MODULE 1. FREEWAY MANAGEMENT CONCEPTS

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MODULE 1. FREEWAY MANAGEMENT CONCEPTS

Figure 1-1. I-35 Freeway in Austin, TX.

1.1 INTRODUCTION

Freeways were originally conceived and designed to provide continuous, free-flow, high-speed movement of traffic on limited-access facilities. In their original design, little thought was given to providing for the needs of traffic management and control systems to maintain a high level of mobility on these facilities. However, as urban areas continued to grow, the freeway system became more congested. Today, the previous approach of constructing more freeway lane-miles to relieve congestion is often politically and socially unacceptable and economically infeasible. It is incumbent on transportation agencies planning, constructing, operating, and maintaining freeway infrastructure to make the best possible use of available capacity.

Freeway management systems are a primary means that transportation agencies can use to manage traffic flow and make better use of the existing freeway system. Freeway management systems make use of control strategies, and operational activities such as incident management and information dissemination to 1) keep congestion from occurring in the first place, and 2) lessen the duration and extent of congestion when it does occur.

While the term *freeway management system* was probably not applied to the tasks, early freeway management systems consisted primarily of fixed signs on the roadway providing regulatory and directional information and police officers handling traffic during incidents. As freeway systems have matured and traffic demands have grown in urban areas over the past half century, freeway management systems have evolved and developed to provide many and varied services.

This handbook discusses the concepts and functional requirements for a freeway management system. It discusses some of the critical issues associated with planning, designing, operating, and maintaining each of the individual elements of a freeway management system. However, prior to comprehensive treatment of the various freeway management elements, it may be helpful to define management systems, the problems they address, and why they are important.

CONGESTION

Congestion on a freeway occurs when demand exceeds capacity. A section of freeway where traffic demand exceeds freeway capacity is called a bottleneck. Bottleneck (or congested) conditions occur either when demand has increased to a level greater than capacity or when capacity has decreased below a level that can accommodate the demand.[1]

Bottleneck conditions are commonplace on the freeway system in many urban areas. Generally, congestion can be classified as either recurring or nonrecurring. Recurring congestion is usually caused when the amount of traffic wanting to use the freeway exceeds the available traffic-carrying capabilities of the system. Generally, recurring congestion occurs at a predictable location during specific periods of the day. Nonrecurring congestion, on the other hand, is less predictable. It is generally caused by random or less predictable events, such as vehicle crashes and incidents, that temporarily reduce the capacity of the freeway, or by special situations (such as sporting events, construction and maintenance activities, inclement weather, etc.) that temporarily increase the demand on the freeway.

Understanding the type and primary causes of congestion in the freeway network is the first step in determining and evaluating options for addressing identified problems with a freeway management system. The strategies that might be implemented to address the recurring congestion problems are not necessarily the same as those that are effective in mitigating the impacts of nonrecurring congestion. From a driver's perspective, however, the impacts of congestion, regardless of whether it is recurring or nonrecurring, are the same:

- Reduced travel speeds.
- Erratic travel speeds characteristic of stop-and-go movement.
- Increased and inconsistent travel times.
- Increased potential for vehicle crashes.
- User dissatisfaction and frustration.

The inability to provide a reliable, albeit sometimes lower, level of service is perhaps a more severe problem than the inability to eliminate congestion altogether. If users know to expect a certain level of congestion during a travel period, they can plan their trip accordingly. If, on the other hand, drivers are unaware of the extent or nature of congestion, they cannot make accommodations to adjust their transportation mode, departure time, or route choices. From this standpoint, one objective of a freeway management system is to provide travelers a consistent level of operation on the freeway.

Measuring Congestion

A motorist usually thinks of congestion in terms of overcrowded freeways, freeway crashes, stop-and-go driving conditions, and the frustration and discomfort of restricted maneuverability. The transportation professional, on the other hand, often expresses congestion in terms of traffic variables such as flow rate, density (or occupancy), and average space speed, together with the fundamental relationships surrounding them. For example, figure 1-2 illustrates the fundamental relationship between flow rate and density. As traffic density increases from zero to some value, k_1, traffic flow rate increases, and the resulting operation is defined as uncongested. As density increases from k_1 to k_2, however, though flow rates tend to increase, traffic operations become unstable, and the probability of serious breakdown increases. Further increases in density above k_2 result in a decrease in flow rate until, theoretically, it reaches zero at jam density, k_j. The traffic flow regimes occurring at densities greater than k_2, are classified as congested.

