monitoring the particular location in question. Monitoring, detection, and control of a ramp should be as automated as possible. Even with detection, it is recommended that each interchange be viewed with a CCTV camera on a periodic basis to ensure smooth operations. To make this task easier, a camera "tour" can be set up so one monitor is dedicated to constantly cycling through the live images of each interchange.

When observation through detection equipment or CCTV is not available, in-field reviews of ramp meter effectiveness should be conducted on at least a quarterly or seasonal basis. This will involve field crews observing the operation of the ramp meters and how they affect ramp traffic and the local arterial traffic. Wait times should be observed along with violation rates, effects on mainline as well as arterial traffic, and ways to improve the operation.

For ramp closures, step-by-step procedures are needed to assure that a ramp is closed safely. These procedures include how to operate electronic and mechanical equipment used for closure as well as where and how to place any barriers and signs that are needed for the closure.

Maintenance procedures are needed for maintaining field equipment, such as ramp meters and detectors. Maintenance procedures cover preventive and response maintenance actions and diagnostics.

4.5.2 Operations, Training, and Maintenance Manuals

Training information can either be incorporated into the SOP or reside in a stand-alone document. For example, if the strategy is ramp metering, training manuals should include the information noted above as being part of the SOP as well as detail on the following:

- Theories behind ramp metering.
- Where, when, and why ramp metering is effective.
- How to determine what type of timing plan to use.
- What type of adjustments should be made based on performance.
- How to track ramp performance and associated measures of effectiveness.
- How to use the existing tools at the TMC to monitor ramp performance.

The reason for including theoretical background information in the training manual is so that operations staff can understand why a certain ramp management strategy is being employed and what to expect. This will allow the operator to better identify when a particular strategy is either producing the desired effect or is not improving ramp performance.

For maintenance personnel, their training manual should include the above information as well as detailed information on how the actual ramp metering equipment is to be maintained or replaced. In addition, it should include equipment manuals, installation and maintenance instructions, maintenance schedules, and troubleshooting guides.

4.5.3 Operations and Maintenance Tools

Practitioners responsible for ramp management must provide their staff with the tools needed to effectively operate, maintain, and troubleshoot ramp management strategies. As such, the practitioner responsible for ramp management must be aware of the various technical issues that may affect an operator's ability to perform his or her duties. Additionally, the practitioner responsible for ramp management must also identify and make known the tools that operators can use at their discretion to improve operations.

Practitioners should provide software that helps improve and make operations more efficient. For instance, detection equipment may be available and installed to automatically alert operators when queues approach the storage limit for a particular ramp, when frequent violations of ramp controls are taking place, or when exit ramp traffic has backed up onto the mainline roadway. Software at the TMC or central system needs to be in place to support the field equipment in these instances. Tools like these will reduce operator workload, which helps operators work more effectively and think more clearly.

Maintenance personnel will require the proper diagnostic equipment and tools to maintain ramp metering systems, as well as other ramp management systems including automated gates and signs. Vehicles should be equipped similarly to a traffic signal technician's vehicle, with the associated tools and replacement equipment. Depending on how ramp meter timing is adjusted, the maintenance personnel may require a ruggedized laptop with the associated software loaded that will allow them to make field adjustments to the ramp meter timing. It is imperative that the hardware and software be kept up-to-date for maximum effectiveness of staff.

Maintenance personnel will also need tools that identify and troubleshoot problems before they occur or become larger. These tools may consist of equipment, such as battery testers, devices to test communications bandwidth, and/or vendor-supplied manuals.

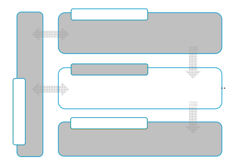
4.6 Chapter Summary

It is now evident how important the Traffic Manager's role is in supporting the agency's ramp management activities. Establishing strong inter- and intra-agency relationships is critical. Beyond that, he or she must possess a deep understanding of the day-to-day issues, operations and procedures that are necessary of a seasoned Traffic Manager. This ability to coordinate well with other internal and external partners will lead to the continued growth and effectiveness of the agency's ramp management activities.

Issues such as staffing, skill levels, and training must be addressed. In addition, knowledge of how to utilize and manage these resources is required to support ramp management. Using the guidance provided in this chapter, the practitioner now has the tools to implement successful ramp management strategies that can be carried out within the framework of the traffic management program. Chapter 5 discusses ramp management strategies that may be included in the traffic management program and have been implemented around the country. Chapter 6 presents a framework to help the practitioner decide which strategies are appropriate for the conditions he or she faces.

5

RAMP MANAGEMENT STRATEGIES



Decision Making

Chapter 5: Ramp Management Strategies

Chapter 6: Developing and Selecting Strategies and Plans

Chapter 7: Implementing Strategies and Plans

Chapter 8: Operation and Maintenance of Strategies and Plans

5.1 Chapter Overview

Chapter 5 is the first of four chapters that comprise the ramp management decision making process. Chapter 5 introduces and describes commonly used strategies that may be implemented to better manage traffic on and adjacent to freeway ramps. In doing so, this chapter lays the foundation from which practitioners may successfully develop and select strategies and plans (Chapter 6), implement strategies and plans (Chapter 7), and operate and maintain strategies and plans (Chapter 8). Together, Chapters 5-8 feed into Chapter 9 (Visibility Module), where practitioners will be able to monitor and evaluate the selected ramp management strategies.

Chapter 5 begins with an overview of four ramp management strategies (see Section 5.2) followed by four separate sections that describe each of these strategies in greater detail (see Sections 5.3-5.6). The strategies discussed here in this chapter and throughout the rest of this handbook include: ramp metering, ramp closure, special use treatments, and strategies implemented at the ramp-arterial terminal (i.e., intersection). These four strategies give agencies the ability to control the rate that traffic is allowed to enter the freeway facility; temporarily or permanently restrict traffic flow, provide priority to special vehicle uses, and implement treatments at the ramp-arterial terminal to improve traffic operations on and along ramps and adjacent arterials. For each strategy, a number of

Chapter Organization

5.2 Overview of Ramp Management Strategies

5.3 Ramp Metering

5.4 Ramp Closure

5.5 Special Use Treatments

5.6 Ramp Terminal Treatments

associated techniques and approaches exist, some of which will prove to be better than others at fulfilling agency goals and objectives.

To help facilitate reader understanding of this chapter, several objectives were developed. These objectives are outlined below.

Chapter 5 Objectives:

- Objective 1: Become familiar with the four basic strategies used to manage traffic on freeway entrance and exit ramps.
- Objective 2: Gain a high-level understanding of what each ramp management strategy entails and the benefits and impacts of implementing each.
- Objective 3: Identify where ramp metering strategies have been applied and the results that strategies produced.
- Objective 4: Understand the unique issues associated with each strategy and why these issues are important.

5.2 Overview of Ramp Management Strategies

The four ramp management strategies discussed in this chapter may be used separately or in combination with one another to manage traffic on a ramp or at the points where ramps connect to adjacent freeways and/or arterials. The advantages and disadvantages of each strategy differ, thereby requiring practitioners to closely analyze each to determine its appropriateness for satisfying existing problems and conditions. Before deciding which strategy is most appropriate for addressing a specific problem or situation (Chapter 6), it is important that practitioners understand the purpose of each strategy and its advantages and disadvantages. This understanding will help narrow the focus and to identify the one strategy, or set of strategies, that is most appropriate given a set of unique issues and characteristics. A brief overview of the available ramp management strategies is provided in the following section, while Sections 5.3 through 5.6 describe each in greater detail. The strategies discussed are bulleted below in the order that they are discussed.

- Ramp Metering.
- Ramp Closure.
- Special Use Treatments.
- Ramp Terminal Treatments.

5.2.1 Ramp Metering

Ramp metering is the deployment of a traffic signal(s) on a ramp to control the rate vehicles enter a freeway facility. By controlling the rate vehicles are allowed to enter a freeway, traffic flow onto the freeway facility becomes more consistent, in essence smoothing the flow of traffic on the mainline and allowing efficient use of existing freeway capacity.

Ramp meters may be programmed to release vehicles one at a time or in a small (usually two-vehicle) platoon to mitigate the impacts that vehicles entering the freeway have on freeway traffic flow. A ramp meter may be coordinated with other ramp meters to smooth traffic flow at a point or along a stretch of freeway or alternatively for several freeways within a regional network. Additionally, ramp meters may be programmed to optimize freeway flow and/or reduce congestion and its effects (collisions, delay, emissions, and fuel consumption). However, it should be noted that motorists may elect to bypass metered ramps in lieu of other ramps upstream or downstream of those that are metered. The potential for diversion is an issue that practitioners need to take into consideration before deploying ramp meters.

Ramp metering has been a practice used since the late 1950's and early 1960's when ramp meters were deployed in Chicago, Detroit, and Los Angeles. Since this time, more than 2,100 ramp meters have been deployed in 29 metropolitan areas within the United States (U.S.).[19] Table 5-1 identifies major ramp metering programs and their approximate number of meters.

Table 5-1: Major Ramp Meter Programs[19]

Metropolitan Area	No. of Meters*
Los Angeles – Anaheim – Riverside, CA	1,316
Minneapolis – St. Paul, MN	419
San Diego, CA	288
San Francisco – Oakland – San Jose, CA	191
Houston – Galveston – Brazoria, TX	128
Phoenix, AZ	122
Seattle – Tacoma, WA	120
Milwaukee – Racine, WI	118
Chicago, IL – Gary, IN – Lake County, IL	113
Portland, OR – Vancouver, WA	110

* Figures shown were current as of 2002.

Typically, ramp meters are deployed on ramps that connect freeways with local or arterial streets; however, there have been several instances in the U.S. where meters have been deployed on ramps that connect one freeway with another. Of the 10 major ramp meter programs identified above, freeway-to-freeway ramp meters have been deployed in over half of them. These cities are:[19]

- Minneapolis – St. Paul, Minnesota.
- San Francisco – Oakland – San Jose, California.
- San Diego, California.
- Milwaukee – Racine, Wisconsin.
- Portland, Oregon – Vancouver, Washington.
- Seattle, Washington.

Case Study: Minneapolis, Minnesota Ramp Metering Program

In early 2001, a report that documented the results of an evaluation of the ramp metering program in Minneapolis – St. Paul, Minnesota was released. The evaluation which was formally conducted in the fall of 2000, sought to measure the benefits and impacts of ramp meters in the Twin Cities, and to make comparisons of this program with others in the United States. Since ramp meters were already in place, the first phase of data collection focused on collecting data to baseline conditions "with ramp meters". During the second phase, meters were turned off, and data were again collected to measure conditions in the after phase of when ramp meters were turned off. Analysis of the data that were collected indicated that ramp meters had a net positive effect on traffic operations. When ramp meters were turned off, traffic volumes, travel time, travel time reliability, safety, emissions, and fuel consumption measurements were worse than when meters were on.

Benefits

Experience with ramp meters has shown safety, travel time, speed, throughput, and environmental benefits. When ramp meters were turned off for a six-week study in Minneapolis a before and after evaluation concluded that meters were responsible for a 21 percent reduction in crashes and a nine percent increase in mainline volumes. Surveys in Minnesota and Glasgow, Scotland showed a majority of motorists viewed ramp metering as a beneficial traffic management strategy.

Advantages of ramp meters in regard to freeway operations include:

- Improved system operation.
    - Increased vehicle throughput.
    - Increased vehicle speeds.
    - Improved use of existing capacity.
- Improved safety.
    - Reduction in number of crashes and crash rate in merge zones.
    - Reduction in number of crashes and crash rate on the freeway upstream of the ramp/freeway merge zone.
- Reduced environmental effects.
    - Reduced vehicle emissions.
    - Reduced fuel consumption.
- Promotion of multi-modal operation.

Table 5-2 provides a sample of reported benefits.

Impacts

Potential negative impacts of ramp meters in regard to freeway operations include:

- Potential for traffic diversion – Motorists may elect to bypass queues that form at ramp meters in lieu of arterials that parallel a freeway facility. This is especially true for motorists who take short trips, in which case wait times at meters may exceed the additional travel time in taking slower arterial routes. If available routes cannot support diverted traffic, operations on nearby arterials may be negatively affected.
- Equity – Arguments have suggested that ramp meters favor suburban motorists who make longer trips, versus those that live within metered zones who make shorter trips. This argument is based on the assumption that the suburban motorist lives outside a metered zone and is not delayed by ramp meters when entering a freeway and traveling through a metered zone. As such, the possibility exists that the motorist who lives closer to a downtown area may have a proportionally unfair commute when comparing travel time against travel distance. As such, ramp meters are sometimes considered to promote longer trips.
- Socio-economic considerations – Ramp meters may shift traffic congestion and associated impacts from one location to another. In areas where traffic problems are minimized, or are all together eliminated, property values may increase due to the fact that these areas are seen more favorably. Consequently, in areas where traffic congestion and associated problems are increased, property values may decrease. Ramp meters have the potential to create queues on the ramp that may flow into the adjacent arterial intersection. This may cause more delay on the arterial which negatively affects the immediate neighborhood and surrounding businesses.

Table 5-2: Ramp Metering Benefits by Performance Measure[1,8]

Measure	Location	Benefits
Safety	Minneapolis, MN	26% reduction in peak period collisions and 38% decrease in peak period collision rate.
	Seattle, WA	34% decrease in collision rate.
	Denver, CO	50% reduction in rear-end and side swipe collisions.
	Detroit, MI	50% reduction in total collisions, 71% reduction in injury collisions.
	Portland, OR	43% reduction in peak collisions.
	Long Island, NY	15% reduction in collision rate.
Travel Time and Speed	Long Island, NY	9% increase in average vehicle speed.
	Portland, OR	26 to 66 km/h increase in average vehicle speeds (16 to 41 mi/h).
	Denver, CO	69 to 80 km/h improvement in average vehicle speeds (43 to 50 mi/h).
	Seattle, WA	Decrease in average travel time from 22 to 11.5 minutes.
	Minneapolis, MN	64 to 69 km/h improvement in average peak hour speeds (40 to 43 mi/h).
Throughput	Minneapolis, MN	25% increase in peak volume.
	Seattle, WA	74% increase in peak volume.
	Denver, CO	18% increase in peak volume.
	Long Island, NY	2% increase in throughput.
Environmental	Minneapolis, MN	2 to 55% reduction in fuel consumption.
		Savings of 1,160 tons of emissions.

Despite the benefits of ramp meters, there are several other considerations practitioners need to consider before selecting this strategy, or any of the other strategies discussed in this chapter. Practitioners need to consider if resources (e.g., staff, funding, equipment) are available internally to support ramp metering programs and if these systems can be effectively maintained. If resources to deploy, operate, and maintain these systems are not available, ramp metering programs will ultimately fail. In addition to these resources, staff must also consider how they intend to enforce ramp meter compliance, and must investigate if law enforcement is committed to the ramp meter program. Considerations such as these are discussed in further detail in Chapters 7, 8, and 9.

5.2.2 Ramp Closure

Closing an entrance or exit ramp to all traffic, or to specific vehicle classes on a temporary, intermittent, or permanent basis is a strategy generally considered for safety benefits at locations with severe geometric limitations. Ramp closures change traffic patterns that have been established over a substantial period of time and therefore should be rarely considered for situations where another ramp management strategy may be successfully deployed. Additionally, before a decision is made to close a ramp, consideration should be given for re-routing traffic that normally uses the ramp. This may include development of detour routes and public information/involvement campaigns to disseminate information to the public. Besides locations with severe geometric deficiencies, ramp closures may also be a viable option for managing special event traffic or controlling traffic in or around work zones.

Benefits

Little research is available that document the benefits of ramp closures in improving exiting traffic conditions and safety. Advantages of ramp closure in regard to freeway operations are generally thought to include:

- Reduction in total number of crashes and crash rate, especially rear-end and sideswipe collisions.
- Reduced neighborhood impacts.
- Increased freeway vehicle throughput.
- Increase in freeway vehicle speeds.

These benefits are generally supported by an experiment of peak-period ramp closures conducted on a 5 km (3 mi) stretch of the John C. Lodge Freeway in Detroit. This experiment produced the following findings:[20]

- Freeway volumes increased 3.5 to 13.7 percent.
- Average freeway speed (averages over all periods and locations) increased from 43 to 60 km/h (27 to 37 mi/h) in the AM peak period and from 41 to 62 km/h (25 to 39 mi/h) in the PM peak period.

Impacts

Potential negative impacts of ramp closure in regard to freeway operations include:

- Potential for traffic diversion.
- Promotion of longer trips.

- Increases in fuel consumption and emissions (for diverted trips).
- Socio-economic changes (e.g., neighborhood and business impacts).
- Changes in local land values.

5.2.3 Special Use Treatments

Special use treatments for ramp management focus on providing preferential treatment to a specific class or classes of vehicles and can be applied to either entrance or exit ramps. Special use treatments include exclusive access to ramps for a class of vehicle (e.g., high occupancy vehicle (HOV), emergency, freight, or construction) or special lanes on a ramp for the exclusive use by these vehicle classes. Special use treatments often require regional support to be successfully deployed and funded. Special use treatments are best undertaken in a coordinated effort with other special use treatments and programs. For example, transit management programs may identify candidate ramps where transit vehicle priority considerations may be deployed.

Benefits

Advantages of special use treatments in regard to freeway operations include:

- Promotion and greater acceptance of high-occupancy trips through incentives such as travel time savings.
- Reduction in vehicle emissions.
- Travel time savings for specific vehicle classes.
- Improved incident response.
- Reduced delay by separating or removing different vehicle types.
- Improved safety by controlling the mix of different vehicle types.

Impacts

Potential negative impacts of special use treatments in regard to freeway operations include:

- Increased merging complexity (merging between dedicated HOV lanes and regular use lanes), which could lead to safety problems.
- Possible increased congestion in regular use lanes (if the special use lanes were converted from regular use lanes).
- Equity of infrastructure issues (i.e., a new interchange for transit buses may not be perceived as a fair use of infrastructure if a very small percentage of commuters ride transit or if very few buses will be able to use the new interchange).

5.2.4 Ramp Terminal Treatments

Ramp terminal treatments include signal timing improvements, ramp widening, additional storage or new turn lanes on arterials, and improved signing, and pavement markings on or adjacent to ramps. These treatments are geared to improving localized problems at either entrance or exit ramp terminals. Treatments focus on providing solutions to problems at the ramp/arterial intersection, on the freeway (e.g., exit ramp traffic queuing onto the freeway mainline), or on freeway ramps. At exit ramp terminals, the strategies are aimed at reducing queue spillback on the freeway, but may also be aimed at improved arterial flow by limiting the amount of freeway traffic that can access certain areas in the arterial network. At entrance ramps, the strategies generally are aimed at:

- Better coordination of ramp terminal signal timing and ramp metering timing.
- Sufficient storage space, either on the ramp or in turn lanes on the arterial, to contain queues from ramp meters or from a congested roadway.
- Signing to inform motorists approaching a ramp what to expect at the ramp. The types of signing range from information on the status of ramp meters (on or off), freeway congestion, or ramp closure.

Benefits

Advantages of ramp terminal treatments in regard to freeway operations generally include:

- Reduced delay.
- Reduced queuing.
- Improved safety.
- Reduced downstream arterial impacts.

Benefits of ramp terminal treatments will vary depending on the type of treatment implemented. Additional information on the benefits of ramp terminal treatments is provided later in this chapter.

Impacts

The direct negative impacts associated with ramp terminal treatments in regard to freeway operations are generally minor, but may include:

- Increased trip length and travel time, in the case of turn restrictions.
- Increased traffic signal delay for some traffic movements for certain signal timing strategies.

5.3 Ramp Metering

"…Ramp metering is the use of traffic signals to control the flow of traffic entering a freeway facility."

As briefly stated earlier in this chapter, ramp metering is the use of traffic signals (posted either above or alongside freeway on-ramps) to control the flow of traffic entering a freeway facility. Ramp metering can be an effective tool to address congestion and safety concerns that either occur at a specific point or along a stretch of freeway. The application of ramp metering, however, must be consistent with overall agency and regional transportation policies, goals, and objectives. Ramp meters should not be deployed until metering goals and objectives are integrated into a larger transportation management program and policies that support ramp meter implementation exist.

Assuming that ramp metering fits into the transportation management program, there are several aspects associated with ramp meter operation that practitioners should be aware of prior to making the decision of whether or not to implement ramp meters. These aspects affect how a ramp meter or system of ramp meters control traffic based on agency goals and objectives and on local conditions. Aspects of ramp metering that need to be considered are listed below:

- Metering Strategy.
- Geographic Extent.
- Metering Approaches.
- Metering Algorithms.
- Queue Management.
- Flow Control.
- Signing.

Each of these aspects is described in greater detail in Sections 5.3.1 through 5.3.7.

5.3.1 Metering Strategy

An effective and successful ramp metering strategy meets the goals and objectives it was intended to address. In general, a successful implementation strikes a balance between freeway mainline improvements (generally speed increase and crash reduction) and vehicle wait times and queuing on entrance ramps. In other words, the metering strategy seeks to improve conditions on the freeway while minimizing, to the greatest extent possible, queuing and delay on the ramp. Queuing and delay are impacts that result as vehicle demand approaches freeway capacity and traffic flow begins to deteriorate. Ramp metering helps improve vehicle flow by reducing areas of turbulence.

Metering strategies should reflect the goals and objectives of the system. If the primary objective is to reduce crashes at specific areas near merge points and overall congestion is not a concern, then a ramp metering strategy that implements isolated ramp meters that meter on-ramps at demand (i.e., establishing the metering rate equal to or greater than the ramp demand) may be sufficient to meet the objective. On the other hand, if there is a complex set of objectives that include congestion reduction, regional mobility improvement (more attractive rideshare and transit alternatives), safety improvement, and perhaps others, then a system of ramp meters, probably managed by a central computer system, will be required with a more complex control strategy or algorithm.

There is not a pre-determined set of metering strategies from which one selects the most appropriate. A metering strategy embodies a set of decisions on individual aspects or elements of metering. Each decision should be made to best address the specific goals and objectives of the metering system. Specifics of these decisions are discussed below. Chapter 6 contains guidance on making these decisions. However, it is important to first discuss the philosophy of ramp metering in more depth.

Metering Philosophy

One of the goals of ramp metering is to control the amount of traffic entering a freeway facility such that the mainline flows (i.e., traffic demand) do not exceed maximum volume levels. As mainline flows increase, density increases with a corresponding decrease in traffic speed. As traffic demand approaches highway capacity, traffic flow begins to deteriorate. This increases the probability of flow breakdown (i.e., transition from a stable state to a congested state). This concept is illustrated in Figure 5-1.

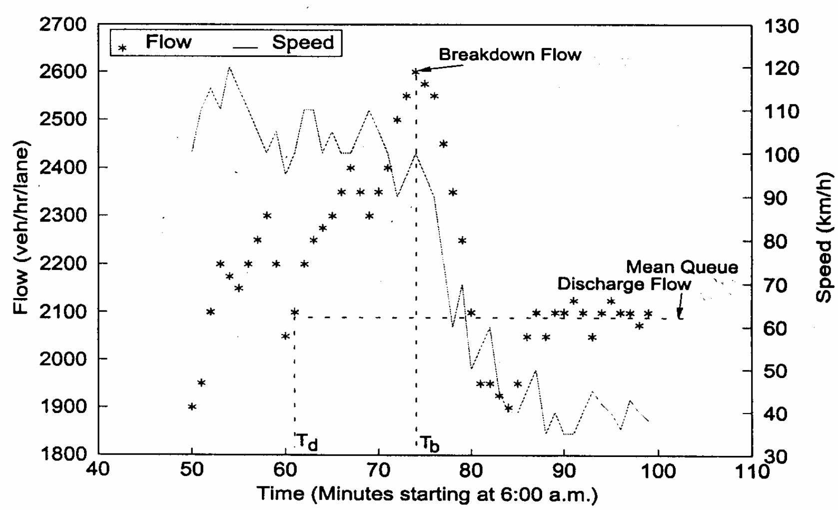


Figure 5-1: Time Trends for Speed and Flow (Typical Morning Rush)

Ramp metering helps balance capacity and demand. Even in an uncongested state, a platoon of vehicles merging onto a freeway can cause enough turbulence (stop-and-go conditions as freeway vehicles slow down or quickly change lanes to accommodate the merging vehicles) to cause localized congestion around the ramp merge area. Metering can minimize these impacts by releasing vehicles in a controlled manner depending on the freeway mainline's ability to accept traffic. With that said, however, it is important to note that motorists who wait longer than 15 seconds at the signal before proceeding through a ramp meter begin to believe that the meter is not working properly.[21] These beliefs lead to decreased compliance of the meter.

Ramp metering may also accomplish the following:

- Reduce the flow at metered ramps during certain time periods and redistribute it to later time periods. This reduces the flow at critical times to reduce congestion at merge points and at downstream bottlenecks.
- Change driver behavior. These changes include the time of day that metered ramps are accessed, the ramp they access, or their overall selected route. Some may also change mode of travel, but this is a relatively small proportion of the overall ramp traffic.

There have been several studies that have compared the properties of non-congested, stable flow with that of congested, unstable flow, including the transitions between these conditions. The pertinent points of this research is described with reference to Figure 5-2.[22,23,24]

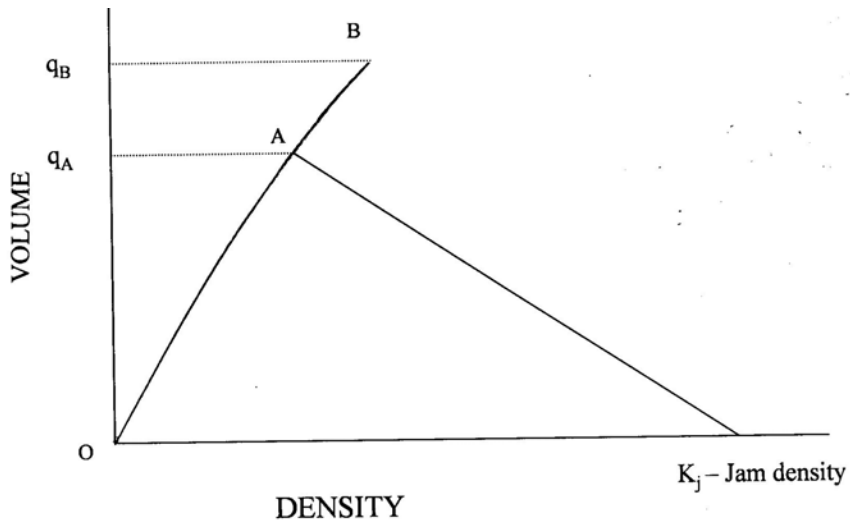


Figure 5-2: Volume-Density Relationships

As volume increases, average density increases in an approximately linear relationship until the volume reaches the level q_A. This near linear relationship implies little speed change. When volume exceeds q_A, a probability arises that the flow will transition to an unstable state, which is generally characterized by lower volume, lower speed and higher density. In Figure 5-2, this transition occurs in the region that is to the right of line AB. If transition has not occurred and if volume continues to increase, operation continues along AB toward point B. Transition will have occurred prior to reaching point B or at that point. After transition, unstable flow conditions may lie to the right of line OB in Figure 5-2. Some researchers represent the average of flow conditions in this area by line AK_j; however, the actual conditions may vary considerably.

Selecting a Metering Strategy

When deciding on or developing a specific metering strategy, practitioners need to first review the goals and objectives that metering is intended to address. Strategies that were developed or have been shown to address those objectives should be considered for implementation. The strategy that appears to best meet the goals and objectives of the system, consistent with local practice and resource constraints, should be selected. With that said however, most applications rely on metering rates that reduce the number of vehicles entering the freeway during certain portions of the metering period or over the entire peak period.

The primary objectives of ramp metering systems are to reduce freeway congestion and/or reduce freeway crashes. However, other objectives may also be addressed by ramp metering. For example, ramp metering may be used to reduce traffic that cuts through neighborhoods or sensitive areas. If traffic is avoiding freeway congestion by driving through these areas to access a downstream ramp, the downstream ramp can be metered. If this ramp feeds the bottleneck that causes the freeway congestion, the problem can be attacked on two fronts. First, ramp metering can improve the flow on the mainline, thereby reducing the need for traffic to cut through the neighborhood or sensitive area. Second, the ramp meter will add a delay to the cut-through trip, again reducing the incentive to cut through the area of concern. In this case, ramp delays may not be a major concern. If the ramp traffic during the metered time is primarily traffic diverting from upstream ramps and the ramp has enough storage, long delays may be advantageous in meeting the objective.

The following sections describe elements of a ramp metering strategy. In selecting a strategy one must consider each of the following elements:

- Geographic extent – the area that will be covered by ramp metering and whether the meters in that area will be operated in an isolated manner or as part of a larger system of meters.
- Ramp metering approach – local or system-wide and pre-timed or traffic responsive.
- Metering algorithm – the specific logic and calculations used to select or determine a metering rate.
- Queue management – how the metering rate will be affected by ramp queues and how the agency will keep queues at a manageable and acceptable level.
- Flow control – how traffic will be released from the meter, one at a time or two at a time in one lane or multiple lanes.
- Signing – how drivers will know that a ramp meter is on or off.

5.3.2 Geographic Extent

The geographic extent of ramp metering (i.e., whether or not one or more ramp meters will be deployed, and on which ramps on which freeways) is primarily based on program goals and objectives and the extent and locations of congestion or other traffic or safety problems or concerns. The geographic extent of ramp metering is determined by assessing whether or not problems are isolated or linked. In other words, are problems confined to a single location (i.e., isolated ramp) or do problems extend along a stretch of roadway containing two or more ramps (i.e., ramps that are linked)? The result of this assessment will affect the selection of an appropriate metering approach (see Section 5.3.3), and therefore is important to the selection of appropriate ramp management strategies. A suggested process to help agencies decide on an appropriate ramp metering strategy is described in Chapter 6. The following paragraphs explain the difference between isolated and linked problems.

Isolated

If traffic or safety problems on a freeway are isolated (i.e., occur at specific locations not adjacent to each other), ramp meters may be used independently to reduce the impact of the problem. When problems are isolated, a single ramp meter may be deployed at the location where the problem is occurring to resolve or reduce the impact of the problem. However, the negative impacts of ramp meter installations should be considered before meters are deployed. Any time a meter is deployed, the potential exists for impacts to occur such as those discussed in Section 5.2.1 (i.e., traffic diversion).

Linked

If traffic or safety problems on a freeway extend beyond the area of a single ramp, to include two or more adjacent ramps, ramp meters should probably be coordinated to effectively address the problem(s). Depending on the extent of the problem, ramp meters may need to be deployed along a freeway segment, an entire corridor, or system-wide to effectively address the problem.

5.3.3 Metering Approaches

There are several approaches, and likewise algorithms, that can be used to meter ramps. This section defines each of the available metering approaches and discusses the advantages and disadvantages of each. This discussion acts as the foundation needed to select a specific metering approach and algorithm (see Chapter 6) based on local conditions and agency needs. A summary of metering approaches is provided in Table 5-3.

Local versus System-Wide Metering

Ramp metering control schemes can be divided into two types, operating under two methods of control. The two types of control schemes are described below:

Table 5-3: Summary of Ramp Metering Approaches

	Pre-timed	Traffic Responsive
Local	▶ Appropriate for localized problems. ▶ Detection in the field is not needed. ▶ Requires periodic manual updates. ▶ Not effective for non-static conditions. ▶ Higher operations costs compared to traffic responsive systems.	▶ Appropriate for localized problems. ▶ Detection in the field is needed. ▶ Higher capital and maintenance costs compared to pre-timed systems. ▶ Yields greater benefits because it responds to conditions in the field.
System-wide	▶ Appropriate for widespread problems. ▶ Detection in the field is not needed. ▶ Rarely used compared to system-wide, traffic responsive systems.	▶ Appropriate for widespread problems. ▶ Detection in the field is needed. ▶ Most useful for corridor, system-wide applications. ▶ Greatest capital and maintenance costs, but yields most benefits.

Local (or isolated) Control
Local control is a process of selecting metering rates based on conditions present at an individual ramp, rather than conditions along a segment of freeway, freeway corridor, or regional freeway network. Therefore, local control is appropriate for individual, non-adjacent ramps where problems are isolated. When local ramp metering is used, one or more ramps may be metered, however, there is no effort made to coordinate the effects of ramp meters. The primary concern is improving conditions and reducing congestion near the local ramp. In some cases, when local ramp metering is used, congestion problems at the local ramp may appear to be fixed, when in reality problems are transferred to or uncovered at downstream locations. In these situations, local ramp metering is not recommended.

System-wide (or coordinated) Control
Unlike local ramp metering, which only addresses a congestion- or safety-related problem at a specific location, system-wide control takes into account conditions beyond those adjacent to the ramp when determining metering rates for an individual ramp. To this extent, system-wide control can be used for a freeway segment, an entire corridor, or several freeway corridors where problems extend from ramp to adjacent ramp. The primary concern therefore focuses on improving freeway conditions for a broader freeway system(s). This makes system-wide control more flexible than local control in handling reductions in capacity that occur as a result of delay, collisions, and road blockages.

System-wide control systems typically include local control functionality to ensure that ramp meters remain operational even if communications are lost.

When multiple corridors are metered, consideration should be given to metering freeway-to-freeway ramps. Freeway-to-freeway ramp metering has been implemented in numerous areas such as Los Angeles, Seattle, Minneapolis, and Portland (Oregon). Chapter 6 provides considerations for freeway-to-freeway metering.

Pre-timed versus Traffic Responsive Metering

The two methods of controlling ramp meters are:

1) Pre-timed (also referred to as time-of-day or fixed time). Meter rates are pre-set based on historical conditions and are fixed according to the time of day. Meters are activated based on pre-set schedules.
2) Traffic-responsive. Real-time data are used to determine control parameters, perhaps including when ramp meters are active. Traffic responsive systems can also be constrained to operate only during selected times of day, based on policy decisions.

Pre-timed Metering
Pre-timed metering is the simplest and least expensive form of ramp metering for construction and installation. The low cost of this approach is due in part to the fact that detection and communication with a Traffic Management Center (TMC) is not required. However, this approach is also the most rigid because it cannot make adjustments for real-time conditions including non-recurring congestion (i.e., congestion that occurs as a result of weather, collisions, etc.). Similarly, as pre-timed metering rates are based on historical data, metering rates will typically be

slightly (or significantly, if the rates are not updated periodically) too low or high for current conditions. This may result in less restrictive metering rates than optimal when congestion is heavy, resulting in more freeway congestion than necessary. It may also result in over restrictive metering rates when congestion subsides, resulting in unnecessary queuing and delays on ramps and arterials.

As such, pre-timed metering approaches are best applied to address traffic problems that are a direct result of recurring congestion or localized safety problems that can be reduced by simply breaking up the queues of vehicles entering the freeway. In other words, pre-timed metering is best used to address conditions that are predictable from day-to-day. Pre-timed metering may also be effective in construction zones or for other temporary metering, including special events that do not recur at the same place or on a regular schedule. The low cost of these systems make them attractive backups to other metering approaches or for situations when the primary approach fails. If there is no mainline or ramp detection, agencies must regularly collect data by alternative means in order to analyze traffic conditions on the freeway and determine the appropriate metering rates. The metering operation will require frequent observation so rates can be adjusted to meet traffic conditions.

Traffic Responsive Metering

Traffic responsive strategies use freeway loop detectors or other surveillance systems to calculate or select ramp metering rates based on current freeway conditions. Traffic responsive metering systems often produce results that are generally five to ten percent better than those of pre-timed metering.[25] A traffic responsive approach can be used either locally or system-wide. Both of these approaches are discussed below.

Local Traffic Responsive

Local traffic responsive metering approaches base metering rates on freeway conditions near the metered ramp (i.e., immediately upstream and downstream of the ramp, or at the merge point). Similar to pre-timed systems, local traffic responsive systems are proven strategies that are often used as backups when system-wide algorithms fail. Unlike pre-timed systems, surveillance of the freeway using traffic detectors is required. Although, more capital costs are required to implement traffic responsive systems, they more easily adapt to changing conditions and can provide better results than their pre-timed counterparts.

System-wide Traffic Responsive

The goal of system-wide traffic responsive systems is to optimize traffic flow along a metered stretch of roadway, rather than at a specific point on the freeway (as is the case of local traffic responsive systems). As such, metering rates at any given ramp will be influenced by conditions at other ramps within the system or corridor that is metered. Like local traffic responsive systems, system-wide traffic responsive systems require data from ramp detectors and local freeway detectors. In addition to these components, system-wide traffic responsive systems are unique in the fact that data is also needed from downstream detectors and/or upstream detectors at multiple locations, potentially from cross-street signal controllers, and from the central computer. System-wide traffic responsive systems have the most complex hardware configuration compared to the other metering approaches discussed so far (i.e., pre-timed and local traffic responsive). A summary of the advantages and disadvantages of system-wide traffic responsive systems is listed in Table 5-4.

Metering at Demand

Metering at demand, also referred to as non-restrictive ramp metering, establishes the metering rate equal to or greater than the ramp demand. This approach is often used when the sole objective is to reduce the collisions on the mainline due to vehicle platoons that form on ramps; however, it may also be useful in delaying the onset of congestion on the freeway. Because the metering rate is set equal to ramp demand, the main benefit occurs when platoons are broken up to smooth the flow of traffic onto the freeway. Metering in this fashion is beneficial when ramp metering is first introduced in an area, since it allows motorists to become familiar with metering operations while not subjecting them to lengthy delays. As motorists become familiar with the system, meter rates can be set gradually more restrictive. Metering at demand may also be used at ramps within a corridor where traffic diversion is not acceptable or at specific ramps where there is not enough ramp capacity to support normal, more restrictive metering. In this regard, metering at demand ensures that queues do not spill onto the upstream arterial.

Operator Selection of Meter Rate

Operator selection is a method, initiated by an operator, to select a metering rate based on prevailing conditions. Usually, operator selection is used to address special conditions such as incidents or special events, where the system algorithm does not respond effectively.

Table 5-4: Summary of Ramp Metering Approach Advantages and Disadvantages

Metering Approach	Advantages	Disadvantages
Pre-Timed (Local & System-Wide)	▶ No mainline detection devices are needed. ▶ No communication with a TMC is required. ▶ Simple hardware configuration compared to other approaches. ▶ Provides safety benefit by breaking up platoon of vehicles entering the freeway. ▶ Can effectively relieve recurring congestion if it is fairly constant day-after-day.	▶ Requires frequent observations so rates can be adjusted to changing traffic conditions. ▶ Often results in over restrictive metering rates leading to unneeded ramp queuing and delays (unless metering at demand is employed), which could affect arterial operations as well. ▶ Not responsive to unusual conditions, such as non-recurring congestion, which in turn can lead to public dissatisfaction.
Local Traffic Responsive	▶ Ability to better manage freeway congestion than pre-timed metering approaches (especially for non-recurring congestion). ▶ Operating costs are lower than pre-timed (due to automatic, rather than manual, meter adjustments), so the extra investment upfront may pay itself off over time.	▶ Higher capital and maintenance costs than pre-timed. ▶ Increased maintenance needs because of mainline detection. ▶ Reactive versus proactive. In other words, improvements are made after the fact, rather than before problems occur. ▶ Doesn't consider conditions beyond the adjacent freeway section, making it difficult to optimize conditions for a downstream bottleneck.
System-Wide Traffic Responsive	▶ Provides optimal metering rates based on real-time conditions throughout the system or corridor. ▶ Some algorithms, such as the fuzzy logic algorithm, have the ability to address multiple objectives (e.g., freeway congestion and ramp queues).	▶ Requires mainline detection (both downstream and upstream detectors). ▶ Requires communication to central computer. ▶ Requires technical expertise for calibrating and implementing system. ▶ More expensive than local traffic responsive in implementation resources needed and communications maintenance.

5.3.4 Metering Algorithms

The following sections describe several algorithms commonly used to meter ramps. All of the described algorithms are considered system-wide traffic responsive (although some have the built-in capability to operate as local traffic responsive).

Minnesota Zone Algorithm

The Minnesota Zone Algorithm, a stratified zone metering algorithm, attempts to balance traffic volumes entering and exiting predetermined metering zones to maintain a consistent flow of traffic from one zone to another. The algorithm incorporates entering and exiting traffic volumes of each zone and adjusts the metering rate at individual ramps to hold traffic as needed to maintain consistent traffic flow on the mainline. The algorithm selects one of six predetermined metering rates, ranging from no metering to a cycle length of 24 seconds (meter rate of 150 veh/h).

Metering zones are typically three to six miles in length, and may include several ramps that are not metered. The upstream portion of each zone is typically a free flow area not subject to high incident rates. The downstream portion of a zone typically includes areas defined as bottlenecks, where demand is the greatest.

Key features of the Minnesota Algorithm are:

- Ramp queue lengths are calculated based on queue detector measurements. The queue waiting time is limited to a prescribed value (e.g. four minutes), and the ramp meter rate is raised, as necessary to assure that this condition is met.
- Filtered mainline loop detector data at 30-second intervals is used for the meter rate setting algorithm.
- Spare capacity is calculated from mainline measured volume and speed data.
- Meters are grouped into zones. The intent of the metering algorithm is to restrict the total number of vehicles entering a zone to the total number leaving (including spare capacity). Zones are organized by “layers”. Higher-level layers feature larger zones with greater overlap among zones.
- Metering rates are calculated by distributing the spare capacity among the meters in a zone. If the required metering rates are lower than the minimum metering rates allowed, the metering rates are recalculated for the next higher layer. This process is repeated until all of the minimum rates are satisfied.

There are three variables by which vehicles can enter a zone (inputs) and three by which they may leave (outputs), as summarized in Table 5-5 and Table 5-6.

Table 5-5: Inputs of the Minnesota Algorithm

Input Variable	Input Variable Description
(M)	Metered Entrances: Entrance ramps onto any given freeway that are metered.
(A)	Upstream mainline volume: Total number of vehicles entering a zone through the station at the beginning of the zone.
(U)	Unmetered Entrances: Entrance ramps onto any given freeway that are not metered.

Table 5-6: Outputs of the Minnesota Algorithm

Output Variable	Output Variable Description
(X)	Exits: All exit ramps off any given freeway.
(B)	Downstream Mainline Volume: Total number of vehicles leaving a zone through the station at the end of the zone often a result in an unreasonable volume.
(S)	Spare Capacity: If a zone is free-flowing with little traffic, there is said to be "spare capacity" on the mainline, and meters will not need to be as restrictive. For this reason, the spare capacity is regard as an output.

The objective of a stratified metering algorithm, like the Minnesota Algorithm, is to regulate zones through metering so that the total volume exiting a zone exceeds the volume entering. For this to happen, the relationship of inputs and outputs within a given zone is as follows:

$$M + A + U \leq B + X + S \quad (5.1)$$

Therefore,

$$M \leq B + X + S - A - U \quad (5.2)$$

M is the maximum number of vehicles allowed to pass through all meters in any given zone between stations A and B. The key to stratified zone metering is to disperse the volume M throughout the zone suitably depending on demand (D) on the metered entrance ramps.

Based on demand, the following calculation gives a proposed rate for every meter to run in according to a percentage of M.

$$R_n = (M*D_n)/D \qquad (5.3)$$

Where R_n is the proposed rate for meter n (n is a meter within the zone), and D_n is the demand for the meter n.

Seattle Bottleneck Algorithm

The Seattle Bottleneck Algorithm calculates both a local control metering rate and a bottleneck metering rate. Calculation of the bottleneck rate occurs when both the following conditions are met:

- A threshold occupancy is exceeded.
- Vehicles continue to be stored in the section.

When conditions are not met, just the local control metering rate is determined.

The local metering rate is based on mainline occupancy adjacent to the metered ramp. For every metered ramp, a meter rate/mainline occupancy relationship is defined by five occupancy-metering rate pairs. The algorithm compares mainline occupancy adjacent to the ramp to predefined occupancy-metering rate pairs. The metering rate is determined by interpolating between these pairs for the actual mainline occupancy.

The bottleneck rate is based on traffic volumes downstream of the ramp. A specific number of upstream ramps are identified for every freeway segment, defined by two adjacent mainline detector stations. The bottleneck metering rate reduces the number of vehicles entering the mainline from these ramps by the number of vehicles stored in the freeway segment. Each ramp may have multiple bottleneck metering rates calculated, one for each downstream segment for which it has been identified. The algorithm selects the most restrictive of these as the final bottleneck metering rate.

The algorithm compares the final bottleneck metering rate to the local metering rate and selects the more restrictive of the two. The final step is to adjust the metering rate for ramp conditions, such as queuing. Two queue detection loops are located on each ramp. If traffic queues onto either of these, the metering rate is adjusted upward so the queuing can be eased. A larger adjustment is applied when queues reach the queue detector farthest back from the ramp meter. The final adjusted metering rate is implemented for each ramp.

Washington State DOT Fuzzy Logic Algorithm

The Washington State DOT (WSDOT) Fuzzy Logic Algorithm was developed in response to the limitations in the Seattle Bottleneck Algorithm. The drawbacks in the Seattle Bottleneck Algorithm include:

- When queuing occurs, the metering rate is adjusted upward without trying to reduce metering rates at nearby meters. The result is that queues form as the freeway conditions improve or stay stable. The metering rate becomes less restrictive when the queues reach the queue detectors, which eases the queuing but causes freeway conditions to deteriorate, which then triggers a more restrictive the metering rate, thereby causing ramp queues to form once again in an iterative manner.
- The Bottleneck Algorithm is reactive versus predictive, meaning that problems must first occur before solutions are set in place.

The Fuzzy Logic Algorithm was developed to address the drawbacks of the Bottleneck Algorithm. The WSDOT Training Manual for the fuzzy logic algorithm states:[26]

"There are four main reasons why FLC (Fuzzy Logic Control) is well-suited for ramp metering. 1) It can utilize incomplete or inaccurate data. 2) It can balance conflicting objectives. 3) It does not require extensive system modeling. 4) It is easy to tune."

The first reason addresses inherent problems with data accuracy and reliability in loop detector data and the second addresses the cyclic nature of the Bottleneck Algorithm mentioned above. The Fuzzy Logic Algorithm uses mainline speed and occupancy data from the immediate upstream detector station and up to several downstream detector stations and occupancy data from ramp queue detectors to determine the best metering rate for conditions. Consideration of ramp queues is built into the algorithm rather than adjusting metering rates in a separate calculation.

Fuzzy Logic

Although the WSDOT algorithm provides an improvement compared to non-metered operation, observations over a period of time identified the following areas where the algorithm could be improved:

- The algorithm required congestion to develop before it could react.
- The algorithm tended to oscillate between controlling mainline congestion and dissipating excessive ramp queues.

Taylor, et al. (15) describe a new algorithm employing fuzzy logic designed to address these deficiencies. Fuzzy logic has the ability to address multiple objectives (by weighing the rules that implement these objectives) and to implement the tuning process in a more user-friendly fashion (by the use of linguistic variables rather than numerical variables). Rule groups used by the algorithm include:

- Local mainline speed and occupancy.
- Downstream speed and occupancy.
- Ramp queue occupancy.
- Quality of the ramp merge.

There are six inputs to the fuzzy logic controller (FLC). These include speed and occupancy from the mainline and downstream detector stations, the queue occupancy detector and the advanced queue occupancy detector (at the upstream end of the ramp storage location). "Fuzzification" translates each numerical input into a set of fuzzy classes. For local occupancy and local speed, the fuzzy classes used are very small (VS), small (S), medium (M), big (B), and very big (VB). The degree of activation indicates how true that class is on a scale of 0 to 1. For example, if the local occupancy were 20 percent, the medium class would be true to a degree of 0.3, and the big class would be true to a degree of 0.8, while the remaining classes would be zero (top of Figure 5-3). The downstream occupancy only uses the very big class, which begins activating at 11 percent, and reaches full activation at 25 percent (bottom of Figure 5-3). The downstream speed uses the very small class, which begins activating at 64.4 km/hr and reaches full activation at 88.5 km/hr. The queue occupancy and advance queue occupancy use the very big class. For ramps with proper placement of ramp detectors, the parameter defaults are for activation to begin at 12 percent, and reach full activation at 30 percent. For each input at each location, the dynamic range, distribution and shape of these fuzzy classes can be tuned.

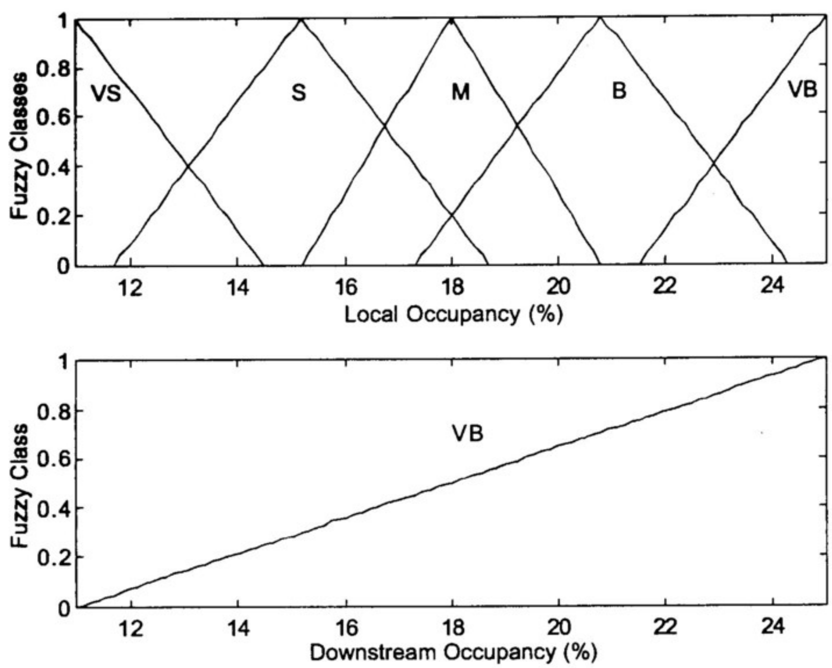


Figure 5-3: Fuzzy Classes

After the fuzzy states have been developed, weighted rules are then applied to develop the metering rate. Examples of weighted rules are shown in Table 5-7.

Table 5-7: Example Rules Used to Develop Fuzzy Logic Meter Rate

Rule	Default Rule Weight	Rule Premise	Rule Outcome
6	3.0	If local speed is VS AND local occupancy is VB	Metering Rate is VS
10	4.0	If downstream speed is VS AND downstream occupancy is VB	Metering Rate is VS
12	4.0	If advance queue occupancy is VB	Metering Rate is VB

Note: (VS) Very Small, (VB) Very Big

The last step is to generate a numerical metering rate based on the rule weight and the degree of activation of each rule outcome.

Denver, Colorado Helper Algorithm

The Denver, Colorado Helper Algorithm is based on a local traffic responsive algorithm with centralized control. Under centralized control, meters are polled every 20 seconds to collect detector and metering data. If the meter is operating at its most restrictive metering rate and if the detector's threshold occupancy value is exceeded, the algorithm defines the meter as "critical". Based on this classification, the algorithm begins to override upstream ramp control. If a ramp remains critical for more than one minute (three consecutive, 20-second periods), the algorithm reduces at the next upstream meter by one metering rate level. The algorithm continues this process for every meter within the system for each consecutive 20-second period until the problem is resolved or until all ramps have been overridden.

The algorithm assigns up to seven ramp meters to as many as six groups or zones (maximum of 42 ramp meters).

Northern Virginia Algorithm

The Northern Virginia Algorithm bases the meter rate in a particular "zone" on predicted demands. The algorithm defines a link as the freeway segment between two entrance ramps. Metering zones can include up to ten links.

The meter rate is determined as the difference between the predicted demand and the capacity of the link that contains the ramp. The predicted arrival demand is calculated sequentially in each zone starting at the link furthest upstream in the zone. The available capacity is sequentially calculated in each zone starting at the link furthest downstream in the zone.

SWARM Algorithm

The System-Wide Area Ramp Metering (SWARM) Algorithm is used for coordinated, system-wide metering approaches. The SWARM Algorithm essentially is the product of two independent control algorithms collectively referred to as SWARM1 and SWARM2.

SWARM1, the more complex of the two, uses previously recorded data to forecast future volumes. Based on this forecast, SWARM1 determines the onset of congestion and restricts real-time volumes from exceeding pre-determined saturation values. The general flow of information for the SWARM1 Algorithm is shown in Figure 5-4.

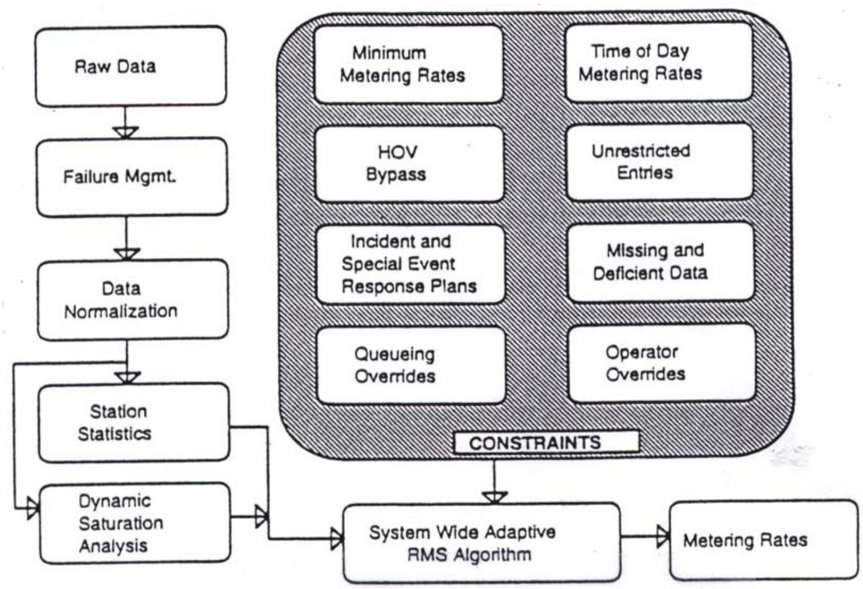


Figure 5-4: SWARM1 Data Flow

SWARM2 is basically a local traffic responsive algorithm. The overall SWARM algorithm compares the metering rates of both SWARM1 and SWARM2 and picks the more restrictive of the two.

5.3.5 Queue Management

In part, the success of a ramp metering approach depends on the ability to smooth the flow of traffic entering the freeway while adequately containing queues on the ramp. When demand exceeds the metering flow rate, and storage on the ramp cannot handle the excess demand, traffic will queue onto the adjacent arterials, causing delays and increased risk of rear-end crashes. Ramp metering approaches must consider whether and how ramp queues may be managed.

No Queue Limits

Few metering algorithms do not take queue lengths into account at all. If there is no queue management in place, queues may back up onto surface streets. Generally, queue lengths are a sensitive issue with local agencies and the surrounding neighborhood, as well as with the drivers in the queue. Approaches that do not take ramp queues into account are not recommended unless metering rates will always be set at or above ramp demand.

Queue Adjustments

Most ramp metering algorithms have specific philosophies for managing queues, either by:

- Providing sufficient storage for worst-case queues, or
- Detecting queues and adjusting metering rates accordingly.
  - Queue detectors are placed on ramps upstream of the meter stop bar at critical locations.
  - If a queue is detected at the detector, the meter rate is increased.
  - Some algorithms will increase at one level when the queue first extends to the detector and increases the metering rate at a higher level if the queue still exists after a programmable amount of time.
  - Some systems have a second queue detector further upstream that will cause the metering rate to increase sharply to more quickly reduce the queue length.
  - Some algorithms take the increased metering rate caused by ramp queues at one ramp into account at other ramps and will adjust those metering rates downward to try to keep the level of traffic on the freeway close to the pre-queue adjustment level.
  - Some algorithms, like the fuzzy logic algorithm, use queues as an integral part of the algorithm that calculates the metering rate.

5.3.6 Flow Control

Flow control refers to the manner and rate by which vehicles are allowed to enter a freeway from a ramp meter. The theoretical maximum rate that vehicles merge with traffic on a freeway facility and the length of queues that result from metering applications is in part a result of the type of flow control implemented at the ramp. The selection of a flow rate depends on several factors. These factors include ramp length, number of lanes, and traffic volume.

There are three strategies for controlling the flow of vehicles entering freeway facilities from a ramp. These strategies are described in the following sub-sections and summarized in Table 5-8.

Table 5-8: Characteristics of Ramp Metering Flow Controls[1,27]

Flow Control Scheme	No. of Lanes	Cycle Length	Approximate Range of Metering Rates (veh/h)	Capacity (veh/h)*
One Vehicle Per Green	1	4 – 4.5 sec.	240-900	900
Multiple Vehicles Per Green	1	6 – 6.5 sec	240-1200	1100-1200
Tandem	2		400-1700	1600-1700

* Depending on driver behavior, capacities slightly greater than these shown may be possible.

One Vehicle per Green Metering (Single Lane)

One vehicle per green metering permits vehicles to enter the freeway one-by-one, as vehicles are detected. When a vehicle approaches the ramp meter, it passes over the presence or demand detector which notifies the signal to turn green. As a vehicle passes over the passage detector, the signal is then notified to terminate the green cycle. If a vehicle is not present on the demand detector, the signal indication remains red until a vehicle is detected. One vehicle per green metering has a capacity of 900 vehicles per hour (veh/h). If a capacity greater than 900 veh/h is desired, a multiple vehicle per green approach may be suitable.

Multiple Vehicles per Green Metering (Single Lane)

The multiple vehicles per green approach (also known as platoon or bulk metering) allow two or more vehicles to enter the freeway facility per green cycle. Typically two and in some cases three vehicles are permitted to pass the ramp meter per each green signal indication. Although this approach doubles or triples the throughput of vehicles per green indication, similar results cannot be expected for vehicle throughput as longer cycle lengths are required. Compared to the one vehicle per green approach, the multiple vehicle per green approach results, on average, in an increase in throughput of 200-400 veh/h.

Tandem or Two-Abreast Metering (Dual Lane)

Tandem or two-abreast metering permits two or more vehicles to enter the freeway facility per cycle, depending on the number of lanes at the meter (one vehicle per lane). To smooth the flow of vehicles merging with freeway traffic, vehicles in each lane are released in a staggered fashion.

Tandem metering may be combined with multiple vehicles per green in some locations when demand is extremely heavy.

5.3.7 Signing

When ramps are metered, appropriate signing needs to be implemented along the ramp as well as on nearby arterials to alert motorists to the presence and operation of ramp meters and to the specific driving instructions they need to perform when approaching a ramp. Signing needs for metered ramps also depend on the selected metering approach, number of available lanes, and whether or not HOV policies are in place. A description of the possible signing types for metered ramps is provided below.

Advance Warning

Drivers need to be alerted to the presence and operation of ramp meters in advance of the last decision point for the ramp. In general, advance warning on the arterial is needed to inform motorists of the status of the specific ramp(s) where metering operations are in effect. Advance warning on the ramp is needed to reconfirm the status of metering operations (i.e., meters on or meters off).

For arterial applications, many agencies install advanced warning signs that consist of a sign and flashing beacon to advise motorists of the presence and operation of ramp meters.[28] The need for these types of signs varies with the metering application in place. For instance, advance warning signs should always be implemented when traffic conditions determine the hours of operation. Because these meters may be turned on and off and different times each day, drivers cannot predict when they may be on and need to be informed of ramp meter status before they enter the ramp. Advance warning signs for meters that are activated on a strict time-of-day basis may not be needed, but consideration should be given to installing advance warning signs where drivers may not be able to see the ramp meter signal head or the back of the queue in time to safely stop. Also, if meters always operate on a strict time-of-day basis and there is no variation, then a static sign that states the hours of metering operations can substitute for an advance sign with warning beacon.

Stop Here on Red or Wait Here for Green

Signs that read “Stop Here on Red” or “Wait Here for Green” should be placed on one or both sides of the on-ramp at the stop bar to identify the stopping location. This sign helps align motorists over the demand detectors placed upstream of the stop bar.

“X” Vehicle(s) per Green

This sign is used to indicate the number of cars that are allowed to pass on each green signal. It should be placed at every ramp signal. A variation on this sign is “X” vehicles per green per lane.

Form Two Lines When Metered

In some locations, ramp shoulders are used during metering operations to help manage queues. Other locations convert wide on-ramps to a defacto two-lane configuration during ramp meter operations. This sign should be positioned near the beginning of the queue storage area and is used to convert the single-lane on-ramp into a dual-lane queue storage area.

5.4 Ramp Closure

Ramp closure is one of the simpler forms of controlling traffic on ramps. Closures may involve controlling automatic gates or manually moving barriers or gates at the ramp. More extreme methods such as physically removing the ramp are also options for permanent applications. Regardless of the method used to close the ramp, closures will have a significant impact on existing traffic patterns. Closures will result in traffic diverting to upstream and downstream ramps. As a result, traffic volumes and congestion will likely increase on nearby ramps and adjacent arterials. Similarly, traffic problems that had once occurred at the closed ramp may shift to other locations. Considering these impacts, ramp closures should only be considered for severe safety problems that cannot be addressed through any other ramp management technique.

Little research is available that documents the effects ramp closures have on traffic operations. The results of the research that is available indicate that although ramp closures have a significant impact on traffic patterns, when properly conceived and implemented, they can increase average travel speeds and decrease delay on freeways (see Section 5.2.2). Safety issues may arise at locations where ramps are closely spaced and weaving is made difficult or where on-ramps have inadequate acceleration lanes. Ramps constructed in central business districts are often closely spaced and ramp closures there maybe a better solution to congestion and safety problems than in suburban areas where ramps tend to be more widely spaced. Other situations that may require ramp closures include construction, major incidents, emergencies including severe weather conditions, or special events.

5.4.1 Types of Closure

There are three general types or classifications of ramp closures. The three types of ramp closures are:

- Permanent.
- Temporary.
- Time-of-day or Scheduled.

Each type of ramp closure is discussed in greater detail below, and the advantages and disadvantages of each are summarized in Table 5-9.

Permanent

Of the three types of ramp closures that will be discussed in this section, permanent ramp closures will have the most significant impact on existing travel patterns and, as such, are the least preferred approach. Although temporary and scheduled ramp closures restrict access to ramps at certain times, motorists are still able to use ramps during the period(s) when they are open. Permanent ramp closures do not give the motorists the option of using the ramp again, permanently affecting motorist travel patterns, surrounding land values, and access to and from nearby businesses. As a result of these impacts, permanent ramp closures are rarely implemented. However, severe safety problems and impacts of ramp traffic on surrounding areas may necessitate permanent ramp closures when all other efforts to resolve these problems fail. Careful consideration of the possible impacts of closure should be considered before ramps are closed.

Table 5-9: Advantages and Disadvantages of Ramp Closure Methods

Closure Method	Advantages	Disadvantages
Permanent	▶ One time cost (i.e., no costs associated with on-going operations). ▶ On-going operations not needed.	▶ Significant impact on existing travel patterns. ▶ Significant socio-economic impact.
Temporary	▶ Less permanent impacts than permanent closures. ▶ Significantly reduces conflicts between vehicle types during construction or maintenance on or near the ramp.	▶ Moderate impact on existing travel patterns.
Time-of-Day/Scheduled	▶ Less permanent impacts than permanent closures. ▶ May significantly improve mobility during peak periods or others times of recurring congestion.	▶ Moderate impact on existing travel patterns. ▶ On-going operations costs. ▶ Greater risk of vehicle/person conflicts when manual methods are used to close the ramp.

Temporary

Ramps may be considered for closure on a temporary basis during construction, to perform maintenance activities on the ramp, to manage special events, or when severe weather conditions threaten safety. Construction and maintenance related closures eliminate potential conflicts between through traffic and construction/maintenance vehicles. The more potentially dangerous conflicts between construction workers and through traffic are also eliminated, creating a safer working environment. The benefits of temporary ramp closures, however, are not limited to safety. Temporary ramp closures may expedite construction or maintenance activities by freeing up space in and around the work zone. This may increase productivity and lead to considerable time and cost savings as projects are more likely to be completed on time.

Temporary ramp closures may also provide a critical tool in managing traffic near a special event venue. In some situations, heavy special event traffic demands may overwhelm the ability of the roadways to handle traffic. Closing ramps may be the only viable solution to effectively manage special event traffic. Ramp closures for special events may be modified to allow access only to certain types of vehicles, such as emergency vehicles, delivery vehicles, or HOVs (see Section 5.5 for a discussion of special use treatments). In any case, ramp closures should only be used for special events when they are part of the overall special event traffic management plan.

Ramps may also be closed on a temporary basis when severe weather conditions are present or when travel on a roadway is unsafe. For example, freeway entrance and exit ramps may be closed when significant amounts of snow, ice, or water cover roadways. Weather related closures prevent vehicles from entering the freeway facility and through hazardous condition. Typically, ramps will remain closed until conditions improve, or when maintenance vehicles have finished clearing the roadway of snow or debris.

Time-of-Day or Scheduled

Ramp closures may occur at specific times of day, most notably during the morning and afternoon peak periods when recurring congestion is likely to pose a severe safety problem. Weaving at the ramp freeway merge point and backups on the ramp that extend onto the adjacent arterial are two safety problems that may be resolved through time-of-day/scheduled ramp closure.

Motorists that are unfamiliar with the time-of-day/scheduled approach may become confused over the status of a ramp (i.e., open or closed) when approaching it. Therefore, it is recommended that additional measures be implemented to reduce driver confusion. Such measures may include additional signing and/or establishing a specific time that the closures will occur at each day and not deviating from this time.

5.4.2 Methods of Closure

There are three commonly accepted methods to close a ramp. These methods are discussed below. In all cases, signing is needed to alert motorists that ramps will be closed. Signing should remain posted until ramps are officially closed and methods used to close the ramp make it obvious to motorists that the ramp has been closed. When ramps are closed on a temporary basis, additional signing may be needed to indicate the current status of the ramp (i.e., open or closed).

Manual Barriers

Manual barriers can be classified as being either portable or fixed. Portable barricades include gates, cones, and other equipment that can be moved from one location to other. As they can be physically moved from one location to another, portable barricades are typically reserved for temporary closures, though this is not to say that they cannot be used to close ramps on a more frequent basis. Doing so, however, may not be as practical, safe, and cost effective since staff must physically travel to the site to close and re-open the ramp. In these situations, fixed barricades may be more practical. Fixed barricades include vertical and horizontal swing gates that have been permanently installed alongside the ramp. Since fixed barricades have been permanently installed, staff are not required to haul gates to and from the ramp, but rather simply swing the gate into position every time the ramp is closed or opened (manual process). However, the disadvantage of fixed barricades lies in the fact that they cannot be moved from one location to another, and are therefore not as flexible as portable barricades in their day-to-day use. In other words, portable barricades can be used for any ramp, whereas fixed gates can only be used for one specific ramp. Other drawbacks of fixed barricades include:

- Expensive to install compared to portable barricades.
- Requires significant clear space (horizontal or vertical) to swing.
- Is subject to conditions in the field that can prevent their use, such as parked cars, snow drifts, and other large objects that cannot be easily removed.
- Barrier equipment mounted on the side of the road represents a fixed-object safety hazard.

Regardless of whether a barricade is portable or fixed, the fact remains that manual barriers must be deployed by a person in the field. If staff are not available, manual barriers cannot be deployed. Similarly, since staff must be available to deploy these barriers, their use is not as practical for time-sensitive closures (i.e., time-of-day closure). In addition, manual barriers also pose a greater safety threat than their automated counterparts, especially portable barricades, due to the fact that the individual responsible for deploying them must walk out onto the roadway to deploy them. Some portable barricades can also be blown down by high winds, thus creating confusion as to whether or not the ramp is open.

Automated Barriers

An alternative to the labor intensive, manual methods of ramp closure are automated barriers. Automated barriers installed at entrance or exit ramps increase the flexibility of closing a ramp, and may prove more beneficial for long-term, permanent applications. Automated barriers can be activated from a TMC or other remote facility or in the field by pressing a button at the control assembly. If the location cannot be visually monitored at the TMC or other remote facility, the latter option may be preferred since staff located in the field can determine if it is safe to close a ramp at any given moment.

Like any other automated system, automated barriers have the potential to stop working at any given time, increasing the risk of a serious safety issue. This issue can be mitigated with on-going preventative maintenance program. However, other issues, like driver disregard of automated gates can be a more continuous, long-term maintenance problem. For instance, DOT staff in Milwaukee, Wisconsin have stated that gates used to close ramps to I-43 are often broken by motorists determined to use the ramp even though the gate is closed.

Enforcement Personnel

The last commonly used method of closing a ramp, is completed through stationing enforcement personnel at the ramp. Enforcement personnel may be an effective means of closing a ramp when automated systems are not present and when maintenance staff are not available to deploy temporary barricades. In these situations, enforcement personnel may be used on a temporary basis to prevent traffic from accessing the ramp until maintenance personnel can deploy barricades. The use of enforcement personnel should be held to only severe situations in which the ramp cannot be otherwise closed. The use of enforcement personnel for any other condition is not the best use of an officer’s time, and using personnel in this way can pose a threat to their safety.

5.5 Special Use Treatments

Special use ramp management treatments include strategies that give "special" consideration to a vehicle class or classes to improve safety, improve traffic conditions, and/or encourage specific types of driving behavior. The most popular special use ramp management application is the designation of high occupancy vehicle (HOV) bypass lanes or ramps. Designation of HOV bypass lanes and ramps limit use of these facilities to only those vehicles with multiple occupants in an effort to reduce overall freeway delay.

5.5.1 HOV bypass Lanes

When ramps are metered, HOV bypass lanes allow HOVs (i.e., public transit vehicles, carpools, vanpools) and emergency vehicles to bypass metered vehicles without having to stop. When ramps are not metered, HOV lanes offer a means for HOV and transit traffic to bypass queues built up from traffic entering the freeway. However, HOV bypass lanes should be designed properly to reduce the potential safety hazard posed by single-occupant violators who attempt to jump metered queues by using the bypass lane.

5.5.2 Dedicated Ramps

Special use treatments also come in the form of separate ramps that are used to give preferential treatment to a specific class or type of vehicle. Construction vehicles, delivery vehicles, and trucks are three classes that may be targeted for special use ramp treatments; however, transit and other HOVs may be considered as well. In regard to construction vehicles, delivery vehicles and trucks, special use applications are focused on reducing conflicts between these vehicles and other vehicles that typically use ramps. In addition, special use applications for these types of vehicles may reduce the impact these vehicles have on neighborhoods. In regard to transit and HOV vehicles, special use applications may include freeway to park-and-ride direct fly-over ramps. These ramps provide travel time incentives for vehicles designated as HOV by allowing them to by-pass arterials leading to and from the freeway and park-and-ride.

Special use applications that give priority to certain types of vehicles must support policies that are in place and conform to local, state and regional goals and objectives. Without support, special use applications may not receive the needed funding to implement or maintain strategies. Additionally, special use ramp applications may be negatively perceived by those who can't use them. Therefore, additional public information campaigns may need to reassure the public as to the need for and benefits of special use applications. Finally, agreements must be made with law enforcement, so special use treatments are actively enforced.

Case Study: Truck-Only Ramps

In 1999, the Southern California Association of Governments (SCAG) commissioned a truck lane feasibility study for SR-60. SR-60 is a major east-west corridor from downtown Los Angeles, connecting back with Interstate 10 east of LA in Coachella Valley. Caltrans has estimated that some segments of SR-60 carry as much as 28,000 trucks each day (15% of the total traffic). Several truck lane configurations were evaluated, but all had common features. The objective was to build a limited access facility that would serve longer-haul freight movements.

The configurations were based on the assumption that trucks would have their own entrance and exit ramps to and from the freeway. The “high” option consisted of exclusive (and physically separated) truck ramps at freeway-to-freeway interchanges. The “low” option used existing mixed flow ramps with additional truck-only lanes. Additional planning and engineering studies began in 2003.

Another study, also conducted in Los Angeles, examined a proposed interchange concept for I-710. This interstate is a major access route between downtown Los Angeles and the Ports of Los Angeles and Long Beach. In 2000, the Port of Long Beach estimated that it generated 40,000 daily truck trips, the majority of which accessed I-710 for a portion of their trip.

The proposed interchange concept for the I-710 truck lanes uses the existing general purpose (GP) ramps and builds additional truck lanes. The concept involves constructing truck lanes on an elevated structure. Initially, trucks would use dedicated lanes on the existing interchange ramps, merge into the mixed flow traffic and then enter the truck lanes from the mixed flow lanes. Exiting trucks would first exit to the mixed flow lanes and then access the truck-only exit ramps. Configuring the access points for the high truck volume interchanges limited the number of entry and exit points as well as where they could be placed. This design reduces the cost of building separate truck-only interchanges and substantially reduces the right-of-way acquisition that would be necessary. However, it does not address all of the merge problems that trucks face throughout the corridor. The redesign of weaving sections must be accomplished as an additional feature of the design.

These two Southern California studies suggest that truck lanes and truck-only ramps can be an important tool for improving freight mobility in congested urban areas. When planning for successful truck lanes, the application is not solely dependent upon high truck volumes. It is also a function of the length of truck trip (short distances during the midday period). For the majority of truck trips, expanded multi-purpose capacity may provide the greatest overall benefits. However, in corridors with concentrated origin-destination locations and extremely high volume facilities (as in corridors with inter-modal facilities and ports – such as the I-710 project in Los Angeles), truck lanes and truck-only ramps may be feasible. This is especially true if the existing facilities operate in congested conditions throughout most of the day. And, finally, the safety benefits of separating auto and truck traffic may be one of the most compelling reasons to consider dedicated truck lanes. The role that truck-auto interactions play in accident levels should be accounted for in the analysis.

5.6 Ramp Terminal Treatments

Ramp terminal treatments are those that can be implemented at the ramp/arterial intersection to better manage traffic entering or exiting the ramp facility. Ramp terminal strategies are focused on managing queues that form on the ramp that spill back onto either the adjacent arterial or the freeway facility. Ramp terminal strategies implemented at entrance ramps will provide better flow of arterial traffic not destined for the freeway, whereas ramp terminal strategies implemented at exit ramps will reduce queues that flow onto the freeway facilities lessening the frequency of rear-end collisions occurring on the mainline. Queues that form on the ramp facility create unsafe conditions that may be minimized or altogether eliminated through consideration and implementation of one or more of the following strategies.

There are at least four different strategies that can be implemented at ramp terminals that can improve traffic conditions (e.g., traffic flow and safety) on or near ramp facilities. The cost to deploy each of these strategies is relatively low when compared to the other ramp management strategies discussed in this handbook. These strategies are listed below and discussed in Sections 5.6.1-5.6.4, respectively.

- Adjustments to signal timing and phasing adjustments.
- Ramp widening.
- Additional or changes to turning movements/storage lanes.
- Additional or improvements to signing and pavement markings.

5.6.1 Signal Timing and Phasing Adjustments

Adjusting the traffic signal timing at the metered ramp/arterial intersection, as well as nearby intersections, will help smooth the flow of traffic entering and exiting ramp facilities. Coordinating ramp meters with traffic signals may prove beneficial to operations on the adjacent arterial and freeway, as well as the ramp. On the arterial, adjustments to left-turn phasing and/or timing will help accommodate ramp bound traffic during metering periods. On the freeway mainline, signal timing adjustments will allow high volumes of exiting traffic to clear the freeway reducing queue spillback on the freeway facility. For exit ramp applications, special attention should be given to the capacity of the arterial to make sure high volumes of exiting traffic do not affect operations.

"Studies have shown that the benefits of investing in signal timing outweigh the costs by 40:1 or more."[29]

Adjusting signal timing not only improves the flow of vehicles entering and exiting the freeway, it also reduces the amount of time these vehicles are delayed as well as the environmental impacts these delays cause. A recently released evaluation of traffic signals, gave overall traffic signal operation within the U.S. a score of D-.[30] This poor score was in part attributed to the lack of proactive management of traffic signals. The evaluation concluded that "traffic signal timing is rarely reviewed, resulting in outdated signal timings that do not reflect current traffic and pedestrian needs." Because traffic signal timing is rarely reviewed, local agency traffic staff cannot determine if traffic signals are operating effectively. This makes it difficult to coordinate traffic signals operated by different agencies, which is often the case for traffic signals located at the ramp/arterial intersection and those located on the ramp (i.e., ramp meters). At a minimum, the evaluation recommends that traffic signal plans be reviewed every three to five years, and that agencies develop and document an approach for tracking the performance of these relatively inexpensive investments, and performing maintenance. Completing these tasks may achieve the following benefits:[30]

- Reduce average delay between 15 and 40 percent.
- Reduce average travel time up to 25 percent.
- Reduce fuel consumption by up to 10 percent.
- Reduce vehicle emissions by up to 22 percent.

5.6.2 Ramp Widening

There are several reasons why entrance ramps may need to be widened. First, ramps may need to be widened to provide additional storage capacity. For instance, metered ramps where traffic frequently backs up into the adjacent arterial may be a candidate for widening. Second, ramps may need to be widened to provide enforcement zones, where respective personnel can be stationed safely and where ramp meter operations are clearly visible. Similarly, ramps without adequate room to perform maintenance activities, such as removing debris, trimming nearby vegetation, or repairing infrastructure, may also need to be widened. Lastly, ramps may need to be widened if providing designated lanes for special classes of vehicles, such as HOVs. The additional capacity in these situations would promote use of transit and carpooling/vanpooling by providing benefits in terms of reduced delay for these vehicles.

Likewise, there are several reasons for widening exit ramps. First, more storage may be required at the ramp terminal traffic signal to keep queues from backing on to the freeway. Second, traffic movements at the traffic signal may need to be separated to provide efficient or safe signal operations. Finally, additional turn lanes may be needed to efficiently handle high traffic volumes (see Section 5.6.3).

Widening on either entrance or exit ramps may be implemented in conjunction with adjustments to traffic signal timing to prevent queues from forming on the arterial or freeway. On exit ramps, ramp widening may be implemented with pavement markings (see Section 5.6.4) to separate different traffic movements.

Whenever construction is needed to widen a ramp, practitioners may find it beneficial to complete additional work, if needed, while the ramp is being widened. Such work may include fixing geometric deficiencies, repairing the roadway surface, and posting additional signs. In these situations, it may be more cost effective to complete additional work if the ramp is already closed and/or if the resources are readily available. This reduces the level of effort required to close the ramp and to set up work zone related equipment (signs, barriers, cones, etc.). In cases where the ramp must be closed, completing additional work may also reduce the number of times the ramp must be closed, which consequently reduces the impact on the public.

5.6.3 Turning Movements and Storage Lanes

Queues that form as a result of ramp meter operations should be held on the ramp to avoid possible backups onto adjacent arterials. If storage on the ramp is exceeded, and neither the metering rate can be adjusted nor the ramp widened, turn/storage lanes on the adjacent arterial should be considered to hold vehicles waiting to turn onto the ramp. An illustration of how a turn lane provides additional storage for vehicle waiting at a ramp meter is shown in Figure 5-1. Comparing the two diagrams in Figure 5-1, it is easy to see that the addition of a right turn lane on the arterial as depicted in the diagram on the right provides additional capacity for queues that extend beyond the ramp terminal, allowing through traffic on the arterial to flow freely. Without a right-turn lane on the arterial as depicted in the figure on the left, queues that form on the ramp may flow back onto the adjacent arterial, preventing the smooth flow of traffic in the right lane.

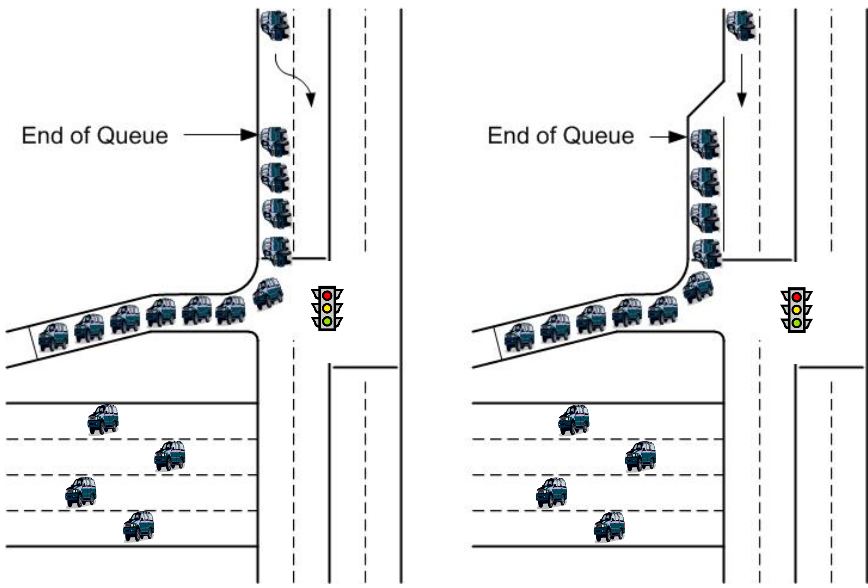


Figure 5-5: Comparison of Ramp Meter Queue Storage With and Without a Right-turn Lane on the Arterial

Construction of arterial turn/storage lanes may be implemented along with other treatments, such as signal timing, to limit traffic entering the ramp to prevent queues from spilling back through the intersection. Storage lanes may also be needed on exit ramps to contain queues and keep traffic from backing onto the freeway mainline.

Turning movements may be restricted to limit access to a ramp or arterial. For instance, turn restrictions to limit access to ramp may be implemented to intentionally divert traffic away from a ramp either because the ramp does not have enough capacity to hold turning traffic or queues that form on the arterial exceed the storage limits of the turn lane, and because of this traffic flow on the arterial is often impeded. Sometimes turn restrictions are implemented to reduce conflicts (either with other vehicles or with pedestrians) and improve safety and sometimes to improve traffic flow or limit downstream impacts. Consideration should be given to where traffic will re-route in response to these restrictions and whether the roadways in these areas can accommodate increased traffic demands.

5.6.4 Signing and Pavement Marking

As a ramp terminal treatment, signing is normally used in support of other terminal treatments. For example, signing will be used in conjunction with pavement marking (and sometimes widening) to add new lanes on an exit ramp. Signing, usually with pavement markings, is also used to designate turn lanes. Signing may also be used to guide motorists to freeway entrance ramps.

Advanced warning should be provided on metered ramps to alert motorists of ramp metering status before the last decision point to divert from the freeway. Advance warning will allow motorists to bypass metered ramps to avoid possible delays. This may be especially beneficial to motorists who take short trips on the freeway. In general, advance warning on the arterial is needed to inform motorists of the status of metering at specific ramps where metering operations are in effect. Advance warning on the ramp is needed to reconfirm the status of metering operations (i.e., meters on or meters off). Additional information, including design requirements for signing can be found in Chapter 10.

Similar to signing, the types and placement of pavement markings depends on the type of terminal treatment or metering system implemented at a ramp. Pavement markings are needed to delineate traffic movements on arterials approaching ramps, and on the ramps themselves. At a minimum, markings are needed to define the lane line, stop bar, channelization (if more than one lane), and HOV markings (if necessary).

5.7 Chapter Summary

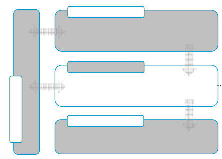
In previous chapters of this handbook, the practitioner responsible for the implementation and operation of ramp management strategies was primarily focused on answering the question, “Is ramp management needed, practical and feasible?” If the answer this question is no, there is no need to investigate ramp management strategies further. However, if the answer to the question is yes, then the practitioner will likely need to answer the question, “What strategies are available to control traffic on ramps?” After reading this chapter, practitioners should be aware of all the possible strategies that can be used to manage and control traffic on ramps, and be able to use this knowledge to select the specific strategies that best address existing problems.

There are four types of strategies for managing and controlling traffic on freeway entrance and exit ramps discussed in this handbook. Each of the strategies also has a subset of strategies or methods in which they can be applied, as discussed in this chapter. For instance, ramp closure can be applied permanently, temporarily, or on a time-of-day basis. Each strategy or subset of strategies is unique, and best applied to different sets of problems or situations. However, the strategies presented may not individually solve problems being observed in the field. In some instances, it may be best to implement a combination of strategies to derive maximum benefits.

The answer to the question “Which strategies or combination of strategies is best for existing problems?” is a difficult one to answer. The overview of strategies provided in this chapter provides the foundation for answering this question and will be used extensively in Chapter 6, which discusses the process of selecting strategies in more detail.

6

DEVELOPING & SELECTING STRATEGIES AND PLANS



Decision Making

Chapter 5: Ramp Management Strategies

Chapter 6: Developing and Selecting Strategies and Plans

Chapter 7: Implementing Strategies and Plans

Chapter 8: Operation and Maintenance of Strategies and Plans

6.1 Chapter Overview

Chapter 6 outlines the next step in the decision-making process for implementing ramp management strategies. This chapter builds upon the high-level discussion of ramp management strategies presented in Chapter 5, by discussing the various issues that agencies should take into consideration when developing and selecting appropriate ramp management strategies. The discussion presented in this chapter feeds directly into Chapter 7 (Implementing Strategies and Plans) and Chapter 8 (Operation and Maintenance of Strategies and Plans), which collectively represent the next logical steps: implementing and managing the ramp management strategies selected in this chapter.

As presented in Chapter 5, several ramp management strategies are available. The key, therefore, is to determine which strategy best addresses a particular problem or situation. Depending on the problem or situation, one or more of the ramp management strategies presented in Chapter 5 may be suitable, but certain strategies may be more beneficial than others. This chapter addresses ramp management strategies with respect to the situations or problems they best address, and the impacts that are likely to result when they are implemented.

Chapter Organization

When developing or selecting a ramp management strategy, individuals responsible for making this decision need to address a series of questions before they determine that one strategy is more suitable than another. These questions include:

- How do I determine that the freeway or corridor will benefit from ramp management strategies?
- What ramp management strategies are best suited for the conditions found?
- How do I implement selected ramp management strategies?
- How do the day-to-day operational procedures of ramp management strategies differ? Can operational procedures be supported?
- How do I ensure that the ramp management strategies continue to be effective once implemented?
- Do I have access to adequate technical expertise to design, implement, operate, and maintain the needed ramp management strategies?
- Can I make an accurate estimate of the financial and personnel resources needed to design, implement, operate, and maintain the ramp management strategies? Do I have the required resources?

To help answer these questions and to guide readers through the process of developing and selecting ramp management strategies, several objectives were established for this chapter. These objectives are outlined below.

Chapter 6 Objectives:

Objective 1:	Determine the need for ramp management strategies, including ramp closure, ramp metering, and special-use and ramp terminal strategies.
Objective 2:	Understand the potential impacts of ramp management strategies on the freeway and adjacent arterials.
Objective 3:	Understand the recommended decision-making process for each ramp management strategy and the benefits of using a structured process.
Objective 4:	Become familiar with the tools available for comparing and selecting ramp management strategies, and the level (i.e., high-level or detailed) at which each is best applied.

6.2 High-Level Screening of Ramp Management Strategies

Ramp management strategies are used to address several traffic-related impacts or problems. Most ramp management strategies address problems related to safety, mobility, or a combination of the two. Other strategies are focused on reducing the impacts associated with certain vehicle classes (e.g., construction vehicles, trucks, etc.) as well as special event traffic. Lastly, ramp management strategies can promote local, regional, or state policies. For instance, strategies may be implemented on ramps to promote the use of transit, encourage carpooling, or provide quicker response for emergency vehicles.

Several ramp management strategies exist, so the process of selecting and developing a strategy that best addresses an existing problem or situation may be a difficult task. As such, it is recommended that the list of acceptable strategies be narrowed before beginning a detailed analysis. In other words, practitioners should begin the process of selecting ramp management strategies by focusing their efforts on narrowing the list of available strategies to those that may be best applied based on existing situations or problems. This will help expedite the selection process and will lead to considerable time savings. After the list of ramp management strategies is narrowed, the impacts of each strategy should be analyzed to make sure that strategies do not result in new problems or shift existing problems from one location to another. Last, but not least, the indicators or warrants that justify a ramp management program and strategies should be analyzed, and the strategies that best satisfy observed indicators should be selected.

Figure 6-1 illustrates a process that may be used to narrow down the list of available ramp management strategies to those that meet an agency's goals, objectives, and policies and can be applied to remedy specific problems and/or situations. After applicable strategies are selected, practitioners may proceed to the section(s) where these strategies are discussed, to determine which of the applicable strategies are most appropriate for the situation or problem at hand. Each major step in the process, as illustrated in Figure 6-1, is described in chronological order in Sections 6.2.1 through 6.2.4.

6.2.1 Assess Transportation Management Policies, Goals, and Objectives

The process of selecting ramp management strategies should begin by revisiting an agency's or region's transportation management program policies, goals, and objectives. Further clarification and understanding of program goals and objectives will help practitioners identify the ramp management strategies that best fit within an agency's transportation management program. A solid understanding of these goals and objectives will also act as the foundation from which strategies can be selected and applied to address existing situations and/or problems.

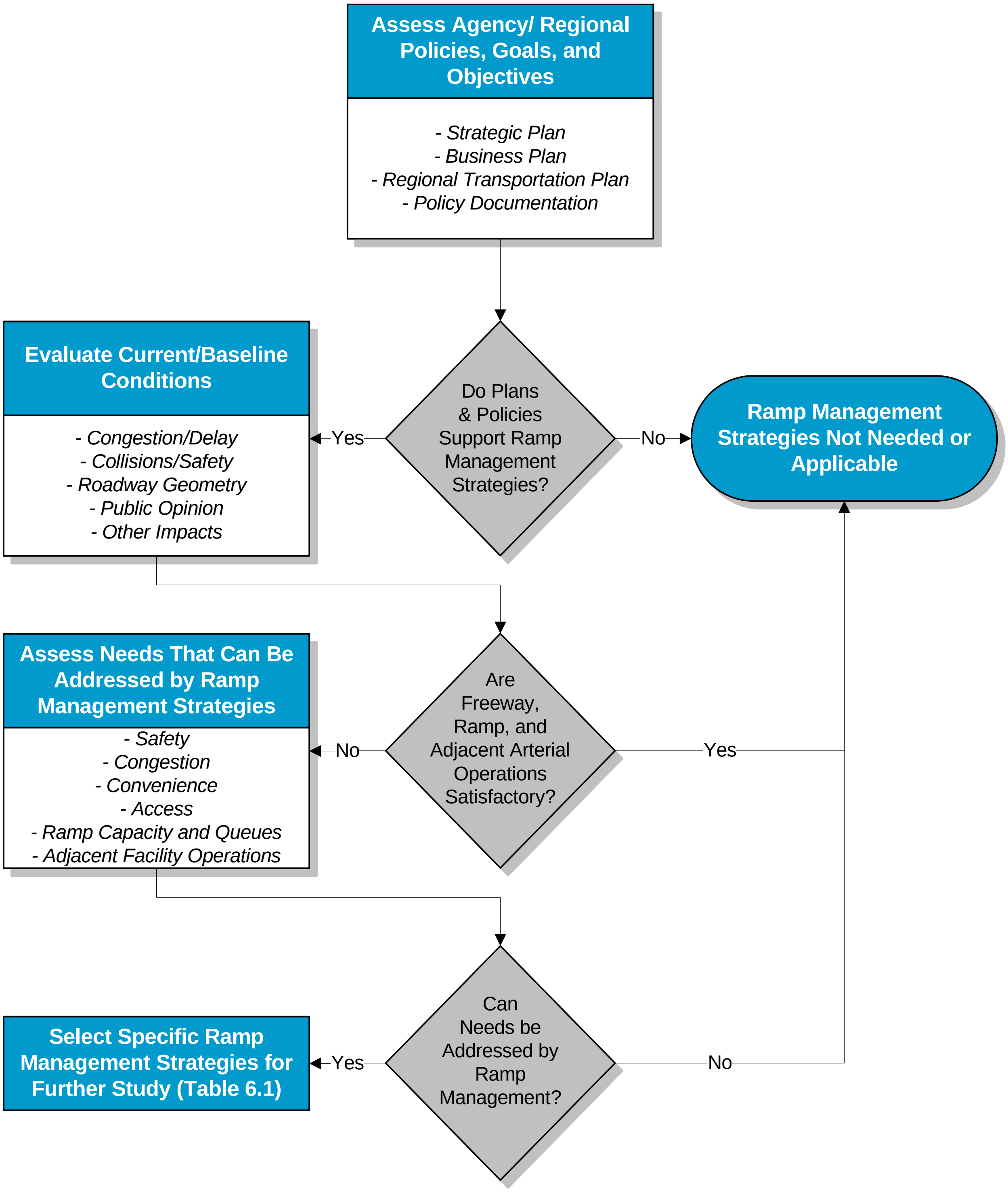


Figure 6-1: High-Level Screening for Ramp Management Strategies

Only the ramp management strategies that support transportation management system policies, goals, and objectives should be considered for implementation. Additionally, ramp management strategies should be viewed as elements of a transportation management program and be applied with other traffic management strategies, where possible, to accomplish transportation management program goals and objectives. This will "promote the efficient and effective movement of people and goods, to improve the safety of the traveling public, and to improve the environment by reducing both the duration and extent of recurring and nonrecurring congestion on the freeway system".[4] For example, a ramp metering program may benefit from adjustments to signal timing and additional lanes on the ramp, as these improvements prevent queues that form at ramp meters from backing up into the adjacent ramp/arterial intersection.

"Only the ramp management strategies that support transportation management system policies, goals, and objectives should be considered for implementation."

Typically, ramp management strategies are used to reduce congestion, reduce collisions, and improve travel time reliability. As a result, improvements to travel speed, travel time, delay, and crash rates are commonly observed.

Although ramp management strategies typically address safety and mobility problems, they may also be used to support local, regional, and state policies. For instance, High-Occupancy Vehicle (HOV) strategies implemented along a ramp can support goals and objectives related to improving transit operations and encouraging multi-occupant modes of transportation (i.e., transit, carpools, and vanpools). HOV strategies give preferential treatment to multi-occupant vehicles, allowing these vehicles to bypass queues that result from vehicles stopped on the ramp or freeway facility.

Revisiting program policies, goals, and objectives is just the first step in the process of identifying, developing, and selecting ramp management strategies. Other considerations, including indicators and impacts of ramp management strategies, must also be taken into account. The latter is discussed in the next section.

6.2.2 Evaluate Current/Baseline Conditions

After revisiting program policies, goals, and objectives and gaining a better understanding for how ramp management strategies fit into the transportation management program, agencies should evaluate current or future-year baseline conditions to determine what problems exist and whether ramp management strategies are appropriate. The fact that a ramp management strategy is feasible and fits into an agency's transportation management program does not necessarily make it appropriate to implement. It is certainly possible that existing conditions do not warrant ramp management strategies or that conditions cannot be adequately addressed through their implementation. Therefore, it is critical that agencies analyze conditions on the ramp, near the ramp freeway merge point, and along adjacent arterials before selecting a ramp management strategy, so the nature of the problem(s) can be more accurately assessed. A more accurate assessment of existing problems will also help determine which strategies are most appropriate if it is deemed that ramp management is appropriate. For instance, ramp management strategies can unintentionally "push" problems from one location to another, despite being implemented properly. Evaluating existing or baseline conditions before strategies are selected will help ensure that the strategies selected are the most appropriate given local conditions and observed problems.

Ramp management strategies should also be considered when performing long-term transportation planning or other long-term transportation investment decisions. For example, a corridor study of a freeway corridor may base the analysis and transportation investment decisions on a 20-year forecast of traffic volumes. This forecast is often referred to as the baseline conditions, with which alternative transportation investments are considered and compared. Understanding the baseline traffic conditions, such as locations of traffic congestion and delays, is important in this step so that ramp management strategies can be considered using the remainder of the decision-making process described in this chapter.

6.2.3 Assess Needs that Can be Addressed by Ramp Management Strategies

Practitioners who consider implementing ramp management strategies should analyze traffic operations on the freeway mainline, ramps, and adjacent arterials. This was done in the previous step of evaluating current or baseline conditions. The next step is to match the identified needs (or problems) with conditions that ramp management strategies are known to help mitigate. If these conditions, referred to as indicators in this handbook, are present in the current or baseline conditions, then ramp management strategies are likely warranted for further study. These indicators, which may warrant ramp management strategies, are discussed in the following subsections.

Safety

High collision rates on freeways or in the vicinity of freeway/ramp merge/weave areas may warrant the implementation of strategies to improve traveler safety. Of particular importance are crashes linked to ramp operations, including rear-end collisions upstream of ramps and at the merge, diverge, and weave areas of ramps. High collision rates at these locations may indicate that freeway operations are being jeopardized by vehicles either entering or exiting the freeway facility. For instance, turbulence from vehicle platoons entering the freeway may cause an unexpected decrease in vehicle speeds at freeway/ramp merge areas, resulting in an increased likelihood of rear-end collisions immediately upstream of the merge area and side-swipe and lane-change collisions at the ramp/freeway merge point. Similarly, vehicles that attempt to exit the freeway facility onto ramps where traffic is queued onto the freeway facility may be forced to stop short of the ramp and wait for queues to clear while waiting on the freeway. This results in a bottleneck situation at the exit ramp, which subsequently creates congestion on the freeway and leads to reductions in safety, especially for traffic in the right lane(s) where vehicles are stopped.

Analysis of recent collision rates, by total collisions and by collision type, should include the entire length of freeway for which ramp management strategies are considered. Results from this analysis can be used to conclude whether collisions are more prevalent at a single ramp or longer section of freeway. Based on this information, the scope of the ramp management program is made more apparent.

Congestion

Collisions or other incidents are some of the principal causes of freeway congestion. Other causes include vehicle queuing on ramps that spill back onto the freeway, bottlenecks, geometric deficiencies including those that limit motorists' ability to smoothly enter the freeway facility, and increases in demand (i.e., entering demand exceeds existing capacity). It is critical that the causes of congestion are known and understood before selecting a ramp management strategy. In some cases, ramp management strategies may not be applicable or less favored when considered side by side with other types of improvements. Specific methods that can be used to pinpoint congestion problems are discussed in the following sections.

Level of Service

Freeway Level of Service (LOS) and freeway speed are good indicators of whether or not ramp metering or other strategies are needed. Low freeway speeds suggest a problem and may in part be due to the fact that traffic from one or more ramps is entering the freeway in platoons. Freeways with LOS D or worse are good candidates for ramp metering or other ramp management strategies. For more information regarding LOS and their respective values, please refer to the Transportation Research Board's Highway Capacity Manual (HCM).[31]

Similar to freeways, ramps with a poor LOS may also be candidates for ramp management strategies. Ramp LOS may be affected by a number of problems, one of which is congestion at the freeway/ramp merge point that occurs as a result of vehicle platoons entering the mainline. Another reason is the lack of available capacity to handle ramp traffic volumes.

Queue Jumping

Bottlenecks often result in a type of driving behavior known as queue jumping. Queue jumping occurs where drivers exit the freeway and reenter the freeway at a downstream entrance ramp, to avoid freeway queues that result from recurring bottlenecks. Queue jumping is unfair to motorists who remain on the freeway and often moves congestion from one location to another downstream location. In the design phase, it is important to strategically identify entrance ramps that may be subject to queue jumping and design the ramp management strategy accordingly. One way to address queue jumping is to meter the downstream entrance ramp.

Convenience

Ramp management strategies may be used to make traveling more convenient. Ramp management strategies help reduce congestion and travel times, which helps improve motorists' overall driving experience by reducing the amount of delay they experience in traveling to their destination. This also reduces the stress motorists may experience when delayed in traffic. Strategies implemented at ramps may improve conditions so much that motorists may elect to change their driving behavior as once congested links in the network are now uncongested.

Transit and Emergency Vehicle Access

Congested ramps may prevent transit vehicles from arriving at stops as scheduled. Significant delays in transit operations cause rider frustration and may lead to reduced use of transit agency services and investments. This in turn adds to congestion problems as riders seek other less efficient means of transportation. Similarly, congestion on or near ramps may delay emergency vehicle response to and from incidents. As a result, injured persons receive proper treatment in a less timely fashion. In either case, ramp management strategies such as priority treatments and HOV designations may improve transit and emergency vehicle access to ramps and freeways so the public can be better served. In most cases, policies will need to be in place prior to the deployment of these types of treatments.

Ramp Capacity and Queues

Ramp capacity and queues should be taken into account before ramp management strategies are selected. In the case of ramp meters, ramps must have adequate capacity and queue storage for ramp metering to be successful. In Minneapolis, the storage requirement for any given ramp is calculated by taking 10 percent of the pre-metered peak hour volume. Therefore, 70 vehicles is an adequate storage for a ramp with a peak hour volume of 700 vehicles per hour (veh/h). If there is adequate capacity and storage on the ramp, practitioners must then look at queues that form at meters and choose how they wish to manage them. If queues affect operations on the adjacent arterial, it may be an indicator that ramp terminal treatments (e.g., channelization, widening, signal timing, etc.) may be needed to offset impacts that result from metering operations. When possible, efforts should be made to hold traffic to the ramp without having traffic back up onto adjacent arterials. Traffic that backs up onto local arterials may disrupt traffic operations on the arterial and other streets that feed into it.

Adjacent Facility Operations

Facilities adjacent to ramps (i.e., freeways and arterials) should be examined to determine if problems occur at these locations and if operations on the nearby ramps contribute to the problem. Operations on adjacent facilities may be affected by traffic that backs up on the ramp and spills either onto the freeway mainline or adjacent arterials. Therefore, ramp management strategies are typically applied at the ramp terminal to eliminate or minimize the effects of traffic queues at these locations. Possible solutions may include adjusting signal timing, adding capacity to the ramp or adjacent arterial, or adding or modifying pavement markings.

6.2.4 Select Specific Ramp Management Strategies for Further Study

The selection of appropriate ramp management strategies begins with an assessment of the needs that can be addressed through ramp management. Ramp management strategies and approaches may be used to improve existing conditions, reduce the impact of special events adjacent to or near ramp facilities, or give priority to specific vehicle classes (e.g., transit, emergency, construction vehicle, or a combination of the three). If needs such as these exist, further consideration can be given to the implementation of ramp management strategies and approaches.

However, these needs alone do not justify the use of ramp management strategies. Agencies must also take into consideration the fact that although ramp management strategies may provide additional benefits, existing conditions on the freeway, ramp, or arterial may be satisfactory. Considering this, it may be to the public's benefit to instead use funds to improve conditions deemed unsatisfactory. Additionally, agencies considering ramp management strategies may not have the policies in place to support ramp strategy implementation. However, if it appears that operations or conditions on the ramp or nearby freeway or arterial facilities are unsatisfactory and policies are in place, ramp management strategies may be needed and applicable.

Figure 6-1 illustrates the process described above and directs readers to consider certain ramp management strategies based on the specific type of problem (i.e., safety, potential impacts, congestion or policy) that exists. The last step in this diagram (Select Specific Ramp Management Strategies for Further Study) acts as the starting point for considering specific ramp management strategy implementation. The process is shown in the high-level screening matrix in Table 6-1. The ramp management strategies that may be used to address various problems at different locations are indicated by a check mark within the matrix. For example, ramp metering, ramp closure, and special-use treatments may be appropriate for addressing safety-related problems at merge points.

6.3 Selecting Ramp Metering Strategies

Selecting ramp metering strategies is a multi-step process that requires several decisions to be made before strategies can be selected. However, before decisions are made and strategies selected, it is recommended that practitioners be well versed on ramp metering concepts and terminology (see Chapter 5). Practitioners should be aware of the different metering strategies that are available, the geographic limits for which strategies may be applied, the methods for controlling traffic flow at ramp meters, and all other aspects inherent to ramp metering. This will ease the decision-making process and lead to considerable time savings.

As presented in the high-level screening box within Table 6-1, ramp metering strategies may be used to address certain types of safety and congestion-related problems. Ramp metering can also be an effective strategy to offset certain neighborhood-related impacts and impacts that occur as a result of special events or construction activities. Despite these uses, however, ramp metering may not always be an appropriate solution for all conditions. Agencies should consider the effects ramp metering will have on safety and mobility once implemented.

If Table 6-1 indicates that ramp metering may be used to address existing problems or needs, further analysis of ramp metering can be conducted to determine if ramp metering should be selected. A decision tree outlining the steps agencies can follow to analyze and select a ramp metering strategy is shown in Figure 6-2 and Figure 6-3. The remaining discussion in this section describes each step in the decision tree.

Table 6-1: High-Level Screening Matrix

Need/Problem	Location/Reason	Ramp Management Strategies			
		Ramp Metering	Ramp Closure	Special-Use Treatments	Ramp Terminal Treatments
Safety	Merge Point	✓	✓	✓	
	Ramp Terminal		✓		✓
	Freeway Mainline	✓	✓		
Impacts	Neighborhood	✓	✓	✓	✓
	Construction	✓	✓	✓	✓
	Special Events	✓	✓	✓	✓
Congestion	Freeway Mainline	✓	✓		
	Ramps		✓		✓
	Ramp Terminal		✓		✓
	Arterial		✓		✓
Policy	Transit			✓	
	HOV			✓	
	Freight			✓	

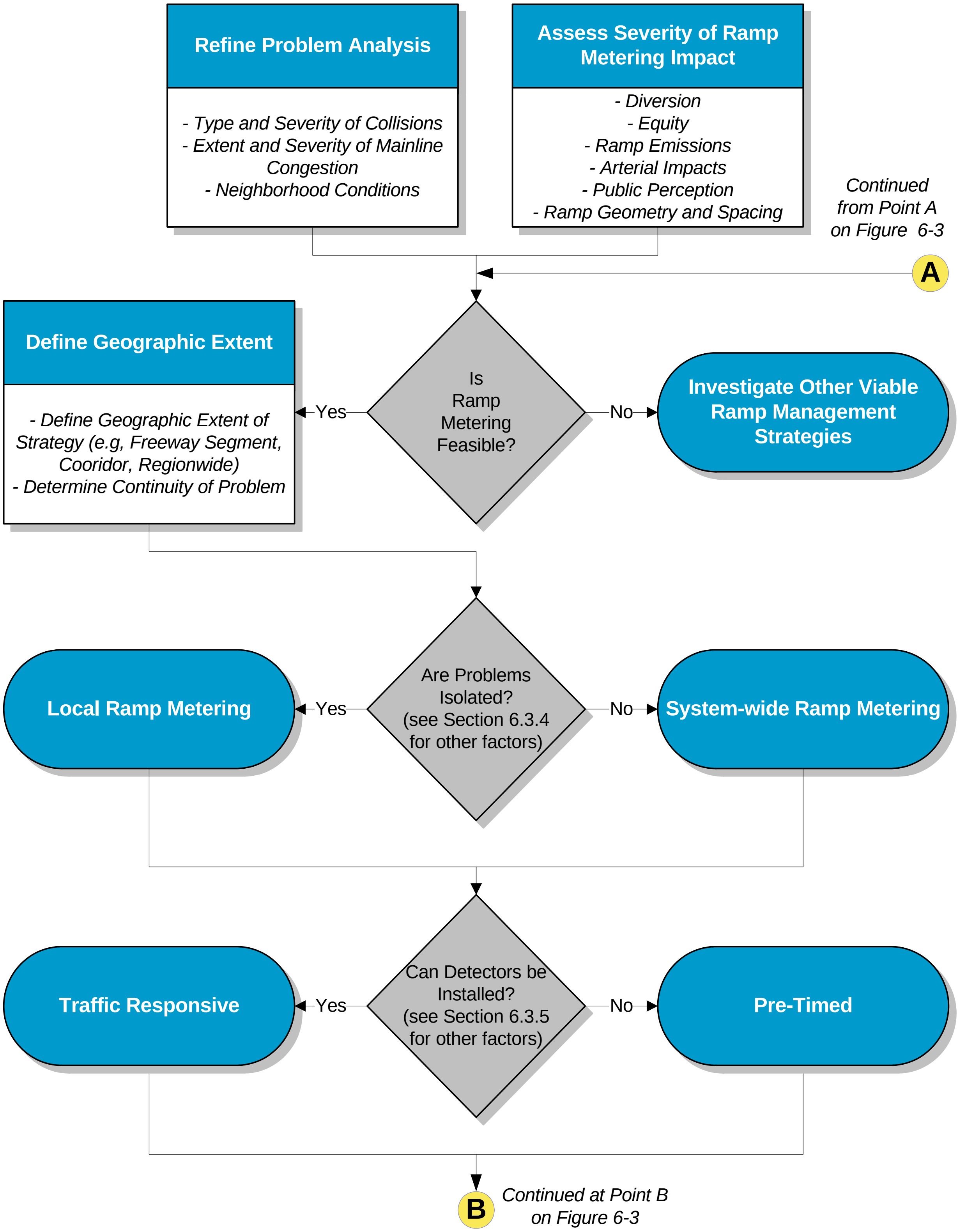


Figure 6-2: Ramp Meter Selection Decision Tree (1 of 2)

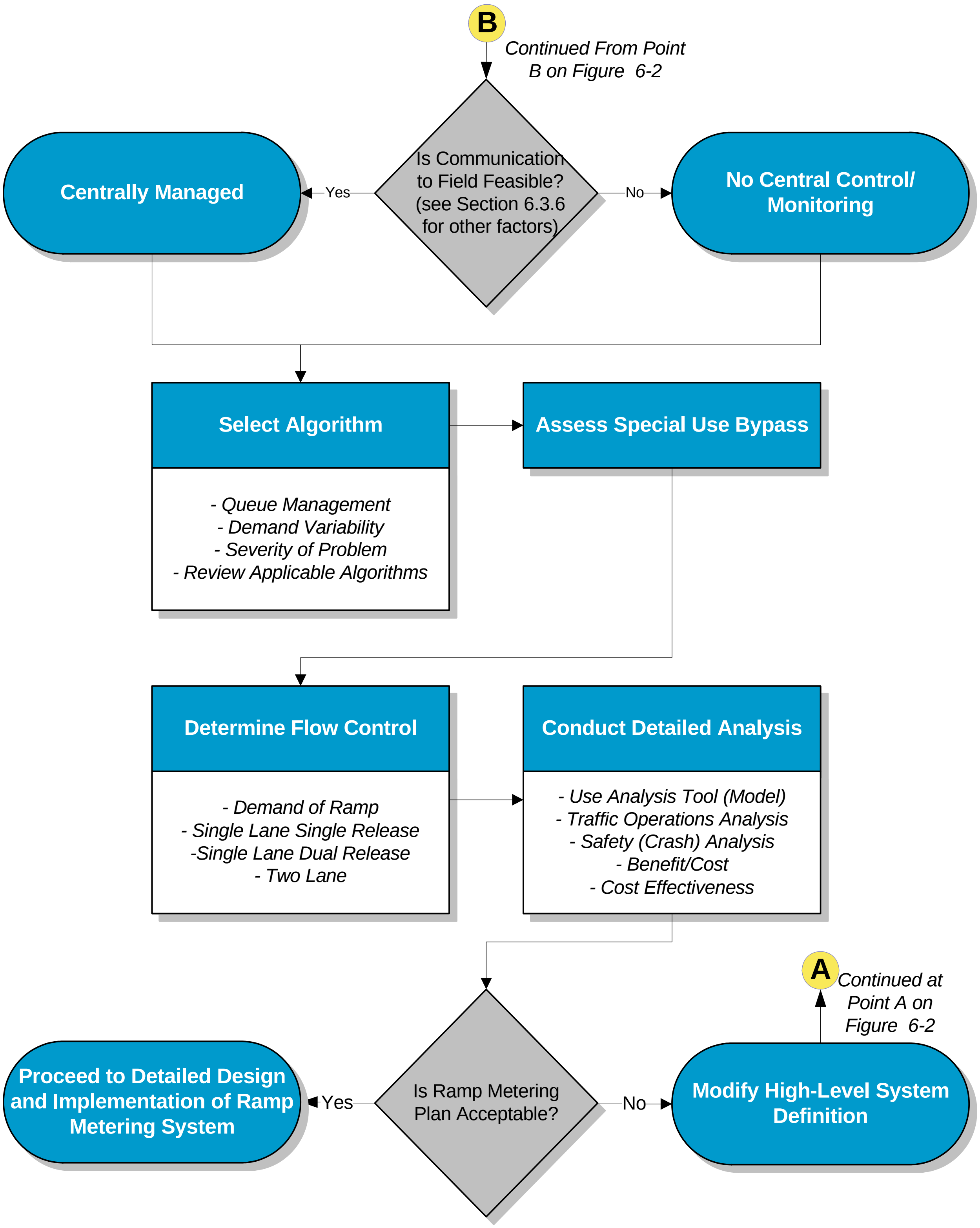


Figure 6-3: Ramp Meter Selection Decision Tree (2 of 2)

6.3.1 Refine Problem Analysis and Assess Severity of Ramp Metering Impact

The selection of ramp metering as a strategy to address freeway-related problems requires a high-level analysis of existing conditions and a thorough assessment of the impacts of metering. Depending on the results of this high-level analysis, ramp metering may or may not be feasible or offer the greatest potential for cost-effective improvement compared to other ramp management strategies. Metering may also result in adverse effects, such as excessive ramp queuing, that may offset expected benefits. As such, ramp metering may or may not be an appropriate strategy to address existing problems or situations.

Refine Problem Analysis

After determining that ramp metering may successfully address existing/baseline problems, the next step in determining the viability of ramp metering is to refine the current understanding of the problem that was previously performed at a high-level (as shown in Figure 6-1). Practitioners should refine the problems to be addressed, including the severity of collisions, congestion problems, and conditions on neighboring surface streets and arterials. An in-depth analysis of existing problems will help develop a solid understanding of the environment in which problems are occurring, allowing practitioners the flexibility to see the "whole picture" not just the most apparent problems that lie at the surface. Practitioners who refine problems before they begin the process of selecting strategies will be comforted by the fact that they have all the information needed to determine if ramp metering is a viable solution to identified problems.

When taking a closer look at existing/baseline problems, practitioners should consider the geographic extent of the problem(s) encountered. This will help determine the extent to which ramp meters should be deployed (i.e., should ramp meters be installed at one, several, or all ramps in a region?), so resources can be expended effectively. In addition, the type and severity of collisions may give some indication as to which specific metering approaches may best rectify the existing safety problem. This information will help practitioners develop and select strategies appropriate to the problems observed.

Assess Severity of Ramp Metering Impact

Practitioners should estimate the impacts that ramp metering will have on the problems identified in the previous step (e.g., congestion, safety, queuing, adjacent arterial and neighborhood conditions, etc.). This evaluation is done at a high-level (or sketch-planning level) at this stage, because the actual ramp metering system has not yet been defined. The purpose at this stage is to merely determine whether ramp metering is feasible. Sketch-planning models such as the ITS Deployment Analysis System (IDAS) can be used to estimate the impacts of ramp metering. If impacts of ramp metering offset the problems being addressed, ramp metering may be appropriate.

Impacts commonly assessed include:

- Change in collision rates.
- Change in freeway flow (volume, speed, travel time).
- Change in arterial flow (volume, progression, speed, travel time).
- Change in ramp volumes.
- Change in ramp queues.
- Travel time reliability/predictability.
- Travel time impacts on long versus short trips.
- Air quality analysis including air quality at individual ramps.
- Environmental justice.
- Public attitude/acceptance.

These impacts may be considered for ongoing performance monitoring, as described in Section 8.4.1.

Traffic analysis models are normally used before implementation to predict the impacts of the strategies on existing traffic patterns and operations. Additionally, "before and after" studies can extend beyond operation to include an assessment of public attitude and acceptance. Through both modeling and in-field measurement and evaluation, the impact of the selected ramp management strategies can be assessed. Chapter 9 covers the application of proper traffic analysis models.

Along with assessing whether ramp metering will help solve the problems identified in the previous step, it is also important to estimate the potential negative impacts of ramp metering. Potential negative impacts could include traffic diversion, equity issues, vehicle emissions on ramps, adjacent arterial impacts, and public perception issues. The following paragraphs discuss each of these potential negative impacts.

Diversion
Implementation of ramp meters may result in a portion of the existing traffic diverting from freeways to arterials. At locations where ramp meters are installed, motorists may elect to bypass queues that form at ramp meters in lieu of arterials that parallel a freeway facility. This is especially true for motorists who take short trips, in which case wait times at meters may exceed the additional travel time spent on slower-speed arterials.

Traffic diversion may or may not be a problem depending on the availability of routes able to carry diverted traffic. If a sufficient number of routes are available, diversion may be a benefit because it makes more efficient use of existing capacity. However, if available routes cannot support traffic diversion, operations on nearby arterials may be negatively affected. This may also cause jurisdictional disputes and conflicts, because ramp and arterial facilities are typically managed by different agencies and one agency's operations may negatively impact another's. In Portland, Oregon, the relationship between ramp meters and diversion was studied. The results are outlined in the following case study.[2]

Case Study: Ramp Metering Diversion (Portland, Oregon)

After ramp meters were installed on I-5 in Portland, traffic volumes on adjacent streets were closely monitored to determine if volumes had increased by more than 25 percent (a pre-determined threshold that was agreed upon by the state and local city officials). If volumes had exceeded this 25 percent threshold, the deployed ramp meters had to be either removed or adjusted to cut the increased volumes to below 25 percent. Observations after ramp meters were installed indicated that the effect of ramp meters on arterial traffic volumes was "not substantial". In other words, there was little indication that motorists diverted from using ramps to travel on adjacent nearby surface streets.

Equity

The goal of most ramp meter programs is to improve the overall throughput and safety of the freeway facility. However, equity arguments against ramp meter implementations have suggested that ramp meters favor suburban motorists who make longer trips versus those who live within metered zones and make shorter trips. This argument is based on the assumption that the suburban motorist lives outside a metered zone and is not delayed by ramp meters when entering a freeway and traveling through a metered zone. As such, the possibility exists that the motorists who live closer to a downtown area may have proportionally unfair commutes when comparing travel time against travel distance.

Detroit, Atlanta and Seattle have employed different techniques in an effort to minimize the issue of equity. In Detroit and Atlanta, ramp meters were initially operated for the outbound direction to eliminate the city-suburban equity problem. After a period of time operating in this mode, the effectiveness of the system was demonstrated and used to justify the use of meters in both directions. The Seattle system approached the equity issue by implementing more restrictive metering rates farther away from the downtown area.

Emissions on Ramps

Ramp meters smooth the flow of traffic entering freeways so vehicles can merge with freeway traffic with minimal effect on traffic flow. Reductions in vehicle emissions and fuel consumption on the freeway can be attributed to ramp metering, but the reductions are partially offset by increases in emissions and fuel consumption from vehicles waiting on ramps. At metered ramps, vehicles are subject to delays that result in higher emissions than under free-flow ramp conditions.

Arterial Impacts

During periods of high demand, there may not be enough capacity on the ramp to hold traffic waiting at ramp meters. Queues may form that spill into the ramp/arterial intersection, causing unexpected delays on the adjacent arterial. This will obviously affect traffic on the arterial. However, the institutional relationships that govern operations at the ramp/arterial intersection may be affected as well. The mixed jurisdiction over the freeway and arterial may make it more difficult to coordinate ramp meter operations with arterial operations and signal systems.

Public Perception

Without public support, ramp metering may fail or not be implemented at all. Public opposition toward ramp metering usually stems from the fact that delays occur as a result of ramp metering and its associated benefits may not be obvious. For example, a portion of the public may perceive ramp metering as an approach that does not work. This perception can be altered though persistent public communication and involvement. Agencies must be proactive in disseminating information to the public as well as demonstrating the many benefits metering has to offer.

Ramp Geometry and Spacing

Ramp geometry and spacing also affect traffic operations on or near freeway ramps. Ramps with inadequate acceleration or merge distances and major weaves are problems closely tied to ramp geometry and spacing. Others include ramp-to-ramp spacing and sight distances.

- Closely Spaced Ramps - Ramps located less than one mile apart may be a factor in collisions and delay on the freeway. In many instances, ramps that are too closely spaced do not offer the merging distances needed for vehicles to safely enter and exit the freeway at freeway speeds. The lack of available merging distance is made worse because significant speed differences often occur in the merging zones of upstream entrance ramps and downstream exit ramps. Closely spaced ramps are more often a problem in older downtown locations versus newer, suburban locations.

- Inadequate Acceleration Distance - The distance from the ramp meter to the ramp/freeway merge point must be a length sufficient to allow all types of vehicles to adequately accelerate to freeway speeds. If acceleration distances are inadequate, safety along the ramp, freeway or at the freeway/ramp merge point may be jeopardized. First, vehicles entering the freeway at speeds lower than those observed on the mainline may force vehicles approaching the freeway/ramp merge point to slow down or change lanes to allow vehicles from the ramp to enter safely. As a result, rear-end, lane-change, and side-swipe collisions are more likely to occur at locations immediately upstream of the freeway/ramp merge point. In severe cases, slow-moving vehicles entering from a ramp may be forced to wait for gaps in mainline traffic at the freeway/ramp merge point before entering the freeway facility. Severe slowing or stopping to merge may contribute to increases in side-swipe collisions at the freeway/ramp merge point as well as rear-end collisions on the ramp.

- Sight Distance - Sight distances on ramps are often limited by the curvature of the ramp or vegetation located alongside the ramp. Metered ramps with limited sight distance will require advance warning signs posted at strategic points along the ramp to alert motorists that they will need to stop at the ramp meter when it is operating.

- Merge/Weave Operations - Traffic congestion and safety problems (e.g., rear-end and side-wipe collisions) that occur at ramp/freeway merge points may be direct results of platoons entering the freeway from ramps. In these situations, ramp metering can be implemented to break up platoons so vehicles may merge with mainline traffic individually at freeway speeds. Congestion and safety problems may also occur at merge points when ramps are spaced closely together.

6.3.2 Analyze Feasibility of Ramp Metering

Practitioners can use their understanding of existing situations or problems and estimated impacts to determine if the benefits of ramp metering will offset the negative impacts likely to occur after implementation. Practitioners should also compare ramp geometry and spacing issues to determine if it is even possible to implement ramp metering. If ramp geometry and spacing issues are satisfactory and metering benefits are shown to offset impacts, practitioners should continue to analyze ramp metering by comparing it against other appropriate strategies, to come to a final decision on the best strategy or strategies to implement. The analysis should include an assessment of how the ramp metering system is proposed to operate. If ramp metering is not feasible, then the practitioner should investigate other viable ramp management strategies.

6.3.3 Define Geographic Extent

If ramp metering is deemed feasible in the previous step, then practitioners should define the geographic extent of the metering system envisioned. The geographic extent should be based on the problems encountered. Entire freeway corridors are typically considered for ramp metering, but situations may exist where local ramp metering at specific points along a freeway may be more practical. Results of the analysis performed in the previous step should be used in making this determination. Considerations for selecting the geographic extent include:

- Extent of recurring congestion (bottlenecks).
- Extent of safety problems.
- Jurisdictional boundaries.
- Limiting diversions.
- Political/institutional boundaries or issues.

Practitioners should also determine if the problems within the geographic extent are confined to a few spot problems, or if problems extend throughout most of the geographic area defined. Some ramps within the corridor may be considered to operate without ramp metering control, such as during the following conditions:

- Add-Lanes – Ramp meters may not be needed when ramps connect with the freeway at locations where new lanes are added. The added lane may eliminate the immediate need for vehicles leaving the ramp to merge with freeway traffic. However, there may also be reasons to meter these ramps, including the overall volume of traffic entering the freeway and the downstream characteristics of the freeway. Each case should be considered based on the local conditions.
- Inadequate Storage – Ramps with inadequate storage may need to operate without ramp meter control, since meters may cause traffic queues to back up into adjacent ramp/arterial intersections. Practitioners should first consider ways to reduce the demand on the ramp or to accommodate the expected queues. If no practical alternative can be found, the ramp may need to be left unmetered. Care must be given to this decision, because one unmetered ramp in the midst of a metered system may attract more traffic than desired.

- Driver Diversion – Ramps may need to operate without ramp meters if metering results in drivers diverting to nearby arterials that cannot handle the additional volume.
- Political/Institutional Issues – Ramps may need to operate without ramp meters if political or institutional support is not strong enough to acquire the needed funds to implement, operate, and maintain them.

Upon selection of the geographic extent and location of ramp meters, the practitioner should then decide on the ramp metering approach (local or system-wide), as discussed in the next section.

6.3.4 Local versus System-Wide Metering

Following the determination of geographic extent, the practitioner responsible for deploying ramp meters must decide whether meters will operate independently of each other or as an integrated system. This decision is based on several factors, including an assessment of where problems are occurring. The following subsections provide guidance on how to select between local and system-wide ramp metering. The discussion in this section builds off the basic description of these two approaches provided in Chapter 5.

Local Ramp Metering

Sometimes a single ramp or a series of ramps is metered based strictly on conditions adjacent to that ramp, with no consideration given to upstream or downstream conditions. This approach is known as local ramp metering. Local ramp metering is not recommended when congestion extends to some distance upstream of a bottleneck, but some conditions exist where it is appropriate. When considering local ramp metering, certain factors must apply. Typically, local ramp metering is employed when one or more of the following conditions exist:

- Collision experience at the ramp/freeway merge point is the primary problem being addressed.
- Traffic congestion at a spot location can be reduced through metering if no widespread congestion problems occur within the corridor.
- Traffic congestion is predominantly a recurring problem and if there is no history of major incidents or major route diversions.
- Several ramps in a freeway section are to be metered but are separated by a significant distance, or are separated by a number of unmetered entrance ramps or several exit ramps, which results in independent operation of the ramps.

Conversely, local ramp metering should not be used when:

- Safety or congestion problems are continuous or exist at many places within the corridor.
- Problems at a bottleneck are severe enough that metering a single ramp cannot result in acceptable traffic conditions.
- Traffic diversion or redistribution causes freeway congestion at upstream or downstream ramps, or on the freeway mainline sections associated with those ramps.

System-Wide Ramp Metering

System-wide metering addresses more complex problems than local ramp metering. It is normally preferable to meter ramps in a coordinated fashion, thus system-wide metering is often the choice. System-wide ramp metering may be the preferable option where:

- Collision problems are not clustered at isolated locations, but rather extend along a facility or throughout a corridor.
- Multiple bottlenecks/locations of recurring congestion on the freeway are observed.
- Optimization of freeway throughput requires coordinated rates for several ramp meters.
- The situation requires the improved ability to address non-recurring congestion problems.
- Flexibility to address changing conditions over time more rapidly is needed.

When multiple corridors are metered, consideration should be given to metering freeway-to-freeway ramps. Freeway-to-freeway metering aims to improve traffic conditions downstream of major merges. Guidelines for the selection of appropriate sites for freeway-to-freeway metering are listed below.[32]

- Consider locations where recurrent congestion is a problem or where route diversion should be encouraged.
- Consider route diversion only where suitable alternative routes exist.
- Avoid metering twice within a short distance.
- Avoid metering single lane freeway-to-freeway ramps that feed traffic into an add-lane.
- Do not install meters on any freeway-to-freeway ramp unless analysis ensures that mainline flow will be improved so that freeway-to-freeway ramps users are rewarded.
- Install meters on freeway-to-freeway ramps where more than one ramp merges together before feeding onto the mainline, and congestion on the ramp occurs regularly (4 or more times a week during the peak period).
- If traffic queues that impede mainline traffic develop on the upstream mainline because of a freeway-to-freeway ramp meter, then the metering rate should be increased to minimize the queues on the upstream mainline, or additional storage capacity should be provided.
- Freeway-to-freeway ramp meters should be monitored and be controllable by the appropriate traffic management center.
- Whenever possible, install meters at locations on roadways that are level or have a slight downgrade, so that heavy vehicles can easily accelerate. Also, install meters where the sight distance is adequate for drivers approaching the meter to see the queue in time to safely stop.

The considerations differ slightly for high-speed versus lower-speed system merges.

At this point in the process, the practitioner should select a general metering approach of either local or system-wide metering. Once this has been done, then the next logical step is to choose between pre-timed or traffic-responsive metering control, as discussed in the next section.

6.3.5 Pre-Timed Versus Traffic Responsive Metering

In Chapter 5, pre-timed and traffic responsive metering approaches are described, and the advantages and disadvantages of each are outlined. As stated in Chapter 5, pre-timed and traffic responsive metering differ in several aspects, including the methods by which metering rates are determined, flexibility in responding to real-time conditions (especially non-recurring congestion), and implementation costs. Based on each of these criteria, practitioners can gain a sense for which metering approach may be best suited to their needs and unique situations. However, the selection of a pre-timed or traffic responsive metering approach may be based on other factors, most notably of which is the ability to install traffic detectors on the freeway adjacent to the ramp merge area. If traffic detectors cannot be installed, traffic responsive metering cannot be used and therefore pre-timed metering must be selected. For example, it may not be possible to install detectors for budgetary purposes because the system will only be temporary (e.g., work zone project), or there may not be time or funding available to install detectors.

Cost is another factor that may affect the decision of whether pre-timed or traffic responsive metering should be selected. At first glance, it may appear as though traffic responsive metering will have a higher cost, due to the fact that there are more components to install (e.g., loop detectors and communications equipment) and traffic responsive systems have greater complexity. However, these higher capital and maintenance costs are typically offset by operating costs that are lower than the day-to-day monitoring and set-up tasks required with pre-timed meters. The assumption sometimes is that pre-timed meters require little operator oversight because metering rates are fixed. This, however, is not the case. Operators must periodically gauge whether or not pre-timed meters are operating as desired. This requires operators to frequently recalculate or adjust pre-timed metering rates to optimize performance, whereas traffic responsive systems complete this task automatically.

After selecting between pre-timed and traffic responsive metering control, the next logical step is to select the means of communication and control of the ramp meters. This is described in the next section.

6.3.6 Communications and Control

Ideally, all ramp meter controllers would communicate to a central location. However, sometimes communication is not feasible because of the area in which ramps are to be metered or the temporary nature of the ramp metering project (e.g., a special event or work zone). Communications may also be too expensive or take too long to implement for the initial operation of the system. In cases where communication is feasible and cost effective, a centrally managed system should be selected so the operation of the metering system can be monitored and controlled from a central location. This will allow a central algorithm to be used and operators to monitor metering operations and make adjustments to metering parameters in real-time from a central location.