The specific value of density used to define congestion depends on a number of factors including the geometrics of the freeway section, the composition of the traffic, and local driving habits. The 1994 *Highway Capacity Manual* defines the density of the freeway at congestion (i.e., Level of Service F) to be between 24.8 and 29.9 passenger cars per kilometer per lane (39.7 to 47.9 pc/mi/ln), depending on the original freeway flow speed of the freeway.[(2)] McDermott has reported that lane occupancies (a surrogate measure for density) in the range of 0 to 20 percent, 20 to 30 percent, and 30 to 100 percent indicate uncongested, unstable (impending congestion) and congested operations, respectively.[(3)] Figure 1-3 shows generalized freeway traffic operations curves that relate lane occupancy to flow rate and average space speed.[(2)] As lane occupancy exceeds 20 percent, travel speeds on the freeway decrease because of the following:

- There are fewer and shorter gaps between vehicles.
- Drivers have greater difficulty in changing lanes.
- There are generally more restrictive traffic flow conditions.

Causes of Congestion

Freeway congestion may be characterized as either recurring (generally caused by demand exceeding fixed capacity or fixed geometric restrictions) or nonrecurring (where fixed capacity is reduced due to non-normal events such as vehicle crashes, stalls, spilled loads, weather, or maintenance activities). FHWA estimates that nonrecurring congestion accounts for approximately 60 percent of all congestion.[(4)]

Factors and situations that may cause a freeway segment to become congested include the following:[(5)]

- Geometric design.
- Traffic operations (including capacity deficiency).
- Incidents.
- Maintenance and construction.
- Weather.

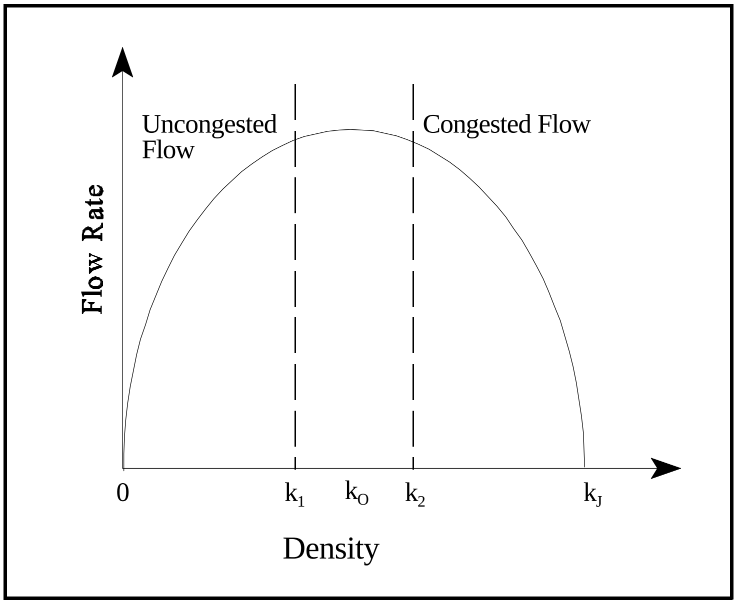

Figure 1-2. Congestion and the Fundamental Relationship Between Flow Rate and Density. [4]

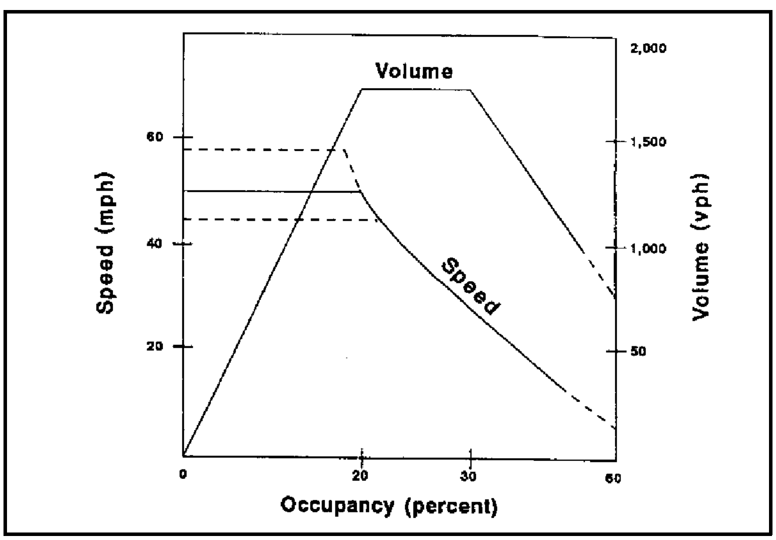

Figure 1-3. Generalized Traffic Flow Relationships. [3]

Geometric Design

The capacity of a freeway usually does not remain constant along its entire length. Certain physical features result in capacity restrictions. Upstream and downstream from the location of these features, capacity usually proves slightly higher, resulting in bottleneck conditions. Table 1-1 lists some of the features that restrict capacity of the freeway and are a source of congestion.