After selecting the means of communications and control, the next logical step is to select the most appropriate ramp metering algorithm. This is described in the next section.

6.3.7 Select Algorithm

Algorithms are used for traffic-responsive systems. Therefore, if meters will be pre-timed, practitioners do not need select appropriate algorithms. Selection of the appropriate metering algorithm depends on answers to several questions, such as "Are problems isolated?" and "Can detectors be installed?". Some of these questions have been discussed previously. Another decision factor includes limiting ramp queues, especially to avoid queue spillback onto adjacent arterials. Based on the answers to these questions, the selection of appropriate algorithms can be narrowed to just a few possibilities. For instance, if problems are isolated and not widespread, one should look at selecting a local traffic-responsive algorithm, versus a system-wide algorithm like the SWARM algorithm. Other factors to consider when selecting metering rates or algorithms include:

- Variability of demand – how much does demand vary over the metering period, from day to day, and from season to season? The more variability, the more flexible and robust the algorithm should be and the more it should take into account direct field measures from detectors.
- Severity and extent of congestion – the more severe the congestion problem and the more congestion extends upstream from the bottleneck, the greater the need for an algorithm that takes into account conditions throughout the corridor.
- Severity and types of safety problems addressed – if freeway mainline rear-end and side-swipe collisions occur throughout the corridor, the greater the need for an algorithm that takes into account conditions throughout the corridor.
- The need to coordinate the arterial street signals with ramp meters to minimize queuing.
- Data requirements to support ramp metering – the type of metering will affect the type and amount of data collected for analyzing the strategy and used as input into an algorithm.
- Freeway and arterial management efforts to support metering.
- The likely extent of ramp queues – the need to manage ramp queues effectively.
- Complexity of algorithm – whether the required technical expertise is available to the agency.
- Previous success of algorithm – whether or not the algorithm has a proven track record of working in other areas with similar issues and conditions. This includes the amount of maintenance required in previous implementations.

Answers to these questions will help further narrow the list of available algorithms to those that are applicable. Refer to Chapter 5 for a description of specific algorithms. The purpose of this discussion is not to provide all the details about a particular algorithm, but rather to provide sufficient detail from which specific algorithms may be chosen. This will reduce the time needed to investigate options and to select an algorithm that is best suited for the agency's specific conditions.

Upon selection of the appropriate metering algorithm, the practitioner will have defined the extent and type of metering system most appropriate for the problems identified and conditions in the field. The next step is to consider whether special-use bypass lanes are appropriate, which is discussed in the next section.

6.3.8 Assess Special-Use Bypass

Agencies considering ramp metering should evaluate the potential for and benefits of special-use (such as HOV) bypass lanes at ramps considered for metering. HOV bypass lanes provide a travel time incentive for multi-occupant vehicles (e.g., transit, carpools, and vanpools). The occupancy requirements of HOV lanes may be adjusted higher in order to lower HOV volumes. A policy decision could be made that every metered ramp must include a special-use bypass or that only specific ramps that meet specific thresholds may include bypasses. Considerations include wait times (ability to reduce target delay), the need to minimize overall queues (will the bypass help reduce queue lengths?), and location of the ramp in special-use corridors.

6.3.9 Determine Flow Control

The method by which vehicles are permitted to enter a freeway facility from a ramp meter location is referred to as the ramp meter flow control. Under normal conditions a single-lane, uncontrolled ramp may have a throughput capacity of 1800 to 2200 veh/h.[33] When flow controls are implemented on the same ramp, the capacity of the ramp is reduced and excess demand above capacity is queued on the ramp.

Chapter 5 provides an in-depth discussion of the available flow controls that may be employed at ramp meter locations. Readers unfamiliar with the types of flow controls should read Chapter 5 before reading further. This section provides a brief overview of the available flow controls presented in Chapter 5 and provides additional discussion and criteria that can be used to select appropriate flow controls.

Three types of controls can be used in conjunction with ramp meters. These controls are described below:

- Single Entry – Permits vehicles to enter the freeway facility one by one, as vehicles are detected.
- Tandem or Two Abreast – Permits two or more vehicles to enter the freeway facility per cycle, side by side in adjacent lanes depending on the number of lanes at the meter (one vehicle per lane per cycle).
- Platoon – Permits two or more vehicles to enter the freeway facility per ramp meter signal cycle, in each lane that is metered (multiple vehicles per lane per cycle).

Selection of appropriate flow controls depends on answers to the following questions:

1) What is the demand on the ramp without a meter?
2) What is the available storage on the ramp?
3) What is the extent of diversion expected after meters are deployed?
4) Does the ramp have enough lateral clearance to accommodate more than one lane?

The demand on the ramp is used to determine the frequency at which vehicles must be released so queues do not back up and flow onto the ramp/arterial intersection. Table 6-2 provides some guidance for initially determining what flow control options may be appropriate for ramps given the pre-metering demand on those ramps.

Table 6-2: Flow Control Options for Ramp Demand Levels

Pre-Metering Ramp Demand (veh/h)	Flow Control Scheme	Number of Lanes
< 1,000	Single Entry	1
900 – 1,200	Platoon	1
1,200 – 1,800	Tandem	2

Note that there are overlapping demand levels for the various flow control schemes presented in Table 6-2. Depending on the likely diversion away from the ramp in question, higher ramp demand could be considered for the flow control schemes shown. Also note that additional ramp lanes could be added, but the reason for additional lanes should be more related to providing additional storage than providing for higher demand. The ramp merge point or even an add-lane on the freeway could not carry much over 1,800 veh/h. Finally, it is possible to combine platoon metering with tandem (or multiple lane) metering.

Storage on the ramp is used to hold traffic waiting at the meter. Practitioners should make every effort to contain vehicles on the ramp so queues do not spill onto and affect operations at the ramp/arterial intersection. If there is little or no available storage on the ramp during peak periods, strategies may need to be implemented to increase storage. Storage on the ramp may be increased by adding additional lanes, either by widening the ramp or restriping lanes. At locations where storage on the ramp cannot be increased, storage lanes may be added to adjacent arterials to hold traffic destined for the freeway via the ramp.

Traffic diversion from freeways onto adjacent arterials is a potential byproduct of ramp metering that needs to be carefully considered when analyzing flow controls. Traffic that diverts onto arterials may raise neighborhood issues such as increased traffic, reduced safety, and increased noise levels. Diversion of traffic onto arterials is likely to increase with increases in wait times at ramp meters. Therefore, practitioners should consider ways to reduce wait times at ramp meters so motorists will not view arterial travel more favorably then freeway travel. However, for short trips, vehicles that divert to other roadways may be more of a benefit than a drawback if available roadway capacity will be more fully utilized. This helps to improve traffic flow on the freeway mainline by reducing demand.

Upon selection of the appropriate flow control scheme, the entire ramp metering system will have been defined at a high-level. The practitioner is then ready to conduct a more detailed analysis, as discussed in the next section, to help decision makers make a "go/no-go" decision on whether to proceed with design and implementation of the selected metering system.

6.3.10 Conduct Detailed Analysis

Now that a specific ramp metering plan has been selected, it is important to conduct a detailed traffic operations analysis (to assess the benefits and negative impacts), a safety (crash) analysis, a cost analysis (capital, operating, and maintenance costs), and a benefit/cost or cost-effectiveness analysis to determine if it is worth implementing this particular strategy. The traffic operations analysis undertaken at this point should be more thorough than the one completed earlier in the refine problem analysis step. At this stage, all impacts should be identified and understood to a degree that a decision can be made on whether ramp meters should be implemented. If the impacts of ramp metering are offset by the severity of the problem, metering may be considered. The tools discussed in Section 6.7 may be used to better gauge the expected benefits and impacts of metering. These tools can also be used to determine if the benefits ramp meters will offset their costs.

6.3.11 Implementation Decision

This is the final step in the ramp meter decision process, where a final "go/no-go" decision is made to pursue the ramp metering plan. This decision is typically made by upper management or other decision makers and not by the practitioner(s) performing the detailed analysis. However, the detailed analysis should feed into the final decision. In addition to the detailed analysis, the decision makers could also consider the political impacts, risks of public rejection, funding considerations, or other potential risks to the plan. In the end, decision makers will decide on one of the following outcomes:

- Embrace the proposed ramp metering plan, in which case the next step is to pursue the detailed design and implementation of the plan.
- Modify the plan by feeding back to the beginning of the process and considering an alternate geographic extent or entire system altogether.
- Reject ramp metering altogether and pursue other viable ramp management strategies.

Section 6.7 discusses tools that can be used to support making a decision as to whether or not to implement ramp meters. Practitioners should embrace these tools and use them to assess the likely impacts of ramp metering. If all or some impacts are not acceptable, practitioners may wish to modify decisions made in previous steps, mitigate impacts, or investigate other ramp management strategies.

6.4 Selecting Ramp Closure Strategies

Ramp closure may be a viable solution for safety and congestion problems and to mitigate impacts associated with neighborhood impacts, construction activities, and special events. Ramps should be considered for closure only when closing them does not present a more severe problem than currently exists. If existing conditions are more severe than the impacts associated with closing the ramp, operations should be analyzed to determine if ramps should be closed by time-of-day, permanently, or temporarily when events occur. Regardless of which type of closure is selected, the selected strategy should be analyzed in greater depth to determine the specific effects or impacts of the strategy selected. If the benefits of the selected strategy offset the impacts of the problem and no other options are available, ramps may be considered for closure. However, if the benefits of the selected strategy do not offset the problem, other ramp management strategies should be analyzed to resolve the problem. A decision tree outlining the steps agencies can follow to analyze and select a ramp closure strategy is shown in Figure 6-4. Before following the steps provided in Figure 6-4, the type and location of the selected problems should be analyzed to determine if ramp closure is a potential solution. Table 6-3 provides a matrix that maps the three different types of ramp closures to specific needs or problems.

6.4.1 Refine Problem Analysis and Assess Severity of Ramp Closure Impact

To determine if ramp closure is practical, a high-level assessment should be first made to determine if the benefits of ramp closure offset its negative impacts. This assessment should include the following actions:

- Refine the problems to be addressed, including the severity of collision and congestion problems and conditions on surrounding surface streets and arterials. Refer to Section 6.3.1 for a more detailed description on performing a refined problem analysis.
- Determine if there are any special vehicle classes that have critical access needs that may prevent ramps from being closed, or vehicle classes that are a significant cause of the observed problems on or near the ramp.
- Assess the positive and negative impacts that are likely to arise from closing the ramp (i.e., neighborhood, safety, congestion and mobility impacts). To perform a high-level assessment, a sketch-planning tool or macroscopic traffic analysis model may be used to assess changes in congestion, safety, traffic diversion, or other impacts.

If the negative impacts of ramp closure are less than the existing safety/congestion problem, the next step is to conduct an operational analysis to determine the extent to which ramp closure should be considered. If the high-level problem assessment indicates that ramp closure impacts outweigh existing impacts and the benefits of this strategy do not offset them, then other viable ramp management strategies should be considered.

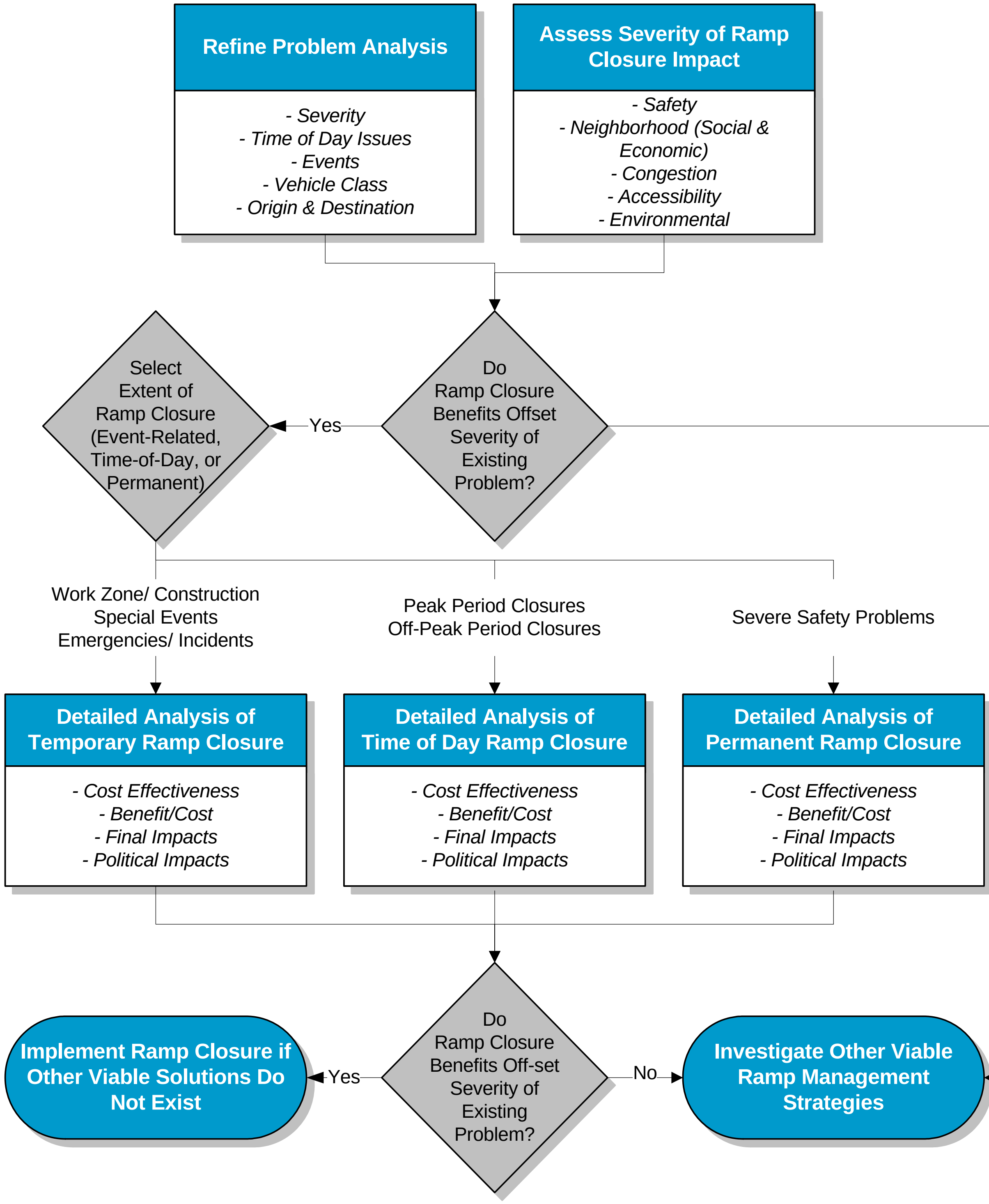


Figure 6-4: Ramp Closure Decision Tree

Table 6-3: Ramp Closure High-Level Screening Matrix

Need/Problem	Location/Reason	Type of Closure
Safety	Merge Point	Time-of-Day, Permanent
	Ramp Terminal	Time-of-Day, Permanent
	Freeway Mainline	Time-of-Day, Permanent
Impacts	Neighborhood	Time-of-Day, Permanent
	Construction	Temporary
	Special Events	Temporary
Congestion	Freeway Mainline	Time-of-Day
	Ramps	Time-of-Day
	Ramp Terminal	Time-of-Day
	Arterial	Time-of-Day
Policy	Transit	Time-of-Day, Permanent
	HOV	Time-of-Day, Permanent
	Freight	Time-of-Day, Permanent

6.4.2 Ramp Closure Extent

Depending on the type of ramp closure being considered, practitioners need to take into account other considerations that may negatively affect the viability of ramp closure strategies. First, the impacts of diverted traffic need to be assessed to determine if there is enough capacity on alternate routes to service diverted traffic. If not, practitioners need to determine if capacity improvements or operational enhancements can be implemented on these routes to provide the needed capacity. Similarly, practitioners need to consider if there are any special circumstances that prevent a ramp from being closed. For instance, it may not be feasible to close a freeway exit ramp, even if there is a safety problem, if the stretch of freeway immediately downstream of the ramp is susceptible to recurring severe incidents and there is no other exit ramp nearby to provide additional routing. The ramp in this case must remain open so motorists can exit the freeway and re-enter it at a location downstream of the location where incidents occur. The impacts to businesses and event venues near closed ramps should also be considered. Public education campaigns may mitigate the impact of ramp closure on local businesses.

In situations where ramp closure is deemed practical and beneficial, the extent of ramp closure needs to be determined so as not to close ramps when situations do not warrant it. Depending on when problems occur, ramp closure may be:

- Temporary (event-related).
- Permanent.
- Based on time of day.

Each of these closures is discussed in greater detail below.

Detailed Analysis of Temporary Ramp Closure

Ramps may be closed on a temporary or event-related basis to improve safety or mobility during special events or when construction activities are scheduled. Special event closures intentionally divert traffic from entrance or exit ramps and arterial streets that cannot handle the traffic volumes associated with the special event to ramps and arterials that can. Special event-related ramp closures should be part of an overall special event Traffic Management Plan.

Besides special events, temporary ramp closures may be implemented to provide a safer incident scene for responders and victims when collisions occur on or near ramps.

Ramps may also be closed on a temporary basis to facilitate construction or maintenance work zones. For instance, ramps adjacent to construction zones may experience high traffic volumes that must enter the freeway on a substandard taper because of the location of the work zone. The safety impacts of keeping an entrance ramp open in such a situation may well offset the impacts of closing the ramp. When impacts are severe, ramps adjacent to construction zones may be temporarily closed. Ramps may be closed to all vehicles, or all vehicles except construction vehicles. Additionally, ramps may be closed at certain times of day (most likely at night when traffic volumes are minimal), during certain phases of a construction project or for the entire length of the construction project. Construction or maintenance-related ramp closures should be part of the overall work zone/construction Traffic Management Plan.

Case Study: Wisconsin DOT Temporary Ramp Closure Procedure for Construction Activities.

The Wisconsin DOT has developed an approach for temporarily closing entrance and exit ramps when needed to support freeway mainline construction activities. The intent of this approach is to reduce the demand through the work zone (i.e., reach an acceptable freeway queue length and delay) in an overall effort to improve safety. The approach begins by analyzing peak-period entrance ramp closures to determine if closures during the peak period are capable of reducing freeway mainline volumes. If queue lengths and vehicle delays are acceptable, then the peak period entrance ramp closure is implemented. If queue lengths and delays are not acceptable, then full-time ramp closures are analyzed to see if additional volume reductions are sufficient. If reductions from full entrance ramp closures are still not acceptable and a downstream high volume exit exists, then this process is repeated for exit ramps. In severe cases, when entrance and/or exit ramp closures do not produce acceptable queue lengths and delay times, staff may consider implementing freeway-to-freeway ramp closures. However, this is only permissible when the impacts of closures are analyzed and deemed acceptable.

Detailed Analysis of Time-of-Day Ramp Closure

Time-of-day ramp closure is often used when the impacts are limited to certain hours of the day. Impacts could be severe enough that closing the ramp is only acceptable when ramp volumes are relatively low (leading to off-peak closures) or because ramp volumes are high enough to create problems when volumes are very high (leading to peak closures).

Under rare circumstances, ramp closure may be used during peak hours of the day when traffic conditions and ramp geometrics combine to cause severe safety or congestion problems, when these problems do not arise during other times, and/or when no other options are available to correct the problems and there is a compelling reason to allow the ramp to be open during the other hours of the day. A case study of Toronto's experience with time-of-day closure is highlighted below.[34]

Case Study: Toronto's Time-of-Day Ramp Closure

In the early 1970s, the City of Toronto implemented time-of-day ramp closures at two entrance ramps in response to a high rate of crashes and congestion observed at these locations. Both ramps were located adjacent to Toronto's Gardiner Expressway, a downtown urban expressway with a speed limit of 90 km/h (55mi/h).

The westbound ramp from Lake Shore Boulevard (at Jameson Avenue) had several geometric deficiencies, including a short acceleration lane and steep downgrade. The ramp also ended in a large concrete bridge abutment, which was believed to contribute to the safety problem at this location. To remedy the severe safety problem, the westbound ramp from Lake Shore Boulevard was closed from 4:00 to 6:00 PM, Monday through Friday. This helped to stabilize traffic flow entering the expressway from the westbound on-ramp.

The other time-of-day ramp closure in Toronto is on the eastbound on-ramp from Lake Shore Boulevard (at Jameson Avenue). Similar to its westbound counterpart, the problems here were in part directly related to the influx of vehicles entering the mainline from the on-ramp. However, unlike the geometric deficiencies observed at the westbound on-ramp, problems here were primarily related to the lack of capacity on the mainline and the mainline's inability to accept heavy traffic volumes originating from the ramp. From the hours of 7:00 to 9:00 AM, approximately 1,400 vehicles were entering the mainline via the eastbound on-ramp. This fact, combined with the fact that the mainline was already operating at capacity, prompted officials to close the ramp. By doing so, it was anticipated that turbulence and congestion on the mainline would be reduced and existing capacity on Lake Shore Boulevard would be more efficiently used. The results showed that traffic flow on the mainline did improve because of the eastbound on-ramp closure.

Ramp closure can be used for either on- or off-ramps, and is typically used at locations with high collision rates, or in response to severe local or neighborhood traffic-related problems.

Detailed Analysis of Permanent Ramp Closure

Permanent ramp closures should only be considered for severe safety problems that cannot be addressed by other ramp management strategies. For example, permanent ramp closures may be a viable option for ramps where a severe safety problem exists, either on the ramp itself or on the freeway mainline at the ramp merge area, and where ramp metering is not a viable option due to inadequate queue storage on the ramp. However, before the decision is made to permanently close a ramp, consideration should be given to public reaction, impacts on neighborhood traffic patterns, and impacts on surrounding businesses and land use.

6.4.3 Conduct Detailed Analysis

This step is similar to the high-level feasibility and impact analysis completed earlier. However, this analysis is carried out to a greater level of detail. It is important to conduct a detailed traffic operations analysis as well as a safety (crash) analysis, cost analysis (capital, operating, and maintenance costs), and then a benefit/cost or cost effectiveness analysis. This will help identify and understand all the impacts associated with ramp closure, which in turn will ease the decision-making process when determining whether or not to close a ramp.

If the impacts of ramp closure are offset by the severity of the problem, closures may be considered. Before implementing a closure, however, other ramp management strategies should be considered. If no other strategies can offset the severity of the observed problems, ramp closure may be implemented. On the other hand, if ramp closure benefits cannot offset the severity of the problem, closure should not be considered and other viable solutions should be considered.

6.4.4 Implementation Decision

This is the final step in the ramp closure decision process where a final “go/no-go” decision is made to pursue the ramp closure. If the results of detailed analysis indicate that ramp closure is a viable solution to the identified problem, closure may be implemented. If ramp closure does not help to offset the severity of existing problems, then other viable strategies should be considered.

Specific implementation issues are discussed in Chapter 7. Among the most important ramp closure issues is how to physically close the ramp (barricades, cones, etc.). The safety of personnel closing the ramp and the cost required to implement and maintain ramp closures should be primary concerns in deciding on the method to implement ramp closures.

6.5 Selecting Special-Use Ramp Treatments

In addition to ramp metering and/or ramp closure, special circumstances may arise in which additional measures are needed to manage traffic on or near freeway ramps. Special-use ramp management strategies can be used in conjunction with, or independently of, other ramp management strategies to help mitigate traffic-related problems occurring on or near ramps. Selecting a particular strategy depends on the type of problem (i.e., whether on not the problem is related to safety, neighborhood impacts, congestion, or policy). For this purpose, Table 6-4 provides a high-level screening matrix that maps specific special-use ramp treatments to specific problems based on their type and location. This table allows a practitioner to select specific special-use ramp treatments for further study based on the specific problems that exist, or are forecast to exist, in their region.

As Table 6-4 shows, the reader is referred to Figures 6-5 through 6-9 depending on the type and location of the problem(s). These figures present decision trees for further analyzing and selecting specific special-use treatments:

- Figure 6-5 – selecting special-use treatments that target safety impacts at merge points.
- Figure 6-6 – selecting special-use treatments that target neighborhood impacts.
- Figure 6-7 – selecting special-use treatments that target construction impacts.
- Figure 6-8 – selecting special-use treatments that target special event-related impacts.
- Figure 6-9 – selecting special-use treatments that target policies.

Table 6-4: Special-Use Treatments High-Level Screening Matrix

Need/Problem	Location/Reason	Special-Use Treatments
Safety	Merge Point	Figure 6-5
	Ramp Terminal	NA*
	Freeway Mainline	NA*
Impacts	Neighborhood	Figure 6-6
	Construction	Figure 6-7
	Special Events	Figure 6-8
Congestion	Freeway Mainline	NA*
	Ramps	NA*
	Ramp Terminal	NA*
	Arterial	NA*
Policy	Transit	Figure 6-9
	HOV	Figure 6-9
	Freight	Figure 6-9

*NA – Not Applicable

Applying each of these decision trees to select appropriate special-use ramp treatments is explained in the remainder of Section 6.5.

6.5.1 Special-Use Treatments for Safety Problems

Poor geometry on or near the ramp can contribute to safety problems, especially in the ramp/freeway merge area. If geometric problems do exist, the first step would be to try to fix these problems. In some cases this may be too expensive or not physically possible, thus special-use treatments such as truck restrictions should be considered.

Special-use treatments that address safety problems typically focus on efforts that restrict certain classes of vehicles such as trucks, construction vehicles, or other slow-moving vehicles from ramps. For example, if the acceleration lane taper on a freeway merge is not sufficient, slow-moving vehicles and/or trucks may not be able to accelerate to freeway speeds in time to merge smoothly. When this situation is exacerbated by poor sight distance on the mainline or a severe uphill grade on the ramp, a safety problem will likely result that can potentially be addressed through truck restrictions. Also, if the geometrics on the ramp, such as a sharp curve with insufficient superelevation, make it difficult for trucks, over-height, or wide loads to negotiate the ramp safely, restrictions should also be considered.

The decision-making process for addressing safety problems at a freeway/ramp merge area through special-use treatments is illustrated in Figure 6-5. The first two steps in determining whether truck restrictions or other special-use treatments can be used to address safety problems on a ramp are: 1) refine the problem analysis to better understand existing problems and 2) assess the severity of special-use impact. These two steps should be completed simultaneously, because inputs from each are needed before additional decisions can be made.

Safety problems on or near ramps should be analyzed to determine when problems occur, if problems are attributed to geometric deficiencies, and if vehicle mix, speeds, and/or volumes contribute to the problem. For example, if roadway geometry is not a contributing factor to the safety problem, then truck restrictions will not help and therefore are not appropriate. Truck restrictions in this case will not provide justifiable benefits and will only push problems to other local ramps.

On the other hand, if roadway geometry contributes to the problem, truck restrictions on the ramp may improve safety at the merge point or at the location on the ramp with the geometry deficiency. The extent to which trucks should be restricted depends on further analysis of the safety problem and whether or not the problem exists all day or if it occurs only at certain times within the day. Depending on the results of this analysis and based on whether or not geometrics contribute to the problem, truck restrictions may be implemented at certain times of the day rather than on a permanent basis. In either case, a final analysis of truck restrictions should be completed to determine if it is beneficial to implement a restriction based on cost effectiveness or benefit/cost analyses, potential political impacts, and budgetary considerations. Once a detailed analysis is complete, decision makers can use the results of this analysis to determine whether to proceed with truck restrictions or to analyze other viable ramp management strategies.

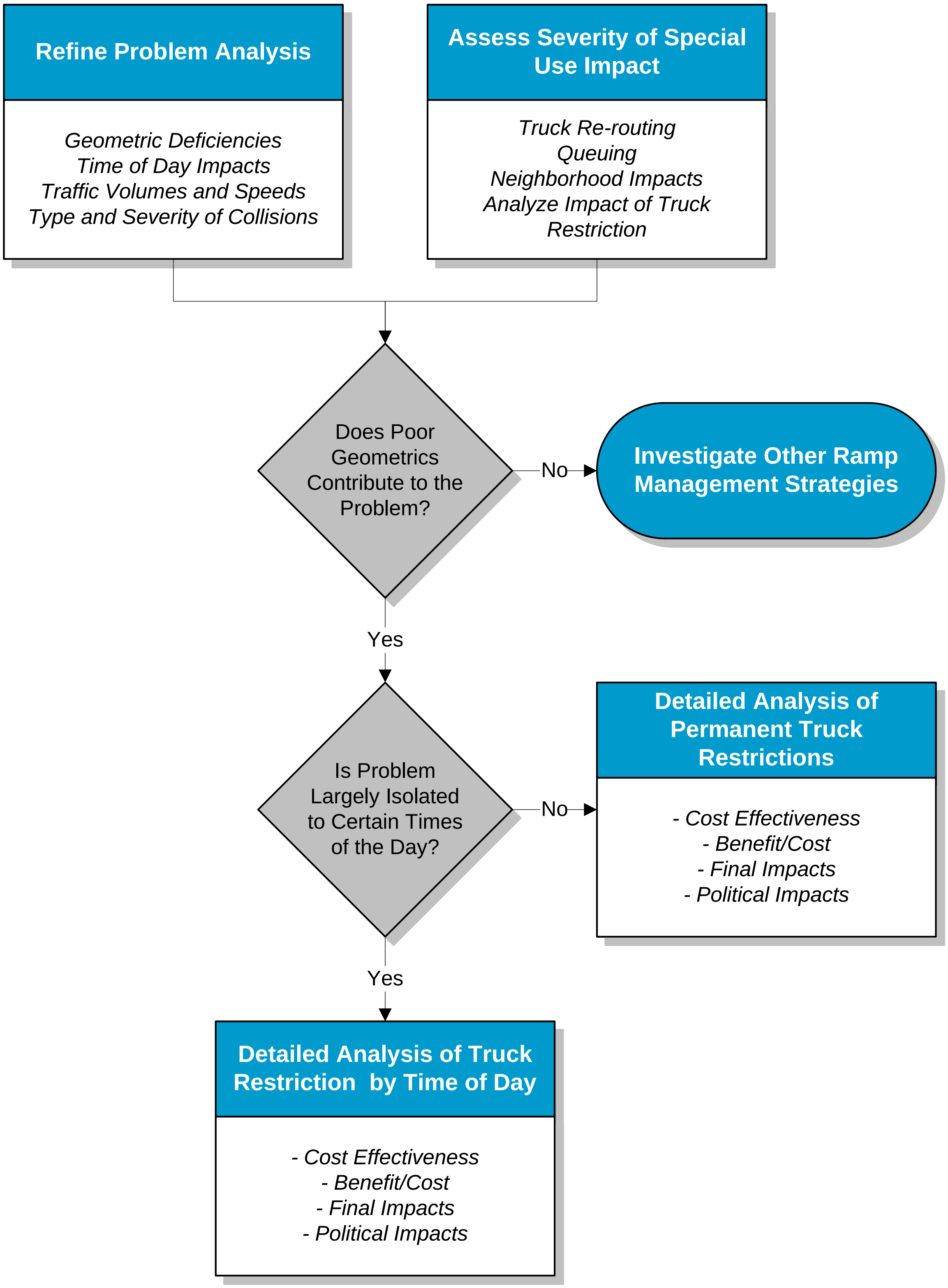


Figure 6-5: Decision Tree for Special-Use Treatments that Target Safety Impacts at Merge Points

6.5.2 Special-Use Treatments for Neighborhood Impacts

High truck volumes on ramps that lead to nearby arterials may contribute to problems in nearby neighborhoods if the arterial streets are not designed for truck traffic or if land use patterns are inconsistent with heavy truck traffic (e.g., residential neighborhoods). Large volumes of trucks that access a freeway from neighborhood streets or that leave the freeway and travel on a neighborhood street may create problems if the arterial is not designed to accommodate trucks, or if land use patterns create conflicts with heavy truck traffic.

Special-use ramp treatments for neighborhood impacts are similar to those for improving safety. Treatments for neighborhood impacts take into account deficiencies in the geometry of the ramp or downstream arterial, and traffic volumes and speeds on ramps and nearby arterials. Based on the analysis of geometry, traffic volumes, and traffic speeds, applications such as truck restrictions may be implemented to mitigate, to the extent possible, the problem affecting the neighborhood.

The decision tree showing special-use treatments for neighborhood impacts is illustrated in Figure 6-6. The first step in determining special-use treatments that address neighborhood impacts is to refine the understanding of the problems affecting the neighborhood. This analysis should identify the following:

- Geometric deficiencies.
- Existing traffic compositions and patterns.
- Target traffic levels and speeds (i.e., Level of Service requirements set by local agencies).
- Truck impacts.
- Safety/crash analysis.
- Neighborhood survey of perceived impacts.

Based on the results of the problem analysis, the practitioner must first determine if target traffic levels and speeds are achieved by restricting trucks. If target levels and speeds can be achieved then the practitioner can perform a more detailed analysis of truck restrictions. If target traffic levels and speeds cannot be achieved through truck restriction alone, the practitioner must determine if the ramp's geometry contributes to the problem. If the answer to this question is yes, then truck restrictions combined with other strategies may be analyzed. However if geometry does not contribute to the problem, then the practitioner should investigate other viable ramp management strategies.

Detailed analysis should focus on the cost effectiveness of the full set of impacts (traffic and political) of the strategy being analyzed.

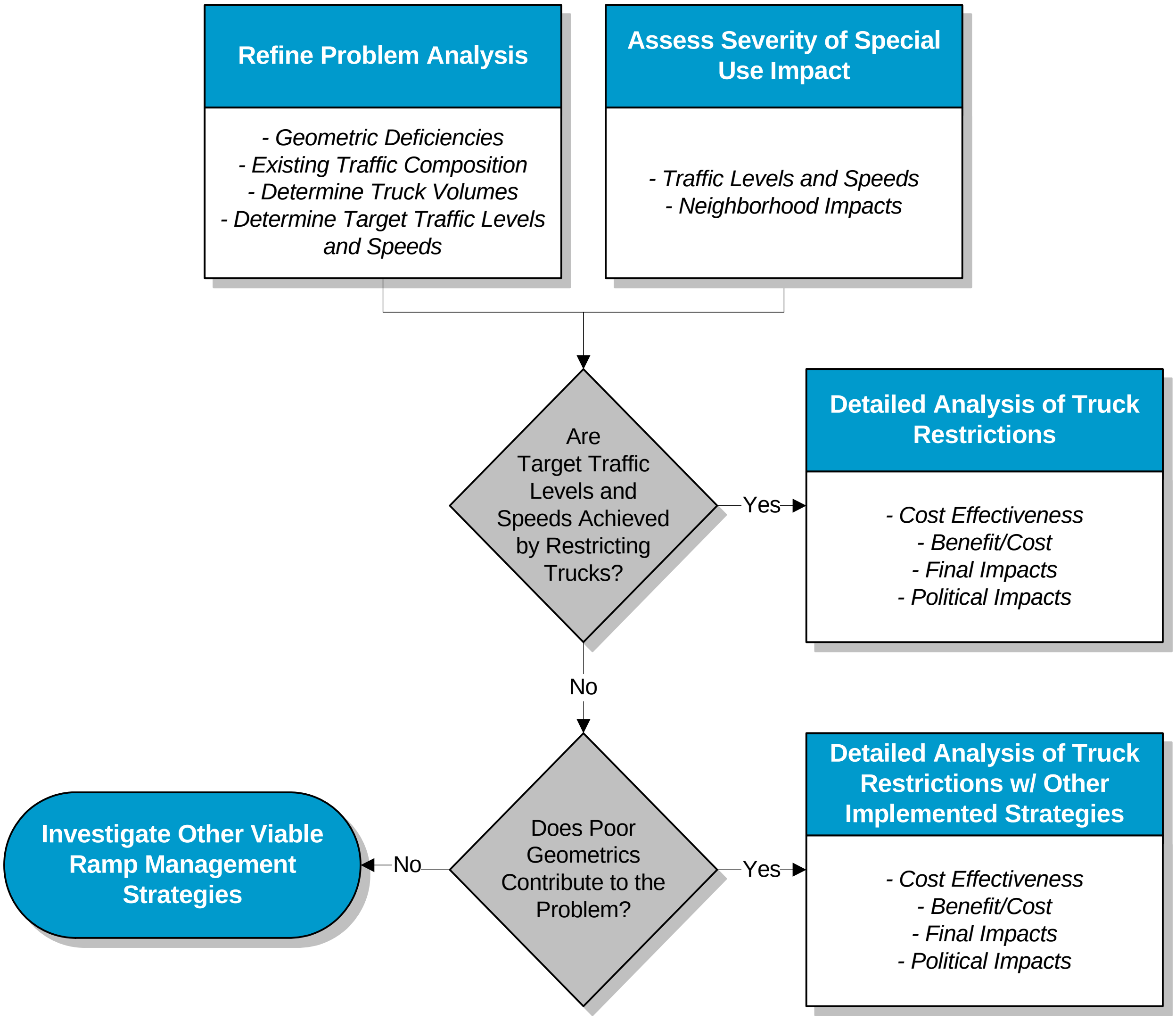


Figure 6-6: Decision Tree for Special-Use Treatments that Target Neighborhood Impacts

6.5.3 Special-Use Treatments for Construction Impacts

Special-use treatments, including full closures and truck restrictions, may be implemented at freeway ramps to improve safety and to minimize the impacts that construction vehicles, personnel, and equipment have on ramp traffic and vice versa. The special-use treatments for construction impacts decision tree is illustrated in Figure 6-7. Practitioners looking to implement special-use treatments for construction impacts should begin with a refined analysis of problems on the ramp and surrounding areas, including geometric deficiencies, type and location of crashes, traffic volumes and speeds, and other problems affecting construction or traffic on the ramp.

Based on the results of the first step (Refining Problem Analysis), the second step in implementing special-use treatments for construction is to assess whether or not the impact of construction activities on normal ramp operations will be severe (e.g., a high mix of slow-moving construction vehicles causing significant differences in speeds, frequent occurrences of construction vehicles entering and exiting the roadway, presence of construction workers working near the roadway).

If construction impacts are severe, then the feasibility of ramp closure should be considered. If full ramp closure (closed to all vehicles) is feasible, the ramp(s) should be closed during the appropriate phases (when construction impacts are most severe) of the construction project. However, if full ramp closure is not feasible, then vehicle restrictions should be considered. For example, restrictions may be enacted that simply allow only construction vehicles to use the ramp, thereby reducing the likelihood of safety problems from occurring if other vehicles were present. Alternatively, restrictions to all heavy trucks could be implemented when the ramp geometry is inadequate and this poor geometry contributes to the problem.

If the construction impacts on a ramp(s) are not deemed severe and the ramp geometry is adequate, the practitioner responsible for ramp management should review the work zone traffic control plan to see if ramp management strategies are included in the plan. If ramp management strategies are included in the plan, then the practitioner should perform a detailed analysis of the ramp management strategies included in the plan. If ramp management strategies are not included in this Plan, the practitioner should assess whether demand on the ramp needs to be further reduced. It is also recommended that practitioners determine if further reductions in demand are needed after the detailed analysis of the ramp management strategies listed in the Traffic Control Plan. If further reductions in demand are needed then practitioners should conduct a detailed analysis of vehicle class restrictions and priority treatments. If priority treatments currently exist within the region, similar treatments could be considered at the analyzed ramp locations. Otherwise, special-use treatments should not be implemented until vehicle priority policies are implemented, in use, and practical at the analyzed ramp locations. If demand on the ramp does not need to be further reduced, practitioners should consider other Viable Ramp Management Strategies to reduce the impacts of construction on ramp traffic.

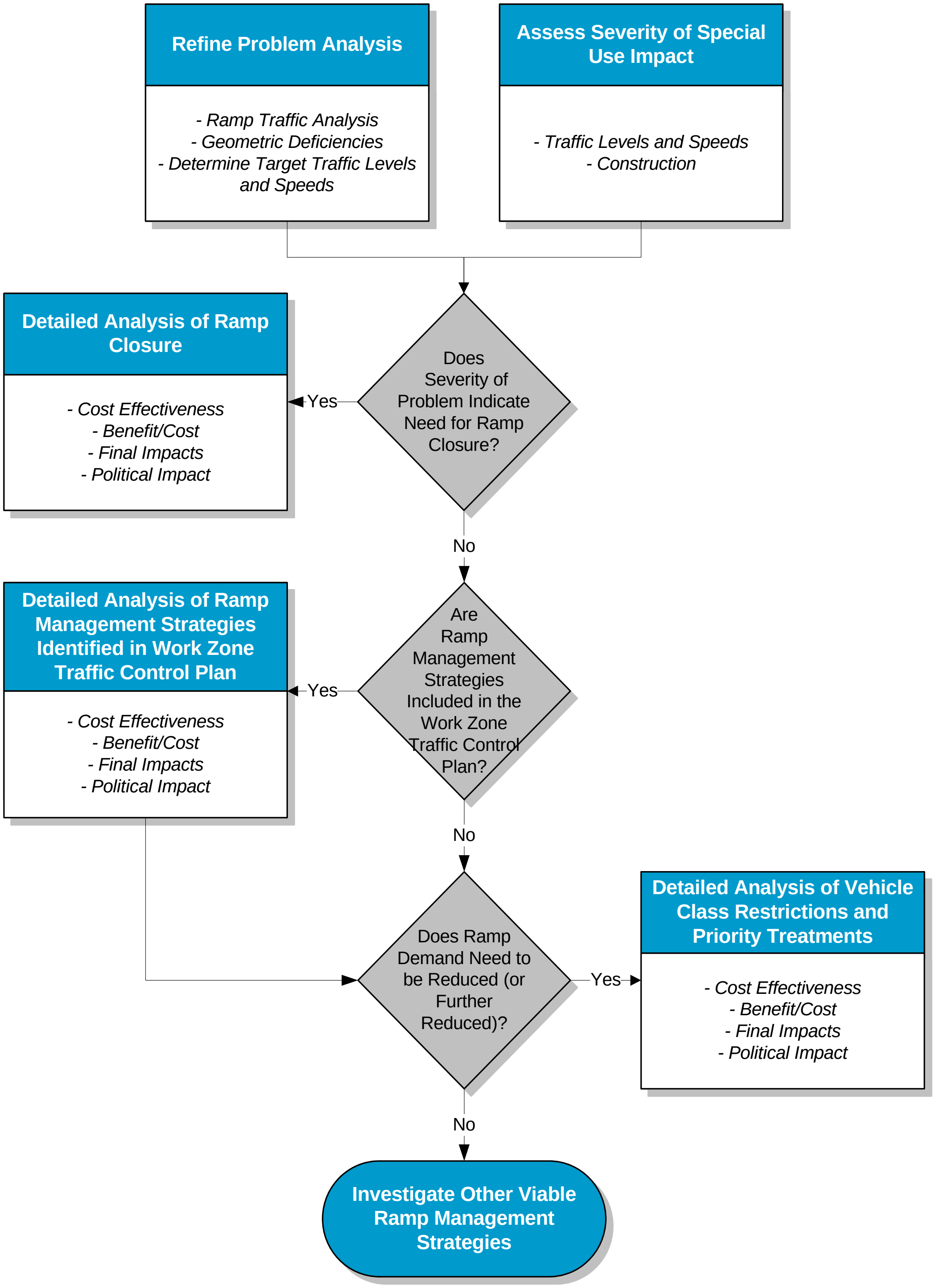


Figure 6-7: Decision Tree for Special-Use Treatments that Target Construction Impacts

6.5.4 Special-Use Treatments for Special Events

When special events occur, ramp capacities may be temporarily exceeded, resulting in safety, congestion, and mobility problems on ramps and immediately upstream of the ramp. Due to the high volumes of traffic during a special event, queues may form at the ramp/arterial intersection. These queues may extend the entire length of the exit ramp and may spill onto the freeway. This may increase the risk of rear-end and side-swipe collisions. Additionally, traffic congestion on the ramp may prohibit the quick, efficient movement of emergency vehicles responding to incidents at the special event venue or at other nearby locations. When the impacts of special event traffic are severe, practitioners may consider full ramp closure as a means of diverting traffic to ramps with greater capacity. The special-use treatments for special events decision diagram is illustrated in Figure 6-8.

The first step in deciding whether or not to implement special-use treatments to mitigate the impacts of special events is to better understand the problems that currently exist. The refined analysis should seek to understand the following:

- Local traffic conditions.
- Special event congestion.
- Special event collision history.
- Queue and delay impacts.
- Impacts that may occur downstream of the analyzed ramp.
- Availability of alternate routes.
- Need for emergency vehicle access.

If there is a special event Traffic Management Plan, much of the information mentioned above should be found in this Plan. Based on the analysis of existing problems, one can begin to assess whether or not special-use treatments are needed for special events and what these treatments may be. Regardless of the treatments selected, they must be compatible with and integrated into the special event Traffic Management Plan.

First, as mentioned above, the severity of the problem will dictate whether a full ramp closure is needed or not. If full closure is indicated, emergency vehicle access needs to be considered. If the ramp is the most direct or quickest route for emergency vehicles to access the venue or to travel through the neighborhood surrounding the venue, the ramp closure should allow for emergency vehicles access. In either case, a detailed analysis of the impacts of the closure should be undertaken before a final decision is made. The analysis should consider cost effectiveness, the assessment of traffic impacts, and the assessment of political implications.

If the severity of the problem does not require ramp closure but is significant enough to trigger the need for mitigation, the special event Traffic Management Plan should be reviewed to determine if HOV or transit policies were approved, incentives are encouraged, or HOV/transit trips constitute a major component of transportation to and from the special event venue. If so, implementing HOV or transit incentives on ramps near special event venues, such as HOV or transit-only lanes, should be considered through a detailed analysis of the cost effectiveness, benefit/cost, and additional impacts. If not, HOV or transit incentives should not be considered, yet other viable ramp management strategies could be considered.

Similar to HOV and transit, the needs of delivery vehicles and patrons destined for the special event are issues that must be taken into consideration when making decisions regarding ramp closure. Delivery vehicles must have access to transport goods to and from the special event. Therefore, special-use ramps may need to be designated for delivery vehicles only, if traffic patterns prevent delivery vehicles from arriving and departing the special event venue in a timely manner. Similarly, if the large queues of vehicles that form on entrance or exit ramps spill over onto freeways or adjacent arterials, entrance and exit ramps may need to be closed in order to divert traffic to ramps with greater capacities upstream and downstream of ramps where problems exist.

If a special-use treatment is implemented, the need for delivery vehicle access on the ramp should be considered. If delivery vehicles need access to the ramp to deliver special event goods and the ramp can safely handle this traffic under the special event Traffic Management Plan, delivery vehicle access and/or priority on the ramp in question should be considered.

6.5.5 Special-Use Treatments for Policy

Some special-use treatments, such as full-time or time-of-day priority for transit, HOV, or commercial vehicles (trucks) are only applicable in situations where agency or regional policies are in place to support them. Without such policies, these special-use treatments will fail to gather the support needed for successful implementation. If policies are in place to support one or more special-use treatments, the high-level analysis of problems should be refined. The refined analysis should seek to understand the following:

- Special class demand (i.e., vehicle and/or passenger demand for transit, HOV, or other special class vehicles).
- Downstream attractors/upstream generators (i.e., where the special class trips start and end).
- Traffic volumes and operations (i.e., overall traffic volumes and traffic operations, using measures such as average speed, delay, queues, etc.).

Based on the above analysis, a decision to implement a special-use strategy on the ramp can be made. The criteria for making this decision will vary based on the beliefs of individuals responsible for making this decision, however public input may be a contributing factor. The special-use treatments for policy decision diagram is illustrated in Figure 6-9.

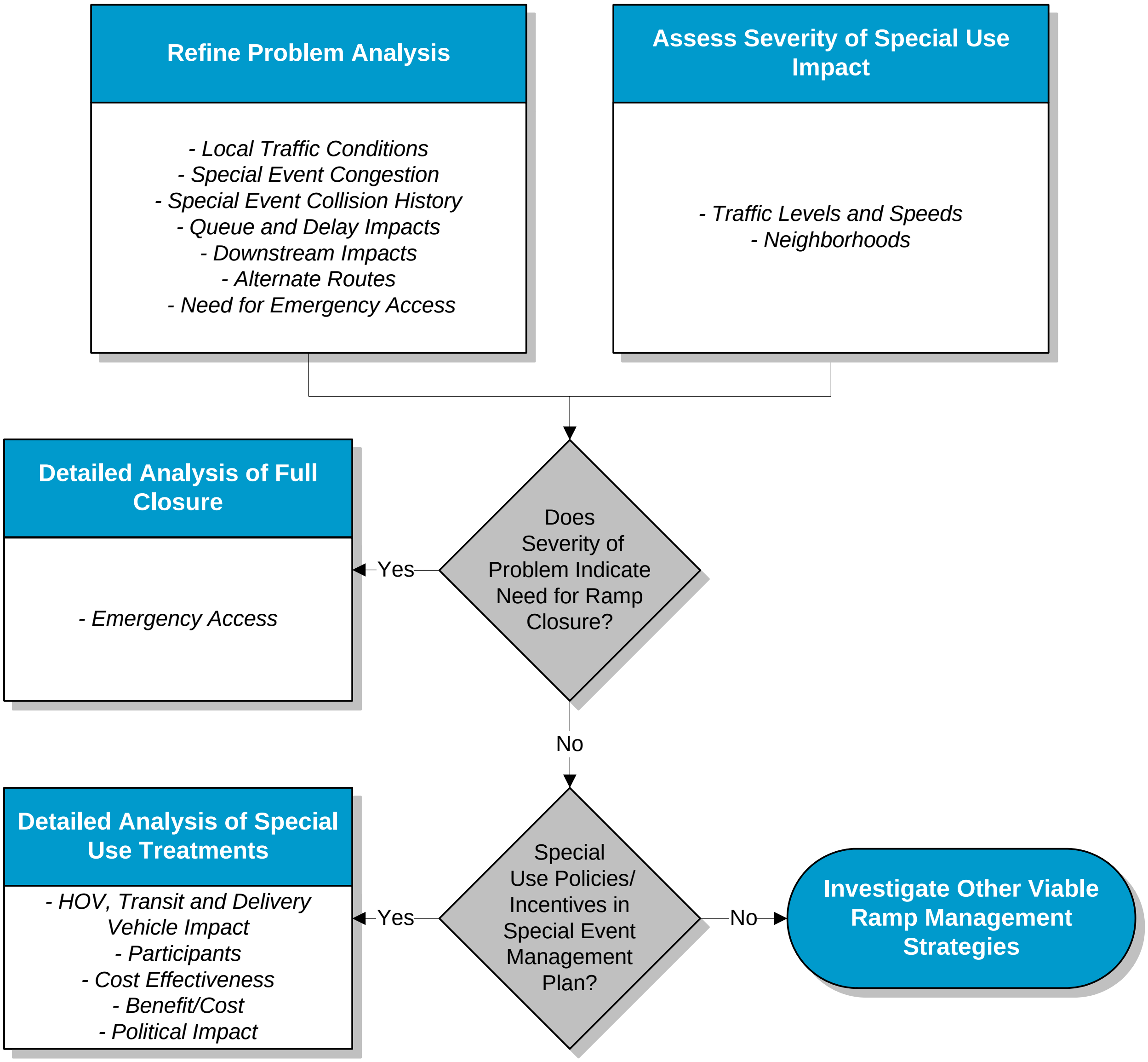


Figure 6-8: Decision Tree for Special-Use Treatments that Target Special Event Related Impacts

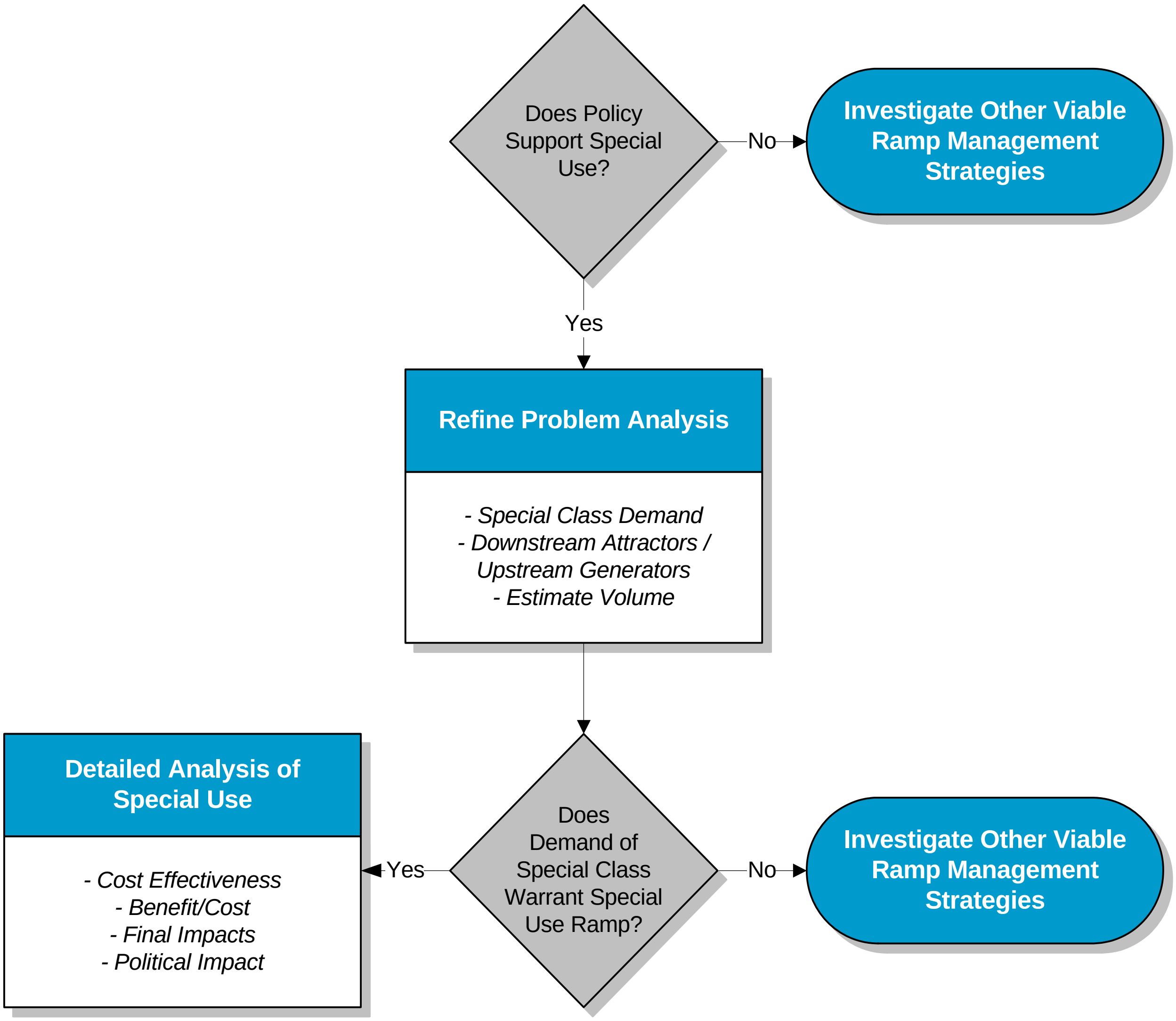


Figure 6-9: Decision Tree for Special-Use Treatments that Target Policies

6.6 Selecting Ramp Terminal Treatments

Improvements at ramp/arterial terminals can reduce the occurrence of unacceptable traffic queues, number of collisions, vehicle delay, and other impacts at or downstream of the ramp/arterial intersection. The specific ramp/arterial improvement depends on the type and location of the problem. Using the matrix in Table 6-5, the type and location of the selected problems are mapped to ramp terminal treatments.

Table 6-5: Ramp Terminal Treatments High-Level Screening Matrix

Need/Problem	Location/Reason	Ramp Terminal Treatments
Safety	Merge Point	
	Ramp Terminal	✓
	Freeway Mainline	
Impacts	Neighborhood	✓
	Construction	✓
	Special Events	✓
Congestion	Freeway Mainline	
	Ramps	✓
	Ramp Terminal	✓
	Arterial	✓
Policy	Transit	
	HOV	
	Freight	

These strategies may be stand-alone improvements or a coordinated effort with the other ramp management strategies described in this chapter. The need for ramp terminal strategies will depend on conditions that occur on the ramp.

These strategies and all the strategies discussed in this chapter must support agency policies, goals, and objectives. Conflicting goals may need to be prioritized and compromises considered. Examples of two conflicting goals are: 1) managing freeway traffic to minimize delay, and 2) managing queues at ramp meters so they do not affect arterial operations. The ramp terminal treatment decision tree is illustrated in Figure 6-10.

Refine Problem Analysis

- Ramp & Arterial Traffic Analysis
- Special Event Congestion and Traffic Flow
- Historical Collision Analysis
- Geometric Deficiencies
- Determine if There are Target Traffic Levels and Speeds
- Upstream and Downstream Trip Generators

Impacts	Location to Implement Strategy	- Widening	- Channelization	- Signal Timing	- Turn Restrictions	- Geometrics (Tapers, Sight Distance, etc.)	- Warnings (Signing, Pavement Marking, etc.)	- Lane Assignment
Congestion (Queuing & Delay)	On-Ramp	X	X	X				
	Off-Ramp	X	X	X				
	Arterial	X	X	X	X			
Safety - Collisions	On-Ramp	X	X	X		X	X	
	Off-Ramp	X	X	X		X	X	X
	Arterial	X	X	X		X	X	X
Downstream Arterial Impacts	Off-Ramp		X	X	X		X	X
	Arterial		X	X			X	X

Figure 6-10: Ramp Terminal Treatment Decision Tree

6.6.1 Ramp Widening

Ramps may need to be widened to improve safety and traffic flow on the ramp or the arterial, or to support other ramp management strategies. Implementation of ramp meters, for instance, may require that entrance ramps be widened to increase capacity and/or provide additional storage on the ramp. Likewise, ramps that give priority treatment to HOVs may need to be widened to provide a separate lane adjacent to the general-purpose lane so that HOV vehicles can bypass queues at the meters. Exit ramps may need to be widened if additional storage or turn lanes are needed at the ramp terminal intersection. However, it may not be possible to widen a ramp, if there is a lack of right-of-way or other restriction present. For instance, it may not be possible to widen a ramp if there is not enough room after the ramp is widened to perform maintenance activities or adequately position maintenance equipment (e.g., bucket trucks) near the ramp. Practitioners need to carefully analyze the possibilities of widening ramps before they make the decision to widen.

6.6.2 Channelization

Channelization helps delineate and separate traffic movements, thus reducing driver confusion and improving overall roadway safety. Channelization in the form of new turn or storage lanes may extend on the adjacent arterial to separate through traffic from traffic destined for the ramp. This helps hold traffic destined for the ramp without impeding the movement of through traffic.

6.6.3 Signal Timing

Traffic signals at the ramp/arterial intersection may be retimed to reduce queuing on the ramp and to prevent queues from backing up into the intersection (entrance ramps), onto the freeway facility (exit ramps), or onto the arterial (entrance ramps). Where possible, agencies involved should coordinate ramp meters with arterial management systems to optimize flow at intersections. Agencies may need to enter into agreements to specify the manner in which traffic signal systems will be operated.

At entrance ramps, signal timing may be adjusted to hold traffic destined for the ramp on arterials so vehicles do not stop within the intersection when queues form. This ensures that through traffic is not affected by ramp metering operations and jurisdictional issues do not arise. However, practitioners should make sure that approaches or lanes that lead to the ramp have sufficient capacity or storage to hold ramp-bound traffic.

At exit ramps, signal timing may be adjusted to permit all vehicles waiting on the ramp to clear the intersection. This will minimize the length of queues that form between green phases, so that queues do not back up onto the freeway facility.

Signal timing at the interchange may also be modified to support traffic management on the arterial downstream from the ramp interchange. In some cases, traffic from the interchange can overwhelm the ability of the arterial downstream to handle traffic. Queues may form in areas not well suited to accommodate backups, such as closely-spaced intersections.

In these cases, ramp terminal signal timing may be set to limit, or "gate", the traffic destined downstream of the interchange.

6.6.4 Turn Restrictions

Turn restrictions at ramp terminals may be considered as a method to restrict volumes on the arterial downstream of the interchange, similar to the signal "gating" strategy discussed previously. Turn restrictions can either be permanent, during the signal's red interval (no right turn on red), or by time of day, depending on the severity of the downstream arterial problem and times that the problem exists.

6.6.5 Improvement to Geometry

Poor geometry is a leading cause of many collisions on or near freeway ramps. Improving the geometry of ramps will smooth the flow of traffic entering the freeway facility, and will reduce potential vehicle conflicts that result from motorists taking corrective measures because of geometric deficiencies. Examples of geometric improvements that may be included are improvements to sight distance and reduction in horizontal and vertical curves in the roadway. When making improvements to ramp geometry, special consideration should be given to the hours when improvements will be made, so as to reduce impacts to traffic using the ramp during construction. It is possible that delays caused by construction on or near the ramp may impede traffic flow, which may result in queues that back up onto the adjacent surface street (in the case of entrance ramps) or freeway (in the case of exit ramps). If possible, construction should be completed at night or during off-peak hours to mitigate these negative impacts.

6.6.6 Signing and Pavement Marking

A certain level of signing and pavement marking is needed to support any of the ramp strategies discussed. Signing and pavement marking improvements are generally used to inform drivers of downstream conditions or to provide guidance to drivers approaching or on a ramp. Pavement markings are implemented to delineate traffic and help facilitate vehicle movements.

6.7 Tools to Support Selection of Ramp Management Strategies

Several traffic analysis tools are available to practitioners responsible for developing and selecting ramp management strategies. Because several tools are available, practitioners must select the appropriate tools needed to perform required analyses. In other words, is the analysis going to be conducted at a high-level or at a more detailed level? The answer to this question will help identify the appropriate tool or tools needed. Data collection activities that will be relied upon during high-level and detailed analysis include:

- Crash records.
- Observations.
- Traffic counts.

The extent and depth to which the data collected through these activities will be used will increase as the analysis becomes more detailed.

6.7.1 High-Level Analyses

Throughout this chapter, one of the first steps undertaken in the decision-making process is to refine the problem analysis. This is a high-level analysis undertaken to gain more insight into the problem, to support selection of a particular strategy or set of strategies from among all the potential ramp management strategies. The high-level analyses rely heavily on observations of existing conditions and data, and on high-level analysis tools. Each section of this chapter describes the high-level analyses appropriate for the subject decisions.

Tools to support the high-level analyses described in this chapter include:

- Sketch-planning tools.
- Analytical/deterministic tools (HCM-based).

A more detailed discussion of these tools can be found in Chapter 9, Section 9.4.

6.7.2 Detailed Analyses

Throughout this chapter, nearly the last step in the decision-making process is to perform a detailed analysis of the selected ramp management strategy. These analyses are described in each decision-making section. Most of them include a determination of cost effectiveness, benefits and costs, and final impacts. These detailed analyses require more powerful tools that often take more time to use and more data than the high-level tools. For example, the impacts of implementing complex ramp management strategies often require the use of simulation models. The models provide an estimate of the traffic operations impacts, and those impacts are then used to determine cost effectiveness (i.e., benefit/cost ratio). The output of the models also helps provide input to decision makers to judge what the likely political impacts will be.

Tools to support the detailed analyses described in this chapter include:

- Macroscopic simulation models.
- Microscopic simulation models.
- Mesoscopic simulation models.

A more detailed discussion of these can be found in Chapter 9, Section 9.4. Additional information can be obtained from FHWA's *Traffic Analysis Tools Primer, Volumes 1 and 2*.[35,36]

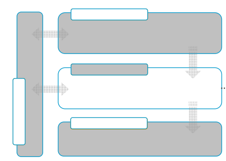
6.8 Chapter Summary

Practitioners can choose from four primary categories of ramp management strategies to improve traffic flow on ramps. As is the case with most new projects, a fifth strategy also exists, which is to take no action. Determining whether ramp management strategies are needed and/or which strategy or combination of strategies is "best" for addressing existing problems or conditions are decisions that may be difficult to make. This is due in part to similarities between ramp management strategies. For instance, both ramp metering and ramp closure can be applied to resolve safety-related problems at the ramp/freeway merge point. The selection of the best strategy in cases like these requires a complete and thorough analysis and comparison of each strategy's impacts as well as their benefits. For instance, even though strategies may address similar problems, the associated impacts of deploying one strategy versus another may be substantially different. In some cases, it may not even be feasible to implement strategies based on the results of this analysis.

Selecting the "best" ramp management strategy or combination of strategies should begin with a cross-comparison of existing problems and conditions with problems and conditions that each ramp management strategy can address. Based on the results of this comparison, practitioners can focus their efforts on the applicable strategies that are capable of addressing existing problems or conditions. From here, practitioners can perform detailed analyses of the applicable ramp management strategies, to identify strategies or combinations of strategies that work best for the agency and the problems or conditions being addressed. Chapter 7 provides additional details on how to successfully implement the strategies that have been selected through guidance provided in this chapter. Chapter 8 discusses procedures on how to best operate and maintain the implemented strategies, so as to maximize return on investment.

7

IMPLEMENTING STRATEGIES AND PLANS



Decision Making

Chapter 5: Ramp Management Strategies

Chapter 6: Developing and Selecting Strategies and Plans

Chapter 7: Implementing Strategies and Plans

Chapter 8: Operation and Maintenance of Strategies and Plans

7.1 Chapter Overview

Chapter 7 represents the third step in the ramp management decision-making process. This chapter builds off the previous two steps discussed in depth in Chapters 5 and 6 by addressing the various issues and activities associated with the implementation of ramp management strategies and plans. This includes activities that occur before, during, and immediately after the period in which strategies are physically deployed and operated. A firm understanding of these issues and activities will help agencies successfully implement ramp management strategies developed and selected using the process outlined in Chapter 6.

Implementing ramp management strategies and plans is a delicate process that must be completed well the first time to ensure success. If not carefully planned, ramp management strategies, like any other transportation investment, can ultimately fail. As a result, transportation and ramp management investments may be viewed unfavorably by the public, which in turn makes it difficult to secure the support and funding needed to maintain and improve implemented strategies. Therefore, considerable time and effort is often spent on deciding how strategies will be implemented well before strategies are physically deployed and first introduced to the public. Included in this effort are various steps, executed both before and after the strategies are implemented, that are intended to make implementation more successful. Examples of these

Chapter Organization

steps include public outreach and inter-agency coordination. This effort is also continued beyond initial operation to confirm that strategies are performing as expected and producing expected benefits.

Chapter 7 Objectives:

Objective 1:	Identify the importance and reasons for phasing ramp management projects.
Objective 2:	Understand the importance of public information campaigns with respect to implementing strategies and plans.
Objective 3:	Provide and discuss techniques for disseminating information to the public, agencies and individuals within the agency implementing a ramp management strategy.
Objective 4:	Identify typical agencies affected by the ramp management strategy implementations.
Objective 5:	Understand the role agreements, policies and procedures have in fostering strategy implementation.
Objective 6:	Understand the need and importance of testing ramp management equipment and the other procedures for starting a ramp management program.

The major aspects of project implementation and their approximate time-frame in relation to other implementation activities are captured in Figure 7-1. Each activity shown in Figure 7-1 is described in the major sections of this chapter, with the section number of the activity shown in parentheses. The order in which the activity is shown in the figure is a general representation of the relative timing of the various activities, and is only presented to give a general idea of when activities occur. The true time frame for when activities occur is dependent on the type of strategy being implemented and the scope of the effort. For instance, a major, region-wide ramp metering project might have a project start date three to five years before ramp meters are turned on. In contrast, a minor ramp metering project that will deploy just a few ramp meters in a corridor that already has metering may have a project start date approximately one year before meters are turned on for the first time.

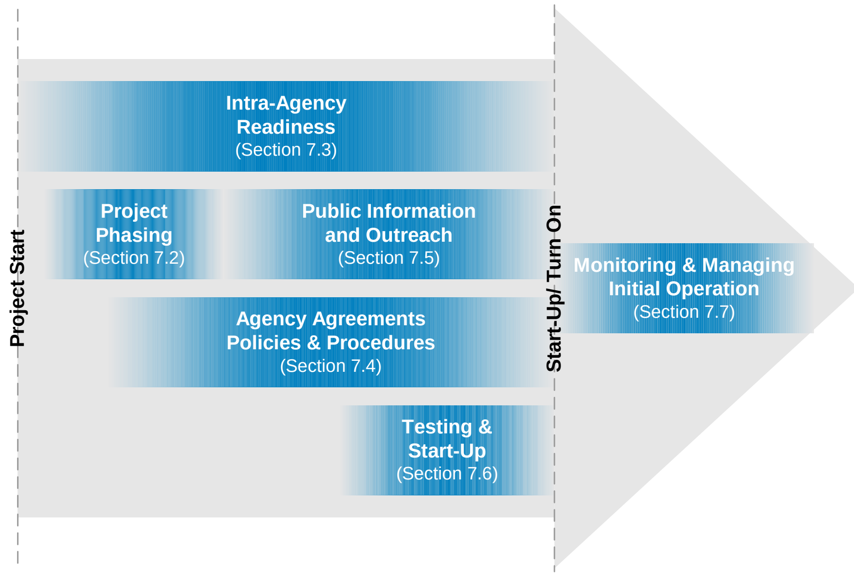


Figure 7-1: General Activities and Timeline for Ramp Management Strategy Implementation

7.2 Project Phasing

The first step to the effective implementation of ramp management strategies is to create a plan that defines the timeframe for when individual projects in the ramp management plan will be phased in. Even if all the funding desired is available, phasing for all but the simplest ramp management plan is important. Ramp management strategies should be phased for the following reasons:

- Allows the agency to become familiar with, and gain an understanding of, ramp management strategies in small steps.
- Allows adjustments in approach as elements are implemented.
- Allows public outreach and inter-agency coordination to be sized in a way that best suits the resources available. Undertaking an outreach and coordination effort that encompasses a large portion of a metropolitan area with many agencies will stretch both the public information office and traffic operations staff thin.
- Can account for the availability of staff to physically deploy strategies, and whether or not they have the capabilities to manage and deploy strategies in a cost-effective manner (see Section 7.3.3). The decision to deploy ramp management strategies without regard to staffing levels and capabilities may significantly delay implementation and erode potential short-term benefits.
- Allows better use of available funding. It is often not possible to have the funds available to implement the entire plan in one project.

An effective phasing plan is one that seeks to deploy ramp management strategies with the available funds in a manner that best suits the experience of the agency, considers the political situation in the area, and maximizes benefits in the short term. This is accomplished by first deploying ramp management strategies at the following locations:

- Where they will produce the most benefit.
- Where the planned deployment of ramp meters is achievable and manageable.
- Where the strategy will be most favorably viewed (it is important to consider whether the strategy is likely to be controversial or require substantial outreach efforts).

For instance, locations where there is a severe safety problem may be targeted first. If this is the first implementation of the strategy, it is important that the local agencies, elected officials, and public are either neutral or in favor of the strategy. This is important so the first implementation can be implemented without major opposition. The next step is to determine a logical segment of the envisioned system to implement.

Using an example of a region that wants to implement system-wide traffic-responsive ramp metering on numerous freeway corridors, the agency might first consider locations where there is historically a high prevalence of rear-end or sideswipe collisions at or upstream of ramp merge points. The geographic extent of the problem in the relevant corridor should then be revisited (see Chapter 6) to make sure there is a logical implementation phase. Metering at isolated ramps should only be deployed if the problems are isolated and if metering these isolated ramps will sufficiently mitigate the problem without unacceptable impacts, such as traffic diversion or unacceptable queues. In many cases, metering only one ramp will not be the best implementation phase. Generally, a more reasonable plan is to phase the implementation in logical groupings of ramps, such as those between major bottlenecks. In some cases, there may be a ramp in a group of metered ramps that is not metered. This is usually the case if the ramp enters the freeway into an add lane, there is a bottleneck immediately upstream of the ramp, and the freeway downstream can absorb the ramp volumes without causing a problem.

Future phases will add additional groups of ramps with the ramp management strategy deployed until the full deployment, as envisioned in the ramp metering plan, can be completed. Additional phases should follow the same logic as the first phase: selecting locations with the greatest potential for benefit in areas where strategies can be most readily implemented, then selecting a logical grouping of ramps on which to implement the strategy.

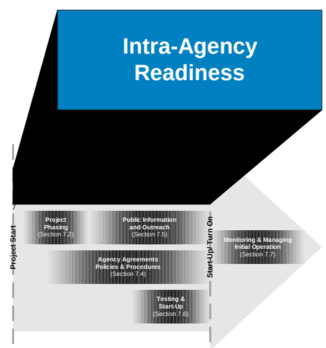
If funding is available to support the implementation of all ramp meters to be implemented, it may be beneficial to install all the equipment needed at that time. However, implementing the strategy (for example turning on the ramp meters) in a phased approach should still be considered. Funding is only one of the reasons mentioned previously for phasing in a ramp management strategy.

Ramp metering lends itself to this type of construction/installation and implementation/turn-on phasing quite well. If other construction projects are being planned for an area that is planned for metering, it is often a good idea to install as much of the infrastructure needed for ramp metering as possible. Conduit, wiring, cabinets, detectors, communication media, and controllers can all be installed well in advance of the meter being turned on. In fact, if a central system already exists, getting detection in the field as early as possible will help in deciding the most appropriate strategy, determining appropriate performance measures, and collecting performance data before implementation for the evaluation of the system.

If the ramp meters won't be turned on for a considerable length of time (e.g., many months to over a year) after the infrastructure for some of the ramps will be installed, consideration should be given to not installing the signal heads until shortly before turn-on will occur. Signal heads may be knocked down by errant drivers and the appearance of signal heads well in advance of signal turn-on, even if carefully planned and intended, may give the impression of severe project delays, wasted public funds, and inefficient management.

In any event, the installation of equipment may be best accomplished and most cost effective by finding opportunities to include it as part of other projects, but this should not affect the phasing decisions for final implementation of the strategy.

7.3 Intra-Agency Readiness



Agencies preparing to implement ramp management strategies should take all the necessary steps to ensure that strategies can be implemented successfully. This includes public outreach efforts and, just as important, intra-agency communication and coordination. Agencies should communicate the goals and objectives of ramp management strategies, as well as the benefits of these strategies, to personnel at all levels within the agency, beginning first with upper management. In doing so, employees will take on the role of ambassadors for ramp management strategies and can speak intelligently about aspects pertaining to the selected ramp management strategies when called upon by outside parties. Despite its importance, in-reach activities only represent the foundation for total intra-agency readiness.

Ramp management strategies should not be implemented until agencies are ready to implement, operate, and maintain selected strategies. Implementing the selected strategies requires planning to ensure that the needs of the agency and the public will be met.

7.3.1 Systems and Software Implementation

Unlike other ramp management strategies, ramp metering requires that agencies deploy systems and software before metering operations can begin. Other ramp management strategies (e.g., ramp closures, special-use treatments, and ramp terminal treatments) may not be automated processes but rather predominantly fixed or manual activities not requiring computer systems and software. However, some implementations of these other strategies may require computer systems and software. For example, ramp closures may include an automated system of dynamic message signing (DMS) when the ramp is closed, or may include automated or partially automated gate operation that requires computer systems and software. Special-use treatments may also include DMS or detection systems that require computer systems and software. Ramp terminal treatments may also include DMS or new signal system features that will require computer systems and software.

This section will use ramp metering to illustrate the considerations needed when implementing systems and software. However, this discussion may also be relevant to any of the other strategies, depending on the specifics of the strategy and how it will be implemented.

Ramp meter instrumentation (loops, signals, signs, controllers, etc.) need to be installed well in advance of when ramp metering is slated to begin. Likewise, software that is used to establish communications in the field and that allow operators to monitor and control systems need to be developed or procured and tested before implementation can take place.

Systems

Systems installed for ramp management should be developed with a systems engineering approach. There are several references available for information on systems engineering, but readers of this document should first refer to the FHWA's *Freeway Management and Operations Handbook* (FMOH), where the systems engineering process as it relates to freeway management is covered (Chapters 3 and 14).[1] This section will only provide a high-level summary of the systems engineering approach.

The FMOH uses the following definition of systems engineering:

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

The FMOH points out that systems engineering helps accomplish four key activities that impact a project's success:

- Identify and evaluate alternatives.
- Manage uncertainty and risk in our systems.
- Design quality into our systems.
- Handle program management issues that arise.

Key components of the systems engineering process are illustrated in Figure 7-2.

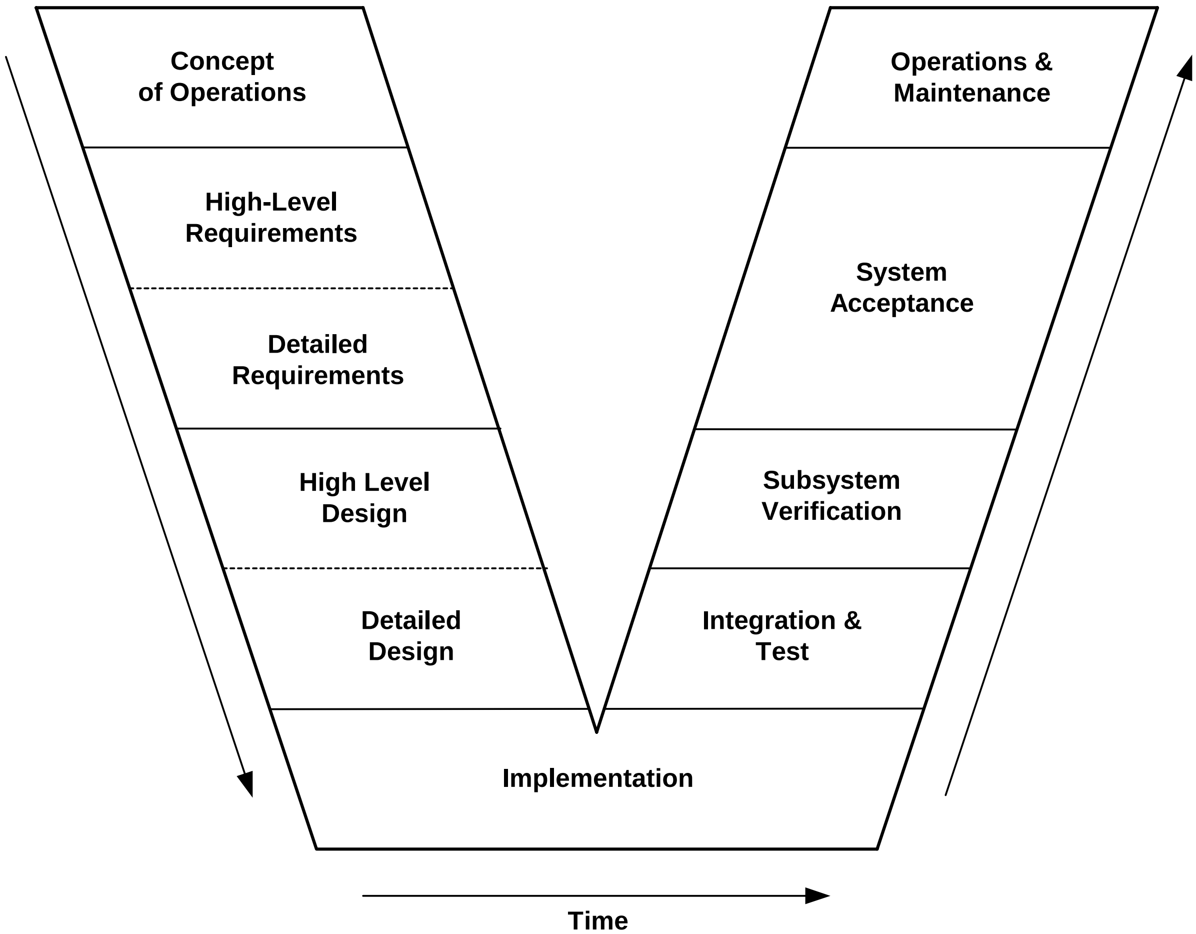


Figure 7-2: Systems Engineering Process ("Vee" Diagram)

One of the key concepts in systems engineering is testing. It is critical to make sure all detection, communication, field controller firmware, and central system software is well tested before ramp meters are turned on. Ramp meters and associated equipment need to be installed well in advance of when strategies are slated to take effect. This gives parties responsible for ramp meter implementation time after meters are deployed but before meters are turned on to test each meter to confirm they are working properly. The FMOH discusses testing in Chapters 3, 14, 15, and 16. Readers should refer to these chapters for additional information on system and component testing.

Software

Ramp metering strategies are implemented and operated through a combination of hardware and software in the field and, in most systems, hardware and software at a central location. Centrally-located software links the systems in the field with operators and central computing platforms. Software requirements will vary based on several aspects of the system, some of which include:

- Presence of central control.
- System build out (i.e., is the corridor currently metered, or are metering operations new to the corridor?).

At a minimum, controllers in the field will need software to operate ramp meters and to collect operational data. If a central computer is available, controllers will usually be programmed to transfer data to the central computer where it can be easily processed by operators at a Traffic Management Center (TMC) or similar facility. Software will also be needed to process loop detector data so it can be incorporated into metering algorithms. In this regard, software helps to synthesize the significant amounts of data that are collected.

Software requirements also extend to operator workstations so operators can remotely monitor and control ramp meter operations. Software functions for operator workstations are also established so operators can view ramp meter databases.

Software products that support ramp metering can be commercial-off-the-shelf (COTS) software or contractor-developed products. It is likely that in the implementation of ramp meters, software will need to be developed or existing contractor software modified. The procurement of software (i.e., software development and integration) does not meet the normal linear process that highway or even TMC construction projects follow. Further, it is complicated with ownership and intellectual property rights. With this in mind, practitioners should beware that procuring and implementing software may be a lengthy process that should be undertaken well in advance of when meters will be turned on. There are several references that can provide more detail on software acquisition and ITS procurement. Initially, readers should refer to Chapter 14 of the FMOH.[1] If additional information is desired, the reader should refer to the FHWA document *The Road to Successful ITS Software Acquisition*.[37]

Training courses from the National Highway Institute (NHI) are also available for ITS Software Acquisition and ITS Procurement.

Software products that are installed to support ramp meter programs and their documentation should be included in an agency's configuration management process. A configuration management process is one that manages changes to a system, to ensure that a system is operated as it is intended throughout its design life cycle. Configuration management includes documenting upgrades and modifications that are performed and other attributes related to this work, including the date and reasoning why the work was completed. Configuration management should go beyond just central software and should include central hardware, communications, and field devices. Chapters 3 and 14 of the FMOH provide an introduction to configuration management.

7.3.2 Data Collection

Before ramp management operations begin, traffic volumes, travel times, and other appropriate performance measures should be collected, modeled, and analyzed to estimate the benefits of implementing the ramp management strategy. Improvements to travel time and travel speeds in a specific corridor, as well as changes in congestion on the mainline and ramps, may be measures of effectiveness that can be used to prioritize locations where equipment will be installed. Depending on the scope of ramp management deployment, this action may need to be completed as much as one year in advance of when the strategy is slated to begin. Chapter 9 discusses evaluation data needs in more detail.

7.3.3 Staffing

Staff is needed to deploy, operate and maintain the ramp management strategies previously selected in Chapter 6. Strategy implementation requires practitioners to determine the number and type of staff needed to deploy, operate and maintain selected strategies. Implementation also requires that managers allow enough time for the hiring and training of new staff needed. Chapter 4 discussed staffing in general for ramp management. This section builds on the concepts presented there. The reader may wish to refer to Chapter 4 as they read this section.

Ramp metering, as well as other ramp management strategies, requires proper operations software and field equipment (e.g., signals, detectors, and controllers). When these devices fail, ramp strategies can no longer be operated correctly and should not be used again until problems are fixed. To ensure devices can be fixed in a timely manner, properly trained staff should be available to resolve issues in a timely manner.

Despite the type of ramp management strategy implemented, staff are needed to perform routine maintenance activities on devices installed at the ramp, to minimize the likelihood of device failure and to troubleshoot field equipment if it does fail. Staff are also needed to manually close ramps when barriers and gates are not automated. Staffing needs, however, vary by type of closure.

Contractors may be hired on a full-time or part-time basis to satisfy or supplement staffing needs, both for maintenance and operations. Contractors can be used to supplement agency staff or can be used to provide all of the maintenance or operations staff needed. Many combinations of agency and contractor staffing are possible. Agencies should carefully consider the advantages and disadvantages of various staffing options and select the ones that best fit the needs and budget constraints of their respective agency.

7.4 Agency Agreements, Policies and Procedures

Before ramp management strategies can be implemented, departmental and inter-agency policies are needed to dictate if and how ramp management strategies can be implemented. An assessment of local, county, state and federal laws, regulations, and policies should be reviewed to determine if additional policies are needed and to assure that the planned strategies fit within the existing legal and policy framework for the local area (see the discussion in Chapter 3.). Agency agreements, policies and procedures may be needed to capture support for ramp management strategies as well as to define agency expectations for how strategies will be designed, implemented, operated, and maintained. Depending on the importance of issues identified, agreements between agencies can be formal memoranda of understanding, less formal letter agreements, or informal handshake agreements. In any case, it is critical that personnel from different agencies as well as personnel from different departments within the agency responsible for ramp strategy implementation coordinate to thoroughly flesh out the details pertaining to proposed ramp management strategy deployments.

The following sub-sections identify several key policies and procedures necessary to design, implement, operate, maintain, and enforce ramp management strategies. Both intra- and inter-agency policies and procedures are described, as well as the policies and procedures that span the two. Section 4.3 of this handbook also includes discussion of the needs for inter- and intra-agency coordination.

7.4.1 Policies and Procedures Internal to Departments of Transportation

Ramp management strategies require approval and support from upper management and other department managers before implementation can be seriously considered. Support is needed from upper management to secure the resources needed for implementation (e.g., personnel, contracts to procure and install communications, field equipment, workstations, and servers as well as any construction needed), operation, and maintenance of strategies. In addition, upper management support is needed to ensure that implemented ramp management strategies will remain an integral aspect of regional transportation directives and that ramp management investments can be expanded to other areas of need, if appropriate. Input from managers of other departments is needed to verify that ramp management strategies fit into current operations and can be seamlessly integrated. Managers of other departments may also identify implementation challenges associated with selected strategies, which can be resolved before strategies are implemented.

7.4.2 Inter-Agency Coordination, Policies, and Procedures

As mentioned in Section 4.3, the implementation of ramp management strategies requires coordination among agencies to establish region-wide policies that guide how strategies are implemented and how associated issues are resolved. Coordination needs to continue beyond the planning stages into the operations stages of ramp management. Several types of agencies with differing agendas will likely be involved with or affected by the operation of ramp management strategies, therefore, policies should be drafted to ensure equity among motorists and agencies across jurisdictional borders. For instance, the state Department of Transportation (DOT) or other agency implementing ramp meters will be doing so to improve operations on the freeway. However, the impacts of ramp metering may expand beyond the freeway to local arterials, increasing the traffic demand on the arterial as well as introducing other unwanted impacts (e.g., reduced safety, increased emissions, increased fuel consumption). Without local agency support, continued operation of ramp management strategies may be problematic. It is important to continue the coordination that was established during the planning stages throughout the life cycle of ramp management strategies. Policies and operational procedures should be revisited and modified if needed to make sure that agency needs continue to be met. Hardware, software, or field modifications may need to be made as well.

Enforcement Agencies

Continued coordination needs to occur between the agency implementing ramp management strategies and local, county, and state enforcement agencies as ramp management strategies are implemented and operated. This should build on the coordination efforts undertaken during the planning phases. Ramp management strategies, such as ramp metering and special-use treatments, require active enforcement to ensure that motorists obey signing, striping, barricades, and ramp signals to maximize the benefits of these investments. Enforcement is particularly important at ramp meter turn-on and the weeks that follow. High visibility of officers during this timeframe will help ensure compliance with the new traffic control devices and reduce driver confusion and the number of crashes attributed to these systems. With this said, however, excessive enforcement may negatively affect driver behavior and directly affect operations on the ramp as officers pull vehicles over on the shoulder. City or state traffic ordinances may need to be amended to ensure that ramp management strategies can be enforced and to dictate penalties for non-compliance. Finally, coordination between enforcement agencies may expedite incident response and clearance.

Ramp metering and special-use treatments are not the only strategy that requires practitioners to coordinate with law enforcement. Coordination may also need to occur when ramps need to be closed due to an emergency, or when severe weather conditions threaten the safety of motorists. In these situations, coordination with law enforcement is needed to restrict access to ramps that lead to roadways where problems are located (e.g., freeways, and roadways adjacent to freeways).

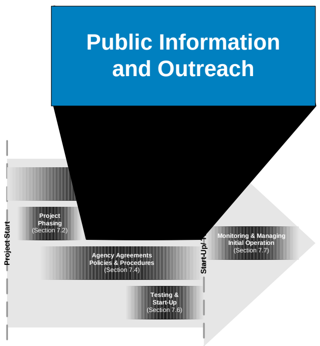
Local and County Traffic Operations

Where applicable, agencies responsible for the implementation of ramp management strategies must also actively coordinate with municipal and county traffic operations departments to ensure that ramp management operations fit well with arterial operations. During the planning and implementation phases, coordination focused on the selection, implementation, and design of ramp management strategies. Memoranda of understanding (MOU) may have been drafted during the planning or implementation phases. If not, they should be considered early in the operational phase. Multi-agency MOUs will show region-wide commitments to ramp management strategies as a congestion mitigation strategy. It is important that agreements consider agency roles and responsibilities, including how traffic signals near metered ramps are operated. MOUs should also include provisions on data sharing, especially if control strategies like ramp metering will interconnect with the traffic signal system and other traffic management elements (e.g., closed-circuit television) operated by either the DOT or local agency.

Local Transit Authority

Coordination with transit agencies should occur throughout the life cycle of ramp management strategies. During the planning and strategy selection stages, decisions were made to either minimize the impact on or enhance transit operations. After strategies are implemented, coordination with the transit agencies involved should include reviewing the operation of the ramp management strategies to make sure impacts to transit are acceptable or to see how transit operations can be further improved.

7.5 Public Information and Outreach



As mentioned in Chapter 6, public support and understanding of ramp management strategies are critical to ensure that strategies successfully meet their objectives. The goal of any public information campaign should seek to lay the foundation needed to build consensus and understanding of strategies proposed for implementation.

Without a public information and outreach campaign, public or agency opposition to the implementation of ramp management strategies may pose a challenge that can significantly delay or eliminate their implementation. Considerable time should be spent on planning and selecting strategies, otherwise delays may lead to significant and unexpected cost expenditures. In severe cases, public opposition may force agencies to cease the implementation of certain strategies, resulting in wasted effort, inefficient use of limited funds and resources, and perhaps harm to the effectiveness and credibility of the agencies involved. Due to these potentially severe impacts, agencies responsible for the implementation of ramp management strategies should be proactive in their public information and outreach efforts, and they should actively market the reasons for and benefits of proposed ramp strategies.

"Public or agency opposition to the implementation of ramp management strategies poses a challenge that can significantly delay or eliminate their implementation."

Agencies should seek to inform the public, local agencies, and the media at various points during the planning, design, and implementation phases of projects to keep these groups abreast of project progress and to solicit information needed to support subsequent project activities. Agencies should also undertake internal efforts to inform personnel at various levels within their organization of the reasons that ramp management strategies are needed, the benefits they provide, and the timeline for their implementation. In-reach efforts will not only ensure common understanding among personnel, but also provide beneficial media through which ramp management knowledge can be promoted and disseminated to outside groups. Finally, preparations should be made to accommodate questions and concerns likely to be posed by the public after strategies are set in place and become operational.

Public information campaigns are also important from the aspect of obtaining public input. Public input is needed and valuable in evaluating and selecting locations to address with ramp management and what ramp management strategies to implement at those locations. Public input is also helpful in establishing program goals and objectives.

The size and scope of the public outreach effort should be commensurate with the size and scope of the ramp management strategy that is selected. In other words, a large public information and outreach campaign that requires significant financial and staff resources would not be appropriate for the implementation of a single ramp meter. Rather, it may be more appropriate for a large-scale deployment of many ramp meters or closures along a corridor or several corridors.

Steps should be taken to deliver information to the public and the media well in advance of when strategies are slated to be rolled out. For certain ramp management strategies such as ramp metering, public information campaigns may need to be set in place anywhere from one to five years before ramp meters are turned on (timing depends on the scale and scope of the project). This time frame is needed to incorporate public and agency comments into the decision-making process and to assure that there is enough time to implement strategies that best address needs. Additionally, public information campaigns are often repeated several times before systems are turned on. This reduces the potential "surprise factor" that, when left unchecked, can lead to public frustration and opposition to proposed strategies. This helps to smooth the implementation of strategies while at the same time achieving public acceptance and compliance.

Information released to the public, local agencies, and the media should be fair and accurate, to reduce the chance that the reliability of released information will be called into question at a later date.

7.5.1 Target Audience

Public information and outreach should target local leaders, motorists, the media, and external agencies thought to have an effect on, or be affected by, ramp management strategy implementation. At a minimum, support and input from these groups are needed to successfully implement ramp management strategies. Information solicited from these groups will be used in part to properly plan how these strategies will be implemented and operated. Public information and outreach should be tailored to the specific needs and concerns of each group affected by ramp management strategy implementation. Likewise, the reasons for and benefits of ramp management strategies need to be expressed in terms that each group can easily understand.

"Public information and outreach should be tailored to the specific needs and concerns of each group affected by ramp management strategy implementation."

Local Leaders

Local leaders (e.g., elected and appointed officials) can be valuable advocates of or powerful opponents to ramp management strategies. It is important to determine whether local leaders are predisposed to either advocacy or opposition to the proposed strategies, and to develop an outreach program that targets both the advocates and the opponents.

It is important to reach out to advocates to gain their support. It is equally important to reach out to opponents or potential opponents to understand their concerns. Some of these concerns may be ones that can be addressed in the implementation of the strategies. Other concerns may be the products of misconception or misunderstanding that can be lessened by providing accurate information that addresses them.

It is also important to reach out to local leaders to confirm that they have no unresolved issues with the strategies. If no unresolved issues exist, then significant follow through with local leaders would not be necessary and resources could be expended on other aspects of the outreach efforts or other aspects of strategy implementation.

Motorists

Public information campaigns targeted at motorists, as well as general public groups, should convey the reasons for and expected benefits of ramp management strategies, provide information that explains how strategies work, and dictate what (if any) actions motorists need to take to comply with the new strategies. Motorists' initial impressions of ramp management strategies may be negative because negative aspects associated with these strategies are more easily observed than their benefits. For example, motorists may tend to focus on the fact that ramps that were once unrestricted, now have meters installed that delay their trips. What motorists often fail to understand is that the negative aspects are in most cases more than completely offset by the improvements to mainline speed, delay, and safety. Therefore, public information campaigns should emphasize how strategies work, the reasons why strategies are being considered, and the benefits likely to be observed. By doing so, motorists' negative perceptions of ramp management strategies may be mitigated to a greater extent.

Media

The media can provide practitioners with a means to gain positive support for ramp management strategies from motorists and local leaders. Electronic and print media can be used to express the benefits and reasons for ramp management before and after strategies are deployed. Before ramp meter systems are implemented or expanded, it is important that the local media be notified of program goals, objectives, and benefits well in advance of when meters are expected to be turned on.

Although the media can aid in acquiring public support, the media can also be obstructive if not handled properly. If the benefits of ramp management strategies are oversold and unrealistic, credibility of the implementing agency may be questioned.

Enforcement Agencies

Outreach activities should extend to local, county, and state law enforcement agencies. Agencies implementing ramp management strategies should seek input from law enforcement agencies as traffic management strategies are being developed, so their perspectives and needs can be incorporated in the selection of the strategies. After the strategies are selected and the implementation phase begins, it is important to provide law enforcement with information on why ramp management strategies are being implemented and why the help of law enforcement is needed. Outreach should also be used to solicit information from law enforcement agencies to determine requirements for successful implementation. These requirements may include:

- The extent to which compliance should be enforced.
- Times and conditions when ramp operations should be enforced.
- Locations where law enforcement can monitor and enforce operations and locations where additional monitoring needs to be built.
- Staffing needs for enforcement activities.
- Legal concerns.

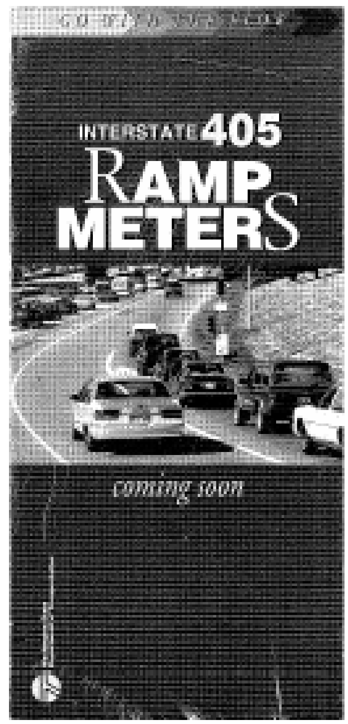
Transit

Ramp management strategies such as ramp closure and preferential treatments may affect transit routes and schedules. Because strategies may impact public transit agency operations, these agencies should be included as part of a ramp management outreach campaign. Transit agencies should be included in project discussions, to resolve issues as they arise and to coordinate project activities with transit operations.

7.5.2 Techniques and Tools

Several techniques and tools are available to agencies seeking to solicit input from and disseminate information to the public, outside agencies and/or individuals within an agency. The selection of techniques and tools depends on the intent of the public information campaign or audience targeted.

- Brochures/Flyers/Newsletters – Brochures, flyers, and/or newsletters may be used to describe ramp management strategies and activities. Brochures, flyers and/or newsletters can be mailed to local residents and business owners located near affected ramps, hand-distributed in locations near ramps, or left for people to take at nearby businesses, public facilities or open house meetings. Mailing lists should be updated to include additional individuals that come forward to provide feedback, to keep them abreast of project activities, timelines and future meetings. Typically, depending on the type of strategy implemented, information contained within the brochure, flyers, or newsletter may pertain to:
    - Description of the strategies to be implemented.
    - Expected date and/or time of day that strategies will be in effect.
    - Expected benefits and cost effectiveness of strategies.
    - Reasons why strategies are being implemented.
    - Public information and outreach activities and details.
    - Locations where strategies will be implemented.
    - Contacts or websites where additional information can be obtained or public comments can be collected.
    - Instructions for complying with strategies.

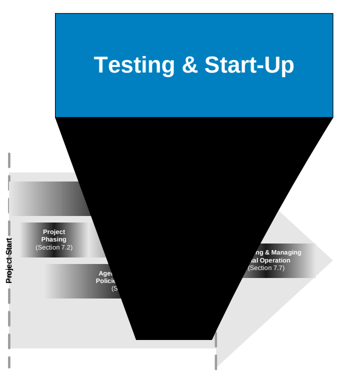


- Websites – The public can be referred to websites specifically set up to provide information on projects where ramp management strategies will be implemented. In Milwaukee, Wisconsin, ramp closure notices are posted to a Wisconsin DOT website. The Milwaukee-area lane and ramp closure website provides the location of the closure, the lanes that are closed, and the duration of the closure.[38] This information provides travelers with advance notification of closures before they embark on a trip, allowing them the opportunity to modify their travel plans accordingly.
- Open House Meetings – Meetings may be held prior to or after major milestones to gather input from and/or disseminate information to the public. Open house meetings are often used to inform the public and local businesses of project progress; to provide a platform for residents, business owners, and motorists to voice their concerns to project staff; and to provide education as to how the strategies will work and how motorists should navigate through them.

  To be successful in these pursuits, open house meetings should be held at times during the week when the highest level of participation is possible. Usually, the early evening hours on weekdays (Monday-Thursday) is suitable. Similarly, meetings should be held at a location that is easily accessible to a wide range of individuals, so as to not unintentionally disregard the thoughts and options of a particular group. In most cases, a location near the ramp where strategies will be deployed, which has plenty of parking and is easily accessible via transit is acceptable. In cases where strategies will be implemented in several locations or an entire corridor, several meetings should be arranged at different locations to give ample opportunity for residents and business owners the chance to attend meetings. In preparing for a public meeting, practitioners should leverage resources from within the agency, such as those used for design open houses.

- Inter-Agency Meetings - Meetings in the form of workshops or round table discussions may be held with local agencies to solicit and gather information regarding the implementation of ramp management strategies. Workshops also give agencies the opportunity to coordinate operations and activities and express needs related to these activities. Supplementary meetings may be needed to address lingering issues and to assign priorities.
- Media Releases – Newspapers and other print media can be used to advertise the location, times, and intent of public information meetings. The DOT or other agencies can release written statements or hold press conferences to release information to the media and to answer questions. In some cases, a short video or graphic presentation may be prepared to strengthen understanding of ramp management strategies. Copies of the presentations can be issued to media agencies as requested, reducing the level of effort and time needed to disseminate information and meet with each media outlet.
- Signs – A public notice sign may be posted on or near ramps to advise motorists of impending improvements. If available, the sign should display a phone number that motorists can call to get more information on the impending activity or to provide feedback.
- Automated Messages – Automated messages may be recorded to give callers basic details pertaining to the ramp management strategy. Messages should provide a toll-free number that may be dialed to obtain additional details via an operator or other information source. The public information number should be passed along to other local and regional agencies, so these agencies can direct callers to the toll-free number.

7.6 Testing and Start-up



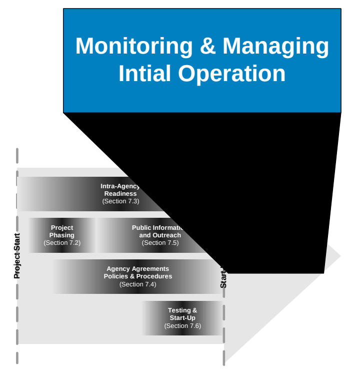
As mentioned in Section 7.3, ramp management strategies should be analyzed for problems and be tested before they are first introduced to the public. Implementation of ramp meters, for example, requires that these devices be tested in advance of when they are first operated to ensure that they are working correctly. This reduces the likelihood that drivers will become confused and/or frustrated.

When testing ramp management strategies, it is good practice to review existing documentation for accuracy. Documentation should be made available to operators to minimize delay in responding to technical problems during start-up. Efforts should be made to update documentation on a periodic basis or when system changes occur. This will ensure that documentation remains up-to-date and confusion does not result when systems require repair or troubleshooting.

Approximately one week before metering or ramp closure takes place, signs indicating the date and time of metering or closure should be placed on selected ramps and also along the mainline. Additionally, the media should be contacted to announce the details of ramp management strategy operation. These actions serve as a final reminder to those that use ramps targeted for strategy deployment.

Before implementing the first ramp meters in an area, it may be advantageous to initially meter ramps at demand (see Section 5.3.3 for a description of metering at demand). This allows motorists to become familiar with ramp meters, while minimizing the impact that meters have on daily travel patterns. This in turn will help facilitate a more positive public perception of ramp meters.

7.7 Monitoring and Managing Initial Operation



After ramp management strategies are implemented, tested and initially operated, they should be monitored and managed to determine if and how the strategies should be adjusted for optimal performance. System operation should be analyzed on a continual basis and more formal evaluations should be conducted several times within the first year and then annually thereafter.

System operation should be observed in the field and confirmed in the TMC. If problems are observed or reported, adjustments to the strategies, maintenance, or another responsive action should be performed. Likewise, problems reported via other agencies and the public should be investigated, addressed, and corrected.

Evaluations at two weeks, six months, and one year after initial operation often meet the needs to report how the system is doing in the first year of operation. However, more frequent evaluations may be needed, depending on local conditions and whether there was reluctant support for the system. Evaluations should address whether the system is performing as expected and if system goals and objectives are being met.

Public surveys may also be conducted on an annual basis to assess public reaction to ramp meter operations and improvements that have been made. Results of this monitoring and adjustment period should be reported to partner agencies, the media, and the public. Performance monitoring is a key concept for this adjustment period and is discussed in greater detail in Chapter 9.

Monitoring and managing initial operation also includes documenting the software and hardware installed and the control parameter settings used to control systems. Documentation should include system errors, how they were resolved, and any system updates that were incorporated to prevent the errors from occurring in the future. In the initial phases of a ramp management program, documentation will help keep an up-to-date record of activities that may be used to address future hardware and software problems. Documentation should be carried beyond the initial operation of ramp management strategies and should be viewed as a life cycle activity that needs to be continually updated. An in-depth discussion on the operation and maintenance of ramp management strategies is provided in Chapter 8.

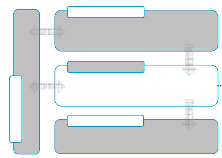
7.8 Chapter Summary

The ramp management strategy or combination of strategies selected in Chapter 6 will not successfully meet defined goals and objectives if they are not implemented correctly. In that regard, ramp management strategy implementation is an activity that must be viewed more broadly than simply deploying equipment in the field. The successful implementation of ramp management strategies, as discussed in this chapter, must begin well in advance of when equipment is physically deployed. The manner in which strategies or elements of the strategy will be deployed must be well thought out and phased according to when the needed resources (e.g., funding, staffing, equipment) will be available. A phased approach to strategy implementation also helps introduce ramp management to the public in small, easy to digest increments. In combination with a proactive and continual public outreach program, this will help capture public support of the strategy or strategies being implemented. A public outreach and information program is also vital in capturing the support of the agencies affected by or involved in the implementation of strategies (e.g., local traffic engineering departments, local businesses, enforcement agencies, and transit).

Before ramp management strategies are physically deployed, they also need to be tested to ensure that they will operate as intended. This reduces the public's exposure to problems in the field while reducing confusion and opposition to ramp management. After strategies are deployed, they need to be periodically monitored and adjusted if necessary, to ensure that they continue to operate as expected. Detailed discussion on the operation of ramp management strategies in provided in Chapter 8. Chapter 8 also explains procedures for maintaining strategies throughout their designed life cycles.

8

OPERATION AND MAINTENANCE OF RAMP MANAGEMENT STRATEGIES



Decision Making

Chapter 5: Ramp Management Strategies

Chapter 6: Developing and Selecting Strategies and Plans

Chapter 7: Implementing Strategies and Plans

Chapter 8: Operation and Maintenance of Ramp Management Strategies

8.1 Chapter Overview

This chapter concludes the four-step ramp management decision-making process. After providing a detailed overview of ramp management strategies in Chapter 5, how to select ramp management strategies in Chapter 6, and how to implement the selected strategies in Chapter 7, this chapter discusses operational and maintenance considerations for keeping the ramp management strategies operating effectively throughout their designed life cycles. This chapter also sets the stage for Chapter 9 by providing information on how ramp management strategies should perform. For instance, ramp meter operators may need to monitor ramp queues to ensure that ramp metering does not cause queues to spill into ramp/arterial intersections. Together, Chapters 6, 7, and 8 provide the basis for understanding the ramp management elements that need to be planned for and designed in capital projects (Chapter 10).

Ramp management strategies can only meet their intended goals and objectives if they are operated and maintained properly. Failure to properly operate and maintain strategies will result in inefficient investment and can result in unnecessary congestion and delays. In some cases, malfunctioning equipment might confuse or inadvertently misguide the public, which adversely affects driving behavior. Therefore, if ramp management strategies cannot be properly maintained, they should not be implemented. Equally important, ramp management strategies need to fit in with the overall operational strategies of the transportation management system. The integration of ramp management strategies with

Chapter Organization

other transportation management elements will offer the best possible means of maximizing benefits from regional transportation investments.

This chapter begins by defining the role of ramp management with respect to overall transportation management operations and maintenance activities (Section 8.2). Additionally, the reasons for and importance of integrating ramp management into the overall transportation management program are discussed. The difference between designed and actual ramp management performance is described, and strategies to address this difference are provided. Finally, operations and maintenance activities are identified and discussed at a high level. Sections 8.3 and 8.4 discuss ramp management specific operations and maintenance activities in greater detail, beginning with operational policies and procedures and concluding with maintenance needs and procedures.

To help facilitate reader's understanding of this chapter, several objectives were developed. These objectives are outlined below.

Chapter 8 Objectives:

Objective 1:	Understand the role of ramp operations and management in overall transportation systems management.
Objective 2:	Identify operational policies and procedures that should be considered related to various ramp management strategies.
Objective 3:	Determine typical operations and maintenance needs associated with ramp management strategies.
Objective 4:	Understand staffing needs related to operating and maintaining ramp management strategies.

8.2 Role of Ramp Operations and Maintenance

The ramp management strategies selected in Chapter 6 and implemented in Chapter 7 cannot simply be implemented then forgotten. Instead, ramp management strategies must be effectively operated and maintained if they are to deliver expected outcomes and benefits. Over the long term, the operation and maintenance of systems that support ramp management strategies will improve the performance and reliability of freeway ramps and other surface transportation components. Failure to actively operate and maintain systems will needlessly waste agency efforts and resources that were expended to deploy these strategies.

Practitioners responsible for the day-to-day operation of ramp management strategies should actively seek cooperation and input from the regional stakeholders (e.g., motorists, decision makers, transportation engineers and planners, enforcement agencies, emergency responders, and transit managers) affected by the implementation of ramp strategies. This input could include how to improve system performance and the reliability of implemented ramp management strategies. Where possible, practitioners should integrate ramp management strategies with other transportation functions. Doing so will maximize return on ramp management investments and will lead to considerable long-term cost savings.

8.2.1 How Operations and Maintenance Fits in with Overall System Operations

Ramp management is only one element of a freeway operations and management program. Ramp management should work in concert with other transportation management activities, to support the overall performance of the transportation management program and accomplish the goals and objectives of the transportation management system. When operating ramp management strategies, practitioners should ensure that ramp management and other freeway management program elements complement each other. Ramp management should be integrated with these other freeway management elements in order to maximize long-term benefits and cost effectiveness. For example, ramp management strategies may be deployed in concert with arterial traffic management strategies to reduce impact at the ramp/arterial intersection when ramp meters are installed. Adjustments to signal timing and/or the addition of lanes may help hold arterial traffic that cannot enter the ramp due to the length of the queue from the ramp meter. Ramp management strategies need to be operated with these interactions in mind in order to accomplish the goals set forth.

8.2.2 Impact on Performance Monitoring and Reporting

Successful operations require that agencies not only consider how systems and strategies will be operated on a day-by-day basis, but also account for future uncertainties such as system upgrades, budgetary requirements, and staffing needs. At a minimum, agencies should have a configuration management plan to help prepare them for this process. According to the Federal Highway Administration (FHWA)'s *Configuration Management (CM) for Transportation Management Systems Handbook*, a configuration management plan is defined as a "holistic approach for effectively controlling system change. It helps to verify that changes to subsystems are considered in terms of the entire system, minimizing adverse effects. Changes to the system are proposed, evaluated, and implemented using a standardized, systematic approach that ensures consistency. All proposed changes are evaluated in terms of their anticipated impact on the entire system. CM also verifies that changes are carried out as prescribed and that documentation of items and systems reflects their true configuration. A complete CM program includes provisions for the storing, tracking, and updating of all system information on a component, subsystem, and system basis."[39]

8.2.3 Ramp Operations and Maintenance Issues

Operators and/or practitioners responsible for the operation or maintenance of ramp management strategies need to be aware of all the internal and external dependencies that may either positively or negatively affect operations on ramps, freeways and adjacent arterials. Operators also need to understand that their actions directly influence the success of ramp management strategies, and as such they must remain cognizant of the policies and procedures that dictate how ramp management strategies are to be operated.

Ramp Metering

From time to time, it is likely that ramp meters or associated equipment will not function as intended. Therefore, it is critical that ramp meters be routinely monitored to ensure that these systems are functioning correctly and that traffic on and adjacent to ramps is not affected. In situations where ramp meters are functioning properly, but perhaps not producing desired effects, ramp meter parameters may be adjusted until desired results are observed.

Part of ramp meter monitoring should focus on queues that form on ramps as a result of ramp meter operations. When a ramp meter is installed on a ramp, the potential exists for queues to spill back to the ramp/arterial intersection. When this happens, operations on the arterial may be affected, resulting in delays and reduced safety. If queues do spill back onto the arterial and affect arterial operation, operators or the system itself should adjust metering rates in an effort to quickly resolve queue-related problems.

Ramp Closure

Similar to ramp metering, the performance of ramp closures need to be evaluated to determine the effectiveness of the ramp closure in satisfying expected goals and objectives. Methods selected to close a ramp should make it apparent to motorists that the ramp is closed. Any uncertainty in motorists' minds may result in attempts to use closed ramps.

Closing a ramp can be a labor-intensive effort, depending on the selected method of ramp closure, the geometry of the ramp, and the traffic demand on the ramp. Methods that employ staff to physically place and remove barriers to close a ramp are only practical for a small number of closures or for temporary closures. For systems where many ramps will need to be closed, the staff levels needed to perform manual closures will likely not be available. Manual ramp closures may also pose a serious safety threat to employees responsible for conducting these actions.

Special-Use Treatments

Wherever possible, motorists should be alerted to and advised of activities pertaining to the construction of new ramps or the addition of new lanes, such as those dedicated for high-occupancy vehicles (HOV) or public transit vehicles only. Such projects, which provide benefits to specific vehicle types, may be negatively perceived by drivers of single-occupant vehicles or other vehicle types not permitted to use the ramp. Signing posted immediately upstream of where construction activities are taking place may be used in part to mitigate the adverse reaction of motorists who oppose construction. In this case, signing will provide advance notification of construction activities, helping to diffuse the potential negative impact of construction activities on normal driving behavior.

Special-use treatments should be monitored to assess their effectiveness in providing benefits to targeted vehicle types and to determine their operational performance. Areas where dedicated lanes merge with traditional traffic on the ramp are potential trouble spots that may need to be addressed.

Ramp Terminal Treatments

Ramp terminal treatments should be monitored to assess the effectiveness of selected treatments in satisfying goals and objectives. Turn restrictions implemented at the ramp/arterial intersection should be monitored through site visits to determine their effectiveness in improving conditions. Similarly, adjustments may need to be made to signal timing to ensure that queues are being cleared each cycle.

8.3 Operational Policies and Procedures

Operational policies and procedures state how, and under what conditions, ramp management strategies should be operated. All staff responsible for the operation of ramp management strategies should be familiar with policies and procedures relevant to ramp management and should be able to reference the operational policies and procedures manual when needed. These policies and procedures are often consolidated into a single operations manual.

This section describes the policies and procedures that should be considered when planning ramp management strategies.

8.3.1 Ramp Metering Operations

On a day-to-day basis, ramp meter operation should focus on monitoring freeway traffic conditions and conditions on and adjacent to the ramps affected by the strategies implemented. Monitoring ramp management strategies that have a high impact on normal traffic operations (e.g., ramp metering) should take precedence over monitoring ramp management strategies that have little immediate impact. The following subsections outline operational procedures common to ramp metering that should be defined before meters are activated and operated.

Hours of Operation

Most agencies operate ramp meters during peak periods only. In some systems that have congestion outside the peak commute hours, meters may be operational for longer periods, during mid-day, evenings, or on weekends. It is good practice for an agency to operate ramp meters only during peak commute hours when ramp metering is first implemented, in order to get staff experienced in operating metering, make the system predictable, and reduce motorist confusion or frustration. Operating at predictable times, especially when metering is first implemented, allows the public to know with relative certainty when ramp meters will be on and off.

As motorists and operators become more familiar with the operation of the system and if congestion occurs outside the peak commuting hours, metering times can be expanded. For instance the Washington State

Department of Transportation (WSDOT) operated meters in the City of Seattle from about 6:00 to 8:30 a.m. and 3:30 to 6:30 p.m. on Monday through Friday when the system was first implemented. Over the years, the window for metering expanded in the morning and evening and now includes the weekends in some areas of the region.

In certain situations, such as when congestion occurs at unpredictable times, mature ramp metering systems (i.e., those that have been in operation for a significant amount of time) may be turned on at any time of the day on any day of the week when conditions warrant their use. Operating ramp meters in off-peak hours, however, is not recommended for relatively newer systems where residents are not familiar with ramp metering. It is important for residents to get used to driving through ramp meters before expanding the times of day that meters could operate.

Mature ramp meter systems may also be activated outside scheduled time frames when emergencies occur or in unique situations. In some systems, meters may be activated automatically during off-peak periods when traffic congestion occurs because of collisions or other incidents.

Practitioners responsible for operating ramp meters should be well trained and familiar with the ramp metering system. They also need to have a strong understanding of typical traffic patterns and problems. Operators should monitor real-time traffic conditions to determine when it is most beneficial to turn on or off particular ramp meter(s).

Ramp Meter Monitoring and Operation

As mentioned previously, most ramp meter systems are turned on at the same times every day. In others, operators monitor conditions and modify the times accordingly. In either case, it is important for operators or operations staff to monitor the operation of the system.

When meters are active, operators should periodically monitor each ramp meter to confirm that meters are functioning correctly and adjust operating parameters when appropriate. Closed-circuit television (CCTV) cameras located on the freeway or local arterial streets may be used to visually monitor metered ramps. If metering is not centrally controlled and if there are no cameras that allow operators to monitor the metered ramps, operations staff should schedule routine field visits to observe the metering operation to determine if adjustments are needed. Operator responsibilities like these need to be documented for quick reference when needed. The operator manual or handbook that documents responsibilities can also be used for training. Figure 8-1 provides an example of general operator responsibilities as they pertain to ramp meter operations. The handbook in which these responsibilities are outlined also provides more specific operational procedures that the operators can reference when needed. An example of more detailed operational procedures pertaining to ramp metering is provided in Figure 8-2.

Operational plans and procedures also need to be developed that dictate how ramp meters are to be controlled during incidents and major emergencies. For instance, if smoke from a brush fire has limited the flow of traffic in all lanes of a freeway, operators need to know if they should turn off meters, and when metering should resume.

Responsibilities of Flow Operators
(continued)

<u>Control Ramp Meters to Maximize Freeway Efficiency</u>

- Activate and deactivate ramp meters at selected freeway on-ramps, based on time of day and need. Adjust fuzzymeter parameters to minimize delay and optimize efficiency on both the ramps and freeway (more on this in the Ramp Metering section). Ramp meters often require special attention when there is a blocking incident nearby that disrupts the merge, so when dealing with incidents, don't forget to pay attention to nearby ramp meters.

Figure 8-1: Example of General Operator Responsibilities Outlined in an Operator's Handbook[40]

Controlling Ramp Meters
(continued)

When meters are activated, it is the operator's responsibility to verify that each meter is functioning. Though some locations require more attention than others, all meters should be inspected with the cameras, if possible, at least once during the time in which they are activated. Following is a list of what a functioning ramp meter should look like:

<u>AM Peak</u>
Generally during the morning, the heaviest traffic will be heading towards Seattle, but there are other commute areas (such as I-90 EB, SR 520 EB, SR 167 NB, and I-405) that must also be considered. Metering must never begin prior to 5:30 AM, no matter the situation.

During the PM peak, both directions of I-5, both directions of I-405, eastbound SR-520, and eastbound I-90 traffic must be closely monitored. The operator must weigh local mainline occupancy as well as downstream conditions in deciding if, when and where to meter.

All ramp meters must be deactivated by 8:00 PM

<u>Weekend Peak</u>
Gauging local mainline occupancy and downstream effects, the operator must use engineering judgment to determine when to activate and deactivate ramp meters. Due to the unpredictable nature of some weekend congestion, ramps should be more closely monitored for unusual congestion, and ramp meters should be turned on or off as required. Some ramps near malls such as 196th St SW near Alderwood Mall is a good example.

Figure 8-2: Example of Detailed Operational Responsibilities Provided in an Operator's Handbook[40]

8.3.2 Ramp Closure Operations

Several unique procedures need to be implemented in order to safely and effectively close ramps. Depending on the type of ramp closure to be initiated, the procedures will differ. However, the general guiding principles inherent to each are the same. With all types of ramp closures, equipment must be deployed in the field to physically restrict access to the ramp. The type of equipment deployed in the field will depend on the method used to close the ramp. For permanent closures, the equipment may only need to be deployed once (typically with a construction project).

On the other hand, temporary ramp closures may need to be conducted on a daily basis. Temporary ramp closure, therefore, can incorporate some degree of automation or can be a completely manual process. Manually closing ramps implies that staff will erect cones or barriers to physically restrict access to the ramp. Although this process has little or no capital cost, it is much more labor-intensive than automated means and may not be practical for situations where staff are not available or where there may be a relatively large number of ramps being repeatedly closed over an extended period of time. Additionally, the safety of staff responsible for conducting the closure must be taken into consideration. Automated gate systems can also be used to close ramps and can be much safer than their manual counterparts. Automated gates can be closed or opened by an operator in the Traffic Management Center (TMC), but are often operated in the field to make sure there are no traffic or roadway conditions that should affect the closure that may not be viewable by the camera system. The safety of both the operator and the motoring public needs to be the primary concern in determining the method used for temporary ramp closures.

Permanent ramp closures may necessitate additional measures to emphasize that ramps will no longer be used. For instance, the actual ramp itself may need to be physically removed to make certain that motorists do not mistake the ramp as being temporarily closed. For either permanent closures or for regularly-occurring temporary closures (e.g., peak period closures), clearly marked permanent signing in advance of the closure is needed. For temporary closures that are not regularly occurring, temporary signing can be used but still requires sufficient advance signing. For specific information about advance signing for ramp closures, please refer to the *Manual on Uniform Traffic Control Devices* (MUTCD)[41] or the *Caltrans Ramp Meter Design Manual.*[28]

8.3.3 Special-Use Treatment Operations

Operational policies and procedures for special-use treatments are usually more straightforward than for ramp metering and ramp closure. These strategies are not influenced by daily traffic patterns and are therefore less dynamic in nature. Special-use treatments such as dedicated lanes for HOVs are typically implemented in a fixed fashion and cannot be manipulated to improve conditions on the ramp or freeway. Strategies that are fixed require few policies and procedures to operate.

As is the case with all ramp management strategies, special-use treatments should be closely monitored to determine whether treatments are successful in accomplishing the goals and objectives they target. In the case of HOV bypass lanes, field observations are needed to determine if merging between HOV and non-HOV vehicles is acceptable. If the special-use treatment is in force by time of day, monitoring will be needed to verify that times of operation are correct for meeting the goals of the treatment. Monitoring is also needed to track usage of the lane or ramp to verify that treatment is neither under- nor over-utilized. In the case of HOV bypass lanes or dedicated ramps, the usage results may lead to decisions about the definition of carpools (generally 2+ or 3+ people) for the facility, corridor, or region. Refer to the FHWA's *Freeway Management and Operations Handbook* and the NCHRP's *HOV Systems Manual* for more information on HOV strategies, including HOV bypass ramps.[1,42] Signing is needed near affected ramps to advise motorists of the ramp restrictions employed. Motorists should be informed of the vehicle types that are able to use ramps and any other operating rules, such as the number of occupants required to be considered an HOV.

8.3.4 Ramp Terminal Treatment Operations

From an operational standpoint, most ramp terminal treatments will not require attention, other than periodic monitoring or observation, to make sure intended goals are being met or determine whether additional treatments are needed.

8.3.5 Unique and Emergency Operations

As was the case with ramp metering, operational plans and procedures also need to be developed that dictate if and how ramps will be closed when unique incidents or emergencies occur. For instance, if a major incident occurs at or immediately downstream of a ramp, it may be beneficial to close the upstream ramp to limit additional traffic from entering the affected area. Improvements are not limited to just the affected area on the mainline, but also extend to the adjacent arterial where queues waiting to enter the freeway may extend, preventing the smooth flow of traffic through the ramp/arterial intersection. By closing the ramp, a portion of the traffic that would normally use the ramp will divert to downstream ramps, where mainline conditions are no longer affected by the incident. Using this same example, closing a ramp to all vehicles except emergency vehicles may speed the response to individuals involved in the incident who are seeking medical treatment.

Procedures for closing a ramp when unique incidents or emergencies occur should be a collaborative effort among regional traffic and emergency management agencies. Together, agencies need to discuss different scenarios when ramp closure is warranted and establish procedures and responsibilities for closing ramps.

8.3.6 Staffing

Agencies implementing or expanding a ramp management program need to actively plan how staff will be used to perform all the transportation management functions associated with a TMC, including operations related to ramp management and control. This process includes analyzing staff duties and availability, staffing levels and shifts, and budgetary requirements; and identifying special needs (e.g., planned special events). See Section 4.4 for more detail on staffing considerations.

Staff need to be available to operate ramp meters as well as other transportation management functions throughout the year. When staff call in sick, take vacation, or quit, their duties must shift to other staff or additional staff must be hired to assume their roles. Typically, there is at least one staff position responsible for operating and addressing issues associated with ramp meters when they are active. This staff person(s) may be assisted by other support staff in a TMC.

8.3.7 Operational Support Tools and Procedures

Several tools and procedures are available to support and ensure successful operation of the four ramp management categories discussed in this handbook. These tools and procedures support the day-to-day system operation and may be largely based on documentation furnished by system suppliers. These documents may also include specific agency policies and procedures. Applicable software manuals could be referenced. These tools and procedures are identified and described in the following sections.

Operations Checklist

An operations checklist lists all of the tasks an operator will perform to accomplish a given function. There is often a routine (i.e., daily) checklist, as well as checklists for a variety of unusual or emergency tasks. Checklists are based on the specific functions and equipment included in the system and the operating policies and procedures adopted by the agency.

After Hours On-Call Roster

An after hours on-call roster containing the names and contact information (phone, mobile, pager, fax, etc.) of individuals to call in case of an emergency should be made available to all operators. The on-call roster should have a schedule of when staff members are on duty and the general types of problems each member is able to address.

Operations Logs

Operations logs are records of system activity that include descriptions of unusual or noteworthy events, when the events occur, and if any manual intervention was needed.

Agency and Jurisdictional Contacts

Contacts for partner agencies affected by or that operate systems that affect ramp management should be documented and easily accessible to staff and operators. An example of a contacts list is provided in Figure 8-3.

Key Personnel: District 6 TMC

First Name	Last Name	Title	Phone	E-Mail
Jane	Doe	Program Manager	555-555-5555 ext. 12	doe@usa.state.gov
John	Smith	Engineer	555-555-5555 ext. 6	smith@usa.state.gov
George	Anderson	ITS Engineer	555-555-5555 ext. 14	anderson@usa.state.gov
Joe	Doe	Maintenance	555-555-5555 ext 23	joedoe@usa.state.gov

Figure 8-3: Example of an Agency/Jurisdictional Contact List

Media Procedures

Local media may significantly affect the success of ramp management strategies. The impact, however, can be either positive or negative depending on the level of interaction with the media. If local media are not actively involved, the benefits of ramp management strategies may not be publicly disseminated to the extent they would have been if there were greater interaction with the media. Where possible, every reasonable effort should be made to alert the media to activities associated with the implementation of ramp management strategies.

The procedures for communication and dissemination of information to media sources should be clearly documented and made available to all operators who have direct contact with the media. Procedures related to media event notification and responses to media inquiries should be outlined in the operator's handbook. Figure 8-4 shows an example pulled from an operator's handbook that details typical media procedures.

Sending Incident Messages

Incident messages are one of the key tools we have for getting incident information out to the media and the public. The incident message provides information that appears on television and radio traffic reports, on web sites, including WSDOT's incident page, the Seattle Times web site, and others.

Sending Messages to the Media and Other TMS98 Users
The Flow Operator is responsible for sending messages to our media Winflow software users (i.e. traffic reporters at radio or TV stations) and the Internet. These messages should contain information of traffic-related incidents gathered from different sources available to us, i.e. the incident may have been observed from CCTV, reported by the Radio Operators, or from the WSP's CAD Log.

Anytime you can visually verify an incident that has a noticeable and enduring traffic impact you should send a text message describing the incident. Also send a message when the incident status changes, for example, a blocking accident becomes a non-blocking incident that is cleared off to the shoulder.

IMPORTANT: Here are a few guidelines to always keep in mind:

- Keep in mind that the TSMC personnel are restricted from sending any non-traffic related details of an incident(s).
- Never include fatalities or the medical status of injured individuals in the messages.
- Do not report any non-traffic related incidents such as TSP (traffic stop) or ROB (robbery) in the messages.
- In most cases, hit-and-run accidents are "standing by" somewhere, and are not affecting traffic whatsoever, and should not be reported. If there's any doubt, check the inquiry page (move cursor to the incident line and press F5).
- We are not responsible for reporting incidents off the state highways and interstate freeways. These are listed on CAD as "NA" in the "HIWAY" column. BUT, every now and then an incident occurs on a busy city street, and it's good to report it, so keep your eyes open.

Figure 8-4: Example Media Procedures from an Operator's Handbook[40]

8.4 Maintenance of Ramp Management Strategies

Systems and devices that support ramp management strategies should be routinely maintained to sustain adequate levels of service and ensure operational stability. When systems or devices fail, staff should be available to fix problems in a timely manner, to reduce the impacts on and exposure to the public. Delays in fixing problems may erode public support for and confidence in ramp management strategies.

As mentioned previously in Chapter 6, if ramp management strategies cannot be adequately maintained due to lack of funding or available staff or for other reasons, they should not be implemented. Additionally, if strategies are implemented and they are not routinely maintained, the potential for equipment malfunction will increase. This in turn would result in a greater likelihood that the public will be negatively affected, lessening support and acceptance of ramp management strategies.

Maintenance activities include:

- Replacing defective or broken components.
- Updating software and system inventories.
- Logging repairs.
- Testing equipment.
- Cleaning system components.

Maintenance helps agencies maximize returns on their investments and offers the best chance for systems to be operated up to and possibly beyond their design life span. This saves the time, effort, and funding needed to purchase new systems before deployed systems reach their designed life span. Failure to maintain ramp management equipment results in disruptions or failure of the strategies or systems that the equipment supports, and makes it difficult to achieve the goals set out for these strategies.

Agencies that implement ramp management strategies should create a maintenance plan that outlines the specific requirements and responsibilities for maintaining equipment and systems. Some of the key issues that should be discussed in an agency's maintenance plan that pertain specifically to ramp management strategies and systems are discussed throughout the remainder of this chapter.

The maintenance plan should cover two categories of maintenance activities: response maintenance and preventative maintenance.

Response Maintenance

Most, if not all, public agencies provide maintenance in response to alarms, customer requests, or identified problems, either with in-house or contracted staff. Response maintenance is defined as the repair of failed equipment and its restoration to safe, normal operation. It requires action based on the priority of the subsystem that has failed and takes precedence over preventative maintenance activities for the duration of the emergency.

Response maintenance is a critical element of a comprehensive maintenance plan. The importance stems from an agency's responsibility to keep traffic systems operating safely at all times. Preserving the safety of the traveling public and minimizing the agency's exposure to liability represent the two strongest reasons for establishing a sound approach to response maintenance. Typically, response maintenance requires that a qualified technician be on-call to receive notice of any and all problems that arise with field equipment.

Preventative Maintenance

Although most, if not all, public agencies provide response maintenance, fewer agencies provide preventative maintenance on a regular, routinely-scheduled basis. Preventative maintenance, or routine maintenance, is defined as a set of checks and procedures to be performed at regularly scheduled intervals to ensure that equipment functions properly. It includes checking, testing, inspecting, record keeping, cleaning, and replacement based on the function and rated service life of the device and its components. Preventative maintenance is intended to ensure reliable mechanical, electrical, and electronic operation of equipment, thereby reducing equipment failures, response maintenance, road user costs, and liability exposure. The emphasis in preventative maintenance is on checking for proper operation and taking proactive steps to repair or replace defective equipment, thus ensuring that problems are not left until the equipment fails. However, preventative maintenance is often neglected because of staffing limitations.

8.4.1 Maintenance Needs

"Maintenance needs should be prioritized based on the importance of each system in meeting the overall goals and objectives of the transportation management system."

Maintenance needs for ramp management strategies will depend on the strategies that are implemented and the extent to which ramp strategies have been deployed. Strategies implemented at one or a few ramps will obviously require much less maintenance than strategies implemented along an entire corridor or in multiple corridors. Similarly, strategies that require computer systems to be in place, such as ramp meters or automated gates for ramp closure, may require that software be updated or reconfigured when errors occur.

Maintenance needs should be prioritized based on the importance of each system in meeting the overall goals and objectives of the transportation management system. Response maintenance on devices deemed to be mission critical (i.e., those that are needed to keep the transportation system operating correctly) or critical to safety should be the highest priority. In these cases failed equipment needs to be replaced or repaired immediately. Response maintenance on non-mission-critical devices should be the next priority, followed by preventative maintenance.

8.4.2 Maintenance Procedures

Systems that are maintained according to vendor requirements will last longer than those that are minimally maintained or not maintained at all. Regularly scheduled preventative maintenance activities will allow agencies to use systems up to and beyond their design life, maximizing an agency's investment. However, system failures will likely happen at some point no matter what level of maintenance is performed. When unexpected failures occur, systems need to be repaired as soon as possible. In emergency situations, systems should be repaired immediately so operations can be restored.

Maintenance personnel should have a direct means of communications with operations staff to help identify and assess maintenance needs. Typically, communications occur via cell phone or two-way radio, however other means are available. Communication between operations and maintenance staff may also help troubleshoot maintenance issues by providing maintenance personnel with additional information on the problem.

System Inventory

An inventory of all implemented equipment and software should be developed and kept up-to-date as new equipment is installed and existing equipment is repaired or replaced. Inventories facilitate maintenance by tracking the numbers of devices that are currently in stock. This reduces the chance that devices will not be available when needed, which in turn reduces the amount of time devices must remain inoperable. The following minimum information should be included as part of the inventory:

- Date equipment was installed.
- Location of equipment.
- Equipment vendor.
- Vendor contact information.
- Equipment model or version.
- Serial number (or other unique identifier).

The system inventory also serves a logistical purpose in facilitating the purchase of spare parts in the quantities that are needed. It also helps determine the level of staff needed to perform maintenance tasks.

Maintenance Checklist

Maintenance checklists list the recommended steps and procedures for maintaining any given piece of equipment. The checklist serves as a means to track the completion of maintenance procedures and to ensure that each procedure is completed at the time that maintenance is performed. There should be a separate checklist for each type of device included in the system inventory.

Preventative Maintenance Procedures

Tables 8-1 through 8-3 provide typical preventative maintenance procedures for systems used for ramp meter and ramp closure applications.[43]

Table 8-1: Preventative Maintenance Procedures for Ramp Metering (Signals and Controller Assembly)

Action	Timeframe
Check the operation of the Blank Out sign - replace any defective bulbs	Monthly
Check the operation of the Ramp Controller - repair as needed	Monthly
Check stop line and make sure that this is clearly visible - make notation for any line that is not visible and report immediately to road marking crew for remarking	Monthly
Check advisory signs to ensure accurate words and facing the motorist	Monthly
Check signal light head for correct operation	Monthly
Replace any burnt out bulbs	Monthly
Check and adjust signal head to face the correct direction	Monthly
Check and adjust where necessary the ramp meter time clocks in accordance with schedules	Monthly
Check the function of the queue loop	Monthly
Document all results on the ramp meter maintenance check list	Monthly
Request control center to send command to turn on or off and verify	Monthly

Table 8-2: Preventative Maintenance Procedures for Ramp Metering (Detectors)

Action	Timeframe
Disconnect loop	Quarterly
With LCR meter measure and record inductance of the loop	Quarterly
With LCR meter measure and record resistance	Quarterly
With a MEGGER meter measure and record the insulation resistance	Quarterly
If readings are outside specification, disconnect lead-in at the splice box and check all three parameters at that level	Quarterly
From the readings determine whether loop or the lead-in need repair	Quarterly
Check cracks in the asphalt at the shoulder	Annually
Check cracks in the sensor at the shoulder	Annually
Check cracks in the sensor at the wheel tracks	Annually
Check cracks at the sensor/asphalt interface	Annually
Using LCR meter measure capacitance	Annually
Use manufacturers recommended procedure for checking detectors	Annually

Table 8-3: Preventative Maintenance Procedures for Ramp Closure (Gates and Barriers)

Action	Timeframe
Open and close gate group from control cabinet	Monthly
Adjust gate opening and closing timing sequence	Monthly
Check isolators associated with the controller for damage and repair or replace if needed	Monthly
Perform visual inspection of the high voltage side of the cabinet (use extreme caution and observe all safety rules)	Quarterly
Check oil level - add oil if needed	Quarterly
Grease all grease nipples and wipe excess	Quarterly
Check for oil leaks in the gate housing	Quarterly
Verify that the lights on the gate flash when the gate arm moves between opening and closing.	Quarterly
Verify that the lights stop flashing and remain on solid when the gate arm is in closed position	Quarterly
Verify that the lights stop flashing and remain off when the gate arm is in the open position	Quarterly
Turn off power to the gate cabinet and use hand crank to open or close gate (this is to ensure that the gate can be opened or closed in the event of power failure)	Quarterly
Replace all burnt out bulbs	Quarterly
Perform physical inspection of the gate arm and replace broken or rotten wood	Quarterly
Check reflectors and replace where necessary	Quarterly
Check and adjust gate clearance (clearance measured from road surface to bottom of gate	Quarterly
Check and adjust limit switches if needed	Quarterly

Maintenance Logs

After responding to a maintenance request, maintenance personnel should log all pertinent information associated with the maintenance issue, as deemed necessary by their supervisor. At a minimum, the log should contain the complaint or request in which the maintenance request was issued, date and time the issue was addressed and resolved, staff that performed the required work, and actions taken to resolve the issue. It is also good practice to report systems or parts that have been replaced, so additional systems or parts can be purchased to replace those that have been taken out of inventory.

8.4.3 Staffing

Trained staff must be available to replace or repair system components or devices when they fail. Similarly, staff are needed to perform regularly scheduled maintenance activities to reduce the probability that failures will occur.

Staffing Approaches:

- In-House.
- Outsourcing.
- Facilities Management.

When implementing new ramp management strategies, agencies need to remain cognizant of the fact that the implementation of new strategies also brings additional maintenance needs and requirements. In many cases, new staff need to be hired to support existing staff in handling these new needs and requirements.

There are no established, accepted guidelines that agencies can utilize to determine maintenance staffing levels by classification for the number and type of ramp management-related devices that it owns and operates. The Oregon DOT's statewide maintenance plan establishes guidelines for that agency based on experience within the department and discussions with equipment vendors. The plan identifies about 1,750 ITS devices such as emergency signal preemption systems, CCTV cameras, and road weather information systems. The plan identifies that eight positions are needed to maintain this inventory.

There are several agencies that maintain ITS devices that have staffing levels and/or practices that can be found in the literature.[44] As of 2000, The Maryland State Highway Administration (SHA) employs eight technicians to conduct both response and limited preventative maintenance for 35 permanent and close to 100 portable variable message signs (VMS). The Maryland SHA has another 11 technicians that are responsible for both response and limited preventative maintenance for 250 field devices, including CCTV cameras, road weather information systems, detectors, and traveler advisory radio units.

In 2000, the Virginia DOT's Northern Virginia Advanced Traffic Management System (ATMS) had seven technicians and one engineer employed on a full-time basis to conduct response maintenance for over 1,500 devices, including CCTV cameras, VMS, and detectors. The Virginia DOT rarely conducted preventative maintenance on the ATMS.

In 2001, the Washington State Department of Transportation (WSDOT)'s Northwest Region had about 1,150 ITS devices, including CCTV cameras, call boxes, and ramp meter systems. (Note: WSDOT does not define their devices down to the component level, such as *video detector* as some of the devices are defined in Oregon or *detectors* as defined in Northern Virginia). WSDOT also maintains over 100 miles of fiberoptic cable system. Twelve maintenance staff employees worked for WSDOT to conduct both response and preventative maintenance for these devices.

These examples indicate that one maintenance staff person can maintain anywhere from 100 to 200 ITS devices. The higher number is for less complicated devices and systems, and the lower number for more complicated devices and systems.

There are three approaches that an agency can follow to provide the maintenance support outlined above: in-house, outsourcing, and facilities management. Each has its own distinct benefits and risks. Agencies should identify and select a course of action best suited to its needs, culture, and existing situation.

In-House Staffing

Using a staff comprised of all agency employees is often considered ideal, because managers and team leaders have a single personnel management system to deal with and team cohesiveness is easier to establish and maintain. However, given today's trends of downsizing and doing more with less, many agencies around the country have a difficult time finding, training, and retaining the required talented staff to maintain their field equipment. Maintaining the skills necessary to support the fast-changing technologies is a problem when utilizing in-house support. Where required, in-house support can be supplemented by outsourcing.

Outsourcing

It is becoming increasingly difficult for public agencies to fill highly technical positions that usually require special classifications and a high pay scale. Personnel departments within the public sector tend to resist creating special classifications and often follow a policy of setting pay scales by the number of persons supervised. Positions requiring highly specialized skills often do not supervise many people, if any at all, making it difficult to justify the pay scales necessary to attract qualified staff.

In an era of government downsizing, state and local agencies often face pressures to cut staffing and freeze existing vacancies. Leaving vacancies unfilled in maintenance positions that support ramp management will usually result in significantly reduced system effectiveness.

Outsourcing can often bypass these problems. Staffing through outsourcing does not result in more staff counted on the agency's payroll. The budgetary item for outsourcing is often treated by the agency administration like a line item for electricity to run the equipment, with none of the negative perceptions involved in financing new staff positions. It is also often easier for a private firm to fill vacancies with appropriately skilled personnel and to fire poorly performing employees.

Although outsourcing offers solutions to the types of staffing problems noted above, it is not without its own set of problems. Some of the problems with outsourcing include the necessity of continuing tight administration of performance under the contract, potential higher turnover rates in contractor personnel than in-house staff, the scarcity of private sector personnel with adequate experience, and friction with in-house staff. Outsourcing requires careful development of a detailed, clearly defined set of contractor requirements including task descriptions, schedules, performance standards, and payment terms.

Facilities Management

The third option is for agencies to engage a facilities management contractor in a public-private venture for the purposes of providing maintenance or operations and maintenance. Although facilities management shares some characteristics with outsourcing, it also provides a level of flexibility and incentives for both parties that a service contract does not.

Facilities management, or facilities outsourcing, involves using private-sector staff to perform traditional government services, working on a broad mission basis and targeting the standard of mission accomplishment. Although facilities management is a new concept in traffic management, it is a tried-and-true method for providing service in other high-technology environments including computer facilities, law enforcement dispatching systems, and telecommunications systems.

Facilities management is different than outsourcing, where the private contractor is required to follow the explicit directions of the government manager. With outsourcing, there is little incentive for the private contractor to control costs, because it is paid by the person-hour employed. Under facilities management, the private-sector firm and the public agency have congruent goals and the same incentive to succeed. Because it is paid for mission fulfillment, the private-sector contractor has the incentive to seek efficiencies and cost-effective techniques for achieving the contract objectives.

8.4.4 Training

Systems and devices that support ramp management strategies can only be used to their furthest extent if staff are trained on how to maintain them. All staff responsible for operating and/or maintaining systems that support ramp management strategies, whether existing or newly hired, will need to be trained on the procedures specific to individual systems and devices, operational policies, and testing and calibration methods. Additionally, staff need to be trained on how to use special vehicles (e.g., bucket trucks) to maintain systems and devices that cannot be easily completed from the ground. Staff must be trained on typical and disaster-specific emergency procedures.

The first step in determining training needs and whether staff is adequately trained is to define the knowledge, skills, and abilities that are needed for each staff position within an organization. A training plan or program should then be developed to identify training opportunities to provide employees with the needed knowledge, skills, and abilities. The program or plan should focus on gaps between the minimum requirements for the position and the requirements to perform in the position at an optimal level. The plan is often developed and maintained in the Human Resources section of the organization. Some organizations include a formal training program to provide needed skills to their employees.

To help facilitate training, many agencies issue step-by-step instructions or handbooks that outline what and when maintenance ought to be performed. Although most agencies rely on in-house training, workshops, seminars, or other outside means are used to support training needs. When procuring a system or software from a third-party vendor, agencies should include a provision within the contract that requires vendors to fully train staff on how to maintain and operate purchased systems.

Ongoing staff training will be needed to keep staff up-to-date and to train new staff members.

8.4.5 Spare/Backup Equipment

Sufficient spare or backup equipment and/or parts are needed so maintenance personnel can keep systems that support the ramp management strategies operational. There must be documentation of the equipment and parts needed, including:

- Inventory of spare and backup equipment.
- Listing of suppliers' and vendors' contact information (e.g., phone, pager, e-mail) associated with equipment and software related to the system.

Additional information pertaining to the documentation of spare/backup equipment as well as other aspects of transportation systems can be found in the FHWA's *Configuration Management for Transportation Management Systems Handbook*.[39]

8.4.6 Evaluation

Maintenance procedures and practices must be evaluated periodically to maintain efficiency in those activities. Evaluation in terms of ramp management maintenance refers to the routine collection and analysis of appropriate data and comparing this data to previously established performance measures. The results of this comparison can be used to assess the benefits or drawbacks of existing maintenance procedures and practices and can offer insights on how to improve them. Ramp management strategy evaluation is discussed in greater detail in Chapter 9.

8.5 Chapter Summary

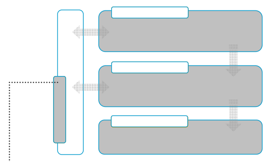
Upon reading this chapter, it is easy to see the importance of properly operating and maintaining ramp management strategies. The strategies selected in Chapter 6 and implemented in Chapter 7 cannot be fully utilized if they are not effectively operated and properly maintained. To be successful, the practitioner responsible for ramp management and operation must first understand that ramp management is only one element of a freeway operations and management program. To maximize benefits and reduce overall operating costs, ramp management strategies must be integrated with other freeway management elements.

The practitioner responsible for ramp management strategy operation and maintenance must also be aware of the various day-to-day issues tied to these activities that may affect the success of the implemented strategy. This awareness allows practitioners to successfully operate strategies throughout their designed life cycles, achieving the maximum return on ramp management investments. Part of this activity is knowing the equipment, materials, and skills needed to operate and maintain implemented strategies. Such knowledge not only allows the practitioner to obtain needed resources in advance of actually needing them, but also provides time savings, which in turn equates to potential cost savings. Continued proper operation and maintenance of strategies also builds public confidence and support of strategies and the agencies that implement them, making it easier for these agencies to obtain funding for future projects.

Successful operations and maintenance of ramp management strategies must also incorporate steps to actively monitor and document needs and requirements, so they can be tied into the next component of the ramp management implementation process - performance monitoring, evaluation and reporting. Tracking needs and monitoring performance of ramp management strategies will make it easier for practitioners to identify and acquire the resources (staffing, equipment, training, etc.) needed to operate and maintain strategies more effectively. Performance monitoring, evaluation, and reporting are discussed in detail in the next chapter of this handbook – Chapter 9.

9

RAMP PERFORMANCE MONITORING, EVALUATION AND REPORTING



Visibility

Chapter 9: Ramp Performance Monitoring, Evaluation and Reporting

9.1 Chapter Overview

Performance monitoring provides a mechanism to determine the effectiveness of the ramp management strategies and actions described in this handbook. Performance monitoring ties the strategies and actions selected in Chapter 6 back to the program goals and objectives outlined in Chapter 3. By doing so, practitioners can easily determine if selected strategies help resolve the problems that occur on or near ramps of interest. Additionally, performance monitoring, evaluation, and reporting promote ongoing support of the ramp management strategies and offer ways to improve them. This leads to improvements in operational efficiency and reduces unneeded expenditures. Finally, performance monitoring and reporting provide feedback for refining agency and traffic management program goals and objectives.

This chapter guides practitioners through the process of monitoring, evaluating, and reporting the performance of ramp operations and the ramp management strategies selected and implemented in Chapters 6 and 7, respectively. The processes and methods that may be used to monitor and evaluate the performance of ramp management strategies are presented. This includes a discussion of the types of ramp management analyses, examples of performance measures, and costs and resources needed to conduct these activities.

Chapter Organization

Traffic Managers should use the information derived in Chapter 6 (selecting ramp management strategies), Chapter 7 (implementing ramp strategies), and Chapter 8 (operating and maintaining ramp strategies) to develop performance measures that are consistent with program goals and objectives (discussed in Chapter 3). The results of the performance monitoring effort feed back to refining and updating the program on a periodic basis.

Throughout this chapter, references are made to previously conducted evaluation efforts, including the recently conducted evaluation of the Twin Cities, Minnesota ramp metering system. This particular evaluation effort is further highlighted as a case study in Chapter 11.

Chapter 9 Objectives:

Objective 1:	Explain what is involved in ramp management analysis, including performance measures and analysis tools.
Objective 2:	Describe how to tailor monitoring and evaluation efforts to meet the needs of the deploying agency.
Objective 3:	Describe how to measure and estimate ramp, freeway and arterial performance.
Objective 4:	Describe analysis methodologies and reporting tools and techniques.
Objective 5:	Explain the importance of performance monitoring, evaluation, and reporting in maintaining an effective ramp management system.

9.2 Ramp Management Analysis Considerations

The analysis of ramp management performance can be performed as a single study, on a periodic basis, or as an ongoing continuous program, depending on the needs and available resources of the deploying agency. For the purposes of this manual, the general steps in analyzing ramp management performance are described as:

- Performance Monitoring – The collection of performance statistics, using either manual or automated methods, to enable the assessment of particular Measures of Effectiveness (MOEs) related to the performance of the ramp management deployment.
- Evaluation – The analysis of the collected data to provide meaningful feedback on the performance of the system.
- Reporting – The output of the evaluation results in a format appropriate to the needs of agency personnel, elected decision makers, the public, and/or other potential audiences.

This section summarizes some of the important considerations in developing a performance analysis process and provides practitioners with guidelines for tailoring performance monitoring, evaluation, and reporting efforts that are appropriate to their needs.

Prior to initiating any ramp performance monitoring or evaluation effort, many factors should be considered that will shape the overall effort. Careful consideration of these factors is encouraged to better ensure that the monitoring and evaluation results are relevant to the objectives of the effort, technically valid, and appropriate to the intended audience. Some important considerations are discussed further in the following sections.

9.2.1 Types of Ramp Management Analysis

One of the first considerations in planning an evaluation is to identify the type of analysis to be performed. The type of analysis to be performed is largely defined by the objectives of the evaluation and type of feedback desired. Ramp management evaluations may be performed prior to implementation, conducted as "before" and "after" snapshot views of performance, or implemented as a continuous monitoring and evaluation process. The evaluation efforts may also be narrowly focused to analyze one specific performance impact, or may be more broadly defined to capture the comprehensive regional benefits of the ramp management application. These analyses may also be intended to isolate the impacts of the ramp management deployment by itself, or to evaluate the performance of ramp management as part of a combination of operational strategies.

This section summarizes the basic types of analysis related to ramp management performance. This section also discusses the implications of how each type of study has different needs that substantially influence the analysis procedures to be performed. Some of the different types of analysis include:

- Pre-Deployment Studies – Analysis performed to determine the appropriateness of ramp management applications for a particular location.
- System Impact Studies – Analysis performed to identify the impact of an existing ramp management strategy on one or more selected MOEs.
- Benefit/Cost Analysis – Comprehensive analysis conducted to evaluate the cost effectiveness of a ramp management application.
- Ongoing System Monitoring and Analysis – Continuous, real-time performance analysis for the purpose of providing feedback to system operators.

The following sections provide descriptions of these various types of analyses and discuss how the intended purpose of the analysis helps to determine the appropriate approach.

Pre-Deployment Studies

Pre-deployment studies are typically performed to assess the feasibility and appropriateness of ramp management applications for a particular location. These studies may be performed to analyze the potential impacts of introducing ramp management deployments in a region that currently does not use these strategies, or may be used to assess the impacts of expanding an existing ramp management program to new locations within a region. These studies may also be implemented to estimate the impact of a proposed change in ramp management strategy at an existing location.

As the name implies, these analyses are performed prior to the actual implementation of the strategy. Thus, the impacts estimated in these studies represent predictions of what will likely occur, rather than observations of what has occurred. These analyses, however, often use observed “before” and “after” results from previously conducted *system impact studies* (described below) of existing ramp management activities in the region, or observed results from other regions as inputs to the analysis process. These inputs may be entered into a variety of planning tools, ranging from simple spreadsheet models to complex microsimulation programs, to evaluate the expected impacts of the potential ramp management application. The U.S. Department of Transportation (DOT) Intelligent Transportation Systems (ITS) Joint Program Office maintains an ITS benefits website that lists observed results for a wide range of ITS projects and elements from regions across the United States.[45]

Pre-deployment studies may be used to analyze ramp management applications by themselves, in combination with other improvements, or as alternatives to other improvements. Although not technically considered an evaluation or monitoring effort, pre-deployment studies are mentioned here since they may use similar analysis approaches and tools. The use of pre-deployment studies in the selection of appropriate ramp management strategies is discussed in Chapter 6 and supported by the decision diagrams. In addition, the planning of these strategies for implementation is discussed in greater detail in Chapter 10.

System Impact Studies

System impact studies attempt to identify the impact of a ramp management application on one or more particular performance measures. These studies typically involve the comparison of conditions “before” the deployment of ramp management with conditions “after” the strategy is deployed. This, however, is not always the case. In the evaluation of the Twin Cities ramp metering system conducted in 2000, the entire ramp metering system was shut down for a period of six weeks to allow the identification of conditions “without” ramp meters for comparison of conditions observed “with” the fully functioning system.

The purpose of these studies is often to provide the system operators with direct feedback on the effectiveness of their implemented strategies. For example, a system impact study may be implemented to assess the success of a ramp management deployment in mitigating a particular system deficiency, such as higher than expected crash rates in a merge area. These studies are also frequently conducted to assess the particular benefits of ramp management deployments. The results may then be communicated to decision makers and/or the traveling public to help justify and promote ramp management as an effective traffic management strategy.

The traffic conditions used for comparison in these system impact studies are typically based on observed data collected in the field using manual or automated data collection methods. In evaluations where the available evaluation resources do not support the collection of ground-truth (observed) data or in situations where the collection of this data is not feasible, various models and/or traffic analysis tools may be used to simulate these conditions for comparison. These tools may include a wide range of sketch planning tools, *Highway Capacity Manual*[31] (HCM)-based tools, travel demand models, or macro- and micro-simulation tools. The FHWA's *Traffic Analysis Toolbox Volumes 1 and 2* provide additional discussion of the available tools as well as guidelines for selecting the appropriate tool.[46]

Benefit/Cost Analysis

In many regards, benefit/cost analyses are similar to system impact studies in that both represent assessments of the impacts related to the implementation of a particular project or strategy. Whereas system impact studies may focus on particular performance measures, a benefit/cost analysis is broader and attempts to fully account for the comprehensive, multi-modal impacts of ramp management strategies. Benefit/cost analysis weighs the complete observed impacts of the system – including both positive impacts (e.g., reduced travel time on the mainline facility) and negative impacts (e.g., increased emissions at the ramp queues) – with the cost of implementing and operating the ramp management strategy.

The purpose of these analyses is typically to identify the relative effectiveness of investment in the strategy proposed for use, by providing a common point of comparison with other strategies that may be used in prioritizing funding for future applications. The information generated by benefit/cost analyses is also used to communicate the relative benefits of the system to decision makers and the traveling public. The comprehensive analysis of the ramp metering system in the Twin Cities region of Minnesota (cited throughout this section and presented as a case study in Chapter 11) represents an example of a regional benefit/cost analysis of a ramp metering system. This analysis was initiated to identify and communicate the benefits of the application to lawmakers and residents in the region.

Benefit/cost analyses are also typically based on comparisons of conditions both with and without the application of the strategy. The compared conditions may represent a snapshot view or may be based on longer-term trends, depending on the needs of the particular study. Due to the more comprehensive nature of benefit/cost analyses, however, these studies often make more substantial use of analysis tools and models to generate estimates of the full range of possible impacts.

Although intended to provide a comprehensive quantitative analysis of the benefits and costs of the ramp management application, there are many impacts that are difficult or impossible to quantify, such as traveler perceptions. No benefit/cost analysis can fully encompass all of the possible impacts of a ramp management system, so it is important to recognize that benefit/cost analysis provides only a partial view of the overall picture that should be evaluated in assessing the success of the strategy.

Similar to the other types of analysis, a benefit/cost analysis can be designed to isolate the particular impacts and benefits related specifically to ramp management. It may also be utilized as part of a broader evaluation designed to capture the benefits of a selected combination of traffic management strategies.

Ongoing System Monitoring and Analysis

The purpose of ongoing system monitoring and analysis is to provide system operators with direct, real-time feedback on the performance of the ramp management strategy, to allow for more active and precise management of the system. If the data collected through this monitoring effort is appropriately archived, additional analysis may be performed to identify trends that show how the impacts of ramp management may change over time or vary under different traffic conditions.

The ongoing nature of monitoring efforts typically requires a dependence on automated data sources, such as loop detector data, radar- or acoustic-based speed detectors, closed-circuit television (CCTV) cameras, and automatic vehicle location systems. Often, these automated data sources may be deployed as part of a ramp metering system or a general freeway management system. Reliable access to accurate data sources such as these is a prerequisite for implementing a successful monitoring and analysis program. Refer to Section 9.4.2 for more detail on the benefits and challenges of automated data collection and monitoring.

Although these ongoing monitoring and analysis efforts are intended to provide performance data to the system operations personnel, it is important to note that the data generated by these efforts may be utilized in other evaluation efforts. For example, automated system data collected by the Minnesota DOT for use in monitoring the real-time performance and making operational decisions, was used extensively in the benefit/cost analysis of the Twin Cities metering system. This historical volume and speed data was used to extrapolate impacts observed during a limited data collection window to other time periods and traffic conditions.

9.2.2 Identifying the Appropriate Study Area

The study area selected can have significant implications on the analysis data requirements, evaluation techniques, resource requirements, and even the results. These implications are discussed in this section to help practitioners identify the appropriate study area suitable to their particular needs.

"Ramp management applications can have impacts far beyond the local area in which they are implemented."

Ramp management applications can have impacts far beyond the local area in which they are implemented. Depending on travel pattern changes, impacts may be observed at freeway bottleneck locations far downstream from the ramp itself, arterial intersections located many miles from the interchange, or even on alternative modes such as transit. Failure to define the study area broadly enough may result in critical impacts not being captured and an overstatement or understatement of reported benefits. On the other hand, defining the study area too broadly may result in the inefficient use of evaluation resources if efforts are diverted toward analyzing inconsequential impacts. Therefore, it is critically important to identify an appropriate study area prior to the implementation of the evaluation effort to ensure the proper assessment of system impacts.

There are no firmly established guidelines for identifying the appropriate study area, however this decision is usually based on:

- Purpose of the Study – Is the evaluation effort being undertaken to identify the ability of the ramp management strategy to mitigate a specific deficiency in a particular location, or does it intend to provide a comprehensive accounting of the region-wide benefits and costs?
- Extent of the Ramp Management Application – Is the evaluation being focused on a single or a very limited number of ramps, or does the application involve multiple ramps?
- Knowledge of Local Traffic Conditions – Local operations personnel are usually familiar with traffic conditions and should be involved in any decision regarding the extent of the study area.

Furthermore, factors such as the particular performance measures being evaluated, the proposed analysis tools, and the evaluation resources available have a symbiotic relationship with the determination of the appropriate study area. The intended performance measures, analysis tools, and resource availability should be considered in the determination of the study area. Likewise, the identified study area may also determine the possible performance measures, the appropriate analysis tools, and the evaluation resources required.

Study areas can be generalized into three categories: localized, corridor, or regional. These categories are discussed below with examples of when they should be used.

- Localized Analysis – This analysis focuses on the impacts observed on the facilities immediately adjacent to the ramp management application and is the most appropriate for limited-scale deployments or for system impact evaluations focused on a narrowly defined set of performance measures. For example, an evaluation effort solely focused on identifying the ability of a ramp meter application to decrease the number of crashes occurring within the immediate merge area might limit the study area to this narrowly defined extent.
- Corridor Analysis – Expanding the study area to the corridor level is more appropriate when multiple ramp locations are involved, or when the deployment is anticipated to affect any of the selected performance measures along an entire corridor. The study corridor extent should be based on the local street pattern and knowledge of local travel demand, in order to determine the freeway mainline, ramp, and arterial facilities to be included. The evaluation of the Madison, Wisconsin ramp meter pilot deployment, presented as a case study in Chapter 11, was conducted as a corridor analysis. In this study, the evaluators were interested in capturing the full impacts of the ramp metering deployment. However, the limited extent of the deployment (five ramps on a single beltline corridor) was not deemed likely to produce any significant impacts outside of the defined corridor.

- Regional Analysis – A regional study area is most appropriate when a comprehensive accounting of all possible impacts is required, or when the deployments are scattered across a large area. The evaluation of the Twin Cities ramp metering system was conducted as a regional analysis because the Minnesota DOT wanted to identify the full impacts of the entire system (approximately 430 meters) on the overall region. Regional analyses can be the most costly analysis to conduct, due to the significant data requirements. Therefore, this analysis will often use various large-scale traffic analysis tools (e.g., regional travel demand models) to estimate the impacts, rather than depending solely on observed before and after data.

Not all evaluation efforts will fit neatly into these study area definitions. Some evaluations may use multiple study area definitions within the same effort based on the performance measures being evaluated or the availability of data. For example, in the Twin Cities evaluation, extensive analysis was first performed on several representative corridors to identify the specific impacts to the freeway, ramp, and parallel arterial facilities. The findings from this corridor-level analysis were then extrapolated regionally using a series of spreadsheet-based analysis tools to estimate the regional impacts.

9.2.3 Performance Measures

The FHWA's *Freeway Management and Operations Handbook* provides the following overview of performance measures:[1]

> "Performance measures provide the basis for identifying the location and severity of problems (e.g., congestion and high crash rates), and for evaluating the effectiveness of the implemented freeway management strategies. This monitoring information can be used to track changes in system performance over time, identify systems or corridors with poor performance, identify the degree to which the freeway facilities are meeting goals and objectives established for those facilities, identify potential causes and associated remedies, identify specific areas of a freeway management program or system that requires improvement/enhancements, and provide information to decision-makers and the public. In essence, performance measures are used to measure how the transportation system performs with respect to the overall vision and adopted policies, both for the ongoing management and operations of the system and for the evaluation of future options.
>
> Agencies have instituted performance measures and the associated monitoring, evaluation, and reporting processes for a variety of reasons: to provide better information about the transportation system to the public and decision makers (in part due, no doubt, to a greater expectation for accountability of all government agencies); to improve management access to relevant performance data; and to generally improve agency efficiency and effectiveness, particularly where demands on the transportation agency have increased while the available resources have become more limited."

The particular performance measures selected for monitoring, evaluation, and reporting have substantial influence over the analysis structure and requirements. Performance measures should be carefully identified and mapped to the specific need of the study. The FHWA's *Freeway Management and Operations Handbook* provides guidelines for developing good performance measures, including:

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

- Stakeholder Involvement – Performance should be reported in stakeholder terms; and the objectives against which performance is measured should reflect the interests and desires of a diverse population, including customers, decision makers, and agency employees. Buy-in from the various stakeholders is critical for initial acceptance and continued success of the performance measures. If these groups do not consider the measures appropriate, it will be impossible to use the results of the analysis process to report performance and negotiate the changes needed to improve it. Those who are expected to use the process to shape and make decisions should be allowed to influence the design of the program from the beginning. Similarly, those who will be held accountable for results (who are not always the same as the decision makers) and/or will be responsible for collecting the data should be involved early on, to ensure that they will support rather than circumvent the process or its intended outcome. The selected performance measures should also reflect the point of view of the customer or system user. An agency must think about who its customers are, what the customers actually expect of the department's activities and results, and how to define measures that describe that view.

- Other Attributes – Good performance measures possess several attributes that cut across all of the "process" issues noted previously. These include:

  - Limited Number of Measures – All other things being equal, fewer rather than more measures is better, particularly when initiating a program. Data collection and analytical requirements can quickly overwhelm an agency's resources. Similarly, too much, too many types or too detailed of information can overwhelm decision makers. The corollary is to avoid a performance measure that reflects an impact already measured by other measures. Performance measures can be likened to the gauges of a dashboard – several gauges are essential, but a vehicle with too many gauges is distracting to the driver.

  - Easy to Measure – The data required for performance measures should be easy to collect and analyze, preferably directly and automatically from a freeway management (or other) system. As an example, in most ramp controllers, the firmware and the detector loops can automatically detect when a vehicle has violated the red signal phase. This information can be collected and used to note high violation areas that could benefit from increased enforcement or perhaps a change in the signal operation timing.

  - Simple and Understandable – Within the constraints of required precision, accuracy, and facilitating improvement, performance measures should prove simple in application with consistent definitions and interpretations. Any presentation of performance measure data must be carefully designed so that it is easy for the audience to understand the information, and the data analysis provides the information necessary to improve decision-making.

- Time Frame – The decision-making "tiers" can have significantly different time frames, both for making the decision and for the effect of that decision to take place. Using performance measures to monitor the effectiveness of a policy plan requires measures that can reflect long-term changes in system usage or condition. Similarly, performance measures for the operation of a TMC should reflect changes within a "real-time" context. Once established, performance measures should be in place long enough to provide consistent guidance in terms of improvements and monitoring, to determine whether the objectives are being met.
- Sensitivity – Performance measurement must be designed in such a way that change is measured at the same order of magnitude as will likely result from the implemented actions.
- Geographically Appropriate – The geographic area covered by a measure varies depending on the decision-making context in which it is used. The scope of measures used to evaluate progress on broad policies and long-range planning goals and objectives often are regional, statewide, and even nationwide. To be effective in an operations context, measures may need to be focused on a specific geographic area (e.g., a corridor or system).

The FHWA's *Freeway Management and Operations Handbook* also provides a synthesis of innovative performance measures identified in recent research efforts into performance-based planning.[1] This handbook will not attempt to document the full inventory of available performance measures. Instead, this section highlights several different categories of performance measures and discusses their potential implications on the analysis effort. In general, when selecting a performance measure, the method to obtain the performance measure data for the evaluation should also be considered. Section 9.2.4 presents guidelines for developing an analysis structure designed to promote the consideration of these factors while drafting the evaluation approach. These performance measures are illustrated with example measures from previously conducted ramp management analyses:

Safety – Safety is most often measured through the change in the number of crashes, segmented by severity (e.g., fatal, injury, property damage only, etc.). This performance measure may also be segmented by crash type (e.g., rear-end, side-swipe, etc.). The data supporting this performance measure is most typically obtained from crash records kept by one or more emergency responder agencies or the Department of Transportation. The format and availability of the regional crash data greatly influences the format of the performance measure used to evaluate safety impacts.

Evaluators should use caution in the development of performance measures and in the actual analysis of the data related to crashes. Crashes are randomly occurring events and may be based on limited sample sizes, particularly in the case of less frequently occurring crashes such as those involving fatalities. Thus, a limited number of crashes may cause the rate to spike over short periods or in particular locations. These spikes in the data may be misinterpreted as being related to the ramp management deployment. Therefore, longer-term historical data should be used to validate the crash rate, or the evaluators should consider consolidating some of the crash segmentations to ensure an adequate sample size. Furthermore, it may be more appropriate to evaluate the change in the crash rate (e.g., number of crashes per vehicle-mile traveled) rather than the actual number of observed crashes to help control for changes in traffic volumes.

In the Twin Cities evaluation, the Minnesota Department of Public Safety maintained a useful database of all regional crashes reported by local police agencies, which was used to obtain the crash data.[47] The length of the data collection period (six weeks) and the extent of the study area (regionally) were sufficient to segment the observed crash data by severity and type. However, no fatalities were observed during either of the data collection periods.

Mobility – Travel mobility impacts are typically measured as a change in travel time, speed, or delay. These measures are targeted at capturing the user's travel experience. Therefore, these measures are most effective when captured on a per-trip basis, such as the change in travel time for a door-to-door trip. Use of aggregate system measures such as total system person-hours of travel (PHT) may not accurately capture user benefits. Likewise, spot measurements of speed may not accurately reflect the individual's overall travel experience.

In the Twin Cities evaluation, travel time and speed were used as performance measures. Travel time was collected for several representative trips utilizing arterial, ramp, and freeway facilities. Spot speeds were also collected to support the travel time findings.

Travel Time Reliability – A number of innovative performance measures have recently been developed to aid in the evaluation of travel time reliability. A few examples include the travel time index (TTI), which is a comparison between the travel conditions in the peak-period to free-flow conditions, and the buffer time index (BTI), which expresses the amount of extra "buffer" time needed to be on time at your destination 95 percent of the time (i.e., late to work one day per month).[48] These performance measures are critically important to ramp management evaluations and the analysis of many other operational improvements. These measures are intended to capture the impact of reducing travel time variability and making travel times more predictable. More predictable travel times allow travelers to better budget their travel schedules and avoid unexpected delays. Ramp metering systems reduce travel time variability and have a potentially significant impact on this measure.

To illustrate the magnitude of this impact, the estimated impacts on travel time reliability in the Twin Cities evaluation outweighed the impacts on average travel time by a factor of ten, and overall accounted for 40 percent of the total benefits identified for the system.

Environmental – Environmental performance measures used in ramp management analyses typically include changes in vehicle emissions and in fuel consumption. Identifying effective environmental performance measures that may be successfully evaluated within the framework and available resources can be a challenge. For example, the implementation of ramp metering can simultaneously reduce emissions and fuel use on the freeway mainline, while increasing these factors at the ramp meters. Therefore, the data collection and analysis methodology for these performance measures must be sensitive to this situation.

In the Twin Cities evaluation, the estimation of fuel use impacts was particularly problematic. This performance measure was estimated based on a fuel use rate based on collected speed and vehicle-miles traveled (VMT) data. Freeway speeds were observed to increase with ramp meters as stop-and-go driving conditions were reduced – a situation that would be expected to result in decreased fuel use. However, the fuel use analysis was based on traditional relationships that estimate higher fuel consumption rates as average vehicle speeds increase. While average speeds did increase in the Twin Cities study, the amount of heavy accelerations and decelerations decreased as traffic flow was more stable and smooth flowing. Thus, in reality, fuel use likely decreased, but this effect was not captured in the traditional analysis.

More advanced fuel estimation methodologies that are sensitive to vehicle acceleration profiles were considered for use in the evaluation. However, the data required for this analysis could not be collected within the timeframe and resources available for the Twin Cities study. Furthermore, limited studies comparing the accuracy of these advanced methodologies with more traditional methods have been inconclusive to date, which hindered their application in this highly visible evaluation.

Similar lack of sensitivity to actual operating conditions in many vehicle emission estimation methodologies can also create difficulties in estimating these performance measures.

Facility Throughput – These performance measures are targeted toward representing the system operator's perspective and typically include one or more of the following: throughput (vehicle or person volumes), level of service (LOS), facility speeds, volume to capacity (V/C) ratio, or queuing measures (length and frequency). The particular performance measure(s) selected in this category greatly influences the format of the data that needs to be collected. In general, performance measures targeted toward assessing person volumes or throughput are more difficult to collect than vehicle-based measures, but often these person-based measures can provide a much more accurate picture of the changes in traveler behavior, especially for special-use treatments on ramps (e.g., HOV bypass lanes). For the majority of smaller-scale ramp management evaluations, vehicle occupancies would not be anticipated to change significantly, which allows the vehicle measures to be used without a significant loss of accuracy.

The Twin Cities evaluation included measures of vehicle volumes on freeways, ramps, and parallel arterials, as well as measures of transit passenger counts to evaluate potential mode shifts. The evaluation also included a queuing analysis measuring queue lengths at the ramp facilities.

Public Perceptions/Acceptance – The perceptions of the traveling public regarding the benefits of the ramp management system and their acceptance of the system performance can be extremely important to measure depending on the purpose of the study. These measures are typically assessed through conducting a series of one or more focus groups, telephone surveys, intercept surveys, or panel survey groups. The collection of this data often requires significant resources to complete. Nevertheless, the information on public perceptions gained through these methods can be invaluable in shaping public outreach campaigns.

These performance measures are often used to support the findings from field data collection and can be used to identify areas where perceptions differ from reality. A critical finding from the Twin Cities evaluation showed that the public's perception of waiting times in ramp queues was nearly twice the actual wait time recorded from the field data. Insight into this perception was a critical input in modifying the system's operational procedures following the evaluation.

Other Performance Measures – Many other performance measures have been used in evaluating ramp management applications that do not fit neatly in the above categories. Most common is the use of system costs in benefit/cost analyses and other studies. In evaluating costs, it is important to identify both the full up-front cost of planning and implementing the ramp management application (capital costs), as well as the ongoing operations and maintenance costs associated with the deployment. Identifying these costs can be problematic, because the costs of ramp management deployment and operation are often lumped in with other programs and it may take some effort to isolate the specific costs relatable to ramp metering. The U.S. DOT ITS Joint Program Office maintains an ITS cost database on their website that provides both unit and system costs of ITS elements and projects throughout the country.[49]

Specific performance measures have been used in other evaluations to test the ramp metering system's impact on other operational strategies. For example, an evaluation conducted in Madison, Wisconsin (included as a case study in Chapter 11) compared the average incident response time both before and after the ramp meters were deployed, to identify efficiency gains in the incident management program attributable to coordination with the ramp metering system.

9.2.4 Analysis Structure

The U.S. DOT ITS Joint Program Office (ITS JPO) has developed guidelines for conducting evaluations for operational tests and deployments carried out under the Transportation Equity Act for the 21st Century (TEA-21) ITS program. Although not all ramp management deployments are subject to the specific evaluation requirements of this program, the guidelines do provide a valid and implementable analysis structure. Conducting evaluations according to a well defined, systematic structure helps to ensure that the evaluation meets the needs and expectations of stakeholders.

These evaluation guidelines are typically intended to guide the conduct of "before and after" evaluations looking to estimate the impact of the deployed improvements on the system performance. These guidelines are also intended to provide evaluation results within a consistent reporting framework that will allow the comparison of results from different geographic regions. With minor modification, however, this evaluation framework may be applied to a variety of evaluation types and may be easily scaled to the size of the evaluation effort and available resources. The basic steps in the analysis structure recommended by the ITS JPO guidelines include:

1) Forming the Evaluation Team.
2) Developing the Evaluation Strategy.
3) Developing the Evaluation Plan.
4) Developing Detailed Test Plans.
5) Collecting and Analyzing Data.
6) Documenting Results.

More detailed discussions of the recommended steps are provided below. The specific steps recommended by ITS JPO have been modified slightly to make them more relevant to ramp management evaluations. These evaluation guidelines focus heavily on the systematic development of evaluation plans to guide the conduct of the evaluation effort. Less specific guidance is provided by these guidelines on collecting and analyzing data and on reporting results. Additional discussions of these crucial evaluation tasks are provided in this handbook in Sections 9.3, 9.4, and 9.5.

1. Forming the Evaluation Team. Each of the project partners and stakeholders designates one member to participate on the evaluation team, with one member designated as the evaluation team leader. Experience has demonstrated that formation of this team early in the project is essential to facilitating evaluation planning along a "no surprises" path. Participation by every project stakeholder is particularly crucial during the development of the "Evaluation Strategy."

2. Developing the Evaluation Strategy. The evaluation strategy document includes a description of the project to be evaluated and identifies the key stakeholders committed to the success of the project. It also relates the purpose of the project to the general goal areas. Example project goals may include:

- Traveler safety.
- Traveler mobility.
- Transportation system efficiency.
- Productivity of transportation providers.
- Conservation of energy and protection of the environment.
- Other goals that may be appropriate to unique features of a project.

For any given evaluation, the goal areas must reflect local, regional, or agency transportation goals and objectives. A major purpose of the evaluation strategy document is to focus partner attention on identifying which goal areas have priority for their project. Partners assign ratings of importance to goal areas, and evaluation priorities and resources are consequently aligned to the prioritized set. This rating process gives partners valuable insights regarding areas of agreement and disagreement and assists in reconciling differences and bolstering common causes.

Each of these goal areas can be associated with outcomes of deployment that lend themselves to measurement. These outcomes resulting from project deployment are identified as measures and have been adopted as useful metrics. The association of goal areas and measures is depicted in Table 9-1.

Table 9-1: Example Evaluation Goals and Measures

Goal Area	Measure
Safety	▶ Reduction in the overall rate of crashes. ▶ Reduction in the rate of crashes resulting in fatalities. ▶ Reduction in the rate of crashes resulting in injuries.
Mobility & Reliability	▶ Reduction in delay. ▶ Reduction in transit time variability.
Public Perception/ Acceptance	▶ Improvement in customer satisfaction.
Improvements in Effective Capacity	▶ Increases in freeway and arterial throughput or effective capacity.
Cost Savings	▶ Reduction in agency costs.
Energy & Environment	▶ Decrease in emissions levels. ▶ Decrease in energy consumption.

The "few good measures" in the preceding table constitute the framework of benefits expected to result from deploying and integrating ITS technologies (including ramp management). While each project partnership will establish its unique evaluation goals, these measures serve to maintain the focus of goal setting on how the project can contribute to reaping the benefits of one or more of the measures.

3. Developing the Evaluation Plan. After the goals are identified and priorities are set by the partners, the evaluation plan should refine the evaluation approach by formulating hypotheses. Hypotheses are merely "if-then" statements about expected outcomes after the project is deployed. For example, a possible goal of implementing a ramp meter system is improving safety by reducing crashes in merge areas. If the evaluation strategy included this goal, the evaluation plan would formulate hypotheses that could be tested. In this case, one hypothesis might be, "If ramp metering is implemented, vehicle crashes will be reduced in the merge areas." A more detailed hypothesis might suggest that such collisions would be reduced by 10 percent. The evaluation plan identifies all such hypotheses and then outlines the number of different tests that might be needed to test all hypotheses.

In addition to hypotheses regarding system and subsystem performance, the evaluation plan identifies any qualitative studies that will be performed. The qualitative studies may address key components of the project, such as, (but not limited to):

- Consumer acceptance.
- Institutional issues.
- Others as appropriate to local considerations.

4. Developing Detailed Test Plans. A test plan will be needed for each test identified in the evaluation plan. A test plan lays out all of the details regarding how the test will be conducted. It identifies the number of evaluator personnel, equipment and supplies, procedures, schedule, and resources required to complete the test. For ongoing monitoring activities or evaluation activities involving automated data sources, the test plan should identify any database design or data archiving issues.

5. Collecting and Analyzing Data and Information. This step is the implementation of each test plan. It is in this phase where careful cooperation between partners and evaluators can save money. By early planning, it is possible to build capabilities for automatic data collection into the project. Such data collection can be used by partners after the evaluation is completed to provide valuable feedback with regard to the performance of the system. Such feedback can help in detect system failures and improve system performance. Refer to Sections 9.3 and 9.4 for more detail on the data collection and data analysis needs, respectively, to support the evaluation.

6. Documenting Results. The strategy, plans, results, conclusions, and recommendations should be documented in a Final Report. Refer to Section 9.5 for more detail on reporting of results.

9.2.5 Controlling Analysis Externalities

Externalities, such as data collection periods or multiple system installations, can have a distorting impact on performance analysis. This section highlights some of the potential impacts and discusses remedies, so that practitioners can anticipate and minimize the impacts of these externalities in their monitoring and evaluation efforts. Specifically, strategies for controlling two analysis externalities are discussed: data discrepancies due to the passage of time, and data discrepancies related to other system improvements.

Controlling for Data Discrepancies Occurring Over Time

Many evaluation efforts, particularly those relying on the collection and analysis of “before” and “after” data, may be adversely affected by the passage of time. Seasonal and cyclical variations in traffic patterns, as well as regional trends, may all serve to distort data collected in different time periods. This makes it difficult to isolate the impacts of the ramp management implementation from the “background noise.” The best way to control for these externalities is to understand these influences and include plans for addressing them in the evaluation plans.

Prior to initiating a data collection effort, historical data should be analyzed to provide a better understanding of any seasonal variations and trends affecting traffic patterns. Data collection and analysis plans should be developed to minimize the impact of these variations and designed to capture performance data during periods with similar characteristics. As a simple mitigating strategy for some before and after studies, evaluators may schedule both the before and after data collection periods as closely as possible to the implementation date to minimize the data window. In addition, care should be taken in using too brief of an "after" evaluation period. Immediately after implementation, motorists will start to become accustomed to the new ramp management strategy. As such, the impacts may be abnormal in these initial stages. After a certain amount of time, these impacts may stabilize as the motorists become more familiar with the strategy. Therefore, the evaluation should be designed to take this initialization period into account.

However, this simple mitigation strategy cannot be used if the evaluators require a longer data collection period or prefer to evaluate the system performance at a sufficient time after the implementation to allow traveler behaviors to change. For these situations, alternative control strategies may be required to normalize the data. In the Twin Cities ramp meter evaluation, historical crash data from the previous five years was analyzed to estimate the number of crashes that would be expected to occur in each of two separate six-week data collection periods. This analysis revealed that seasonal variations resulted in more crashes historically occurring in the second period. These predicted crash rates were compared with the observed data and used to discount this seasonal variation in the second data collection period and avoid the over-estimation of benefits.

Other mitigation strategies involve the use of control data collected from a corridor or region of the network unlikely to be affected by the ramp management deployment. Any differences between the before and after data observed in the control corridor data may be used to represent regional traffic variations that should be discounted from the data collected in the metered corridor, to avoid including these global variations as benefits of the ramp meters.

Controlling for Data Discrepancies Due to Other System Improvements

Another significant externality that may result in data discrepancies is the presence or implementation of other system improvements. For example, if a ramp metering system is deployed simultaneously with an incident management system, it may be impossible to isolate particular impacts attributable to each system. Likewise, construction activity in the freeway corridor or on major parallel surface streets can result in changed travel patterns and negatively affect the overall validity of the analysis.

To control these externalities, evaluators need to identify and understand the potential impact of any other planned system improvements. Prior to implementing any data collection effort, all agencies responsible for managing and maintaining the transportation network in the study region should be contacted to identify any new infrastructure or operational improvements, proposed changes to operational policies or procedures, planned construction or maintenance activities, or any other activities having a possible effect on travel patterns in the study area. To the degree possible, data collection activities should be scheduled around any significant system changes to avoid introducing bias to the data. The phasing of multiple system improvements may also be considered, to provide an opportunity to evaluate the impacts of each improvement separately.

9.2.6 Costs of Evaluation and Monitoring

The costs of evaluation and monitoring are nontrivial and should be carefully considered in the planning of any ramp management application, to ensure that suitable resources are available to successfully conduct these activities now and in the future. The actual costs incurred can be extremely variable depending on the type of evaluation or monitoring activities and the timeframe of the analysis. Agencies conducting these types of efforts have reported costs ranging from under $10,000 to nearly $1 million. Example costs for various evaluation efforts are discussed in several of the case studies presented in Chapter 11.

The cost of data collection for evaluation and monitoring efforts using real-world data can be substantial, often accounting for more than one-half of the total evaluation costs. For studies using advanced traffic analysis tools to evaluate performance, the cost of model development and calibration often accounts for the largest proportion of costs. Other cost items to be considered include:

- Staff labor costs.
- Project management costs.
- Costs associated with developing and updating an evaluation plan.
- Data storage and archiving costs.
- Contracting costs for any outside consultants or researchers.
- Costs of survey activities.
- Costs of developing and distributing reports.

In addition to the type of evaluation or monitoring activities and the timeframe of the analysis, there are a number of additional factors that may affect the cost and resources required. These factors include, but are not limited to:

- Number and geographic distribution of ramp locations.
- Availability and reliability of automated real-time performance data.
- Availability of archived historical performance data and pre-existing data management structures.
- Availability of calibrated traffic analysis tools or models for the analysis region.
- Familiarity of staff in developing and implementing evaluation and monitoring plans.

9.3 Data Collection

This section provides practical guidance on the collection of data required to support the evaluation of ramp management strategies. The collection of data should be related to the performance measures presented earlier in Section 9.2.3. Further information on data collection methods can be found in the *Travel Time Data Collection Handbook* or the *Traffic Engineering Handbook*.[50,51] Practical experience from the Twin Cities Ramp Metering Evaluation and/or other real-world analysis efforts are used where appropriate to illustrate these guidelines.

As discussed in Section 9.2, data collection methodologies should be considered early in the development of the evaluation strategy and in the identification of performance measures. The data collection methodologies should be carefully defined in the Evaluation Test Plans. These data collection plans should minimally include an identification of individuals responsible for conducting the effort, resource requirements, data management plans, and contingency plans, as appropriate.

The following sections highlight some of the data collection implications that should be considered when attempting to assess ramp management impacts related to merge/weave areas, ramp queuing, freeway operation, and arterial operation. Each discussion focuses on the appropriate performance measures, the analysis data needed, and data collection methods and tools.

The discussion does not attempt to be prescriptive. Instead, various options are presented that may be considered based on the particular needs of the evaluator. Additional discussion on the approach to analyzing data is presented in Section 9.4.

9.3.1 Data Collection for Evaluation of Merge/Weave Areas

When analyzing the impacts in merge/weave areas, one must follow the analytical steps outlined in Section 9.2. The merge/weave area impacts are primarily associated with a localized or corridor study area.

Table 9-2 provides a summary of data collection efforts associated with evaluating various performance measures within the merge/weave area. Note that information on all performance measures is not provided within this discussion since some performance measures are not appropriately captured within the focused merge or weave area. Mobility and travel time reliability measures are not included in the table because they are better captured when analyzing freeway and arterial operations, and are discussed further in those sections.

Safety is one of the performance measures that can be evaluated in merge/weave areas. As shown in Table 9-2, the recommended data collection method uses crash records and traffic volume counts. As discussed in Section 9.2.3, the analysis would involve calculating a crash rate using the number of crashes and the vehicle-miles traveled (VMT). The use of videotape is another method to monitor safety conditions by analyzing the number of conflicts (near-crash events).

Environmental performance measures can also be evaluated using travel time runs or “hot spot” detection. “Hot spot” detection uses sensors and equipment to determine where concentrated levels of carbon monoxide (CO) emissions exist. These methods help determine the change in fuel consumption or emission levels. Again, it is important to note that while emissions may be reduced on the freeway mainline, they may increase on the ramp and therefore, the analysis must take ramp conditions into account.

Table 9-2: Merge/Weave Area Data Collection Methods

Performance Measures	Analysis Data Needed	Data Collection Methods and Tools
Safety – Crash Rate	Number of crashes	Crash records
	VMT	Manual or automatic traffic volume counts
Safety – Number of Conflicts	Observation of conflicting movements	Field observation or videotape
Throughput – Traffic Volumes	Observed traffic volumes	Manual or automatic traffic volume counts
Facility Speeds	Spot speed measurements	Automated speed collection (e.g., loop detector, acoustic, radar, etc.)
Environmental – Fuel Consumption	Vehicle speeds and acceleration profiles	Travel time runs (GPS-equipped)
Environmental – Vehicle Emissions	Observed emissions	Hot spot detection

9.3.2 Data Collection for Evaluation of Ramp Operations

Table 9-3 provides a summary of data collection efforts associated with evaluating ramp operations. This particular analysis often makes use of ramp queue observations that record when vehicles join the rear of the queue and when vehicles are released, or ramp queue counts that periodically record the number of vehicles in queues. From this data, a number of performance measures may be estimated, as shown in the table. These queue counts may be collected manually, or through the use of automated detection where appropriately equipped.

The analysis of ramp queuing impacts is primarily a localized or corridor level study area, though some evaluations may analyze queuing on a regional scale. Performance measures such as mobility and travel time reliability can be evaluated with respect to the ramp conditions. The use of manual or automated ramp queue counts is a data collection method that can provide information about the ramp delay and queue length (including the average value, standard deviation, and maximum observed levels). Analysis of this information can address whether or not the ramp management strategy is reducing the variability of travel time and therefore making travel more predictable for motorists.

9.3.3 Data Collection for Evaluation of Freeway Operations

Table 9-4 provides a summary of data collection efforts associated with the evaluation of performance measures related to freeway operations. Many of the same data collection methods are applicable for freeway operations as for the previous two types of needs. Throughput is a specific performance measure that can be evaluated using a variety of methods. These may include manual or automated traffic counts, travel time runs, or automated speed collection. Automated speed collection can be conducted using a variety of methods. These vehicle detection methods can range from Doppler microwave, active infrared, and passive infrared technologies that have a "point-and-shoot" type of setup. Passive magnetic, radar, passive acoustic and pulse ultrasonic devices require some type of adjustment once the device is mounted. Electronic toll tags can also be used to collect travel time information that can be converted to speed data using the data collected at multiple points.[52] In any case, these methods can collect traffic volume or spot speed data that can be analyzed to determine level-of-service, volume-to-capacity (V/C) ratios, or facility speeds. These values are directly tied to facility throughput.

9.3.4 Data Collection for Evaluation of Arterial Operations

Table 9-5 provides a summary of data collection efforts associated with the evaluation of performance measures for arterial operations. Many of the data collection activities are related to capturing the impact of drivers diverting from the freeway as a result of ramp metering or other ramp management strategy. Although most of the highlighted data collection activities are intended to be performed on the arterial facilities, some performance measures may be supported with data collected at the ramp facilities or on the freeway. Each of the data collection methods shown in this table has been discussed previously in Sections 9.3.1 through 9.3.3.

Table 9-3: Ramp Condition Data Collection Methods

Performance Measures	Analysis Data Needed	Data Collection Methods and Tools
Safety – Crash Rate	Number of crashes	Crash records
	VMT	Manual or automatic traffic volume counts
Mobility – Travel Time/Ramp Delay	Seconds of ramp delay	Manual or automated ramp queue counts
Reliability – Travel Time Variation	Standard deviation in seconds of ramp delay	Manual or automated ramp queue counts
Throughput – Volume	Ramp volumes	Manual or automated ramp volume counts
Queue Spillover	Percent of time ramp queue impacts adjacent arterial intersections	Manual or video observation of ramp queue lengths
Environmental – Fuel Consumption	Vehicle speeds and acceleration profiles	Travel time runs, or manual or automated ramp queue counts or ramp queue observations
Environmental – Vehicle Emissions	Observed emissions	Hot spot detection
	Vehicle speeds and acceleration profiles	Travel time runs, or manual or automated ramp queue counts or ramp queue observations

Table 9-4: Freeway Operations Data Collection Methods

Performance Measures	Analysis Data Needed	Data Collection Methods and Tools
Safety – Crash Rate	Number of crashes	Crash records
	VMT	Manual or automatic traffic volume counts
Mobility – Travel Time	Observed travel times and speeds	Travel time runs, or speeds from multiple detection sites
Mobility – Traveler Delay	Observed travel times and free-flow travel times	Travel time runs, or speeds from multiple detection sites
Travel Time Reliability	Observed variability in travel times or speeds	Travel time runs, or speeds from multiple detection sites
Throughput – Volume	Observed traffic volumes	Manual or automatic traffic volume counts
Throughput – Facility Speeds	Spot speed measurements	Travel time runs or automated speed collection (e.g., loop detector, acoustic, radar, etc.)
Throughput – LOS or V/C Ratio	Observed traffic volumes	Manual or automatic traffic volume counts
	Facility capacity	Estimates from HCM, or manual or automatic traffic volume counts
Environmental – Fuel Consumption	Vehicle speeds, volumes and acceleration profiles	Travel time runs (GPS equipped) or manual or automatic traffic volume counts
Environmental – Vehicle Emissions	Vehicle speeds, volumes and acceleration profiles	Travel time runs (GPS equipped) or manual or automatic traffic volume counts

Table 9-5: Arterial Operations Data Collection Methods

Performance Measures	Analysis Data Needed	Data Collection Methods and Tools
Safety – Crash Rate	Number of crashes	Crash records
	VMT	Manual or automatic traffic volume counts
Mobility – Travel Time	Observed travel times and speeds	Travel time runs, or speeds from multiple detection sites
Mobility – Traveler Delay	Observed travel times and free-flow travel times	Travel time runs, or speeds from multiple detection sites
Travel Time Reliability	Observed variability in travel times or speeds	Travel time runs, or speeds from multiple detection sites
Throughput – Volume	Observed traffic volumes	Manual or automatic traffic volume counts
Throughput – Facility Speeds	Spot speed measurements	Travel time runs or automated speed collection (e.g., loop detector, acoustic, radar, etc.)
Throughput – Arterial LOS or V/C ratio	Observed traffic volumes	Manual or automatic traffic volume counts
	Facility capacity	Estimates from HCM, or manual or automatic traffic volume counts
Throughput – Intersection LOS	Observed traffic volumes	Manual or automatic traffic volume counts
	Signal timing settings	Signal timing settings from local agencies
Queue Spillover	Percent of time ramp queue impacts adjacent arterial intersections	Manual or video observation of ramp queue lengths
Environmental – Fuel Consumption	Vehicle speeds, volumes and acceleration profiles	Travel time runs (GPS equipped) or manual or automatic traffic volume counts
Environmental – Vehicle Emissions	Vehicle speeds, volumes and acceleration profiles	Travel time runs (GPS equipped) or manual or automatic traffic volume counts

9.4 Data Analysis

This section provides practical guidance on the analyses needed to support performance evaluation of ramp management strategies. The data analysis procedures and tools discussed in this section build on the data collection strategies discussed in Section 9.3.

9.4.1 Analysis Techniques and Tools

Most ramp management evaluation efforts are conducted using a variety of analysis techniques. Often the analysis involves field measurement data combined with one or more traffic analysis tools or models. These analysis tools and models may be used to enhance field data measurement or as an alternative to field data measurement when data is unavailable. Recent advances in data management technology have provided improvements in the accuracy, functionality, and usefulness of both modeling and measurement processes. Future advances will likely provide further opportunities for improvement and integration of these tools.

This subsection provides a discussion of some of the general implications of using modeling tools compared with direct field measurement, summarizes the various categories of available modeling and analysis tools, and provides guidance on which analysis techniques are most appropriate to different analysis scenarios.

Modeling vs. Measurement

The discussion in this section, comparing the relative strengths and limitations of using traffic models or field measurement in the analysis of ramp management impacts, was adapted from a draft version of the *National State of Congestion Report* developed for FHWA.[53]

A common general rule that is suggested in analyzing congestion is: "Measure where you can, model everything else." This recognizes that measurement using operations data often represents the best combination of accuracy and detail. However, the use of measurement data is often not feasible due to lack of availability, coverage, quality, or standardization. In these situations, modeling may be the better option. In using one or both of the analysis processes, it is important to understand that modeling and measurement each have their own relative strengths and weaknesses. In general:

- Modeling provides an estimate of what would likely happen as a result of a particular change in the system, assuming that individuals reacted similarly to past behaviors.
- Measurement provides an accurate assessment of what *has* happened or what *is* happening (for real-time systems), but has less ability to draw conclusions about what *will* happen.

Table 9-6 provides additional detail on the relative advantages and limitations of these two approaches to analyzing congestion.

Table 9-6: Relative Advantages and Limitations of Modeling Versus Measurement

	Advantages	Limitations
Modeling	▶ Provides predictive capabilities. ▶ Once developed, can provide rapid analysis of multiple scenarios. ▶ Can be developed to provide micro- or macro-level analysis. ▶ Technology advances in data management are providing for more advanced and accurate models.	▶ Only as good as the data used to develop the models. ▶ Only provides an estimate of the real world. Results must be calibrated against observed data. ▶ Difficult to predict travelers' reactions to unique conditions or innovative strategies. ▶ Can be costly to develop initial models.
Measurement	▶ Provides a more accurate assessment of actual conditions. ▶ Can be used to analyze traveler reactions to specific conditions or unique events. ▶ Technology advances in data collection and better data management are providing improved measurements.	▶ Data availability and quality issues may limit usefulness of the data. ▶ Can be costly to implement extensive data collection programs or systems.

Since models are based on observed behaviors, they are most accurate when analyzing predictable conditions. Utilizing models to analyze extreme conditions, innovative operations strategies, or situations where traveler behaviors would be unpredictable is less advised. When the traffic conditions are extremely unpredictable, modeling should only be used if measurement is cost prohibitive.

Figure 9-1 shows the trade-offs between the relative cost of the analysis and the conditions being analyzed, demonstrating the general areas of strength for both models and measurement.

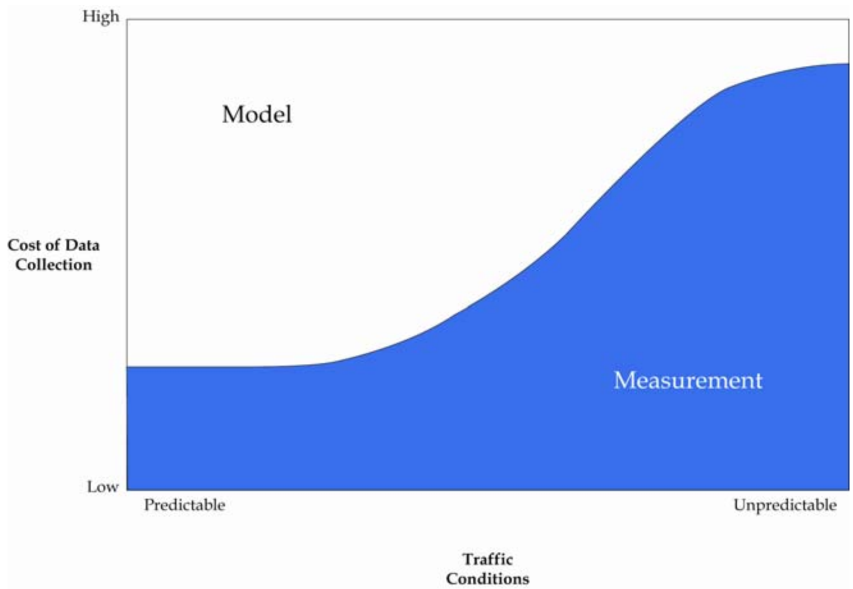


Figure 9-1: Modeling Versus Measurement – When Should They Be Used?[54]

Many agencies still view modeling and measurement as mutually exclusive processes with different end uses. However, many agencies are increasingly integrating the processes to provide even more powerful tools for analyzing congestion.

Examples of the benefits that can be achieved through the integration of measurement and models include:

- Data sets obtained through measurement can be used in the development and calibration of models.
- Models can be tied to real-time data measurement to add the capability of predicting future conditions based on current real-world conditions.
- Models can be used to extrapolate localized measurement data to a regional scale.
- Data generated by models can also be used to provide sensitivity testing as a reality check on measurement tools and data sets, in order to help identify potentially erroneous data or alert personnel of inoperative data collection equipment.

Available Traffic Analysis Tools

A number of tools and models are available to assist in the evaluation of ramp management applications. These tools range from very simplistic spreadsheet-based tools to much more complex microsimulation models. Each tool has strengths and weaknesses, and are better or worse suited to analyzing particular situations.

Recognizing that little guidance currently exists to guide planners and engineers in understanding and selecting among the various tools, the FHWA recently developed a detailed assessment of the available traffic analysis tools to provide this information. The following excerpt from *Traffic Analysis Toolbox Volume 1: Traffic Analysis Tools Primer* provides an overview of available analysis tools that may be applicable to ramp management evaluation.[35] This document includes discussions of the relative strengths and limitations of the various tools.

"To date, numerous traffic analysis methodologies and tools have been developed by public agencies, research organizations, and consultants. Traffic analysis tools can be grouped into the following categories:

- Sketch-Planning Tools: Sketch-planning methodologies and tools produce general order-of-magnitude estimates of travel demand and traffic operations in response to transportation improvements. They allow for the evaluation of specific projects or alternatives without conducting an in-depth engineering analysis. Such techniques are primarily used to prepare preliminary budgets and proposals, and are not considered to be a substitute for the detailed engineering analysis often needed later in the project implementation process. Sketch-planning approaches are typically the simplest and least costly of the traffic analysis techniques. Sketch-planning tools perform some or all of the functions of other analytical tool types, using simplified analysis techniques and highly aggregated data. However, sketch-planning techniques are usually limited in scope, analytical robustness, and presentation capabilities.
- Travel Demand Models: Travel demand models have specific analytical capabilities, such as the prediction of travel demand and the consideration of destination choice, mode choice, time-of-day travel choice, and route choice, and the representation of traffic flow in the highway network. These are mathematical models that forecast future travel demand based on current conditions, and future projections of household and employment characteristics. Travel demand models were originally developed to determine the benefits and impacts of major highway improvements in metropolitan areas. However, they were not designed to evaluate travel management strategies such as Transportation System Management (TSM), Intelligent Transportation Systems (ITS), or other operational strategies, including ramp management. Travel demand models only have limited capabilities to accurately estimate changes in operational characteristics (e.g., speed, delay, and queuing) resulting from implementation of TSM and other operational strategies. These inadequacies generally occur because of the poor representation of the dynamic nature of traffic in travel demand models.
- Analytical/Deterministic Tools (HCM-based): Most analytical/deterministic tools implement the procedures of the *Highway Capacity Manual* (HCM).[31] These tools quickly predict capacity, density, speed, delay, and queuing on a variety of transportation facilities and are validated with field data, laboratory test beds, or small-scale experiments. Analytical/deterministic tools are good for analyzing the performance of isolated or small-scale transportation facilities; but are limited in their ability to analyze network or system effects.

- Traffic Signal Optimization Tools: Traffic signal optimization tools are primarily designed to develop optimal signal phasing and timing plans for isolated signalized intersections, arterial streets, or signal networks. This may include capacity calculations; cycle length; and split optimization including left turns; and coordination/offset plans. These can be important for the signal timing aspect of ramp terminal treatments. Some optimization tools can also be used for optimizing ramp metering rates for freeway ramp control.
- Macroscopic Simulation Models: Macroscopic simulation models are based on the deterministic relationships of the flow, speed, and density of the traffic stream. The simulation in a macroscopic model takes place on a section-by-section basis rather than by tracking individual vehicles. Macroscopic models have considerably fewer demanding computer requirements than microscopic models. However, they do not have the ability to analyze transportation improvements in as much detail as the microscopic models.
- Mesoscopic Simulation Models: Mesoscopic simulation models combine the properties of both microscopic and macroscopic simulation models. As in microscopic models, the mesoscopic models' unit of traffic flow is the individual vehicle. Their movement, however, follows the approach of the macroscopic models and is governed by the average speed on the travel link. Mesoscopic model travel simulation takes place on an aggregate level and does not consider dynamic speed/volume relationships. As such, mesoscopic models provide less fidelity than the microsimulation tools, but are superior to the typical planning analysis techniques.
- Microscopic Simulation Models: Microscopic models simulate the movement of individual vehicles based on car-following and lane-changing theories. Typically, vehicles enter a transportation network using a statistical distribution of arrivals (i.e., a stochastic process) and are tracked through the network over small time intervals (e.g., one second or a fraction of a second). Typically, upon entry each vehicle is assigned a destination, a vehicle type, and a driver type. Computer time and storage requirements for microscopic models are large, usually limiting the network size and the number of simulation runs that can be completed."

Traffic Analysis Toolbox Volume 2: Decision Support Methodology for Selecting Traffic Analysis Tools also provides a detailed decision support methodology for selecting the appropriate type of analysis tool for the job at hand.[55]

Mapping the Analysis Tool to the Needs of the Evaluation

As discussed in the previous subsection, many analysis tools and techniques are available for evaluating ramp management impacts in addition to the direct field measurement of "before and after" conditions. These analysis tools may serve as enhancements to or substitutes for field measurement, depending on the needs of the particular evaluation.

Table 9-7 provides a mapping of the study area to the categories of tools and/or techniques that are most typically applied. The three types of study areas include localized, corridor, and regional, as discussed in Section 9.2. This mapping is further disaggregated by the different general types of analyses, which include:

- Analyzing impacts in merge/weave areas.
- Analyzing impacts of ramp operations.
- Analyzing impacts on freeway operations.
- Analyzing impacts on arterial operations.

Once the study area limits have been determined using the methodology described in Section 9.2.2, the process would then continue with a determination of the types of analyses required. Based on this selection and a determination of the operational impact area, the appropriate tools would be chosen and a detailed analysis focusing on the specific area would be conducted.

This mapping does not intend to be fully inclusive, as the particular analysis tool selected for any situation should be based on the specific needs of the evaluation. It does, however, identify many of the more common approaches. For example, microscopic simulation tools are not often applied to a regional analysis, due to the significant resources that would be required to develop such a model. However, if the precision of microscopic simulation is required in a particular evaluation and sufficient resources are available, this tool should be considered as a possible analysis approach.

9.4.2 Real-Time Performance Monitoring and Evaluation

This section provides an overview of the specialized needs and requirements for collecting and analyzing ramp performance data in real-time. Automated data monitoring sources may be used to provide continuous and immediate feedback to system operators on the real-time performance of the ramp management application. This data may be evaluated and used in a variety of ways to adjust the short-term or long-term performance of the ramp management application, to improve the performance of the system.

A critical aspect of performance monitoring and evaluation is to use this data to manage the ramp management system. The agency should collect, analyze, and archive real-time data, and use it to continuously monitor and understand how the system is working. With this knowledge, the practitioner can make adjustments when the system is not working efficiently. If a system is created that provides real-time performance data to demonstrate whether the system is running effectively, this system can be used to keep the ramp management system running well. Decisions can be made to improve system operations by using the performance data.

Table 9-7: Mapping of Analysis Needs to Common Traffic Analysis Tools

Study Area	Problem Area (Operational Impact)	Traffic Analysis Tool Category: Direct Measurement	Sketch-Planning Tools	Travel Demand Models	Analytical/Deterministic (HCM-Based)	Macroscopic Simulation	Mesoscopic Simulation	Microscopic Simulation	Signal Optimization Tools
Localized	Merge/Weave	✓	✓		✓	✓	✓	✓	
	Ramp Operations	✓	✓		✓	✓	✓	✓	
	Freeway Operations	✓	✓		✓	✓	✓	✓	
	Arterial Operations	✓	✓		✓	✓	✓	✓	✓
Corridor	Merge/Weave	✓	✓		✓	✓	✓	✓	
	Ramp Operations	✓	✓		✓	✓	✓	✓	
	Freeway Operations	✓	✓	✓	✓	✓	✓	✓	
	Arterial Operations	✓	✓	✓	✓	✓	✓	✓	✓
Regional	Merge/Weave	Not typically performed for a regional study							
	Ramp Operations	✓	✓	✓					
	Freeway Operations	✓	✓	✓		✓			
	Arterial Operations	✓	✓	✓		✓			

Current Status of Real-Time Performance Monitoring and Evaluation

Numerous agencies nationwide are implementing systems to provide data on current system conditions in real-time or near real-time. This data is being used to monitor and make modifications to various operational strategies, to better adapt to variations in traffic flow, weather, traffic incidents, work zones, and special events. Regions experimenting with real-time performance monitoring for use in ramp metering applications include, but are not limited to Minneapolis/St. Paul, Phoenix, Portland, San Diego, and Seattle. A FHWA-sponsored field operational test of the use of real-time data in various freeway management strategies is currently underway in the Hampton Roads region of Virginia.[2]

The purpose of these implementations is to provide system management personnel with better information on which to base their decisions. By providing system operators with a better picture of live conditions and allowing operators to observe the impacts of any modifications to operational strategies, it is hypothesized that operators will be able to better leverage the strategies available to them and customize the management of the system to the conditions at hand.

In addition to short-term use, the data collected by these systems is being used to monitor longer-term trends; provide diagnostic capabilities for reviewing the effectiveness of strategies; supplement or replace manually collected monitoring data; and provide for the development and calibration of models and analysis tools specific to a region.

In many cases, the data used in these real-time systems was already being collected through various traffic surveillance deployments or collected by field components associated with the ramp management application itself (e.g., loop detectors). Therefore, the costs associated with the real-time monitoring system have been related more to the establishment of a data management system and linking existing database structures than to deploying additional system surveillance systems.

As an emerging technology, little empirical data is currently available on the success and effectiveness of using real-time monitoring and evaluation of ramp metering applications. System operators at the early adopting agencies have reported encouraging experiences with the systems, and plans are in place to expand the real-time data monitoring capabilities to many additional regions. Furthermore, the continuous streams of data provided by these automated data collection systems have proven invaluable in many non-real-time evaluation efforts. For example, the recently conducted Twin Cities ramp metering evaluation made significant use of archived data from the region's robust freeway surveillance system. Data from this system was used to supplement the field data collection, to expand the evaluation to additional corridors and time periods that would not have been possible if only manual field data collection had been used. Significant challenges remain in successfully utilizing real-time performance monitoring systems, as highlighted in the following subsection. Practitioners should be aware of these challenges when

[2] The field operational test deployment in Virginia is not currently targeted at providing data for ramp metering applications; however, it does represent one of the most ambitious uses of real-time data for operational purposes. The deployment is being accompanied by an evaluation effort to assess the effectiveness of the concept that should yield significant lessons learned and guidance for other deploying agencies.

planning systems that can collect real-time data that might be used for real-time performance monitoring.

Challenges to Real-Time Performance Monitoring and Evaluation

The following discussion on the challenges still to be overcome in conducting real-time performance monitoring was adapted from a draft version of the *National State of Congestion Report* developed for the FHWA.[53] Table 9-8 summarizes some of the remaining barriers to real-time monitoring and discusses challenges created by these issues. Subsequent sections address these challenges in more detail.

Table 9-8: Potential Challenges to Real-Time Performance Monitoring

Issue	Challenge
Availability	Continuous streams of data are not readily available in many regions. The snapshot nature of data availability makes it difficult to analyze conditions during unique events or over time.
Coverage	Data is only available for a portion of the transportation network. Therefore, it is difficult to accurately assess all the impacts of widespread deployment of a given strategy across the regional network.
Quality	Data sets often contain erroneous data or have gaps of missing data. The data sets need significant "cleaning" before they can be used and accuracy may be compromised in this cleaning process.
Standards	Data is not consistently collected, analyzed, and stored across different regions, and often times not within the same region. Standardization is needed to provide for the meaningful comparison of conditions in different regions.

Availability

Continuous streams of data covering all periods and conditions need to be made available to properly assess these conditions and allow for meaningful comparison of trends over time. However, data simply is not available to conduct many analyses, and even when it has been collected, there are often problems that make the data unsuitable.

Traffic data has historically been collected on a periodic basis, providing snapshot views of traffic conditions. Transportation planners have often planned data collection activities to avoid special events, inclement weather, and traffic incidents to provide information of conditions representative of a "normal" day. This provides an incomplete picture of the full range and characteristics of network conditions.

Even in areas that have continuous data collection capabilities built into their traffic management programs, specific data may be difficult to obtain. Many Traffic Management Centers simply “spool off” the collected data for storage, with no real data management plan. The large files that are created make the data difficult to work with or inaccessible in many cases.

A potential solution to this challenge is the development of formal Archived Data Management Systems (ADMSs), which are currently under development in many regions around the country. ADMSs take a more formal approach to archiving data and make them accessible to a variety of users.

Coverage

Limited coverage of performance measurement restricts the usefulness of the data. Automatically or routinely collected data coverage in many areas is limited to particular jurisdictions or facilities. Often, monitoring coverage is limited to several freeway corridors. This requires the analyst to interpolate performance measures for parts of the system that are not covered, which increases the possibility of introducing errors to the data and can limit its accuracy. This partial coverage does not provide a complete picture of conditions throughout the transportation network.

Greater data coverage is needed to provide a greater understanding of impacts and conditions throughout the transportation network. Fortunately, many initiatives are underway to increase the coverage by introducing performance monitoring to new jurisdictions, increasing the freeway coverage in existing jurisdictions, and expanding coverage to include signalized arterials and public transportation systems. The expansion of coverage of monitoring activities will increasingly provide a more accurate picture of conditions across the transportation network.

Quality

The quality of data sets in many locations is often inadequate to perform meaningful assessments of conditions. If not corrected, these data errors can result in inaccurate performance measurement.

The errors in the data sets can be caused for a number of reasons, including improperly calibrated or poorly maintained field equipment and the lack of formal data management systems and processes. There is often very limited funding and resources for these critical tasks.

These data quality problems can be alleviated or minimized through data cleaning and calibration, increased data checking and quality control, and the development of more formal data archiving and management programs. These activities will require that more resources and funding be provided to support these activities.

Frequency

Performance monitoring and evaluation is best utilized when it occurs at regular intervals and on a continuous basis. A re-evaluation should occur if public comments are received or if any changes are made to the ramp management strategies. By using the performance data and public comments, system performance can be adjusted as is necessary.

Standards

The lack of standards presents problems for analysts attempting to compare different regions or identify trends. Different jurisdictions and agencies collect, analyze, and archive data differently based on their own needs. For example, traffic incident data in a region may be collected by a number of different agencies responsible for responding to traffic incidents (e.g., Fire Department, State Highway Patrol, or Transportation Authority). Each of these agencies may collect different data on the incidents to which they respond. This lack of standardization limits the meaningful comparison of the data among agencies.

Furthermore, there is currently little consensus on the analysis methods and performance measures used for transportation performance monitoring. Different jurisdictions often monitor and analyze different performance measures and archive data in different formats than used in other jurisdictions. This creates difficulties in tracking trends and comparing performance among different agencies.

Initiatives to develop standards for archived data are gaining momentum. The success of these initiatives in promoting the adoption of standardization will provide for more meaningful analysis, especially in the comparison of trends across different regions.

9.5 Reporting

This section discusses the final step of the evaluation process discussed in Section 9.2.4 - reporting how the ramp management strategy has performed. Reporting is the bridge between monitoring performance and using that information to improve strategies and refine goals and objectives. Reporting is also key to building support for ramp management activities by showing the benefits of those activities.

The most important consideration in reporting the evaluation results is ensuring that the findings are presented in a manner appropriate to the intended audience. Results reported to non-technical decision-makers or the public should not use technical jargon or assume any prerequisite knowledge of operational concepts. Instead, they should present the findings as clearly and concisely as possible, focusing on performance measures of greatest importance to the target audience. Conversely, the reporting of evaluation findings to a more technical audience should provide sufficient detail on the evaluation methodology and empirical evidence supporting the findings. Evaluators may want to consider developing more than one evaluation report to meet the needs of diverse audiences.

The eventual format of the evaluation report can be extremely varied based on the particular needs of the evaluation. It may be a formal document intended to be widely distributed, or an informal report intended for internal agency use only. The evaluation findings may not even be disseminated with a traditional document, but instead may be communicated through use of presentations, websites, press releases, or other media.

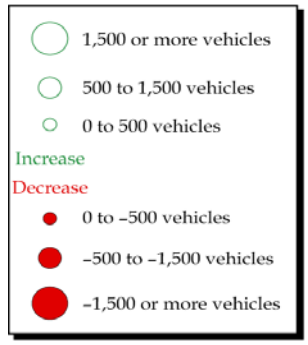
Due to the wide range of reporting formats and audiences, the needs of the reporting phase of the evaluation should receive substantial consideration early in the evaluation effort. The format of the eventual report and the intended audience should be factors guiding the selection of performance measures, the development of data collection plans, and the identification of analysis techniques and tools.

Although the format of the evaluation report may vary, most reports minimally contain information regarding:

- Evaluation Strategy – Provides an overview of the evaluation goals, objectives, and measures.
- Methodology – Summarizes the approach to data collection and analysis. This material is typically a summary of the Evaluation Plan and Individual Test Plans discussed in Section 9.2, but also should discuss any changes in strategy occurring during the implementation of the plans.
- Findings – Presents the results of the data collection and analysis activities.
- Conclusions – Maps the findings from the previous section to the evaluation goals and objectives, and identifies which of the evaluation hypotheses were proven by the findings.
- Recommendations – Suggests action items to be considered in light of the evaluation conclusions.

Understanding the needs of the target audience and structuring the reporting format to meet those needs is the most critical aspect of successful evaluation reporting. Another recommended practice includes the use of figures and graphics to explain complex concepts or findings. When appropriately designed, graphics may be used to promote a better understanding of findings that would be difficult to explain through the use of simple text and tables. Figure 9-2 provides an example graphic from the Twin Cities ramp metering evaluation showing the corridor impacts on volume resulting from the deactivation of ramp metering. The figure provides the reviewer with an instant overview of the direction and magnitude of changes occurring in the corridor. Presentation of this same data in tabular format would require much greater effort for the reviewer to interpret and comprehend.

The amount of information reported should be balanced, to present enough information to allow the reviewer to draw conclusions without overwhelming the reviewer with superfluous data. Evaluators should focus reporting efforts on impacts of greatest importance to the desired audience. However, this approach should not become so focused that key pieces of information are omitted. Again, graphics can often be used to accomplish this goal. Figure 9-3 provides an example of a graphic used to present findings on the impact of a key performance measure (speed variability) while also providing data on various control variables, including facility volumes. This allows the reviewer to evaluate the impact on speed variability with the knowledge that other conditions were comparable.



Average Volumes	I-35E	Rice	Edgerton
With Ramp Metering	14,552	1,652	1,395
Without Ramp Metering	12,140	1,538	1,742

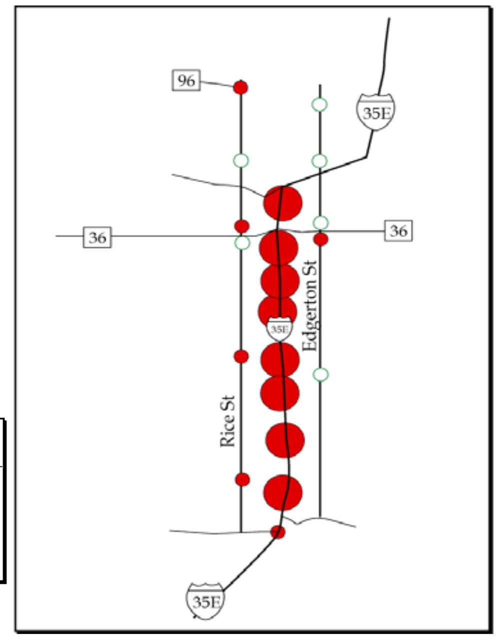
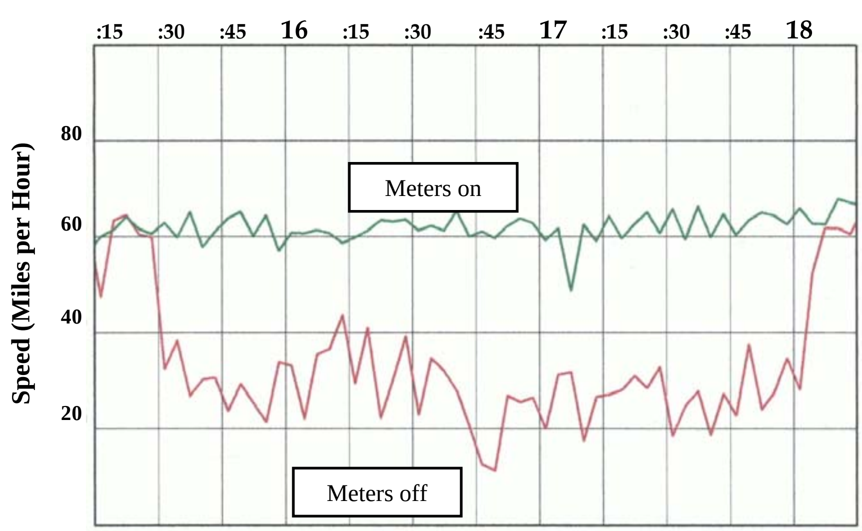


Figure 9-2: Example Graphic Showing Ramp Metering Impacts on Corridor Volumes[47]



Condition	Date	Field	Sample	Volume
Meters off	Mon, Oct 16, 2000	25′	100%	25,181
Meters on	Mon, Oct 9, 2000	25′	100%	25,294

Figure 9-3: Example Graphic Showing Speed Variability Impact Along with Control Variables[47]

Benchmarking the evaluation findings to previously conducted studies can also add additional insight and validity to the evaluation report. The impacts identified in the evaluation may be compared to impacts observed in previous evaluation efforts in the same region or to findings from evaluations in other regions. Any particular impacts from the evaluation that vary significantly from other benchmark measures should be explained.

Many of the traffic analysis tools have innovative reporting capabilities that may be useful in demonstrating particular concepts. These capabilities may include the ability to produce innovative graphs, charts, maps, and plots. Some simulation tools have the added capability of viewing particular conditions in three dimensions (3D), as shown in Figure 9-4. These 3D views can be presented as snapshot images in printed reports, or can be used to provide live-action views of ramp metering impacts during presentations or when viewed from a website. The reporting capabilities of the various analysis tools has been rapidly changing and improving in recent years. The particular reporting capabilities of the analysis tools should be an additional factor that is considered when selecting which tool to apply in the analysis.

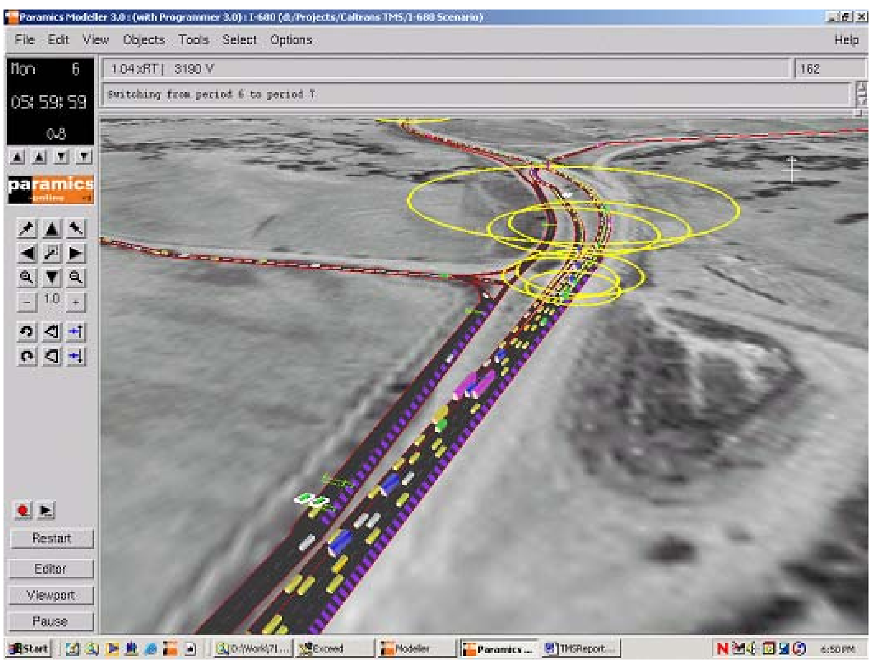


Figure 9-4: Sample 3D Graphic Generated from a Simulation Analysis Tool

When impacts are expressed as a change in a particular performance measure, both the percentage and numerical change should be notated wherever appropriate. This helps to provide the reviewer with a greater understanding of the magnitude of the change and adds credibility to the findings. Presenting the statistical testing/confidence levels analysis along with the data helps to promote greater understanding of the particular impact.

In presenting the results of benefit/cost analysis, the dollar value of the benefits presented in the report should be adequately supported by also presenting the actual performance measure impacts (e.g., number of hours saved, gallons of fuel saved, tons of emissions avoided) that were used in calculating the monetized benefit value. Presenting this supporting information provides the reviewer with improved insight into the findings.

Archiving the results of the analysis, the reports, and the raw data is important and must be considered in the development of databases and document control and archiving systems. Data generated in the evaluation effort may be used in future evaluations to provide comparisons of how conditions change over time, or may be requested by outside researchers for use in their own evaluation efforts. During the reporting phase, all the evaluation data should be archived along with any appropriate descriptions and data dictionaries to allow an individual unfamiliar with the data to successfully access and use the information.

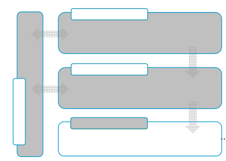
9.6 Chapter Summary

As seen in this chapter, performance monitoring is more than just recording data on how the system is performing. It is the mechanism for ensuring that the ramp management strategies being implemented are effective, efficient, and well worth the funding spent to support them. The evaluation and reporting component helps promote the ongoing support and continuation of the strategy by highlighting areas for improvement. It is important to understand how performance monitoring and reporting provides the impetus for determining how the agency can meet its traffic management program goals and objectives.

Using the guidance in this chapter, the practitioner now has a multitude of processes and methodologies for monitoring and evaluating ramp management strategies. By understanding the level of effort required to complete a thorough analysis, the agency can ensure that the proper analysis tools are available for a tailored evaluation effort that meets their specific needs. It is now clear that performance monitoring, evaluation and reporting are three key components in maintaining an effective ramp management system.

10

PLANNING AND DESIGN CONSIDERATIONS



Influences

Chapter 10: Planning and Design Considerations

Chapter 11: Case Studies

10.1 Chapter Overview

Chapter 10 provides guidance to practitioners who are ready to plan, design, and implement the systems and field elements within individual capital improvement projects that, wholly or in part, support the ramp management strategy selected in Chapter 6. This chapter supplements Chapter 7, which focused on the implementation of the overall ramp management strategy, by addressing specific issues and activities practitioners should consider when implementing smaller, individual capital projects that support the overall ramp management strategy discussed in Chapter 7. This information will help practitioners develop a comprehensive understanding of project planning and design, and it will help ensure that projects are implemented successfully.

Chapter 10 focuses on putting the capital improvement project into place. Once the internal decisions have been made about specific ramp management strategies, staffing within the organization, and system operation and maintenance, the agency can begin the planning and design process. One should understand that no agency can or should implement all of their ramp management activities at once – it takes an ongoing capital improvement process to install the equipment and make required geometric and roadway revisions that support and enable the implementation of ramp management strategies. The system is built in pieces, and many capital projects will be required to realize the agency's overall vision for ramp management. Because this may occur over several funding cycles, the Traffic Manager must ensure that the decisions

Chapter Organization

that were made early on (initial visioning and conceptualization) are periodically revisited. This will allow the capital improvement projects to be consistent with what has been agreed upon, and to be updated to reflect any policy or technology changes. It is important to verify that the ramp management system concept is up-to-date and correct.

The second step in this phase involves applying the best practice for designing and building these pieces of the overall vision. Because the individual capital projects are implemented over time, they must be designed and constructed according to the best practices at the time.

This chapter begins with the environmental review process and by identifying alternatives and key impacts. As part of the design process, a set of alternatives may be selected for evaluation. The alternative analysis process is often required in the environmental review, which helps to ensure that the design is the most appropriate in terms of costs (capital, operations, and maintenance) and impacts on traffic operations, air quality, equity, and surrounding neighborhoods. The next step of this process involves understanding the various operational considerations when implementing ramp management strategies. There are general design considerations, as well as considerations that pertain to the specific ramp management strategy, such as ramp closures or terminal treatments. Finally, the chapter ends with a discussion on planning high-level design for the Intelligent Transportation System (ITS) infrastructure needed to support ramp management strategies.

Chapter 10 Objectives:

Objective 1:	Understand that the decisions made during conceptualization need to be revisited at the beginning of the development of a capital improvement project and potentially updated.
Objective 2:	Be aware of issues that may be encountered during environmental or project review that are specific to ramp management strategies.
Objective 3:	Become familiar with the design considerations for implementing ramp management strategies.
Objective 4:	Identify and understand ramp management hardware and ITS infrastructure needs.

10.2 Environmental Review for Ramp Management Projects

An environmental review is a public process for examining potential significant impacts of major development projects. State agencies are given an opportunity to comment and supply environmental resource information on projects at the earliest possible stage in project development. This process affords the Project Manager and Project Designer time to avoid or minimize potential impacts in the design process. The review examines the impact on the environment and includes consideration of traffic, air quality, noise and vibration, and other factors. It also typically identifies any needed environmental remediation for the site.

The majority of the smaller projects will likely be exempt from the environmental review process. In Oregon, ramp metering projects are categorically excluded from any sort of environmental process because they are deemed not to have a significant effect on the human environment. This may vary from state to state. Agency policies or public concern may require some type of less formal environmental review. Although perhaps not as comprehensive as an Environmental Impact Statement (EIS) or Environmental Assessment (EA), some type of environmental review may be conducted.[56,57] Figure 10-1 shows a graphic representation of the National Environmental Policy Act (NEPA) process.

As an example of the EA process, Sound Transit in Seattle, Washington had a project that called for the implementation of 14 exclusive, direct-access High-Occupancy Vehicle (HOV) ramps in the region to improve regional and local bus service. These ramps were identified as the preferred investment for improving transit speed and reliability, by eliminating the need to weave across general-purpose lanes of traffic to reach HOV lanes. The master agreement with the Washington State Department of Transportation (WSDOT) divided the ramps into four Regional Express capital project groupings with three phases each. Phase 1 dealt with the preliminary engineering and environmental design component. Phase 2 encompassed plans, specifications, and estimates (PS&E) and right-of-way acquisition. Phase 3 handled bidding and construction management. Following the system-level alternatives analysis, the environmental review consisted of a NEPA EA for HOV Access and for Park-and-Ride facilities. The draft environmental document was reviewed by the Federal Highway Administration (FHWA), Federal Transit Administration (FTA), and WSDOT and then was circulated for public comment. After the EA was issued and approved, it was adopted for compliance with the State Environmental Policy Act (SEPA). Staff were then able to proceed with final design and right-of-way acquisition.[58]

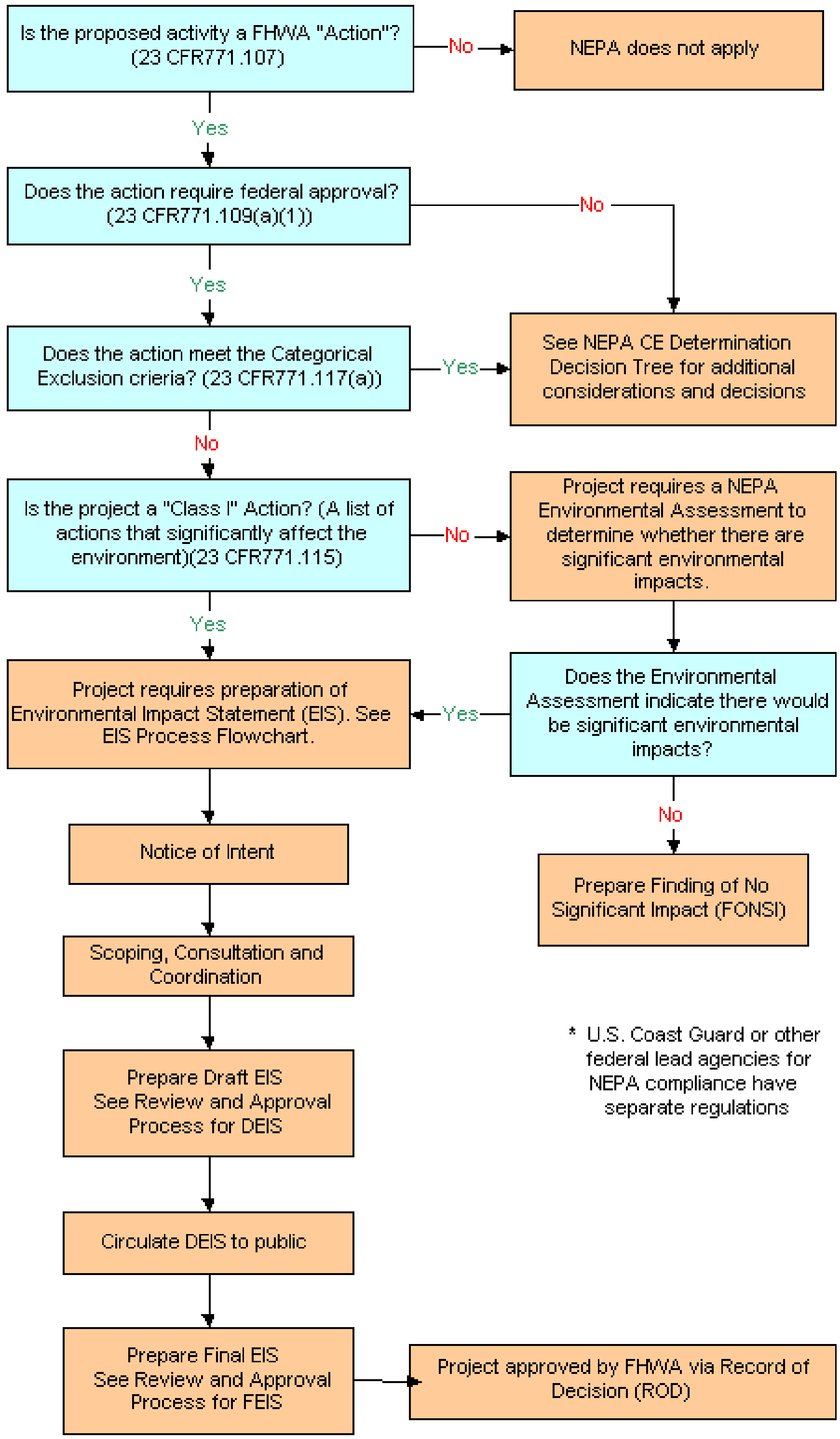


Figure 10-1: NEPA Process Overview[59]

10.2.1 Identifying Alternatives

An alternatives analysis should be conducted as part of the environmental review process prior to the design of an individual capital project. The analysis should address project design alternatives, rather than review alternative programmatic solutions to the same problem. In other words, the decision on the ramp management strategy has been made and an analysis of the different possible design and operational approaches is the next step. The process used to select the preferred ramp management strategy was discussed in Chapter 6. The results from that decision-making process are valuable information that should be considered when reviewing the trade-offs among the various design alternatives.

In the environmental review stage, an alternatives analysis must occur at the project level. The programmatic-level decisions made in Chapter 6 should be reviewed to verify that conditions have not changed that would lead to revising the overall ramp management strategy. Alternative designs should address key impacts such as equity and traffic impacts. Depending on the level of environmental review and potential impacts, the agency may decide to bring forward new alternatives or potential solutions to the problem not considered or selected previously.

10.2.2 Key Impacts of Ramp Management Strategies

Traffic Impacts and Associated Effects

One component of an environmental analysis is the evaluation of traffic impacts. Once a number of design alternatives are developed that will address the need, a detailed analysis is conducted to evaluate the differences among them, as compared to the ”No Action” (or “Do Nothing”) alternative. Elements such as traffic volumes, level of service, traffic-related noise, and vehicle emissions are modeled in the various alternative scenarios along with the potential improvements to mitigate the traffic impacts.

For example, some of the factors that are generally evaluated in a traffic analysis are traffic volumes, vehicle-miles of travel (VMT), level of service (LOS), and vehicle-hours of travel (VHT). Other factors such as noise levels and vehicle emissions are also evaluated. For the issues that often come up with ramp management projects, there are additional analyses that should be included, such as:

- Ramp delays and queuing.
- Travel times on the freeway and adjacent arterial network.
- Traveler safety.
- Diversion or traffic pattern changes that affect neighborhoods or local businesses.

The analysis needs to address both the freeway facilities and the local streets and arterials that may be affected by the ramp management project. It is important to consider how ramp metering will affect travel patterns on facilities neighboring the freeway. Ramp delays and queuing may cause changes in overall travel patterns as some drivers will change their route or time of travel to avoid the worst queuing conditions. Estimates of change in volumes and overall traffic conditions for both freeways and arterials are important impacts to be assessed at this stage of the project. The results of the traffic analysis will serve as inputs to other impact assessments as well, such as air quality, noise impacts, and additional impacts to the surrounding area.

The results of the environmental review are not meant to approve or deny a project, but rather to be used as a source of information to guide approval decisions. In other words, the analysis can point out the problems and potential solutions.

Impacts on Surrounding Areas

If drivers change their travel behavior due to a ramp management project, traffic patterns will change and there could be significant impacts on the surrounding area. Changes in travel behavior and traffic patterns may affect arterial operations and traffic on local or residential streets. If the changes in traffic patterns are significant, area businesses may be affected, especially if the businesses' customers rely on on-street parking or pedestrian movements for access. Residential areas may experience increases in traffic that local residents find unacceptable.

During the environmental review phase of the project, impacts on streets adjacent to and affected by the freeway, neighborhood traffic patterns, and businesses in the affected area need to be analyzed. The traffic analysis discussed above should estimate the changes in traffic patterns that can be used to analyze the impacts on the surrounding areas.

Given existing traffic patterns and estimated changes to traffic patterns in the area, impacts on street operations can be analyzed using a variety of traffic analysis tools, such as those discussed in Chapter 9. As the traffic impact analyses are conducted, it is a good idea to coordinate with the local agencies that are responsible for the operation of the roadways in question. Coordination with the operating agencies was likely initiated during the initial outreach efforts described in Chapter 7. The agencies should be familiar with ramp management strategies, and the coordination needed to ensure accurate impact assessment of the surface street network.

Neighborhood and business impacts may be driven strongly by emotion and perceptions of the impacts on traffic speeds, volumes, or other operations. It may be difficult to convince neighborhood residents and business owners that impacts in their area will not be significant. It is important to provide these stakeholders with an opportunity to voice their concerns early in the analysis and for the analysis to be flexible enough to address these concerns. One effective strategy is to present system impact studies from similar areas to show stakeholders and neighborhood groups the types of impacts to expect.

Equity

Environmental justice is a doctrine in many existing laws and policies (e.g., the Title VI of the Civil Rights Act of 1964 and most recently the Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU)). A 1994 Presidential Executive Order directed every federal agency to make environmental justice part of its mission by identifying and addressing the effects of all programs, policies, and activities on minority and low-income populations.[60]

Environmental justice is based upon three fundamental principles:

1) To avoid, minimize, or mitigate disproportionately high and adverse human health and environmental effects, including social and economic effects, on minority and low-income populations.

2) To ensure full and fair participation by all potentially affected communities in the transportation decision-making process.

3) To prevent the denial of, reduction in, or significant delay in the receipt of benefits by minority and low-income populations.

When properly implemented, these principles will improve all levels of transportation decision-making. They will allow better transportation decisions that meet the needs of all people; help design transportation facilities that fit more harmoniously into communities; and enhance the public involvement process and strengthen community-based partnerships. These principles will also improve data collection and analysis tools that assess the needs and impacts on minority and low-income populations; and avoid disproportionately high and adverse impacts on these groups.

When closing ramps, implementing ramp metering, or implementing special-use treatments on ramps, equity issues must be addressed. The agency must ask the following questions:

- Which geographic areas benefit the most?
- Which have the most impacts?
- Who gets the most from the strategy?
- Who may be negatively affected?

In an environmental justice review, the analysis must assess the impacts on disadvantaged groups. This includes drivers as well as surrounding residents and workers in a given area. For example, public outreach activities need to ensure that there is meaningful participation of minority and low-income populations. If barriers exist, they must be removed so these groups will become engaged to be a part of the transportation decision-making process.[60] Agencies must develop the technical ability to assess the benefits and adverse effects of transportation activities on different groups.

Of particular concern is the potential for a distribution of benefits to suburban groups at the expense of urban dwellers. For example, some believe that ramp metering is advantageous for longer trips on the system (at the expense of the shorter trips). Residents who live closer to urban centers are subject to the delays of ramp metering, and do not receive immediate access to the freeway. Suburban commuters who live outside of the metered zone can receive all of the benefits without any of the ramp delays.[60] This is an important issue to consider when implementing ramp metering.

Each agency can address the equity issue using a variety of techniques. The following are two examples using time-of-day restrictions and metering rate modifications. In Detroit, Michigan, the ramps were only metered in the outbound direction (away from the Central Business District (CBD)) to minimize the city-suburb equity issue. Once motorists understood how effective ramp metering was, the system was expanded with

"Each federal agency shall make achieving environmental justice part of its mission by identifying and addressing, as appropriate, disproportionately high and adverse human health or environmental effects of its programs, policies, and activities on minority populations and low-income populations."

- Executive Order 12898

fewer objections. In Seattle, Washington, WSDOT used a different approach by implementing more restrictive metering rates further away from the CBD. Suburban motorists had the most to gain from improved freeway performance, so this minor additional delay more than offset the reduced mainline travel time.[60]

The equity issue also applies to other ramp management strategies. For example, with ramp closures, the agency must ensure that any affected low-income and minority populations are given a fair opportunity to provide input into the public process. Ramp closures can have extreme impacts, so other strategies should be examined before this strategy is selected. The public involvement activities need to be adapted to the characteristics of the particular stakeholder community. For example, to encourage more local participation and increase attendance, community meetings with hand-delivered notices and a local venue are sometimes needed.

Air Quality and Noise Impacts

The final key impacts that should be considered in the environmental review of a ramp management project involve air quality and noise issues. For air quality, the concerns will primarily be about creating air quality "hot spots" (an isolated location with a significant air quality problem) on ramps with queued vehicles. Corridor-level air quality is often improved with more stable traffic flows and fewer accelerations and decelerations. However, inherent in ramp metering is forcing vehicles to wait to get onto the freeway, creating acceleration and deceleration maneuvers on the ramps. It is important to take air quality hot spots into account in the environmental review process and in the air quality analysis for the ramp management project.

Noise impacts should be estimated for ramp management projects, especially for those that include ramp metering. The primary issue to be addressed with noise impacts is noise from vehicles quickly accelerating from a stopped condition. This situation may be worsened on an uphill ramp with high truck percentages located adjacent to a neighborhood, school, hospital, or other noise-sensitive area.

10.3 General Operational and Design Considerations for Ramp Management Projects

There are a variety of operational and design considerations that must be taken into account when developing and implementing a capital project. In addition to understanding the needs of a particular ramp, corridor, or freeway system, several other factors need to be addressed when planning for ramp management and control strategies. These considerations follow.

Corridor Objectives: This involves reviewing operational considerations and aspects that may influence the project design. The process for selecting ramp management strategies conducted in Chapter 6 must now be translated into design elements. In other words, each operational objective must be understood and incorporated into design criteria to ensure that a designer will understand how to properly address operational objectives in the design.

Operational objectives for the corridor(s) in question should be established. These objectives should be based on the regional goals for a facility, if they exist. Corridor objectives can include:

- Reducing delay for transit and HOV vehicles..
- Balancing ramp delay with freeway delay, or balancing freeway operations with the operations of arterials and other surface streets.
- Reducing crash rates.

These objectives should be reviewed prior to planning, design, and implementation to ensure that projects will be developed with the specific corridor objectives in mind.

Overall policies for ramp management should also be established. For ramp metering, these policies would address issues such as hours of operation, implementation thresholds, and performance policies.

Project Consistency: If the capital project being planned and designed includes more than implementation of ramp management strategies, it is important to make sure the various pieces of the project are consistent with one another:

- Review overall project objectives for consistency.
- Ensure that the project can be staged to keep all investments viable through construction. This involves making sure that construction mitigation elements of ramp management can be operated during construction. It also requires that construction activities that may disrupt critical ramp operational components, such as surveillance and ramp metering, have mitigation planned in the project. The mitigation may include keeping existing systems operational during construction or installing temporary systems for the construction period.
- Review all aspects of the capital project to make sure that physical and geometric revisions of the various components are consistent and support ramp management strategies.

Maintenance: As with virtually any new system, installing new equipment, pavement markings, or signing will have a maintenance impact. Maintenance staff should be consulted early on to determine if they have any input or concerns about the ability to maintain any elements installed as part of ramp management and control. For example, the maintenance staff may have comments regarding the ability to keep equipment manufacturers consistent. Typically, they want to reduce the number of different manufacturers' equipment for the same type of item, because this reduces the required number of spare parts and training manuals, and reduces the time to train staff. They may also have insight as to the pros and cons of a specific type of manufacturer because they work with the field devices on a daily basis.

Other issues such as the location of equipment should also be discussed. Maintenance staff will want to give their recommendations so that they have adequate space to park their maintenance vehicles and can ensure their safety while servicing equipment. Equipment location also plays into ease of access. Depending on the level of maintenance required for a particular item, the ability to access and repair a piece of equipment can be critical.

10.3.1 Design Standards

The design of ramp management elements should conform to the American Association of State Highway and Transportation Officials (AASHTO)[61] standards and the FHWA's *Manual on Uniform Traffic Control* (MUTCD)[41] recommendations for freeway facilities, unless deviations from these standards can be justified according to specific agency guidance and procedures. These guidelines include elements such as geometric design (horizontal and vertical curvature); cross-slopes and drainage design; signing and striping; traffic signal design and operations; and other aspects that must be addressed in the final design. Some projects may require ITS systems. State Departments of Transportation (DOT) generally have their own design standards that are provided in design manuals or other documents. Practitioners should conform to the agency-specific design guidance as well as the national standards.

Many agencies use the basic implementation guidelines that are outlined in the MUTCD, while others have developed specific design standards and guidance for ramp management. One example is the *Ramp Meter Design Manual* from Caltrans.[28] This document contains design criteria for storage requirements, acceleration lanes, stop bar location, and meter locations; hardware criteria for signal heads, detector loops and the controller cabinet; and information for signing and pavement markings. Another example is the WSDOT guidelines outlined in their *WSDOT Design Manual, (Section 860).*[62] Additional information can also be found in WSDOT's *HOV Design Guide*.[63] Agencies should consider developing their own design standards if they intend to implement ramp management to any significant scale. Agencies developing their own design standards may benefit from reviewing those developed by other agencies.

10.3.2 Enforcement

Effective ramp management and control strategies are dependent on motorist compliance. For example, in the case of ramp metering, it should be made clear that ramp meter signals are traffic control devices and should be obeyed just as any other intersection traffic signal. This should be clearly communicated as part of the public information effort. The laws and associated penalties must be explained. As such, a coordinated effort with local law enforcement must also be a part of the implementation. Effective enforcement requires a variety of elements, including; good enforcement access, a safe area to cite violators, adequate staff, support by the courts, and well-designed signs and signals that are enforceable. Motorist compliance is critical to the success of a ramp management system.[2]

Appropriate enforcement elements must be designed into the project, because police need safe and effective locations in order to monitor and enforce compliance. Specifically, this means eliminating the potential for officers to get struck by a motorist when making enforcement contacts or in any other aspect of their duties. Law enforcement agencies that have enforcement jurisdiction in the project area should be consulted in the project development and design stages in order to gain their input and buy-in. Working jointly, agency staff can determine the appropriate design elements, such as the number and design of enforcement areas.

Coordination efforts with state and local law enforcement agencies should also involve developing an enforcement strategy. For example, enforcement considerations for an HOV bypass lane include:

- How will enforcement be used to prevent Single-Occupant Vehicles (SOVs) from using the HOV bypass lane?
- What are the goals of enforcement (i.e., safety or equity)?
- How do the goals relate to or affect the frequency and approach to enforcement?

For law enforcement, this can mean an increased caseload from HOV violations in traffic court and should be balanced with their other duties. Agency staff should work jointly with law enforcement to develop an enforcement strategy. More information on HOV enforcement can be found in the *HOV Systems Manual.*[42]

10.3.3 Performance Monitoring

During the development and design of a ramp management project, it is important for project planners and designers to be familiar with the measures used to monitor the performance of ramp management strategies. Chapter 9 covers performance monitoring in detail and suggests that a performance monitoring and reporting system be in place for ramp management strategies. Systems and processes must be implemented to ensure that ongoing performance measurement can be easily and efficiently conducted. Project planners and designers can facilitate performance measurement and monitoring by incorporating data collection equipment into the design of projects that implement ramp management strategies.

Various types of equipment can be used to conduct performance monitoring. These include data stations, video or radar detection, loop detection, or Global Positioning System (GPS)-equipped travel time runs. With these devices, measurements of travel times, vehicle speeds, traffic counts, or vehicle conflicts can be easily obtained.

10.4 Specific Design Considerations for Ramp Metering

This section discusses specific design considerations for ramp metering. The information included was taken from a variety of ramp metering design manuals or design guides. Several are referenced at the end of this chapter, including those from Caltrans, WSDOT, and the Minnesota DOT (Mn/DOT). Other states also have design guides or manuals for ramp metering. If the agency developing a ramp metering project does not have design guides or manuals that are relevant, the documents from other agencies should be reviewed to see which ones provide the best fit. In the following sections, the Caltrans *Ramp Meter Design Manual* is most often cited because it has very comprehensive coverage of ramp metering elements in a single document and because Caltrans has extensive experience in designing and operating ramp meters.

10.4.1 Ramp Meter Layout

Ramp meters can be installed on existing or newly constructed ramps. Each design element identified in this section should be considered, whether for new ramp construction or an existing ramp being retrofitted with a ramp meter. Figure 10-2 shows basic ramp meter elements. This graphic shows the ramp meter location in relation to the stop bar and the general layout of loop detectors needed to support ramp metering.

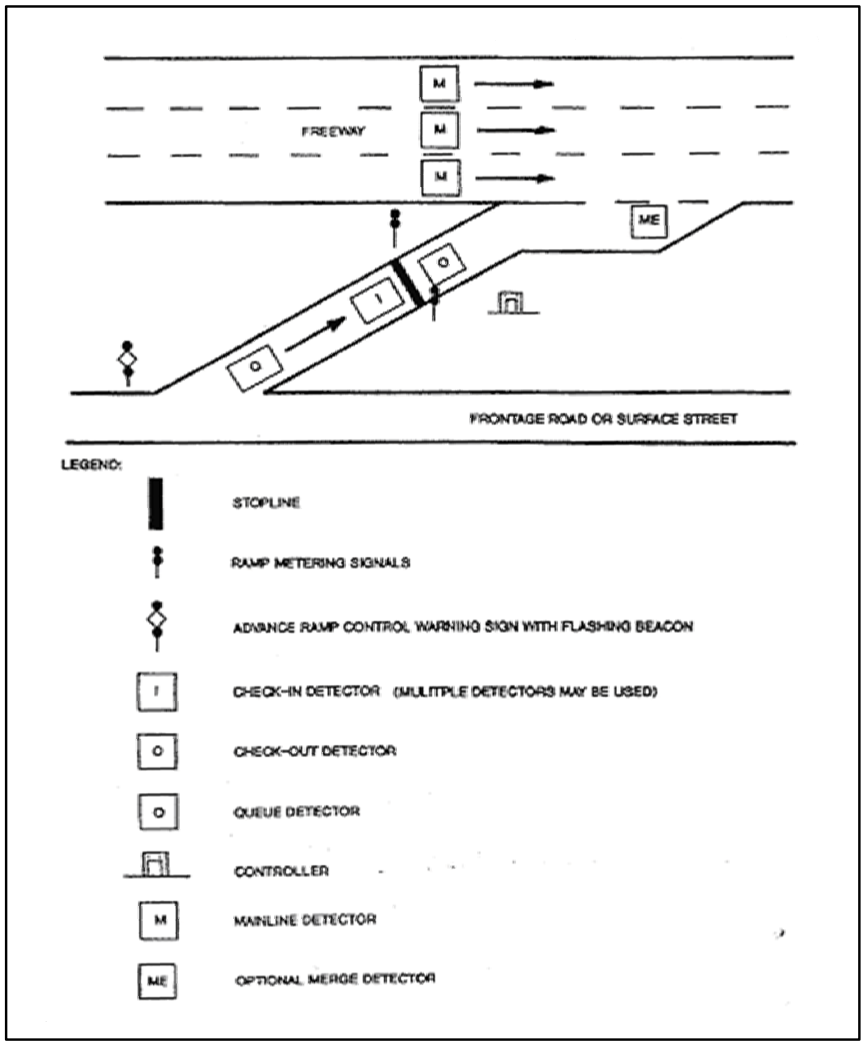


Figure 10-2: Ramp Meter Elements[1]

Location of Ramp Meter

The location of the ramp meter, and therefore the stop line, needs to be located to achieve a balance between queue storage space and acceleration distance to the freeway. In other words, locate the ramp meter so that it maximizes the available storage but also allows sufficient acceleration distance for a vehicle to safely merge onto the freeway from a stopped condition at the ramp meter. Queue storage requirements can be calculated using a range of simple to complex traffic analysis tools (refer to Chapter 9 for more information). Queue lengths can also be roughly estimated by subtracting the metering rate from the ramp volume over a specific time period. Acceleration distance can be calculated using AASHTO standards.

Number of Lanes

The number of needed ramp lanes should be based on the ramp volume, required queue storage, meter release rate (either one or two vehicles allowed per green), and available ramp width. Available ramp width may be based on the existing ramp pavement or the pavement width feasible based on geometrics and topography. Shoulders may also be utilized when ramp meters are operating, to increase the number of effective lanes and thereby increase the queue storage capacity. The estimated queue and available storage distance to the upstream intersection will have an influence on the number of lanes needed.

In general, the maximum discharge rate of a single metered lane is 1000 vehicles per hour (veh/h). This is calculated using a minimum cycle time of four seconds (2.5 seconds of red plus 1.5 seconds of green). The lowest practical discharge rate is 240 veh/h, which is based on a 15-second cycle time.[64] Refer to Table 10-1 for general guidelines on the appropriate number of metered lanes and release rate based on the ramp volume.

"…the maximum discharge rate of a single metered lane is 1000 vehicles per hour."

Table 10-1: Appropriate Number of Metered Lanes and Release Rate Based on Ramp Volume*

If ramp volume is…	…then consider this number of metered lanes…	…with this release rate.[1]
<1000 veh/h	One lane	Single
900 – 1,200 veh/h	One lane	Dual
1,200 – 1,600 veh/h	Two lanes	Single
1,600 – 1,800 veh/h	Two lanes	Dual

Note. Single release rate allows one vehicle per green cycle, and dual release rate allows two vehicles per green cycle.

Single-Lane Metered Design

Single-lane ramp designs should accommodate a minimum width and distance between the stop line and freeway entrance. Caltrans recommends a single-lane metered ramp to have a 3.6-meter (11.8-foot) pavement width for the traveled way, 1.2-meter (3.9-foot) inside shoulder width, and 2.4-meter (7.9-foot) outside shoulder width.[28] The operation can allow for one vehicle per green or multiple vehicles per green depending on the desired flow rate.

Multi-Lane Metered Design

Multi-lane ramp designs can be used to increase the overall vehicle storage within the available ramp length or to accommodate demands that exceed the capacity of a single metered lane. This design requires not only adequate acceleration distance from the stop bar to the freeway entrance, but also adequate distance for the multiple lanes to merge prior to the freeway entrance.

Multi-lane metered designs can release vehicles simultaneously (alternating between the lanes), or they can operate independently of one another. With multiple lanes, it is possible for each lane to operate with a different metering rate.

Ramp Design Speed

The design speed for a ramp is based on the design speed for the freeway mainline. For example, WSDOT follows the guidelines shown in Table 10-2.

Table 10-2: Sample Ramp Design Speed[62]

Freeway Mainline Design Speed km/h (mi/h)	64.4 (40)	80.5 (50)	96.6 (60)	112.7 (70)	128.8 (80)
Ramp Design Speed km/h (mi/h)	56.4 (35)	72.5 (45)	80.5 (50)	96.6 (60)	112.7 (70)

"Many Departments of Transportation have looked back and determined that adequate queue storage space was a significant element to a successful ramp metering program"[42]

Queue Management

Required queue storage is based on the ramp volume, metering rate, release rate, and vehicle length. As an example, Mn/DOT uses a general rule of 10 percent of the pre-metered peak hour volume.[64] Thus, if the peak hour volume is 500 veh/h, storage for 50 vehicles should be sufficient. This storage requirement can then be converted from vehicles to distance by multiplying the vehicles required by the average vehicle length (this can be estimated at 25 feet or calculated through field measurements). It is desirable to contain the ramp meter queue within the limits of the ramp. However, there are times when the queue may extend beyond the available ramp storage. In these situations, there are several methods for handling the additional overflow queues:

1) Provide additional storage on surface streets. In San Diego, storage is not limited to the ramp. A portion of the surface street is used to store vehicles from the ramp queue. This requires traffic signal retiming at nearby intersections to reduce the impact of the ramp queue on non-freeway-bound traffic.

2) Adjust the metering rate to reduce the queue. This will have a negative impact on the freeway operation, but it will prevent the queues from disrupting local arterial operations. When reducing the queue, it is important not to "dump" the entire queue onto the freeway in order to relieve the backup.

There are various locations where detection can be used to assist with queue management (i.e., mid-ramp and end-ramp detection). Ramp queue detection is used to monitor the queue length and adjust the metering rate prior to the queues becoming excessive. It is beneficial to install this additional detection because it allows the agency to monitor and reduce the queues before they cause operational problems.

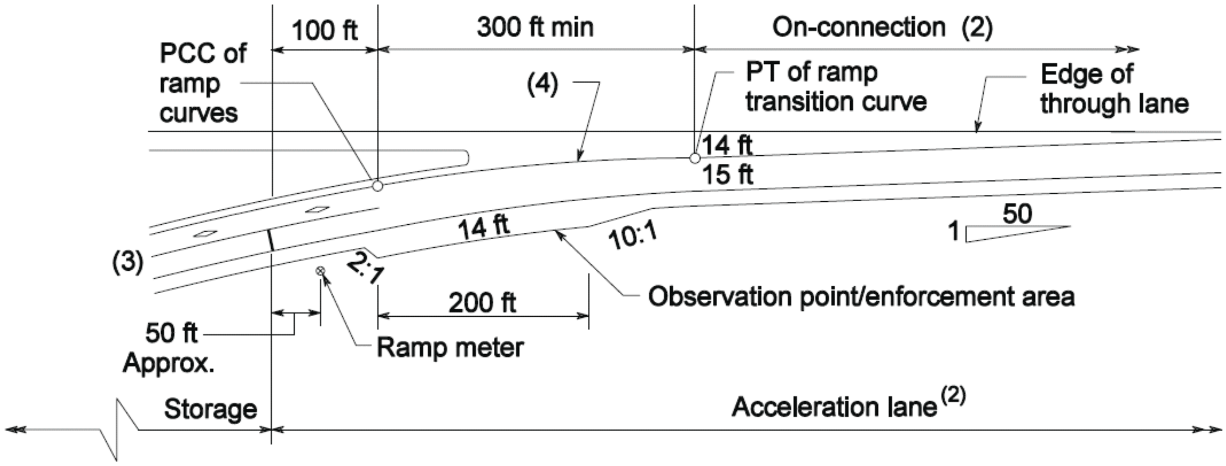
3) Allow platooning. Platooning permits two or three vehicles per green (two vehicles per green is also referred to as a *dual release rate*). Allowing two vehicles per green can increase the practical limit of a single-lane on-ramp from 900 to approximately 1,200 veh/h (see Table 10-1).

4) Provide driver information. Some traffic will naturally divert because of ramp metering and seek routes without queues or meters. There are some ways to inform drivers of the delays so that they can make an informed choice. Where queuing is more severe, an active management approach can be taken to address the queuing with signs upstream of the ramp that inform motorists of the traffic delay. For example, a Dynamic Message Sign (DMS), with the specific delay time or a simple blank-out sign, could be activated when the queues are unacceptable.

HOV Bypass Lanes

HOV bypass lanes are a special-use ramp treatment, as previously discussed in Section 5.5. Adding an HOV bypass lane not only encourages HOV use, but also proportionately reduces the ramp meter queues (HOVs typically make up anywhere from 10 to 25 percent of the traffic volume[64]). This separate lane is typically designed to allow HOVs to bypass the general purpose lane(s) and the ramp meter. Figure 10-3 shows a two-lane metered ramp with an HOV bypass lane. The bypass lane can be used for transit vehicles only or all HOVs. This design element should only be considered if there are policies in place to support HOV and is part of a broader HOV plan.

If dual left-turn lanes from an arterial feed an on-ramp with a single metered lane and an HOV lane, the agency must consider the most appropriate lane allocation for the left-turn lanes. If there are a considerable number of HOVs in the left-turning traffic stream, the left-turn lane directly feeding into the HOV lane could be designated for HOVs only during times when the ramp is metered. This lane assignment would provide easier access to the HOV bypass lane and reduce weaving on the ramp. If the ramp has sufficient length and the left turns have a lower HOV volume, another option would be to keep both arterial dual left-turn lanes open to all vehicles and provide for sufficient merging to the HOV lane on the ramp itself.



Notes:

(1) See Standard Plans for striping details.

(2) See Chapter 940 for on-connection details and for acceleration lane length.

(3) See Chapters 940 & 641 for ramp lane and shoulder widths for a 2-lane ramp.

(4) A transition curve with a minimum radius of 3,000 ft is desirable. The minimum length is 300 ft. When the main line is on a curve to the left, the transition may vary from a 3,000 ft radius to tangent to the main line.

Figure 10-3: Example HOV Bypass Lane[63]

Consideration should also be given to right-turn movements from the arterials to the ramp, especially in deciding which of the two ramp lanes should be designated as the HOV lane. If there is a large volume of right-turning traffic with significant HOV volumes, the agency should select the configuration that will minimize HOV delay and weaving in general. If the right lane from the arterial is a drop lane to the ramp, then the HOV lane should be located on the right side to prevent the high volumes of HOVs from weaving. On the other hand, if there are minimal HOV volumes, then the rightmost through lane could be designated as a through lane and right-turn lane for HOVs only. In this case, the left lane on the ramp should be designated as the HOV lane.

For more information on HOV and other special-use treatments, see Section 10.6.

Enforcement Areas

As discussed in Section 10.3, enforcement should be coordinated with the local and state enforcement agencies during the planning and design phase. Design features such as the number of enforcement areas and their locations and dimensions should be discussed and agreed upon. Enforcement areas may be on the ramp itself or in a nearby area with line-of-sight to the ramp meter. Figure 10-3 shows the general location of an enforcement area on a ramp.

On single-lane ramps, a paved enforcement area is not necessary, but the area should be graded to facilitate future ramp widening. The enforcement area should be located on the right side for queue bypasses and downstream from the stop bar so that the officer can be an effective deterrent. The overall length of the enforcement area may be adjusted to fit the specific conditions on the ramp.[28]

Freeway-to-Freeway Metering

Freeway-to-freeway metering consists of metering a ramp that connects one freeway to another. It is critical in this high-speed environment that adequate sight distance and sufficient advance warning be provided to motorists, as they will likely not be expecting to stop. Figure 10-4 shows an example of freeway-to-freeway metering in Portland, Oregon.

Figure 10-4: Example of Freeway-to-Freeway Metering

Another example of this application is in San Diego, California, where its first use was in 1971. Since then, three more installations have been constructed. One application was implemented in 1978 to relieve congestion and queuing through the interchange. The meter uses an automated, traffic-responsive algorithm that turns the meter "on" during periods of heavy congestion, which is typically only during the peak periods. All three lanes on the ramp are metered (two general-purpose lanes plus an HOV lane). At start-up, the ramp carried 1,900 veh/h during the peak hour with a maximum delay of about three minutes. Currently, the ramp accommodates 2,900 veh/h with a maximum delay of approximately 10 minutes.[65] Despite the relatively high ramp delay, there have been very few complaints. Caltrans believes that this is due to the high level of service provided on the freeway and, in particular, the high speeds that are maintained beyond the meters. Travel time savings are estimated to be up to 20 minutes for certain home-to-work commute trips.[65]

Some suggested policies for the use of freeway-to-freeway ramp metering, as outlined by WSDOT, include:[65]

- Implement at locations where recurring congestion is a problem or where route diversion (to suitable alternative routes) should be encouraged. For example, install meters on freeway-to-freeway ramps where more than one ramp merges together before feeding onto the mainline, and where congestion on the ramps occurs regularly (i.e., four or more times a week).
- Install to improve the freeway mainline flow and on-ramp merge or to help multiple ramps merge into one ramp. Verify with analysis prior to installation.
- Avoid metering vehicles twice within a short distance (i.e., three miles).
- Avoid metering single-lane, freeway-to-freeway ramps that feed traffic into an add-lane, because this underutilizes the 2,000 veh/h capacity of the add-lane by metering at the typical rate of 900 veh/h.
- Monitor and control all freeway-to-freeway ramp meters from a central location, such as a Traffic Management Center (TMC).
- Install meters at locations on roadways that are level or have a slight downgrade so heavy vehicles can easily accelerate. Also, install meters where the sight distance is adequate for drivers approaching the meter to see the queue in time to safely stop.

10.4.2 Equipment

Ramp Metering Equipment Includes:

- Ramp Controller
- Signals
- Detectors

Ramp meter hardware consists of a ramp controller, signal heads, signal pole(s), and detection devices.

Ramp Controller

The controller assembly consists of a cabinet, controller, load switches, input files, loop amplifiers, and other devices similar to a traffic signal at an intersection. The ramp controller typically acts as a data station as well as a signal controller. The most common ramp controllers are type 170s or type 2070s. The 170s are microprocessor-based devices that control the ramp meter signals using information from the loop detectors. The 2070s provide similar functions to the type 170s and are more powerful VME-based (Versa Module Eurocard) controllers with 16-bit microprocessors that provide additional functionality to the older 170s. Figure 10-5 shows the back-top view of a 2070V unit with an additional 7a card installed and the top cover of chassis removed.

Other necessary features include the ability to provide accessible power source and communication with the TMC. Communication can be provided via telephone lines, fiberoptics, microwave, or radio frequencies (RF).

The controller cabinet must be placed where it is easy to access for maintenance, allows a technician to see the signal heads, does not block a vehicle's sight distance, and is protected from errant vehicles.

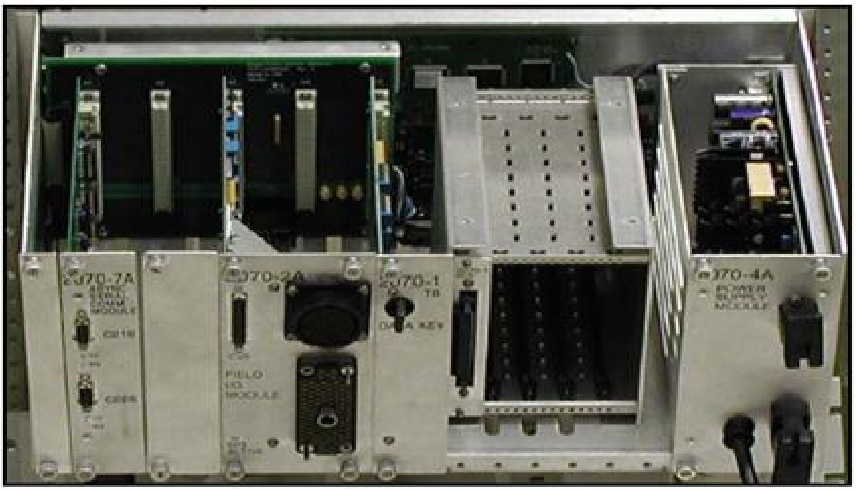


Figure 10-5: Type 2070V Controller[66]

Signals

For single-lane ramps, a Type I signal pole (vertical pole only) with two signal heads should be located on the left side of the ramp, adjacent to the stop line. For two-lane ramps, a Type I signal pole can be located on each side of the ramp or a mast arm-style signal pole with overhead signal heads can be used. For three-lane ramp meters, a mast arm signal pole should be used. All signal poles should be located in a clear zone to reduce the potential for "knock-down."

The FHWA's *Manual on Uniform Traffic Control* Devices (MUTCD) provides standards for placement and location of all traffic signal devices.[41] Practitioners should refer to Sections 4D and 4H of the latest edition for updated guidelines. An FHWA official interpretation of this section of the manual dated September 30, 2005 recommends that for multi-lane metering where staggered or independent release is used, two signal heads per lane should be used.[67]

Mast Arm Signal Pole Requirements:

- The distance from the stop line to the signal faces shall not be less than 12 meters (40 feet) or more than 55 meters (180 feet), unless a supplemental near-side signal face is provided.
- The height of the signal housing over the roadway shall not exceed 7.8 meters (25.6 feet).

Signal Head Placement:

- Mast arm signal poles: one signal head shall be located over each metered lane (unless it is a multi-lane staggered or independent release).
- Signal heads are not needed for unmetered lanes, such as an HOV bypass lane.

Figure 10-6 shows a typical signal standard used by Caltrans.

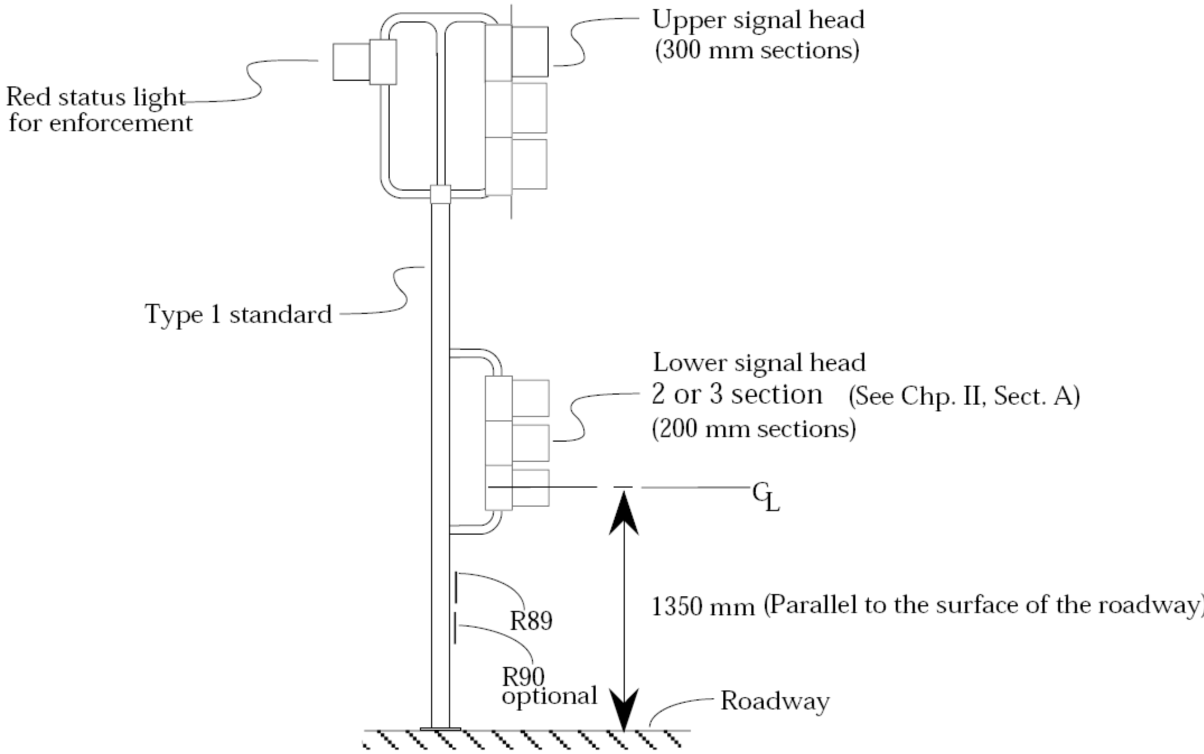


Figure 10-6: Typical Signal Standard (NTS)[28]

Signal Heads:

- Either two-section heads (red and green) or three-section heads (red, yellow, and green). The practitioner should check with state laws and regulations to see if the two-section head is permitted.
- A minimum of two signal heads are required, regardless of the number of lanes.
- Signal faces need not be illuminated when not in use.

The yellow phase is the transition between green and red (and at signal start-up). For operational efficiency, it works best to cycle from red to green during the operational cycle, with no yellow phase. However, practitioners should verify that a yellow phase is not required by local or state law. A yellow phase should be used at start-up to alert motorists that the ramp meter will be activated and begin to meter traffic.

Figure 10-7 shows an example of where the signal heads should be mounted for a three-lane ramp where the HOV lane is metered. If the HOV is not metered, then only two signal heads should be used.

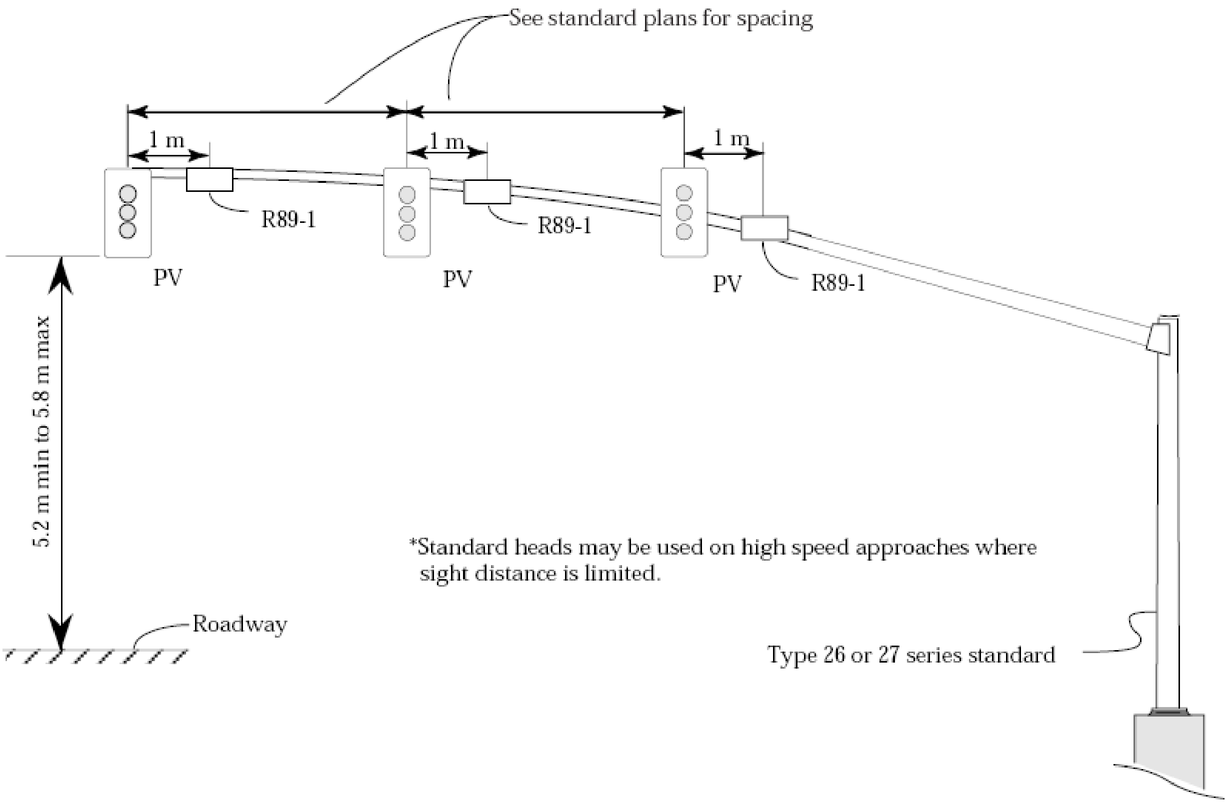


Figure 10-7: Signals Mounted on a Mast Arm (NTS) (simultaneous release only)[28]

Detectors

Several detectors are required to operate ramp signals. Detection has traditionally been implemented in the form of induction loops. However, other detection devices could be used if more suitable to the agency and the environment. For example, Atlanta installed video detection (VIDS) on freeway mainlines to avoid closures and hazards related to installing loops on an operating freeway.

The detector locations are related to the detector functions. The functions include: demand, passage, ramp queue, mainline, exit ramp, and entrance ramp without metering.[64] If no state standards are available, then the detector placement must be reviewed by the operations staff. Figure 10-8 through Figure 10-12 show typical ramp metering detector loop layouts used by Caltrans.

Demand Detectors

Demand detectors are installed in each metered ramp lane, just in advance of the stop bar. The demand detection zone provides coverage in the area just upstream of the stop bar, and operates as a typical traffic signal stop-bar detection zone. Demand detectors sense the vehicle's presence at the stop bar and initiate the green traffic signal display for that specific lane. Figure 10-8 shows a typical layout for passage and demand detectors on a single-lane ramp while Figure 10-9 shows a typical layout for a two-lane ramp.

Types of Detectors:

- Demand
- Passage
- Ramp queue
- Mainline
- Exit
- Entrance

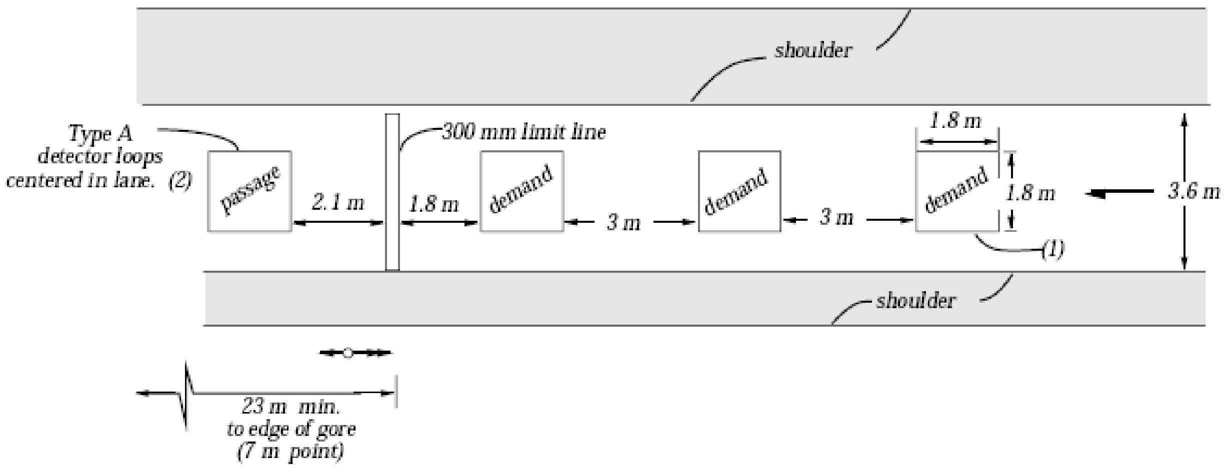


Figure 10-8: Typical Passage and Demand Detector Layout (One Lane Ramp)[28]

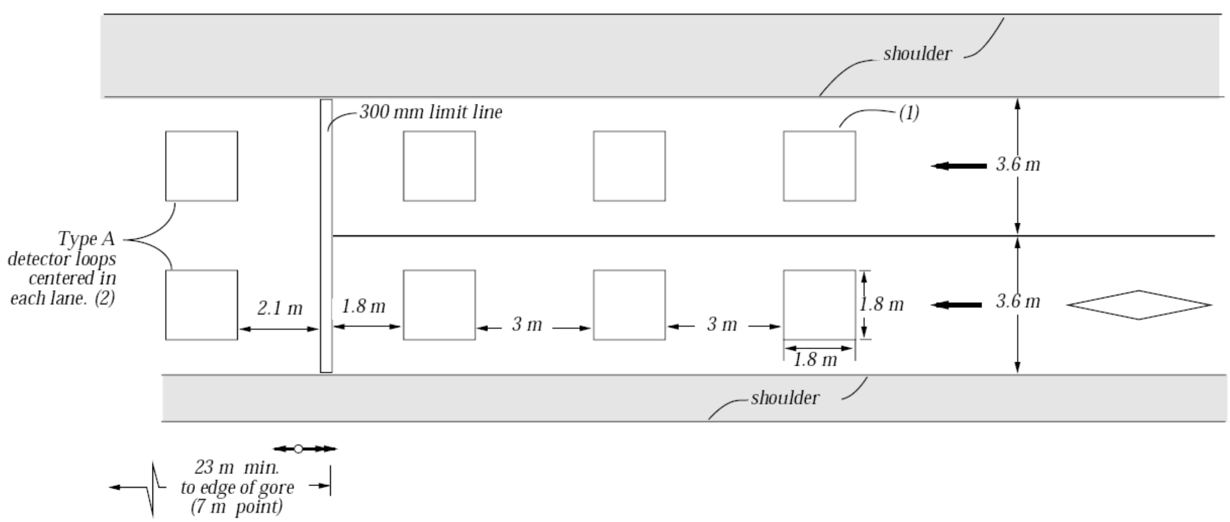


Figure 10-9: Typical Passage and Demand Detector Layout (Two Lane Ramp)[28]

Passage Detectors

Passage detectors are installed immediately downstream of the stop bar. The passage detection zone provides coverage downstream of the stop bar in each metered lane. Passage loops are used to count the number of vehicles that enter the freeway. This information can be used to determine the duration of the green signal display. Figure 10-10 shows a typical layout of passage and demand detectors for a three-lane configuration with a non-metered HOV lane.

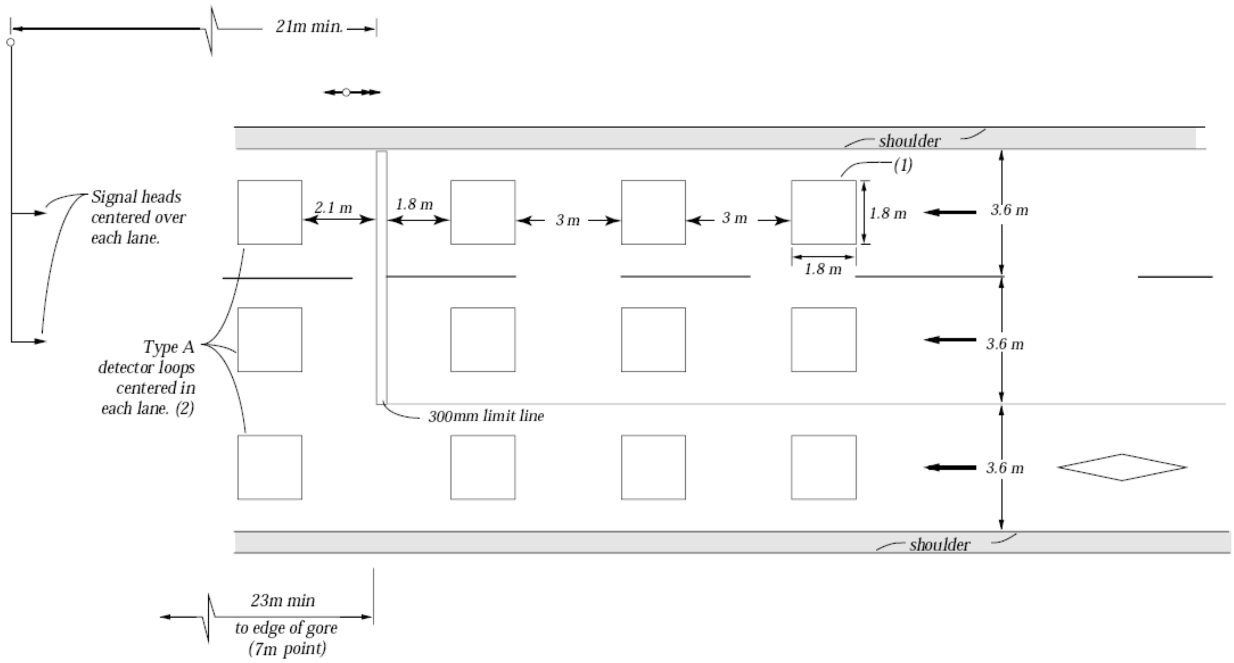


Figure 10-10: Typical Passage and Demand Detector Loop Layout (Three Lane Ramp with a non-metered HOV lane)[28]

Ramp Queue Detectors

Ramp queue detectors are installed near the intersection of the ramp with the adjacent surface street. Intermediate queue detectors may be added to the ramp as well. These intermediate detectors help identify when the queues are beginning to fill the ramp capacity. Ramp queue detectors monitor excessive queues that cannot be contained within the queue storage area, and they provide input to maximize the metering discharge rate to clear excessive queues. This helps prevent queues from spilling onto the local streets and disrupting arterial operations.

Mainline Detectors

Several mainline detection zones are required for ramp meter operations. In isolated operations, the mainline detection zone is located upstream of the entrance ramp gore point (see Figure 10-2). Mainline detectors provide freeway occupancy, speed and/or volume information that is used to select the local, traffic-responsive metering rate. These detectors can also provide data for centralized ramp metering and incident detection algorithms. Figure 10-11 shows a typical layout for mainline detectors as used by Caltrans.

Exit Ramp Detectors

Exit ramp (or off-ramp) detector loops may be installed for traffic count information. For many system-wide, traffic-responsive meter algorithms, exit ramp detection is either highly desirable or required. Figure 10-12 shows a typical layout for exit ramp detectors as used by Caltrans.

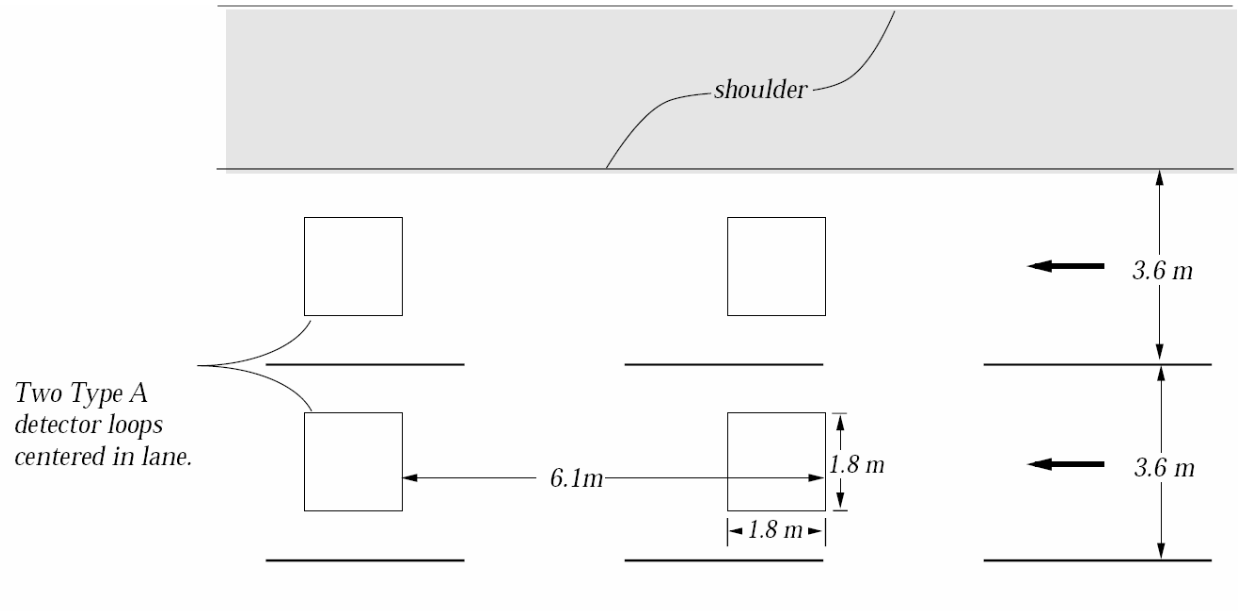


Figure 10-11: Typical Mainline Detector Loop Layout[28]

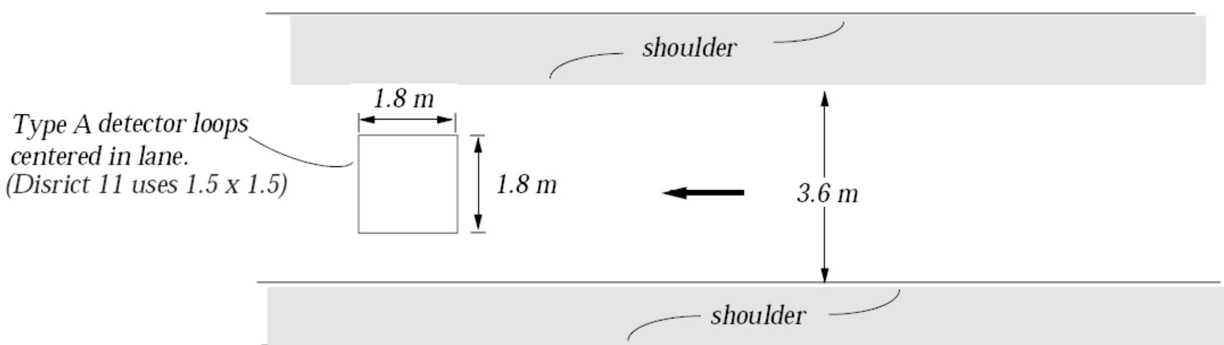


Figure 10-12: Typical Queue/Exit/Count Loop[28]

Entrance Ramp Detectors for Ramps without Meters

For system-wide, traffic-responsive ramp meters, detection is important on entrance ramps that are not metered. Accurate corridor count data ensures that the proper metering rates are implemented at the metered ramps. Data from these detectors can also be used for a variety of other applications, including performance monitoring and planning.

10.4.3 Signing and Pavement Markings

The potential for motorist confusion increases as the metering layout becomes more complex (i.e., more lanes, bypass lanes, signal heads, etc.). In addition, not all motorists are familiar with ramp metering operations. Thus, the signing and pavement markings for ramp metering must be as clear as possible.

Standard Ramp Metering Signs

As mentioned in Section 5.3.7, a variety of signs are used for ramp metering. Table 10-3 provides a description of where each sign is typically located and its specific application.

Table 10-3: Ramp Meter Signing Locations and Applications

Sign	Location	Application
	Placed on the arterial approximately 61 meters (200 feet) upstream of the ramp entrance point. The sign should generally be placed on the right side of the arterial.	This warning sign is accompanied by a yellow flashing beacon that is activated during metered periods to alert motorists of the upcoming controlled ramp.
	Positioned near the beginning of the dual-lane queue storage reservoir on the right side of the on-ramp (or positioned on both sides of the ramp).	This regulatory sign is used to convert the single lane on-ramp into a dual-lane queue storage reservoir during ramp meter operations.
	Placed on both sides of the on-ramp at the signal stop bar. This sign is placed on the signal pole under the post-mounted configuration.	This regulatory sign identifies the signal stop bar location and is used to align drivers over the demand detectors placed upstream of the stop bar.

Sign	Location	Application
	Can be optionally placed either on the signal pole or with the “Stop Here on Red” regulatory sign under a mast arm configuration. There are also signs that state “Two vehicles per green” for dual release.	This regulatory sign is used to inform motorists of the intended traffic control method under ramp metering operations.
	Can be placed on the signal pole.	This regulatory sign is used when converting a non-metered HOV by-pass lane to a metered operation. Also may be used on new installations where potential for confusion exists.
	Placed upstream of the ramp meter and 120 to 180 meters downstream of the “Meter On” sign.	This advance warning sign informs the motorist that the ramp meter is turned on.
	Placed upstream of the ramp meter.	This warning sign is used to inform motorists that a traffic signal is ahead and to be prepared for the potential to stop.
	Placed approximately 30.5 meters (100 feet) downstream of the stop bar on the right side of the ramp when there are two ramp lanes that merge prior to entering the freeway.	This warning sign is used to inform motorists of the need to merge with another ramp lane prior to entering the freeway mainline.

Freeway-to-Freeway Metering Signs

Warning motorists of the metered operation is important because motorists do not expect to stop on ramps. This is especially true for freeway-to-freeway metering applications. Advance warning signs are recommended in advance of all metered ramps. There are different types of warning signs that can be used. These signs may be internally illuminated or accompanied by flashing beacons to draw attention.

"Advance warning signs are recommended in advance of all metered ramps"

Figure 10-13 shows an example of an extinguishable message sign for a freeway-to-freeway ramp metering application. High visibility is a crucial requirement for these signs because motorists do not expect to stop on the freeway. The "Meter On" sign should be installed downstream from the point of the exit gore area. Caltrans recommends installing these signs at least 30 meters (98.4 feet) downstream of the point at which the exit gore is 7 meters (23 feet) wide. The "Prepare to Stop" sign should be installed downstream of the "Meter On" sign. Caltrans recommends installing these signs at least 120 to 180 meters (393.7 to 590.6 feet) downstream of the "Meter On" sign and at least 300 meters (984.3 feet) upstream of the stop line. See Figure 10-14 for a typical layout.

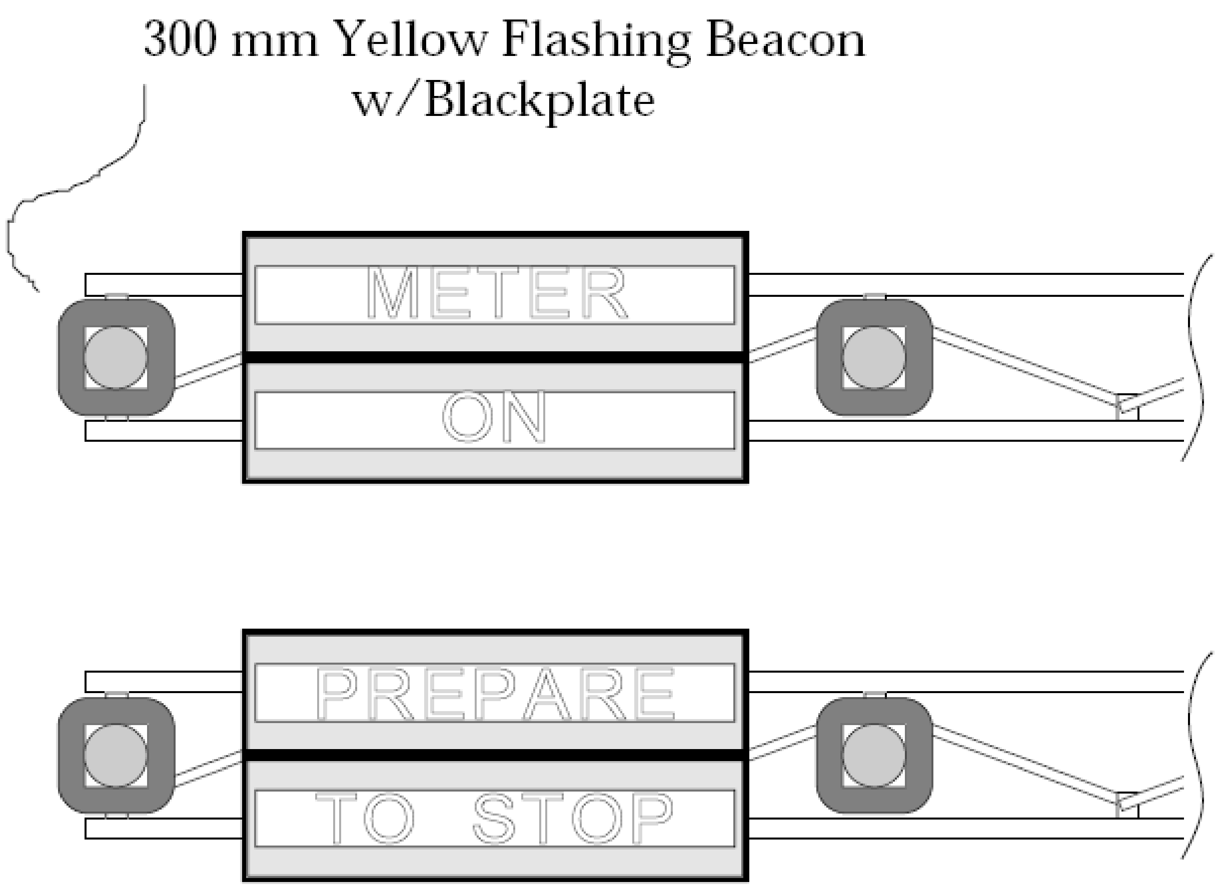


Figure 10-13: Extinguishable Message Signs[28]

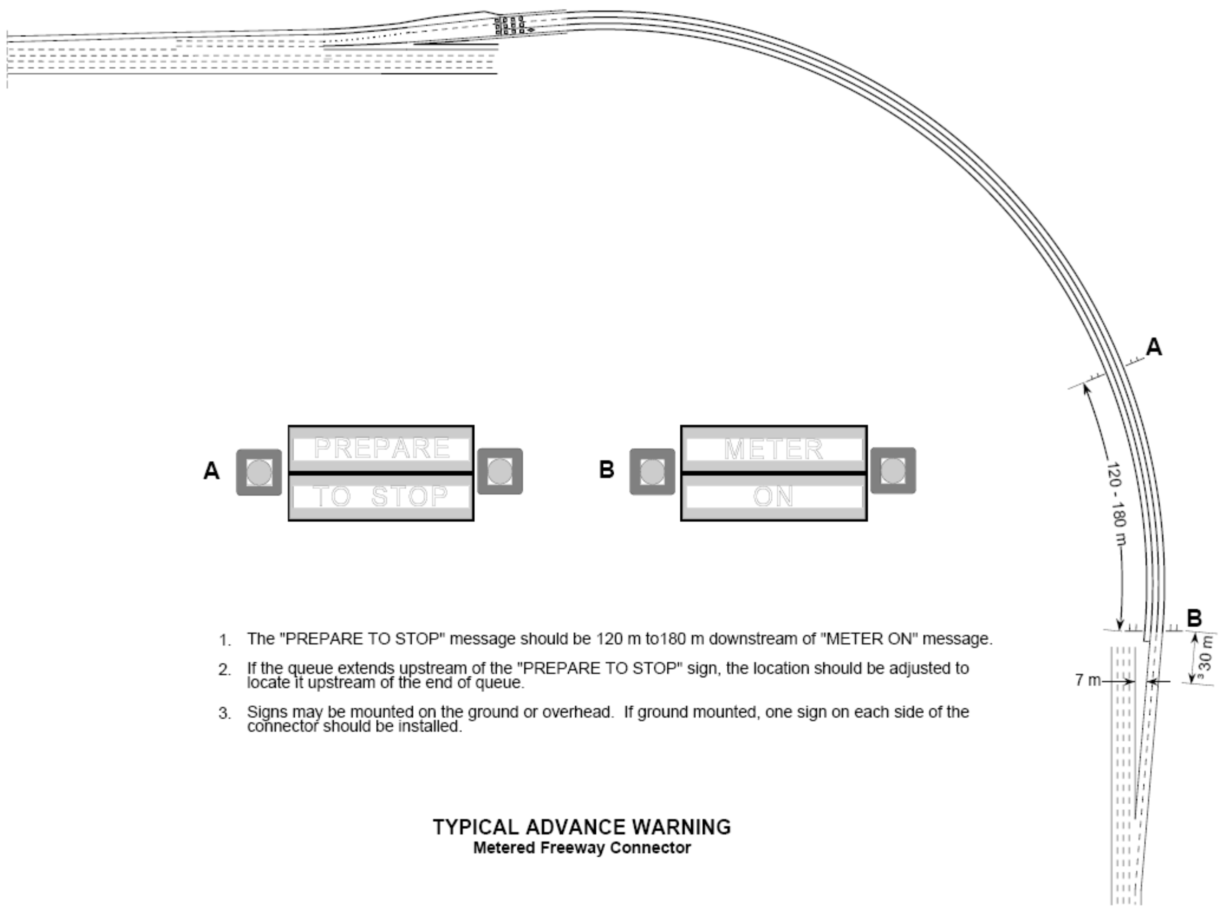


Figure 10-14: Typical Advance Warning Signing Layout[28]

Pavement Markings

Pavement markings usually consist of either paint, plastic, or raised pavement markers. Stop lines should be placed at a location that balances the acceleration and taper length needed downstream of the meter with the queue storage needed upstream of the meter. It is not advised to provide staggered stop lines. Lane lines are needed to separate the metered lanes. There also may be HOV lane markings, which are discussed in the following subsection. When use of the shoulder is permitted during ramp metering, the shoulder should be marked with a stop bar. All the pavement markings should conform to the guidelines set in Chapter 3B (*Pavement and Curb Markings*) of FHWA's *Manual on Uniform Traffic Control Devices* (MUTCD).

HOV Markings and Signing

HOV lane signing and striping should be used for metered HOV lanes and HOV bypass lanes to clearly designate the preferential lane usage. The standard HOV lane pavement marking is the elongated diamond symbol shown in Figure 10-15. Solid white lines (separating the HOV lane from the general-purpose lanes) and dashed extension lines are applied to prevent turning vehicles from entering the HOV lane.

HOV designation signs are required to establish the definition of HOV along the facility (e.g., two- or three-person carpools, transit only, etc.). Signing that provides HOV information signs may also be installed. Figure 10-16 shows a sample HOV sign. Depending on the agency, the pavement legend "HOV LANE" may be painted between the diamond symbols to supplement the standard HOV marking. Figure 10-17 shows another sample of an HOV sign that can be used to designate the preferential treatment. If the designation "when metered" is added to the sign, this allows SOVs to use the lane during non-metering periods.

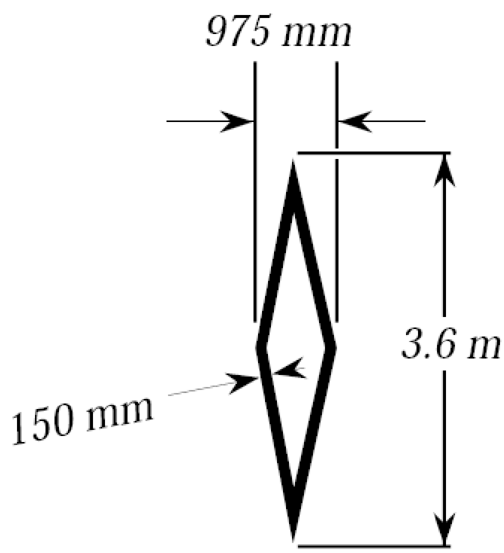


Figure 10-15: HOV Symbol (NTS)[28]

Figure 10-16: Sample HOV Sign[41]

Figure 10-17: Metered HOV Lane Sign

10.5 Design Considerations for Ramp Closures

There are several design considerations to address when providing for ramp closures. Equipment, as well as signing and pavement markings, is required for ramp closures. As discussed in Chapter 5, there are three general types or classifications of ramp closures: permanent, temporary, and time-of-day. This section discusses the design considerations for each of these types of closures, provides some sample ramp closure layouts, and explains the various types of devices that can be used for ramp closures.

10.5.1 Preliminary Design Considerations

The decision to close a ramp permanently can be a very lengthy process. The many requirements include a detailed traffic analysis to show impacts associated with the closure; an extensive public outreach process to make sure that citizens are informed of the potential change and have an opportunity to provide input; and perhaps a temporary closure to observe and experience the actual impacts before a final decision is made. For example, in Seattle, Washington, for the I-5 Tukwila to Lucile HOV Lanes Project, the I-5 southbound Corgiat on-ramp was permanently closed. Extensive traffic analysis was required, and an open house was held to present the findings to the public and obtain their comments and concerns. The WSDOT Project Manager met with several community groups in the area and conducted a trial closure to evaluate the impacts. Since the impacts were not significant, the decision was made to permanently close the on-ramp.[68]

Temporary closures may be implemented due to construction activities, special events or weather-related events. Mitigation needed for a temporary closure is usually not as extensive as for a permanent closure, but the public outreach effort may be just as extensive. Although the disruption may only be temporary, it still has the potential to have severe impacts for users of the ramp. Ramp closures that occur only at times of low traffic demand like night-time hours will have less impact on travelers and may have less severe impacts overall, so the outreach effort will not need to be as extensive as for closures that affect peak traffic hours.

Construction impacts in work zones are also a design consideration for temporary closures. An example of a temporary ramp closure is the 6th Street ramp of I-64 in St. Louis, Missouri, which was closed for a two-year period.[69] This closure was brought about from a request to reconfigure 8th Street to accommodate a proposed stadium in the Central Business District (CBD). The Missouri DOT enlisted a consultant to perform numerous traffic studies, an access justification report for FHWA, and to coordinate with the St. Louis Cardinals baseball team.[70]

In addition to advance information for motorists who intend to use the ramp, information on the alternative route needs to be provided. Alternative route information may be posted on Changeable Message Signs (CMSs) on arterial streets near the ramp entrances. An example of a special event temporary closure is the Tacoma Dome in Washington State, which has required ramp closures in the past. During any major Dome event, Exit 133 (the exit nearest the Dome) used to back up onto the freeway. Since these queues were quite extensive and the ramp lacked the capacity to store the vehicles, this exit was closed using barricades and DMS to warn motorists. Information was also sent to the Dome patrons along with their tickets as a reminder of the freeway ramp closure. Closing the ramp during major special events was successful in eliminating queuing back to the mainline.

The Minnesota Department of Transportation (Mn/DOT) has been using gates since 1996 to prohibit freeway access during unsafe driving conditions such as severe snowstorms and major incidents. Gates on the mainline direct traffic off the Interstate and gates at entrance ramps prohibit access. Additional information about Mn/DOT's program can be found in the *Documentation and Assessment of Mn/DOT Gate Operations Report* (October 1999).[71]

Like temporary closures, time-of-day closures also have the same design considerations with respect to traffic analysis, public outreach and trial closures, except that these types of closures are typically focused on the morning or afternoon peak periods. These types of closures can be used to help to facilitate mainline flow or reduce the occurrence of accidents. As an example, in Milwaukee, Wisconsin, I-43 southbound at State Street is closed daily from 2 to 6 PM. The reason for this recurring peak period closure was the high crash rates on the freeway at this location. The peak period closure was successful at improving safety in the area. The Wisconsin Department of Transportation (WisDOT) conducted a detailed accident analysis at this location because it has an extremely high crash rate (in the range of ten times higher than all other locations in southeastern Wisconsin). The analysis indicated that approximately 80 to 90 percent of the crashes were occurring during the afternoon peak period. The daily peak period closure began in the late 1980s/early 1990s. The ramp was equipped with a gate that automatically closed during the times of closure and opened immediately after. It should also be noted that this gate required extensive maintenance. The gate was often broken (by traffic determined to use the ramp anyway) and would again be broken within weeks of repair. This ramp will be closed permanently with the reconstruction of the Marquette Interchange.[72]

10.5.2 Ramp Closure Layout

There are various ways to provide a ramp closure, and the design or configuration depends on the type of closure and other factors. Figure 10-18 shows an example of how the Hawaii DOT used traffic cones to temporarily close the Lunalilo Street on-ramp and the Vineyard Boulevard off-ramp along the westbound H-1 freeway. More detailed information about this closure can be found in Chapter 11.

When construction occurs on or adjacent to a ramp, the construction may include single lane closures. Figure 10-19 shows a sample layout of a single ramp lane closure according to MUTCD standards.

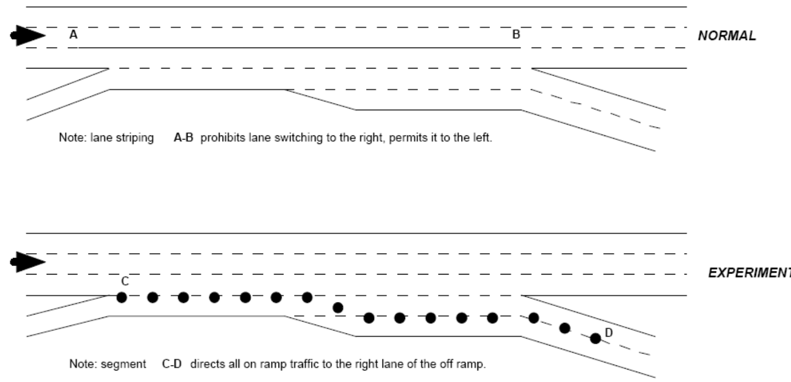


Figure 10-18: Lunalilo Ramp Closure Experiment Layout[73]

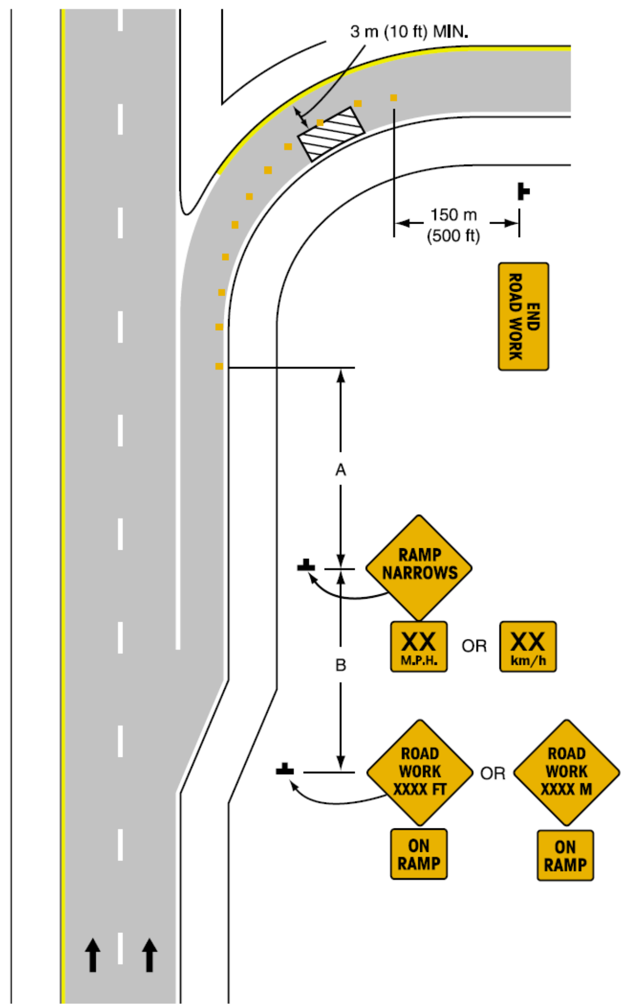


Figure 10-19: Partial Exit Ramp Closure[41]

10.5.3 Ramp Closure Equipment

There are a variety of design considerations in selecting the type of closure device, based on its application. A full ramp closure can be accomplished by using any of several types of barricades or barriers or completely removing the ramp. Some types of devices offer a more permanent type of closure, while others have the flexibility to allow the ramp to be opened at a later date or at other times. Each type of device varies with the level of maintenance required. And, of course, the installation process varies by device as well.

Barricades

Figure 10-20 and Figure 10-21 show barricades used by the Wisconsin DOT for ramp closure. The particular gate type used is dependent upon the part of the freeway where it is to be installed. As an example, Type III barricades are used at locations where closures are infrequent. They can be difficult and labor-intensive to use. Because of their design, an open, flat space is required for storing the posts. However, they are a low-cost installation with high visibility to motorists.

Semi-Permanent Barriers

A variety of types of semi-permanent barriers can be used for full ramp closures on a temporary basis, as done for special events or construction purposes. Examples of semi-permanent barriers include water-filled barrels or flexible pylons. Movable barriers are also an option and include barrels or wooden barricades.

The Long Island Expressway in New York utilizes mainline/ramp closures for construction at night. They have installed "drag net" devices (chain link fence with run-out cables) at the on-ramps to keep traffic off of the freeway mainline.[74]

Gates

Semi-permanent barriers can also be used for ramp closure. In some cases, automatic ramp gates can be used to close the ramp and prevent access to the facility. These gates can be controlled manually by staff or remotely from a Traffic Management Center (TMC) using 170 controllers (as done by WSDOT) or 2070 controllers (as done by Caltrans). This works well for peak-period ramp closures, special events or closures due to poor visibility (e.g., fog). As mentioned previously, automatic gates can require extensive maintenance depending on the motorists' behavior. Gates that are frequently broken must be repaired in a timely manner.

As an example of a weather-dependent closure, the Tennessee DOT installed an automated gate system at ramp entrances to I-75 in conjunction with a fog warning system in 1992.[75] When the visibility decreases, the variable speed limit on the DMS is adjusted accordingly. If the visibility drops below a certain level (i.e., less than 73.2 meters (240 feet)), the on-ramps are closed on a 30.6-kilometer (19-mile) stretch of fog-prone freeway. The freeway has been closed due to fog, but also due to smoke from a nearby fire.[76]

Figure 10-22 is a sample gate closure detail that the Colorado Department of Transportation uses at ramp locations.

Figure 10-20: Type III Barricade (Stored Position)[77]

Figure 10-21: Type III Barricade (Deployed)[77]

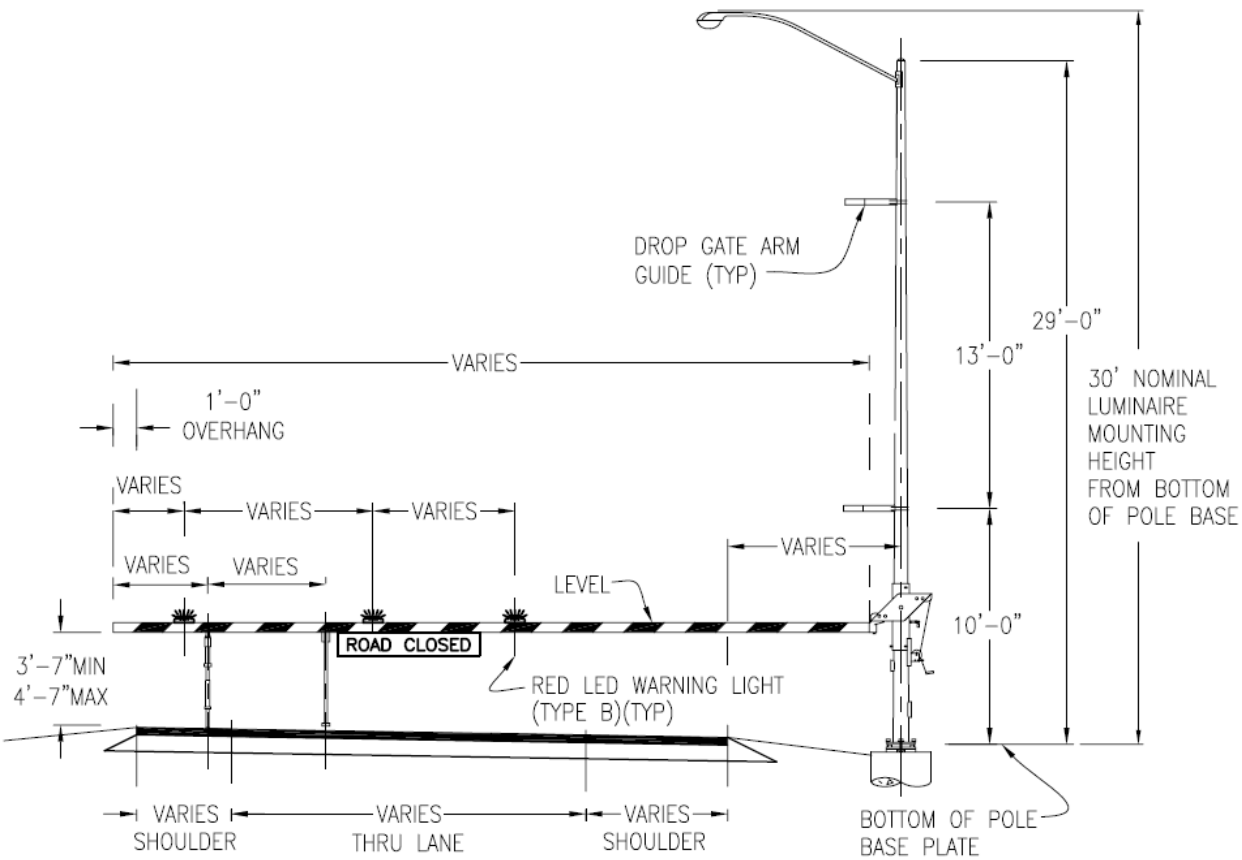


Figure 10-22: Sample Gate Closure Detail[78]

Figure 10-23 shows a traffic gate that the Wisconsin Department of Transportation uses for their ramp closures. The horizontal swing arms are used where closures are anticipated to be more frequent. Like the Type III barricade, they have high visibility to motorists but they require significant clear space to swing, are expensive to install, and need to have two large areas free of underground utilities for the footings. Vertical swing arms are easy to use and also have high visibility to motorists. However, they are difficult and expensive to install and are aesthetically unpleasant.

Figure 10-23: Vertical Swing Arm Traffic Gate (Closed Position)[78]

Ramp Removal

Full removal is a more labor-intensive method and would require the demolition of the ramp and rehabilitation of the right-of-way with landscaping. This can be quite expensive, but allows for some redevelopment near the interchange. An example of this type of permanent ramp closure occurred in 2003 on the SR-91 Freeway in Orange County, California. Caltrans closed an underutilized interchange at Coal Canyon Road (in the Santa Ana Canyon). The interchange ramps have been removed and the right-of-way rehabilitated in order to provide a wildlife under crossing between the Cleveland National Forest to the south and the Santa Ana River to the north. Fences have been erected along either side of the freeway to guide the wildlife.[79]

10.5.4 Signing and Pavement Markings

Advance warning must be given to motorists to alert them of an upcoming ramp closure. This can take place in the form of electronic and print media, postings on the agency's website, as well as signs and flags along the facility.

Signing and pavement markings may also be required at the ramp terminus. For example, if a left-turn lane on an arterial feeds into an on-ramp that is going to be closed, then the left-turn lane should also be closed to prevent access onto the ramp and the facility. The use of signs such as "Left Lane Closed Ahead" and pavement markings can be used to close such lanes. Figure 10-21 shows some examples of signing on the barrier devices at the ramp itself. With regard to pavement markings, for permanent or long-term closures continuing the yellow center line to close off the turn pocket or potentially hatching it may help to avoid confusion for the motorist.

10.6 Design Considerations for Special-Use Ramps

This section discusses design considerations for the various types of special-use ramps that were described in Chapter 6 - HOV/transit ramps and bypass lanes, construction ramps, emergency vehicle access ramps, and freight-only ramps. The following subsections provide additional detail on the types of equipment, signing and pavement markings that are required to implement these alternatives.

10.6.1 Special-Use Ramp Layout

One of the most common special-use ramp treatments is the HOV bypass lane, used in conjunction with ramp metering. This special-use treatment is described in detail in Section 10.4 and a typical layout is shown in Figure 10-2. Other special-use treatments that include a dedicated lane on a ramp should use a similar layout with appropriate signing and pavement marking to clearly indicate what types of vehicles are allowed to use the lane.

Another common special-use ramp treatment is an entire ramp dedicated to a specific type or class of vehicle. Common vehicle types that may have dedicated ramps include transit, HOV, emergency vehicles, or trucks (freight). Generally speaking, these ramps must meet all the standards of a general-purpose ramp. They should be designed to meet the acceleration and other characteristics of the vehicles they are intended to serve.

Freight-only ramps also conform to the concept discussed above. The ramp should be designed according to standard ramp design practices, with a truck as the design vehicle. An important design consideration for freight-only ramps is the distance of the merge and diverge points from the interchange, in order to avoid excessive grades to and from an elevated structure.

10.6.2 Equipment

HOV/Transit Ramps

HOV-only ramps (not HOV bypass lanes) as well as transit-only ramps do not require any special equipment beyond signing and pavement markings, which are discussed later in this section.

Construction Vehicle-Only Ramps

Barricades, barrels, or concrete barriers can be used to limit access on existing ramps that are temporarily designated for construction access only. Flexible pylons may also be used, but are not recommended due to heavy wear and tear they would experience during heavy construction use. Generally, a narrow gap in the barricades is left open with signing to depict that only construction vehicles are allowed to enter.

Emergency Vehicle and Maintenance Access Ramps

Emergency vehicle and maintenance access ramps do not require full design standards because they are not heavily used. Gates or other types of temporary blocking devices like flexible pylons may be used to prevent access of unauthorized vehicles. In some cases, surveillance is also used to monitor these access points.

For example, the I-90 floating bridge (between Seattle and Mercer Island) has special ramps on either side of the bridge dedicated for WSDOT maintenance vehicles and emergency vehicles. These ramps can provide direct access to the bridge during an incident. To avoid any confusion as to the intended users, these ramps are “camouflaged” to the motoring public by use of flexible pylons in one location and a movable barrier/gate in the other.

Emergency or maintenance vehicle access can also be provided similarly to construction vehicles. A small gap in the barricades can be left open with clear signing that only emergency vehicles or maintenance vehicles can enter.

If emergency and/or maintenance vehicles are also provided access to other special-purpose ramps (e.g., HOV or freight ramps), no equipment other than signing is generally required.

Freight-Only Ramps

Signing is used to designate ramps as freight-only ramps. In some cases, surveillance may be used to ensure that these special-use ramps are being utilized correctly.

10.6.3 Signing and Pavement Markings

HOV/Transit Ramps

HOV lanes are typically marked with diamonds every 152.4 meters (500 feet). The diamond size varies according to its application. For example, a diamond used for a freeway application would be larger than one used for an arterial or ramp application. This is directly related to the speed of the vehicles traveling on the given facility.

The HOV/transit ramp must be denoted with signing and pavement markings to indicate the allowable ramp users. Signs will designate the ramp as a "buses and carpool" lane or "transit only". The sign should also indicate the HOV occupancy rate (2 or 3+ people). Where appropriate, the signs should also denote if motorcycles are allowed to use the HOV ramp. Figure 10-17 shows an example of an HOV/transit-only sign in Portland, Oregon on the HOV bypass lane. Signs should be placed so they are visible prior to entering the ramp, to prevent those who are restricted from using the ramp. The AASHTO *Guide for the Design of HOV Facilities*[80] and the MUTCD[41] provide more detail on the signing needed for an HOV or transit ramp.

Construction Ramps

Construction ramps do not usually have traditional signing or pavement markings. By use of barrels or barricading equipment, it is usually apparent that the ramp is not intended for general motorists. Signs may be installed that display the words "Construction Entrance" or similar wording.

Emergency Vehicle and Maintenance Access Ramps

Since many emergency vehicle or maintenance vehicle access ramps are actually "hidden" from the public view, signing and pavement markings may not be necessary. A "Do Not Enter" or "Authorized Vehicles Only" sign may be used as regulatory signs to designate the restricted use of the ramp at the point of restriction. The pavement markings may consist of hatching the lane to alert motorists of the restricted access.

Freight-Only Ramps

Freight-only ramps require advance warning signing to indicate the specific use of the ramp. Typically, no special pavement markings are required.

10.7 Design Considerations for Terminal Treatments

Ramp terminal treatments consist of signal timing and phasing adjustments, ramp widening, and adding or extending turning movements and storage lanes. Terminal treatments are implemented along the arterial street network at the ramp location or on the ramps near the intersection with the arterial. Many different alternatives are possible. One key consideration in the design of terminal treatments is to maintain good flow on the arterial and manage the queues that may result from a traffic signal or ramp meter. The MUTCD[41] and AASHTO[61] guidelines offer information on various design considerations for any ramp or arterial intersection. Each agency may also have its own design manual and guidelines to follow.

Signal timing can be modified in various ways. At entrance ramps, the timing should be adjusted such that the traffic does not block the intersection when queues form from the ramp meter. At exit ramps, care should be taken to ensure that queues do not form and back up onto the freeway facility. As discussed in Section 6.6.3, the agencies operating ramp meters should coordinate the meter timing with the signal timing on arterials in order to optimize intersection flow.

Ramp widening may need to occur if the existing storage capacity of the ramp is deemed insufficient or if an HOV bypass lane is to be provided. There must be sufficient right-of-way to accommodate widening, otherwise use of the shoulder may be investigated. Sufficient space for maintenance personnel and their vehicles also needs to be a design consideration when widening ramps.

Access to the HOV bypass lane can be an issue when there is a dual left-turn lane onto the ramp. Weaving and safety issues may arise if the vehicles must merge into one lane a short distance after two lanes of traffic turn left. This may be a case where advance signing can help direct motorists to the proper lane to avoid or minimize last-minute merging or lane changing.

10.7.1 Terminal Treatment Layouts

Most ramp terminal treatments require no changes to ramp or arterial geometrics. If a storage lane is needed, the agency should refer to their design manual for guidance. Some ramp terminal treatments will require new pavement markings or new signing. These situations are covered in section 10.7.3.

10.7.2 Equipment

Many of the terminal treatment alternatives do not require implementing specific pieces of equipment. Much of their application involves signing or pavement markings. For example, ramp widening would involve restriping the ramp to add a lane, either with or without adding additional pavement. Channelization can involve adding a new turn lane or extending the storage lane onto the arterial street or further upstream on an exit ramp. Signal timing modifications are made at the controller or from a central traffic control system, but no additional equipment is required. With turn restrictions, there can be permanent or time-of-day solutions. The signing and pavement marking requirements are discussed in the following subsection.

10.7.3 Signing and Pavement Markings

If turning movement restrictions are to be imposed, signing is required to inform motorists. Figure 10-24 and Figure 10-25 are two example signs that may be used. These regulatory signs are placed on the local streets with concurrence from the local agency, or on the exit ramp approaching the ramp terminal intersection. In some cases, the hours or days of restriction may be added if the turn restriction occurs only during a peak period or specific time of day. The signing can also consist of other information, such as whether the ramp meter is turned on or off or the state of the freeway congestion.

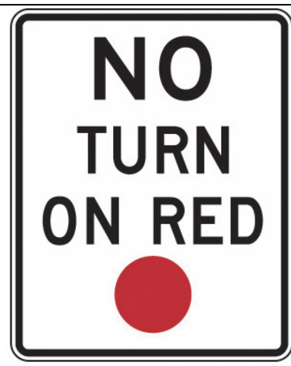


Figure 10-24:
Right Turn on Red Restriction Sign[41]

Figure 10-25:
Left-Turn Restriction Sign[41]

Pavement marking generally consist of striping either solid or skip lines, depending on the application, and pavement arrows to reinforce the messages on signs. For example, if different lane utilization is required at an exit ramp intersection, signs should be placed overhead or on the shoulder to inform the driver of the movements allowed from each lane. Pavement arrows generally will reinforce the signs. If a lane is a right-turn only lane, then a sign should designate the turning requirement and a right-turn arrow should be placed on the pavement.

Specifics of signing and pavement marking can be found in the agency's design manual or in the MUTCD.[28]

10.8 Planning and High-Level Design for ITS Technology and electronic Infrastructure

ITS elements are typically required when implementing many of the ramp control strategies. For ramp closure systems, ITS elements include gate controls, monitoring/surveillance, and electronic signage for driver information. Ramp metering includes extensive field devices (e.g., signals, detection, advanced warning signs), communications, and control software (including controlled firmware and central software). ITS planning follows a systems engineering process, whereby agency staff can guide their ITS projects to success by taking their solutions step-by-step from concept through implementation, operations, and assessment.[81] This process is covered in greater detail in the FHWA Freeway Management and Operations Handbook[1] and the National Highway Institute's course "Introduction to Systems Engineering". The key steps are outlined below.

<u>Concept of Operations</u> – The Concept of Operation (Con Ops) includes the vision, goals, and objectives for the strategy to be implemented. It should include detailed information on how the operating agency wishes to operate the system. The Con Ops should be based on a set of clearly defined user needs.

High-Level and Detailed Requirements – Requirements are derived from the Con Ops and the user needs it identifies. These include functional and technical requirements. The system being implemented and the required interfaces need to be outlined. A systems architecture will help illustrate the systems and define the interfaces.

Various technology options exist for the components of the ramp management strategies. Each should be assess for cost, maintenance, and operational capabilities. These components may include central computer systems, field controllers, gate systems, dynamic message signs, detection, or surveillance.

High-Level and Detailed Design – High-level designs begin to translate the requirements into system components. Detailed design furthers this process to a point that the system can be developed and implemented so that it will meet the requirements established earlier. A traceability matrix should be developed to illustrate which design elements address specific requirements.

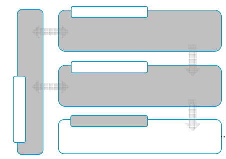
Implementation – This segment of the process outlines the overall plan for the ITS system. It identifies project cost and schedule as well as integration with existing components or capabilities.[1] Implementation actually "builds" and installs the system and its components.

Integration and Testing – Integration and testing puts the components of the system together and tests to make sure the components meet the requirements that apply.

System Acceptance – This step ensures that all of the criteria set forth in the requirements phase have been met in the final system.

Operations and Maintenance – This step includes putting the system to work to fulfill its intended functions. During the operations and maintenance phase, agencies should verify the life cycle costs of the system including training, operations and maintenance. The operating agency should also identify how to upgrade or enhance the system in the future. For many ramp management strategies, this involves getting the maintenance staff on-board during the planning stages, to ensure that they will be able to effectively maintain any new ITS devices.

11 CASE STUDIES



Decision Making

Chapter 10: Planning and Design Considerations

Chapter 11: Case Studies

11.1 Chapter Overview

The purpose of this chapter is to illustrate various aspects of planning, deploying, and operating ramp metering systems by providing overviews of the experiences of various agencies who have implemented ramp metering and other ramp management strategies in their cities. This is intended to provide the reader with a first-hand example of what has been done around the country, providing practical examples of the best practices highlighted in this manual and lessons learned through the process.

Sections 11.2 through 11.6 present case studies that detail how different jurisdictions have successfully deployed and used ramp management strategies presented in this handbook. Each case study analyzes a particular issue in the project life-cycle process (planning, implementation and operations of ramp management strategies). This allows the reader to obtain the information that is useful in their pursuit of managing ramp traffic. The five case studies highlighted in this chapter include:

- Evaluation and Performance Monitoring (Twin Cities, Minnesota).
- Outreach and Public Information (Washington State).
- Safety and Congestion (Madison, Wisconsin).
- Permanent Ramp Closure (Honolulu, Hawaii).
- A Systematic Approach to Ramp Metering (California).

Chapter Organization

Chapter 11 Objectives:

Objective 1:	To learn from jurisdictions across the country about various issues in the ramp management project life-cycle.
Objective 2:	To understand the importance and value of an efficient evaluation and performance monitoring program.
Objective 3:	To realize the critical role that information dissemination has in the success of a newly implemented ramp management strategy and how to conduct an effective public information campaign.
Objective 4:	To learn how agencies have implemented ramp management strategies to improve safety and congestion on their corridors and what it takes to accomplish this.
Objective 5:	To understand the issues surrounding a decision to permanently close a ramp and what resources are required to evaluate a potential closure.
Objective 6:	To gain a sense of how an agency can integrate Transportation Management System strategies in a systematic and coordinate fashion which can result in safer and more efficient operations.

11.2 Evaluation and Performance Monitoring – Twin Cities, Minnesota

This section highlights the experiences of an agency in implementing an evaluation and performance monitoring effort, using the Minnesota Department of Transportation (Mn/DOT) ramp metering system in the Minneapolis/St. Paul region (also referred to as the Twin Cities) as an example.

The ramp metering application deployed and operated by Mn/DOT in the Twin Cities Metropolitan Region is one of the most extensive applications in the nation. This system of over 430 ramp meters is used for corridor and regional traffic control and has historically employed some of the most restrictive metering algorithms in the nation.

The Twin Cities ramp metering system was also subject to an extensive and well publicized evaluation in 2000 when the meters were turned off for a six-week period for evaluation of the impacts of the application. An extensive planning and policy review effort followed to modify the region's metering system to better balance the needs of system operators and regional travelers. Many useful lessons learned resulted from this effort involving the evaluation and performance monitoring of mature metering systems.

Specifically, this case study will highlight the evaluation and performance monitoring experience of Mn/DOT by providing answers to the following questions:

- Why was the evaluation and performance monitoring effort undertaken?
- How was the evaluation performed? What data collection and analysis methodologies were employed?
- What were the outcomes of the evaluation effort?
- What continuing performance monitoring efforts have been implemented?
- What are the experienced and expected impacts of the evaluation and performance monitoring effort? (i.e., What has changed as a result of the effort?)
- What resources were required to conduct the evaluation and performance monitoring?
- How has the effort evolved over time?
- What were the significant lessons learned by the agency as a result of this undertaking?

As this case study documents, evaluation and performance monitoring is an important issue that should not be overlooked when planning and operating ramp management strategies. In addition to this case study, Chapter 9 of this handbook provides additional information and guidance on successful evaluation and performance monitoring of various ramp management strategies.

11.2.1 System Summary

This section provides summary background information of the physical and operating characteristics of the Twin Cities ramp metering system. It should be noted that the planned evolution of the system actually is a decrease in the number of meters. This is because market research studies indicated that travelers perceived their wait times at the ramp meters to be much longer than what they really experienced. In order to improve traveler satisfaction, a number of ramp meters will be removed by 2008. Table 11-1 shows a system summary for the Twin Cities ramp metering system.

Table 11-1: Ramp Metering System Summary - Twin Cities, Minnesota

Characteristic	
Number of Meters	430
Freeway Miles	210 in Twin Cities metropolitan area
Types of Metering Control Applied	Mix of pre-timed, traffic responsive, and system wide ramp metering
Time of Day Operation	Both AM and PM peak periods
Planned Expansion of the System	350 by 2008
Special/Unique Applications or Capabilities	Represents one of the most comprehensive ramp metering systems in the country. Includes some metering of freeway-to-freeway ramps.

11.2.2 Institutional Summary

This section provides a summary of the institutional characteristics of the Twin Cities ramp metering system which is highlighted in Table 11-2.

11.2.3 Lessons Learned

This section focuses on the comprehensive evaluation effort conducted to estimate the impacts of the ramp metering system in the Twin Cities. The lessons learned in this effort illustrate the need for system evaluations, both as a tool for further improving the system and measuring the benefits of the system. Further guidance on how to conduct such an evaluation is discussed in Chapter 9. This case study will further explore the subsequent planning effort that was conducted to modify the operating policies and procedures.

Why was the evaluation and performance monitoring effort undertaken?

The evaluation of the ramp metering system was mandated by the State legislature. This mandate was prompted by a small, but vocal, group of citizens who were opposed to ramp metering. The legislature directed Mn/DOT to suspend the operation of the metering system for a six-week period and provided funding for a comprehensive independent evaluation of the impacts observed during the shutdown period to identify the overall impacts of the system. Throughout the shutdown experiment, the evaluation was extensively covered in the local media and followed by the public.

Table 11-2: Institutional Summary - Twin Cities, Minnesota

Characteristic	
Managing Agency(ies)	Minnesota State Department of Transportation (Mn/DOT)
Year Started	1969 for first testing
Goals of Implementing System	To optimize freeway safety and efficiency in the metropolitan area
Implementation Planning Process	The Mn/DOT system represents a mature ramp metering system that has been deployed and integrated incrementally over more than 30 years. Prior to the evaluation efforts in 2000-2001, ramp metering was automatically implemented as part of all freeway capital improvement projects. Since that time, Mn/DOT has adopted a more performance-based approach, as described in the case study text.
Evolution of the System	Steadily added more ramp meters to manage the flow of traffic through bottlenecks and help traffic merge onto freeways.
Operating Agreements/ Multi-Jurisdictional Agreements	Mn/DOT operates the ramp metering system under long standing multi-jurisdictional agreements with local and county agencies that provide Mn/DOT with great latitude in their operational policies.
Evaluation or Monitoring Activities Performed	Periodic performance evaluations were conducted early in the deployment of the system. A comprehensive, legislative-mandated evaluation was conducted in 2000, as described in the case study text.

How was the evaluation performed? What data collection and analysis methodologies were employed?

System performance data was collected during two six-week periods, both preceding and during the ramp metering shutdown. Data collected prior to the shutdown was used to represent travel conditions "with" the ramp metering system. Data collected during the shutdown period was used to reflect "without" the ramp metering system.

Intensive data collection efforts were targeted at four different freeway corridors selected to represent different types of regional freeways: an inner-city corridor, the regional beltway, a radial freeway inside the beltway, and a radial freeway outside the beltway. Each of the representative corridors was subject to traffic volume counts and travel time runs on the freeway mainline and on parallel arterial corridors. Queue delay studies were also conducted at all on-ramp locations.

The conditions of the representative corridors were then compared for the "with" and "without" periods to determine the impact of the metering system on travel volumes and speeds. The results for the representative corridors were then extrapolated to the remaining corridors in the region based on their type.

Safety impacts were analyzed through the use of the incident reporting database maintained by the Minnesota Highway Patrol. The actual number of incidents (by type) was compared for the "with" and "without" period to analyze the change in the number of crashes occurring on freeway and ramp facilities.

An intensive market research study was also conducted in parallel to the impact study. This effort consisted of several rounds of focus groups and telephone surveys, which occurred before, during, and after the metering shutdown period.

What were the outcomes of the evaluation effort?

Several performance measures were used to evaluate the ramp metering system. These included traffic volumes and throughput, travel times, reliability of travel time, safety, emissions, fuel consumption, and public perception. The highlights are shown below.

- Throughput: Traffic volumes on the freeway mainline were observed to decrease by nine percent when the meters were shut down. There was no appreciable change in the volumes on the parallel arterials observed when the meters were shut down.
- Travel Time: Freeway speeds were reduced by 14 percent, or 11.9 km/h (7.4 mi/h), when the meters were shut down, resulting in greater travel times that more than offset the elimination of ramp queue delays. There was no appreciable change in the travel times on the parallel arterials observed when the meters were shut down.
- Travel Time Reliability: Travel times were nearly twice as unpredictable when the meters were shut down.
- Safety: Crashes on freeways and ramp segments increased by 26 percent when the meters were shut down.
- Benefit/Cost Analysis: The ramp metering system was estimated to produce approximately $40 million in benefits to the Twin Cities region. These benefits outweighed the costs of the ramp metering system by a ratio of 15 to 1.
- Market Research: Survey and focus group efforts were used to gather perceptions and opinions on the metering system. This research revealed that the majority of Twin Cities' residents supported the use of ramp metering and felt that the system provided them with a benefit. However, many residents also supported modifications to

the system to decrease time spent waiting in the ramp queues. The market research findings generally supported the observed impacts of increased safety, improved travel time, and more reliable travel times resulting from ramp meter operation. One noted discrepancy involved the time spent waiting in the ramp queues reported by travelers. Travelers perceived their wait times to generally be twice as great as the observed wait times.

What continuing performance monitoring efforts have been implemented?

The ramp meter shutdown experiment involved the collection of a large set of performance data. This observed data was compared with data generated by the Twin Cities comprehensive traffic detection systems and was found to validate the data automatically generated by these systems. In subsequent evaluation efforts and in continuing system monitoring activities, this automated data has been utilized to a great extent. In conducting the experiment, Mn/DOT also became better aware of the benefits of performance evaluation, monitoring, and reporting. In several recent implementations of operational improvements or modifications, Mn/DOT has included an evaluation component as well as public outreach and education efforts to ensure that the public is aware and understands the benefits of the implementations.

What are the experienced and expected impacts of the evaluation and performance monitoring effort? (i.e., What has changed as a result of the effort?)

Although the evaluation found that the ramp metering system provided benefits that far exceeded its costs and the market research indicated that a majority of travelers supported the use of ramp metering, some modifications were implemented to reduce reported dissatisfaction with the wait time required in the ramp queues. Several policy and operations changes were made, including implementing less restrictive algorithms, decreasing the hours of operation, and deactivating several meter locations. A subsequent evaluation effort revealed an increase in traveler satisfaction as a result of the modifications.

What resources were required to conduct the evaluation and performance monitoring?

The legislative action mandated that an independent contractor be responsible for the evaluation. Mn/DOT contracted with an outside consulting team for approximately $650,000 to conduct the evaluation. Additional internal Mn/DOT resources were required to provide project management, public communication, and various data assembly tasks.

How has the effort evolved over time?

Following the ramp meter shutdown experiment, modifications were implemented impacting meter policy and operation in the region. A subsequent evaluation effort was conducted, utilizing another round of market research activities and system performance analysis. In this subsequent evaluation, automated data sources were used to a much greater extent to reduce data collection costs. Comparisons of the data revealed that the implemented modifications resulted in slightly reduced travel time and safety benefits; however, a greater majority of residents approved of the modified system.

What were the significant lessons learned by the agency as a result of this undertaking?

Prior to the evaluation being mandated by the legislature, the ramp metering system had been implemented and expanded in the region with limited formal assessment of the impacts. While it was assumed that the system produced significant operational benefits for the region's freeways, there was little empirical evidence to justify the system when opponents questioned the benefits. The shutdown experiment provided a unique opportunity to test the impacts of a mature ramp metering system. Following the experiment, Mn/DOT better recognized the value of performance evaluation and monitoring and implemented more formalized efforts to perform these functions.

The impacts observed during the experiment supported Mn/DOT's assertions that the system provided substantial benefits; however, the market research effort revealed that many residents were dissatisfied with certain operational aspects of the system, and did not necessarily understand the tradeoff between more restrictive metering and improved freeway performance. Through these findings, Mn/DOT became more aware of the importance of public information and education campaigns in promoting the operation of ramp meters. The result of the evaluation was the implementation of modifications to achieve a better balance of the operational efficiency of the system with the perceptions of travelers. This effort was combined with an increased focus on public outreach to promote the benefits of the system.

11.3 Outreach and Public Information – Washington State DOT

This section discusses one agency's efforts to provide outreach and public information on their ramp metering system. This case study focuses on the outreach efforts of the Washington State DOT (WSDOT) in the Seattle region.

The Seattle region's ramp metering system, operated by WSDOT, provides an example of a mid-sized system that is currently focused on several high-priority corridors. Several recent planning and evaluation efforts have been undertaken to analyze the current performance of the system and plan for expansion of metering to additional locations. To support the planned enhancement and expansion of the system, WSDOT has undertaken a robust outreach and public information campaign.

WSDOT has done an outstanding job with regard to dissemination of information to the public about their ramp management system. This case study will summarize these outreach efforts by providing answers to the following questions:

- What were WSDOT's objectives in undertaking the vigorous outreach and public information campaign (i.e., What did they hope to gain?)
- How was the outreach and public information campaign implemented? What resources were required?
- What are the experienced and expected benefits of the effort?
- What aspects of the campaign worked well?
- What aspects of the campaign failed to achieve their objectives?
- How has the effort evolved over time?
- What were the significant lessons learned by the agency as a result of this undertaking?

As discussed in this case study, getting detailed information to the public plays a critical role in the success of a newly implemented ramp management strategy. Chapter 7 in this handbook provides additional information on the public information and outreach process of implementing ramp management strategies and plans.

11.3.1 System Summary

Table 11-3 summarizes the physical and operating characteristics of the Seattle area ramp metering system.

Table 11-3: System Summary – Seattle, Washington

Characteristic	
Number of Meters	120 in 2002
Freeway Miles	760 miles
Types of Strategies/ Algorithms Applied	System-wide, Traffic Responsive Control/Fuzzy Logic Algorithm[3]
Time of Day Operation	6-10 AM and 3-7 PM weekdays, and other times during incidents and special events
Planned Expansion of the System	160 by 2008
Special/Unique Applications or Capabilities	Some ramp meters in the future will provide preemption for emergency vehicles and priority for transit vehicles.

[3] Refer to Chapter 5, Section 5.3.4 for more detailed information on this algorithm.

11.3.2 Institutional Summary

Table 11-4 summarizes the institutional characteristics of WSDOT's ramp metering system.

Table 11-4: Institutional Summary - Seattle, Washington

Characteristic	
Managing Agency(ies)	Washington State Department of Transportation (WSDOT)
Year Started	1981
Goals of Implementing System	Reduce freeway delay and improve travel time
Implementation Planning Process	The WSDOT ramp metering system went through the normal design and environmental processes typical of any construction project when initially implemented. There was also extensive public outreach.
Evolution of the System	In 1981, 22 ramps were metered. Slow expansion occurred in the 1980's with major expansions occurring throughout the 1990's.
Operating Agreements/ Multi-Jurisdictional Agreements	With inter-local agreements: King County Metro Transit, Community Transit - Snohomish
Evaluation or Monitoring Activities Performed	On-going evaluation and monitoring

11.3.3 Lessons Learned

This section summarizes the lessons learned from the on-going outreach and public information efforts in the Seattle region. WSDOT gained a great deal of knowledge after the initial I-5 Surveillance/Control and Driver Information (SC&DI) system and HOV lane implementation. When they expanded their ramp metering system for I-90, the process went much smoother and with great success. The following will describe how WSDOT developed their successful public information program.

What were WSDOT's objectives in undertaking the vigorous outreach and public information campaign? i.e., What did they hope to gain?

In December 1979, a private consultant was hired to conduct focus group discussions concerning the awareness of and attitudes toward the I-5 traffic management systems. One of the key findings was that there was little public awareness of either the planned SC&DI program or the

HOV lanes. However, because construction was already evident, participants were angered when they learned about the planned traffic systems after the fact. More than any other idea, the need to inform and educate the public about these programs dominated the discussion.[82]

Based on input at these focus group discussions, the following is an excerpt of what was suggested to WSDOT for consideration:

- Create an awareness program for the introduction of the SC&DI system and HOV lanes using all traditional media, such as television, radio, newspapers, and magazines.
- Work with local groups to provide information and obtain feedback through public workshops sponsored by community clubs, chambers of commerce, service organizations, and other groups.
- Prepare informational materials for public distribution using newsletters, brochures, and newspaper and magazine articles stressing the benefits of the system.
- Provide an ongoing program of education and information.
- Set up an intensive program with employers to enlist their support of these new systems.
- Develop a program for monitoring the effectiveness of the new traffic systems.

Many of these suggestions have now been incorporated into WSDOT's process for implementation of new systems. They took the public's comments to heart and have developed a successful method of gaining public support of their projects. WSDOT has prepared a set of formal guidelines that detail the various levels of effort to initiate a public outreach campaign based upon three conditions:[83]

- Providing ramp metering on an existing non-metered corridor.
- Expanding the ramp metering system within an already metered corridor.
- Adding a meter to a ramp located within an already metered corridor.

When implementing new ramp metering projects, WSDOT prepares three key documents: an evaluation plan, a scoping plan, and a public involvement plan. The evaluation plan measures both the positive and negative impacts of the new system on the traffic flow. The scoping plan describes how other agencies (i.e., city, transit, and county governments) identify potential problems and solutions concerning the new ramp meters. The public involvement plan details the ways that WSDOT can get the public involved in all aspects of the project. All three of these plans are carried through the planning, design, implementation, and operation stages of the ramp metering projects.

Table 11-5 illustrates all activities that are required by WSDOT for implementation of a ramp metering system, starting from three to five years *prior* to the meter activation and continuing through one year after activation. For specifics of each of the activities, refer to WSDOT's *SC&DI Implementation and Operations Plan.*[83]

Table 11-5: Sample Ramp Metering Implementation Schedule[83]

<table>
<tr><th></th><th>Internal Activities</th><th>Public Activities</th><th>Partner Agency Activities</th><th>Measure/Modeling</th></tr>
<tr><td rowspan="5">3-5 Years Prior to Ramp Metering</td><td>Develop Metering Evaluation Plan</td><td>Public Attitude Survey</td><td rowspan="5">Deliver Initial Project Plans</td><td rowspan="2">Develop Measures of Effectiveness</td></tr>
<tr><td>Educate Staff</td><td>Develop Public Involvement Plan</td></tr>
<tr><td>Develop Scoping Plan</td><td>Conduct Open House Meeting</td><td rowspan="3">Pre-Deployment Traffic and Crash Baseline</td></tr>
<tr><td>Develop Public Improvement Plan</td><td rowspan="2"></td></tr>
<tr><td>Incorporate Public Input to Design</td></tr>
<tr><td rowspan="2">Up to 1 Year Prior to Ramp Metering</td><td rowspan="2">Policy Maker Briefings</td><td>Conduct Public Meetings & Design Hearings</td><td>Disseminate Letters to Affected Agencies</td><td rowspan="4">Model</td></tr>
<tr><td>Disseminate Project Information to Media</td><td>Operational Agreements</td></tr>
<tr><td rowspan="2">2-6 Months Prior to Ramp Metering</td><td>Train Operators</td><td rowspan="2"></td><td rowspan="2">Conduct Additional Presentations & Disseminate Information</td></tr>
<tr><td>Policy Maker Briefings</td></tr>
<tr><td>1 Month Prior to Ramp Metering</td><td></td><td>Install Traffic Signs Near Affected Areas</td><td>Media Campaign</td><td></td></tr>
<tr><td colspan="5">Begin Ramp Metering</td></tr>
<tr><td>2 Weeks After Ramp Metering</td><td rowspan="3">Policy Maker Briefings</td><td>Distribute Information to Public and Media</td><td></td><td>Fine Tune Metering Equipment</td></tr>
<tr><td>2-6 Months After Ramp Metering</td><td rowspan="2">Public Attitude Surveys</td><td></td><td>Conduct First Evaluation</td></tr>
<tr><td>6-12 Months After Ramp Metering</td><td></td><td>Conduct Second Evaluation</td></tr>
</table>

After learning from the I-5 traffic management system experience, WSDOT now has multiple objectives for their public information efforts: (1) to increase driver education on how to use the ramp metering systems and addresses enforcement issues and (2) to improve driver acceptance through a provision of a comment and design modification period. The second objective allows WSDOT to see if they should change any element of the design prior to construction. For example, motorists are easily able to inform WSDOT of a problem area where the queues back up to the arterial network because they drive the route everyday. WSDOT can then respond by modifying the ramp design to accommodate two lanes of storage, if necessary.

How was the outreach and public information campaign implemented? What resources were required?

One of the campaign elements was the creation of a speaker bureau comprised of WSDOT employees. The bureau was made up of individuals from all departments within WSDOT, including those who were not necessarily in traffic operations or part of the ramp metering group. WSDOT was able to get more resources involved by educating employees about ramp metering so that they each had an understanding of the system, whether or not they lived in the corridor. Then, each person could, in turn, articulate the benefits to the public, other agencies, friends, and family. This type of "inreach" was very effective.

WSDOT also used various forms of media and outreach. Information dissemination took the form of press releases, printed brochures, and website information with frequently asked questions and answers. Professional copy editors and designers prepared the brochures so that they were polished and professional looking. Public forums were held at community meetings, open houses, and shopping malls. The in-house public relations staff handled the public meetings with the assistance of other WSDOT staff. These meetings gave the public a chance to review the plans and ask the staff questions about ramp metering. One innovative technique that WSDOT used at the local shopping mall was to provide entertainment for the children so that the parents could talk to staff uninterrupted.

Another key to the campaign was using a catchy phrase that the public could associate with the ramp metering project. Coupled with this goes the decision as to what the message discusses or focuses on (i.e., safety or congestion improvement message). Figure 11-1 shows an example of a brochure used for the public outreach campaign.

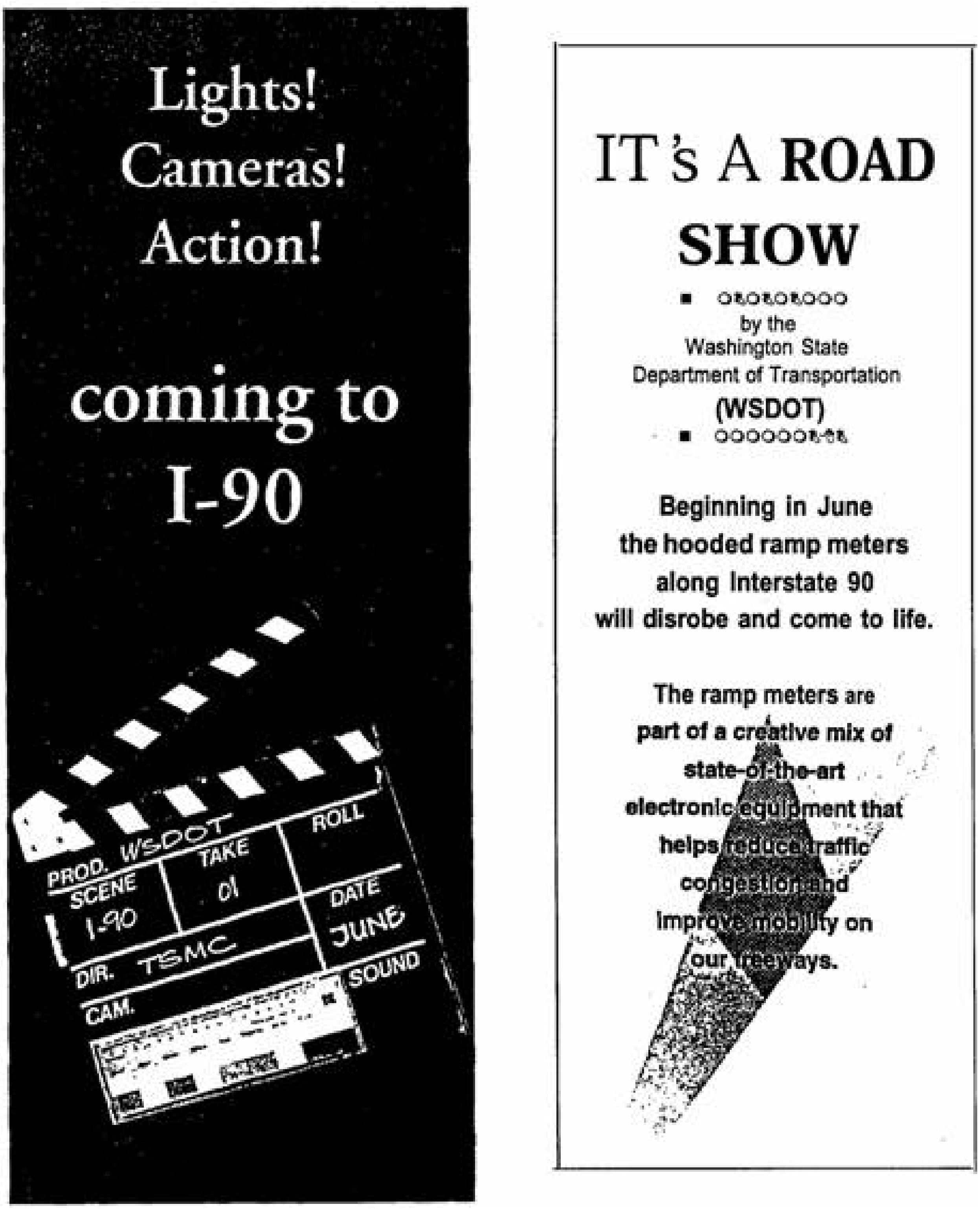


Figure 11-1: I-90 Ramp Meter Brochure

What are the experienced and expected benefits of the effort?

The expected benefits were that the public would have fewer complaints about the new ramp metering system. At the beginning of the I-90 implementation, there were both a high number of driver complaints as motorists were adjusting to the new system. However, there soon was a general acceptance of the ramp metering system. People did not see it as a problem at all. Of course, sometimes there was a ramp meter malfunction that needed immediate corrective action.

Another expected benefit was that motorists would experience travel time savings over the course of their commute. In some cases, motorists found themselves in difficult merges and backups. WSDOT staff corrected the situation and explained the importance of correct metering rates. It was stressed that WSDOT monitors the ramp traffic volumes and queues in order to balance the timing so as not to sacrifice performance of the adjacent arterial streets.

The experienced benefits of ramp metering are as follows:[84]

- Reduction in rear-end and sideswipe collisions by over 30 percent.
- Reduction in freeway mainline congestion of 8.2 percent.

What aspects of the campaign worked well?

WSDOT started the public input process two years ahead of the metering turn-on. This allowed WSDOT staff time to address the public's design concerns. Who better to solicit input from than the motorists who drive the corridor every day and know the traffic patterns and problem areas? By allowing citizens an opportunity to offer their comments in advance of the design, they can begin to take ownership of the project and feel like a critical part of the stakeholder process.

One of the keys to success in WSDOT's public information campaign was the holistic approach they took in addressing every facet of the ramp metering project. It was important to address the whole program, including everything from inreach and outreach, press releases, open houses dedicated to the subject, and distribution of printed materials at every possible public event in the corridor. Getting the word out in advance of construction and receiving public feedback was vital. Once the system was up and running, it was equally important to provide the public an opportunity to offer their comments and feedback to make sure that their initial concerns had been addressed. WSDOT posted "FLOW" signs along the corridor directing motorists to call the TMC with any comments about the new system.[85] "FLOW" is the name given to WSDOT's regional traffic management system, which includes bus/carpool lanes, park-and-ride lots, freeway flyer stops, and the computerized monitoring of traffic flow on the area's freeways.

How has the effort evolved over time?

WSDOT learned a great deal from the initial I-5 ramp metering effort, which was initiated in 1981. This was the first ramp metering application in the Seattle area and therefore much more work was required than in subsequent expansions. With the addition of ramp meters for the I-90 expansion during the early 1990s, the level of effort was significantly reduced because motorists were already familiar with ramp metering.

WSDOT listens to the public's concerns and is constantly refining how they handle implementation projects. Their guidelines are "living" documents that are revised whenever necessary.

What were the significant lessons learned by the agency as a result of this undertaking?

The single most important lesson learned was that pre-planning efforts are crucial to the success of the project. An appropriate amount of time must be spent prior to implementation to ensure that the public understands and is part of the development of the project.

11.4 Safety and Congestion – Madison, Wisconsin

This section discusses the use of ramp meters to mitigate safety and congestion problems in a smaller metropolitan area, using the experiences of the Wisconsin DOT's (WisDOT) pilot deployment of ramp meters in the Madison region as an example.

In this application, ramp meters were deployed on three interchange locations (five on-ramps) along a four-mile section of the Highway 12 beltline corridor. These ramp meters were deployed as part of a pilot program to specifically address safety and congestion deficiencies in particular locations. The Madison ramp meter deployment was subsequently the subject of two separate evaluations which investigated the impacts of the implementation. These evaluations are being used by WisDOT to better understand the effectiveness of the strategy in reducing congestion and safety deficiencies at particular locations. This case study will illustrate the use of ramp meters for this purpose by addressing the following questions:

- What were the characteristics of the locations where ramp metering was applied to mitigate congestion and safety deficiencies?
- Why was metering selected over other strategies as the preferred mitigation method?
- What was the process used in identifying which locations to deploy ramp metering?
- What have been the observed and perceived benefits of the deployment? Has the strategy achieved its goal of mitigating safety and congestion deficiencies?
- What resources were required to plan, deploy, and operate the system?
- What specific challenges were encountered in planning and deploying the ramp meters?
- How has the effort evolved over time? What plans exist for expanding/enhancing the system?
- What were the significant lessons learned by the agency as a result of this undertaking?

The following case study highlights how agencies have implemented ramp management strategies to improve safety and congestion on their corridors.

11.4.1 System Summary

Table 11-6 provides summary background information of the physical and operating characteristics of the Madison ramp metering system.

Table 11-6: Ramp Metering System Summary – Madison, Wisconsin

Characteristic	
Number of Meters	5
Freeway Miles	4
Types of Strategies/ Algorithms Applied	Local, pre-timed control with HOV by-pass lanes
Time of Day Operation	6:30 to 9:00 AM and 3:00 to 6:00 PM
Planned Expansion of the System	Currently under consideration

11.4.2 Institutional Summary

Table 11-7 provides a summary of the institutional characteristics of the Madison ramp metering system.

11.4.3 Lessons Learned

This section focuses on the recent effort to implement ramp metering in a smaller metropolitan area to address safety and congestion deficiencies. Lessons learned in this effort will be related to practices presented in this manual.

What were the characteristics of the locations where ramp metering was applied to mitigate congestion and safety deficiencies?

During an evaluation of the region's incident management program, it was noted that segments of the Highway 12 corridor experienced crash levels higher than the State average, and that facility speeds showed significant declines, decreasing from 89 to 24 km/h (55 to 15 mi/h), during peak periods. Three interchanges along this segment of the Highway 12 Beltline were selected for ramp metering: Whitney Way (eastbound ramp), Fish Hatchery Road (two westbound ramps), and Park Street (two westbound ramps). These locations were selected based on crash records analysis and traffic analysis (using a microscopic traffic simulation tool) that indicated that these facilities could be benefited by ramp metering to mitigate the unsafe driving conditions and congestion.

Table 11-7: Institutional Summary – Madison, Wisconsin

Characteristic	
Managing Agency(ies)	Wisconsin Department of Transportation (WisDOT)
Year Started	2001
Goals of Implementing System	Improve safety and congestion levels in a localized area.
Implementation Planning Process	Deployed as a pilot project to test the effectiveness of ramp meters.
Evolution of the System	The effectiveness of the pilot system is being studied to refine the system and determine the potential for expansion of ramp meters to other locations in the region.
Operating Agreements/ Multi-Jurisdictional Agreements	Pilot program was planned and implemented with the assistance of Dane County, the City of Madison, the Wisconsin State Patrol, and other stakeholders.
Evaluation or Monitoring Activities Performed	The system has undergone several evaluations to understand the effectiveness of the meters.

Why was metering selected over other strategies as the preferred mitigation method?

Several alternative strategies were considered, including geometric realignment of the interchanges. Ramp metering was selected over the alternative options because metering could be implemented more rapidly and at a fraction of the cost of other alternatives. WisDOT also wanted to use the deployment as a pilot test for analyzing the potential effectiveness of the strategy as a safety and congestion mitigation strategy.

What was the process used to Locate Ramp Meters?

An earlier analysis of the incident management system deployed in the Madison region had identified the corridor as experiencing crashes at a rate exceeding the State average. Many of the local transportation professionals attributed the higher than expected crash rate to the congestion caused by difficult merges at several interchanges in the corridor. A subsequent analysis was performed using the Madison region's travel demand model to compare the impact of various alternative improvements including geometric improvements and several ramp metering configurations. The findings of this analysis were used to prioritize the implementation of the meters at the deployment locations.

What have been the observed and perceived benefits of the deployment? Has the strategy achieved its goal of mitigating safety and congestion deficiencies?

Two evaluation efforts have been subsequently conducted to assess the performance of the pilot ramp metering deployment. The first evaluation was conducted by University of Wisconsin transportation researchers using before and after field traffic (traffic volumes, travel speeds, and travel time) and crash data, microscopic traffic simulation analysis, stakeholder interviews, and public surveys. The second evaluation was conducted by a transportation consulting company using a combination of the regional travel demand model and the U.S. DOT's ITS Deployment Analysis System (IDAS) software tool to estimate the impacts and benefits of the ramp meters. Both evaluation efforts found that the ramp metering implementation provided significant benefits and was an effective strategy in reducing congestion and improving safety. Specific findings from the University of Wisconsin study[86] include:

- The number of crashes decreased significantly (50 percent reduction) with ramp meters, particularly during the winter months.
- Most agency personnel reported that the time to clear incidents improved with ramp meters.
- Ramp meters improved freeway mainline average speeds by two to ten percent.
- Speed variability was reduced by 5.5 to 9.2 km/h (3.4 to 5.7 mi/h) with ramp meters.
- Ramp meters increased facility throughput by 29 percent.
- Ramp metering did not cause significant diversion of vehicles from Highway 12 to alternative routes.
- Most drivers obeyed the ramp meters with compliance rates averaging from 85 to 98 percent.
- Public surveys indicated that public acceptance of ramp meters was very high.

Additional findings from the IDAS analysis include:

- The number of crashes was estimated to decline by 36 percent in the areas immediately upstream and downstream of the metered ramps.
- Facility speeds were estimated to increase by three percent with ramp metering.
- Freeway mainline volumes were estimated to increase modestly (1.5 percent) with ramp metering.

What resources were required to plan, deploy, and operate the system?

As part of the evaluation, traffic data was analyzed that had been collected before (September 2000 to May 2001) and after ramp meters were activated (September 2001 to April 2002). In addition, researchers reviewed 911 incident reports for crash data, conducted microscopic traffic simulation modeling, and conducted before and after opinion surveys of Dane County drivers. A survey was also conducted of transportation and law enforcement agency personnel, including representatives of Wisconsin State Patrol – District 1, the Madison Police Department, Dane County 911, and Madison Metro Transit.

The ramp metering evaluation was part of a larger study investigating ITS element costs and benefits. The total study cost approximately $175,000, of which the ramp metering evaluation was a portion of this total.

What specific challenges were encountered in planning and deploying the ramp meters?

The most significant challenge in deploying the ramp meters was related to public acceptance. Although many Madison residents were familiar with ramp metering through travel experiences in Milwaukee, Minneapolis, Chicago, and other nearby cities, many other regional travelers were unfamiliar with the concept. The deployment was accompanied by a public education campaign to explain the operation and purpose of ramp metering. Furthermore, public surveys were conducted both before and after implementation to gauge public acceptance and their understanding of the purpose of the ramp meters. Positive driver perceptions on the effectiveness of ramp metering as a strategy for improving travel time and safety ranged from 32 to 64 percent of drivers prior to the implementation. The percentage of positive responses improved following deployment to a range of 78 to 92 percent of drivers.

How has the effort evolved over time? What plans exist for expanding/enhancing the system?

WisDOT is currently using the results from the evaluation efforts to assess the potential of ramp metering expansion in the region. Given the positive performance of the ramp meters and the public acceptance, the expansion of the system to additional high priority interchanges and corridors is expected as funding becomes available.

What were the significant lessons learned by the agency as a result of this undertaking?

The most significant lessons learned upon completion of this effort include:

- The results of the two evaluation efforts have shown ramp metering to be an effective strategy in mitigating congestion and safety issues in isolated locations.
- The improvements to freeway mainline performance were achieved without diverting a significant volume of vehicles to alternative routes.
- The public has been receptive to the use of ramp meters and the deployment has improved perceptions of the strategy as an effective way to reduce congestion, improve travel time, and enhance safety.

11.5 Permanent Ramp Closure – Honolulu, Hawaii

This section discusses the issues surrounding the decision to permanently close ramps, using the experience of the State of Hawaii Department of Transportation (HDOT) as an example. The following questions will be addressed for this case study in permanent ramp closures:

- What processes were used to analyze and select the ramps to be closed?
- Were other ramp management strategies considered besides ramp closure?
- What were the results of this ramp closure experiment?
- What parts of the planning process worked particularly well?
- What specific challenges were encountered in planning and closing the ramps?
- What resources were required to plan and implement the ramp closures?
- What were the significant lessons learned by the agency as a result of this undertaking?
- What was the final outcome of this experiment?

This case study describes the issues surrounding a decision to permanently close a ramp and what resources are required to evaluate a potential closure. Ramp closures are also discussed in Chapter 5, Section 5.4.

Not surprisingly, there are very few examples of permanent ramp closures. Often, ramp closure is not considered because many metropolitan areas have already instituted a ramp metering solution. Another reason is that freeway congestion has shifted to the suburban areas where freeway segments are designed for higher speeds and provide ramp access at more distant intervals.[87]

HDOT conducted a two-week ramp closure experiment on the Lunalilo Street on-ramp in the fall of 1997. Figure 11-2 shows the ramp geometrics. This case study explores the simulated and real-world results of the H-1 freeway on-ramp closure. The H-1 freeway (eastbound and westbound) qualifies as a severely congested facility because central portions of the H-1 operate below 50 km/h (31.1 mi/h) for at least one hour during the AM peak period.[86]

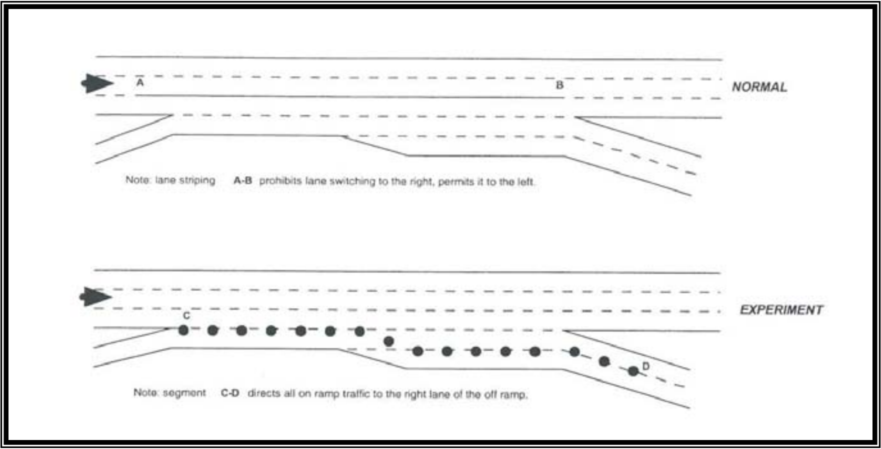


Figure 11-2: Ramp Closure Layout for Lunalilo Street on-ramp

11.5.1 Lessons Learned

This section highlights the key issues and lessons learned regarding the HDOT ramp closure experiment.

What processes were used to analyze and select the ramps to be closed?

There were a variety of steps used in the analysis and selection of ramp closure sites. One of the first steps was looking at the ramp closure experiments conducted on Detroit's Lodge freeway in the early 1960s. These experiments showed considerable improvement in several areas: increase in average freeway speed, decrease in congestion duration, increase in traffic volume serviced on the freeway, decrease in freeway traffic stoppage, and a reduction in the length of the stoppages.[88]

Other urban freeways in North America were evaluated to compare the density of on-ramps with the H-1 freeway. Tabulating forty freeway segments based on the ramp density showed the H-1 westbound ranking as 6th and the H-1 eastbound ranking 11th. It should be noted that the majority of freeway segments that outrank the H-1 are managed with ramp metering. This implies that some sort of freeway management strategy is required for H-1 (metering or ramp closure). Furthermore, a "black spot" analysis was conducted to estimate freeway speeds using average daily traffic (ADT) per lane and the number of ramps per kilometer. The following metric model was used in NCHRP Project 7-13.[89] This simple method (sketch planning tool) provided a good indication of segments where some freeway management would be required.

$$\text{SPEED (km/h)} = 147.1 - 3.2*(\text{ADT/L}) - 4.6*(\text{ACCESS})$$

where SPEED = average peak hour speed in km/h;
ADT/L = average daily traffic per lane; and
ACCESS = frequency of freeway ramps per kilometer.

Figure 11-3: Equation. Freeway Speed.

Several simulations and data collection efforts were conducted to establish the base case. A freeway simulation software developed by the University of Minnesota for Mn/DOT was used to simulate 10.5 km (6.5

miles) of the westbound H-1 freeway. This served to replicate the existing conditions and select an on-ramp for closure to improve the overall flow of the freeway system. Several simulations were conducted to create a reliable base case condition. In addition, other traffic analysis tools were used to model the traffic diversion in the AM peak period. A simultaneous collection of freeway mainline and ramp traffic volume data was conducted along with closed circuit television (CCTV) cameras at four cross-sections to record the four hours in the AM and PM peak periods. The video footage was then analyzed to create approximate speed profiles.

After the base case condition was accurately modeled, it was a straightforward process to simulate various ramp closure and ramp metering scenarios. Motorists were re-routed, based on the analysis alternatives, using information collected in origin/destination surveys at key on-ramps.

Collectively, using the numerous (over 30) simulated alternatives, discussions with HDOT Traffic staff, helicopter surveillance, and driver experience, it was determined that the Lunalilo Street on-ramp was the source of a major bottleneck. This also confirmed what was identified using the preliminary "black spot" analysis.

Were other ramp management strategies considered besides ramp closure?

Ramp metering was considered for the H-1 corridor. However, since both the mainline and on-ramp traffic volumes were very high, the metering rate would need to have a long cycle, which effectively means closing the ramp since less than 30 percent of the ramp volume would be allowed access. This helps to show that ramp metering would not have been the appropriate solution. In addition, ramp metering would not have been effective given the close proximity of many of the on-ramps.

What were the results of this ramp closure experiment?

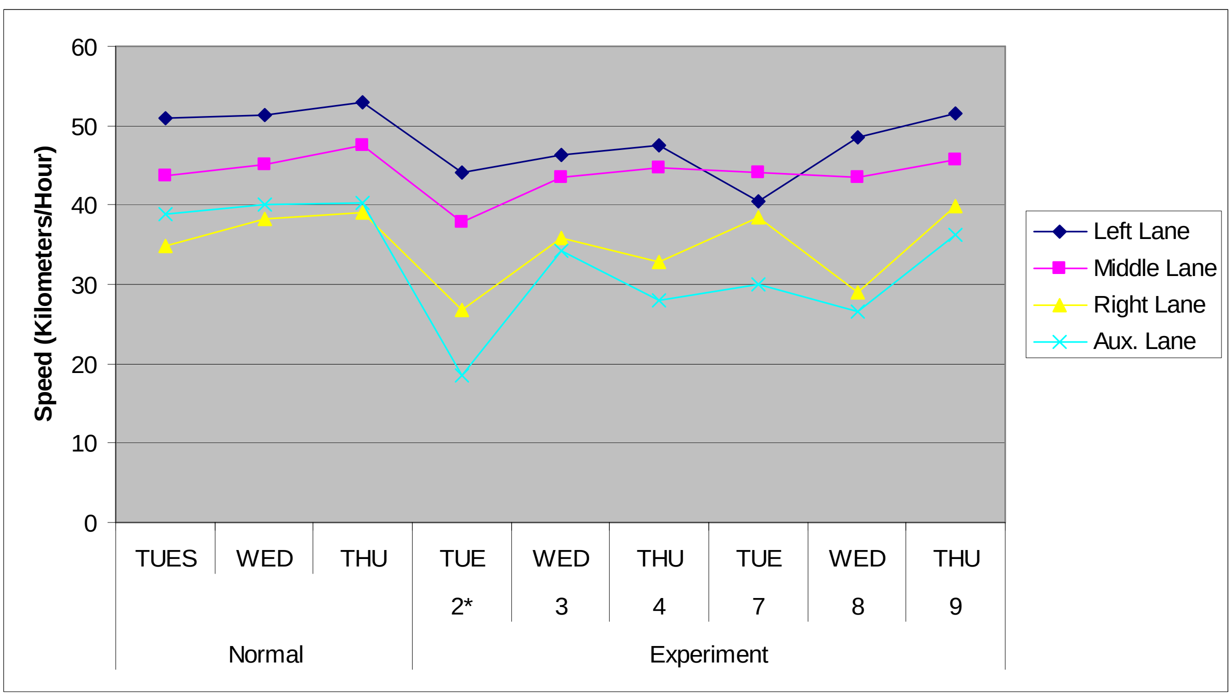
The actual results from the experiment were mixed and modest, at best, and did not match the researchers' and HDOT's expectations. Figure 11-4 shows the evolution of speeds across all lanes. This information demonstrates a decrease in average speed at the cross section of the experiment site, which can be attributed to the motorists' reaction to the coned auxiliary lane. The coning created a type of impedance similar to an incident, instead of a uniform capacity reduction on a given segment.

The auxiliary and right freeway lanes experienced the greatest reduction in average speed. However, at the end of the two weeks, the average travel speeds had recovered to their normal levels. It should be noted that the 'Normal' speeds shown are downstream of the bottleneck. Much slower speeds are experienced upstream of the bottleneck under normal conditions. Although only the 7:45 to 8:00 AM period is shown, all 15-minute periods from 6:00 to 10:00 AM showed a similar trend.

The best result was achieved on the last (10^{th}) day of the experiment. A travel time comparison between the last day of the ramp closure experiment and the following Friday showed a 14 and 24 percent improvement (at 7:00 AM and 7:40 AM). Likewise, a fuel consumption comparison on the same dates and times showed a 15 and 28 percent improvement.

The positive impacts of the ramp closure included:

- Though ramp metering would be a less disruptive alternative, it would have required extensive alignment modifications to meet the storage and acceleration requirements. Therefore, using the on-ramp closure was a much more economical solution.
- The geometry of the Lunalilo Street on-ramp was particularly favorable for a ramp closure. This on-ramp extends to become the right lane of the two-lane Vineyard Boulevard off-ramp. This closure re-routes the traffic to a high-design arterial street (Vineyard Boulevard) which reconnects to the freeway further downstream. And the remaining left lane at the Vineyard Boulevard off-ramp was sufficient to allow mainline motorists off the freeway.
- A majority of the freeway motorists (51 percent) found the experiment to be good or very good. Of the motorists who use the Lunalilo Street on-ramp, 25 percent found the experiment to be good or very good, and 23 percent found it neutral.



* = Numbers represent the numbered day of the experiment.

Figure 11-4: Evolution of Speeds Across the Three Freeway Lanes (7:45 - 8:00 AM)

The negative impacts of the ramp closure included:

- Because the experiment was only two weeks in length, the results were not comprehensive enough.
- Ten percent of freeway motorists rated the experiment bad or very bad. This mostly applied to the drivers who exited early and did not experience the experiment site and therefore perceived longer travel times.
- Fifty-two percent of the Lunalilo Street on-ramp users found the experiment to be bad or very bad.
- Motorists who exited at or past the experiment site gave consistently higher ratings than those who exited earlier. It is clear that the motorists who exited early and did not experience the experiment site perceived longer travel times.

What parts of the planning process worked particularly well?

This demonstration project showed how effectively the two agencies (City and County of Honolulu and HDOT) could work to meet the very demanding requirements and project schedule.

What specific challenges were encountered in planning and closing the ramps?

The planning efforts required a tremendous amount of simulation modeling. Several simulations were required to establish a model with reliable flow conditions. This included an extensive effort to obtain origin-destination information to model motorist re-routings. More than thirty alternatives were analyzed in all.

Closing the ramp required a multi-agency effort. Both the City and County of Honolulu and HDOT worked with local police to ensure that the ramp closure went smoothly. These efforts were especially demanding on the City and State DOT staff.

What resources were required to plan and implement the ramp closures?

HDOT was responsible for the volume counts and overall coordination of the demonstration project. The City and County of Honolulu provided the police staff, helicopter use, and CCTV surveillance. Travel time surveys, coning, and use of the portable variable message signs (VMS) was contracted out by HDOT.

The following is a list of the staffing requirements and equipment needed to implement the ramp closure. This, of course, does not include all of the planning efforts prior to the ramp closure implementation.

- Staff and ten vehicles to conduct travel time surveys along seven routes with departures every 30 minutes.
- Traffic cones every three meters.
- Two police officers at the beginning and ending of coning.
- Three portable VMSs (at the beginning and ending of coning, as well as at the signalized intersection that feeds the Lunalilo on-ramp).

- Continuous monitoring and video recording at six locations through freeway and arterial surveillance CCTV cameras.
- Continuous volume data collection at all on-and off-ramps in the corridor.
- Several hours of helicopter surveillance and video recording.

What were the significant lessons learned by the agency as a result of this undertaking?

Though this ramp closure experiment was just two weeks long, there were some notable lessons learned. First, it is possible to conduct a ramp closure experiment on a major interstate freeway. Not only is it doable and safe, but it is also an affordable option to a ramp metering solution which would require considerable alignment changes in this case. Second, while experimentation is a wonderful method to determine the actual results, a short-term project is not able to attain simulated results because equilibrium and normal driving conditions can not be realized in two weeks time. Third, detailed simulations can be an effective representation of existing traffic conditions and future traffic conditions. Lastly, this experiment demonstrated a successful and cooperative multi-agency effort. Both HDOT and the City and County of Honolulu worked well together to meet the extraordinary demands of this short-term project.

What was the final outcome of this experiment?

In August 2004, HDOT started a formal pilot project aimed at easing congestion on the H-1 freeway. They began closing the Lunalilo Street on-ramp to morning weekday commuters from 6:00 to 9:30 AM. This was an attempt to eliminate a dangerous, traffic-slowing weave on the freeway. Commuters were rerouted to the Punchbowl Street on-ramp via Vineyard Boulevard. The State's preliminary data showed the change was working and has had little effect on area residents. The results were as follows:

- Travel time savings on the H-1 freeway after the project started was 10 minutes.
- The time it took to get from Piikoi Street to the freeway's Queen Emma Overpass via the Lunalilo Street on-ramp was an average of 9.2 minutes before the demonstration. With the rerouting, the same distance was covered in 4.5 minutes.
- There was no difference in the amount of traffic on the Punahou Street H-1 on-ramp before and during the ramp closure project.
- There was a small increase of traffic on the School Street on-ramp, but the increase was not enough to create congestion around the ramp.

In October 2004, the State decided to extend the Lunalilo Street on-ramp closure project until February 2005 so more data could be collected and community concerns answered. This time extension cost about $250,000, on top of the original $200,000 that was set aside. The State Transportation Director wanted to continue to evaluate the effects of the rerouting on the community, and was expected to send surveyors to some of the traffic congestion areas mentioned by the public. The data collected in the initial pilot was skewed because the project coincided with emergency sewer repairs on Kapiolani Boulevard, which shut down two lanes in either direction and suspended morning contraflow (reversible middle lane) that was typical for this arterial. The new data collected in January 2005 would be free from any such projects, holidays, and winter school vacations.[90]

Surveys handed out to motorists since the change show that 70 percent of the drivers near ‘Ainakoa Avenue in Kahala rated the project very good or good. However, 39 percent of the drivers on Vineyard Boulevard, where the Lunalilo Street traffic has been diverted, said the project was bad or very bad.

Closing the Lunalilo Street on-ramp in the morning rush hour has helped thousands of East Honolulu commuters on H-1 freeway get to work faster, but Makiki residents say they have paid the price for the convenience of others. The State Transportation Director said that the demonstration project closing the on-ramp has been a success, but that a final look at the Makiki concerns must be done before making the ramp closure change permanent.[91]

In Fall 2004, the Lunalilo Street on-ramp closure was made permanent. Since this time HDOT staff have been working with a local engineering firm to implement ways to automate the closure with devices such as retractable/collapsible curtain of delineators and a zipmobile for relocating New Jersey style barriers.[92]

11.6 A Systematic Approach to Ramp Metering – Caltrans (California DOT)

This section describes efforts to incorporate ramp metering into a coordinated strategy for deploying operational strategies. The case study uses the recent efforts of Caltrans to develop a systematic and integrated deployment strategy as an example.

In September 2002, Caltrans developed their Transportation Management System (TMS) Master Plan, which is intended to serve as a blueprint for deploying and integrating TMS strategies in the State in a systematic and coordination fashion.[93] The TMS strategies include ramp metering, incident management, arterial signal management, traveler information systems, and the associated support elements.

Caltrans is committed to integrating all prior and future TMS investments into a comprehensive plan that delineates the roles and responsibilities of different transportation agencies and stakeholders, identifies the goals and objectives of the overall transportation operations strategy, and lays out a detailed action plan to reach these goals. The overall operations strategy for the state is described in the Transportation Operations Strategy (TOPS) report published in February 2000. The TMS Master Plan is designed to build on the TOPS findings to define the necessary steps to fully enable the strategies discussed in the TOPS report.

The TMS Master Plan lays out the blueprint for safer and more effective operations of the state transportation system, through system management enabled by intelligent infrastructure. It is intended to be the foundation for all future Feasibility Study Reports (FSR), by laying out the critical milestones for harnessing information technology for system management. Moreover, the TMS Master Plan will guide Caltrans as it works with others to realize its vision.

This section will summarize the efforts to develop this plan, focusing on the issues related to ramp metering, including:

- What was the purpose of developing the plan?
- What are the benefits of developing and implementing the plan?
- What was the process undertaken to develop the plan?
- What significant challenges were encountered in developing and implementing the plan?
- What specific guidelines were identified to improve the planning and deployment of ramp metering systems?
- What specific guidelines were identified to better integrate ramp metering as part of an overall operations strategy?
- What resources were necessary to develop the plan?
- How is the plan expected to be applied? How is the plan expected to evolve over time?
- What were the significant lessons learned by the agency as a result of this undertaking?

11.6.1 System Summary

This section provides summary background information of the physical and operating characteristics of the Caltrans ramp metering system as shown in Table 11-8.

Table 11-8: Ramp Metering System Summary – California Statewide

Characteristic	
Number of Meters	1,000+ meters Statewide
Freeway Miles	Approximately 70 percent of urban freeway miles
Types of Strategies/ Algorithms Applied	Local and system-wide, pre-timed and traffic responsive control
Time of Day Operation	Varies by location. Generally peak periods with isolated operation during special events
Planned Expansion of the System	Planned expansion to over 1,400 locations Statewide by 2008
Special/Unique Applications or Capabilities	Variety of applications and strategies Statewide

11.6.2 Institutional Summary

Table 11-9 summarizes the institutional characteristics of the Caltrans ramp metering system.

Table 11-9: Institutional Summary – California Statewide

Characteristic	
Managing Agency(ies)	California Department of Transportation (Caltrans)
Year Started	Pre-1970
Goals of Implementing System	Improve the safety and capacity in freeway merge areas
Implementation Planning Process	Has historically varied throughout the State. The project described in this case study was initiated to provide a more consistent planning and implementation process Statewide.
Evolution of the System	The system in the State represents a mature system. Processes are being refined to provide a systematic expansion of the system as the needs require.
Operating Agreements/ Multi-Jurisdictional Agreements	Varies throughout the State
Evaluation or Monitoring Activities Performed	Numerous evaluation efforts have been performed in multiple regions. The most recent evaluation effort included an assessment of ramp metering effectiveness when combined with other operational strategies using a traffic simulation model, as described in Section 11.6.3.

11.6.3 Lessons Learned

This section focuses on the recent effort conducted to develop systematic guidelines for deploying and operating ramp metering statewide. Lessons learned in this effort will be related to practices presented in this manual.

What was the purpose of developing the plan?

The plan was developed to provide a more systematic process for deploying and integrating a group of operational strategies, known as Transportation Management System (TMS) in the State. The plan provides operational personnel and planners with greater information on the likely benefits of ramp metering, and other strategies, under a variety of operating conditions. The plan is also intended to provide guidelines for identifying locations where the expansion of ramp metering is warranted. This process is intended to help planners better target the correct strategy, or combinations of strategies, according to the specific deficiency that needs to be addressed.

What are the expected benefits of developing and implementing the plan?

It is expected that the plan will provide for greater consistency of ramp metering and TMS operation in the State and will help maximize the benefits from these deployments. The information in the plan is intended to help planners identify where ramp metering is most beneficial and identify opportunities for integrating ramp metering with other strategies to maximize the benefits of the combined systems. In doing so, the plan is expected to allow an improved prioritization of implementation locations, as well as improved estimates of the future expenditures and resources needed to expand and operate the system.

What was the process undertaken to develop the plan?

The first step in developing the TMS plan was the analysis of the likely impacts of the various TMS strategies under a variety of operational conditions. To complete this analysis, a microscopic traffic simulation model was developed using two corridors, representing the I-405 corridor in Southern California and the I-680 corridor in Northern California. Two different corridors were used to test the strategies' effectiveness under different congestion conditions. A number of scenarios were then developed representing different deployments and varying travel conditions including time-of-day and incident conditions.

Ramp metering types used in the analysis included pre-timed, traffic responsive, and system-wide metering strategies. Each of these strategies was tested with no queue control as well as moderate and aggressive queue control. These strategies were tested, alone and in combination with other strategies, under a variety of conditions. The purpose of this analysis was to identify the likely benefit of the systems under varying operating conditions and to identify which underlying traffic conditions were best improved by different strategies. The outcome of this analysis was the identification of guidelines for deploying ramp meters that identify minimal traffic volumes and conditions that warrant metering implementation at a particular location.

The deployment guidelines were evaluated for locations throughout the State to identify where ramp metering should be expanded based on both the current conditions as well as under future expected conditions. This analysis identified the magnitude of the expansion necessary to provide consistent application of ramp metering strategies throughout the State. This formed the basis for additional benefit/cost comparison of the relative impacts of the system.

What significant challenges were encountered in developing and implementing the plan?

The identification of the likely benefits of different ramp metering strategies was complicated by the sheer number of different combinations of strategies and travel conditions. The need to identify the impacts of these numerous scenarios prevented the use of real-world "before" and "after" studies of impacts of existing ramp metering implementations. Instead, a microscopic traffic simulation model was employed to provide the evaluation team with the flexibility and control over conditions that allowed the meaningful and comparable assessment of impacts.

What specific guidelines were identified to improve the planning and deployment of ramp metering systems?

The guideline identified by the study states that ramp metering should be deployed in urban/suburban locations "where forecasted volume is greater than 1,800 vehicles per hour at the rightmost freeway lane plus on-ramp, and at locations with significant merging problems" (forecasted volumes are generally obtained from regional travel models). Priority should be given to already congested locations whenever possible in coordination with regional and local agencies.

What specific guidelines were identified to better integrate ramp metering as part of an overall operations strategy?

Guidelines similar to the ramp metering deployment guidelines were identified for a number of TMS field elements including vehicle detection, camera surveillance, arterial signal control, changeable message signs (CMS), and other operations strategies. The plan also identifies the likely incremental travel time impacts of combining various combinations of strategies in congested and less congested conditions to provide planners with an enhanced understanding of the likely benefits of integrating various strategies. These are shown in Table 11-10.

What resources were necessary to develop the plan?

The plan was developed by a consultant team at a cost of approximately $200,000 to Caltrans. This cost includes the resources for conducting the analysis of all TMS strategies, including ramp metering. Existing calibrated simulation models were modified for use in the study to reduce the resources needed to perform the analysis. However, a significant effort was still required to add detail to the existing corridor networks and adjust model parameters to provide an accurate analysis of the numerous strategies.

Table 11-10: Peak Period Vehicle Hours Traveled (VHT) Impacts - Combinations of TMS under Incident Conditions

Year 2010 Simulation Scenarios	I-680	I-405/I-5
Existing Incident Management (26 minutes*)	0%	0%
Add Traveler Information	-4%	-3%
Add Traveler Information + Adaptive Arterial Signal Control	-2%	-5%
Add Traveler Information + Simple Adaptive[4] Ramp Metering with Aggressive Queue Control (QC)	-10%	-6%
Add Traveler Information + Adaptive Arterial Signal Control + Simple Adaptive Ramp Metering with Aggressive Queue Control (QC)	-15%	-7%
Add Traveler Information + Adaptive Arterial Signal Control + Corridor Adaptive[5] Ramp Metering with Aggressive Queue Control (QC)	-17%	-6%

* The average incident duration is 26 minutes with multiple incidents using existing Incident Management strategies.

How is the plan expected to be applied? How is the plan expected to evolve over time?

The plan is intended to provide guidelines for practitioners in determining where the deployment of ramp metering and other TMS strategies would be most beneficial. The plan provides additional information for planners analyzing various deployments and aids in the project prioritization process. Although no formal update process has been implemented, these guidelines may be periodically modified as more information becomes available and the different strategies evolve. The plan also included an effort to detail the planned expansion of TMS strategies in the State and provide estimates of the likely costs and benefits of these deployments. Recent changes in the State's budget resources have resulted in significant changes in these plans, and the implementation of this portion of the plan was suspended pending future funding increases.

[4] Simple adaptive is equivalent to a local, traffic responsive system.
[5] Corridor adaptive is equivalent to system-wide, traffic responsive system.

What were the significant lessons learned by the agency as a result of this undertaking?

There were five specific lessons learned that are worth noting:

- Implementation of ramp metering on previously un-metered, congested corridors provided some of the most significant benefits of all the strategies tested.
- Travel time saving benefits of ramp metering were higher in more congested corridors.
- In general, the more sophisticated technologies and strategies brought about greater benefits.
- A comparison of the benefits and costs of upgrading ramp meters in a corridor from traffic responsive to a system-wide metering strategy indicated that the incremental benefits typically do not justify the added expense of system detection needed to operate the system. Therefore, unless the added detection capabilities can also be shared with other strategies (e.g., incident detection), simple adaptive (e.g., local, traffic responsive) deployments should not be upgraded to corridor adaptive (e.g., system-wide traffic responsive).
- Scenarios tested with moderate queue control provided greater time savings benefits than those scenarios using aggressive queue control.

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