Traffic Operations

Traffic operations can also be a source of congestion—anything from too much demand on the freeway to the presence of heavy vehicles in the traffic stream. Some of the traffic operations factors that can cause congestion on a freeway include the following:

- True demands in excess of available capacity.
- Unrestrained ramp access where ramp traffic causes demand for the freeway to exceed the available capacity.
- Exit ramp queues where demand exceeds the ability of the merge area or downstream intersection to process it, causing queues to backup onto the freeway.
- Heavy weaving and merging movements between ramps and the freeway main lanes.

Incidents

Vehicle crashes and other traffic incidents are major sources of nonrecurring congestion. The factors that affect the amount of congestion resulting from an incident include the following:(5)

- The duration of the incident.
- The amount of capacity reduction caused by the incident.
- The amount of travel demand on the freeway at the incident location.

During an incident, the capacity of the freeway is reduced disproportionately to the physical reduction in width of the travel lanes. Table 1-2 shows the amount of capacity reduction imposed on freeways of different sizes by different incident types.

Maintenance and Construction

Maintenance and construction cause congestion with significant accompanying delays. Like incidents, construction and maintenance activities reduce the amount of capacity available to service demand. The impacts of construction and maintenance activities on traffic operations can be lessened by implementing the following measures:(4)

- Schedule activities for times when demand is anticipated to be low (i.e., at night or on weekends).
- Complete all activities in a given section and lane at one time.
- Provide adequate on-site traffic control and advance information to travelers.
- Report expected and current delays in activities.

Weather

The weather can also be a source of traffic congestion. Both rain and snow can significantly reduce the capacity of the freeway. For example, even trace amounts of rain can reduce the capacity of the

Table 1-1. Geometric Design Factors Causing Capacity Reduction. [4]

Design Factor	Result
Reduction in lanes	• May cause congestion where number of lanes is reduced. • Even though lane drop occurs at exit ramp, through volume may exceed remaining capacity. • Weaving out of dropped lanes may create turbulence, cause speed to decrease, and decrease capacity. (May cause problem where multiple freeways merge without maintaining the same number of lanes.)
Horizontal curvature	• Moderately sharp horizontal curve may reduce capacity. • In heavy flow, vehicle may cross into next lane, causing hesitation and speed decreases in adjacent lanes. Even momentary speed decreases during periods of unstable flow can result in congestion.
Vertical alignment	• Grades reduce capacity, particularly with trucks present. • Although design standards impose limitations on acceptable grades, vertical alignment may cause small, but imperceptible, speed changes that affect following traffic and can result in congestion. • Upgrades in tunnels limit capacity.
Other physical features: • Lane widths • Lateral clearance • Ramp design • Surface conditions	• Older freeways may have lanes narrower than 3.6 m (12 ft) standard, resulting in capacity reduction. • Lateral obstructions may reduce capacity if located closer than 1.8 m (6 ft) to a traveled lane. Examples include: - bridge abutments - retaining walls - illumination poles - sign supports • Lack of full shoulder-width bridges reported to result in a point reduction in capacity. • Weaving movements are restricted at access points and exits.

freeways in Houston, Texas by 14 to 19 percent. In Minneapolis, trace amounts of snow have been reported to reduce capacity by 8 percent and for each 0.02 cm/hr (0.01 in/hr) increase, capacity is reduced by an additional 0.6 percent.[4]

Table 1-2. Percentage of Freeway Section Capacity Available Under Incident Conditions. [(4)]

Number of Freeway Lanes in Each Direction	Shoulder Disablement	Shoulder Accident	Lanes Blocked		
			One	Two	Three
2	0.95	0.81	0.35	0	N/A
3	0.99	0.83	0.49	0.17	0
4	0.99	0.85	0.58	0.25	0.13
5	0.99	0.87	0.65	0.40	0.20
6	0.99	0.89	0.71	0.50	0.25
7	0.99	0.91	0.75	0.57	0.36
8	0.99	0.93	0.78	0.63	0.41

1.2 FREEWAY MANAGEMENT

WHAT IS FREEWAY MANAGEMENT?

The 1983 *Freeway Management Handbook* defined freeway management as the " . . . control, guidance and warning of traffic in order to improve the flow of people and goods on these limited access facilities."[(6)] Today, the definition of freeway management should be expanded to encompass all activities undertaken to operate a freeway facility in a manner consistent with predetermined goals and objectives of that facility including those related to the impacts on and the influence of surrounding communities and jurisdictions. Certainly, the efficient movement of goods and people continues to be one of the major goals of freeway management. However, legislative mandates and public pressure regarding environmental concerns, adjacent landowner and homeowner rights, and other issues can further influence the operation of the freeway system.

In many cases, freeway management requires striking a balance between competing goals and objectives. For example, a goal to minimize recurrent congestion may not necessarily be compatible with a goal to maximize the movement of people and goods on a facility, especially if the goal to maximize people movement is accomplished through the use of high-occupancy vehicle lanes. High-occupancy vehicle lanes must offer the user a significant travel time advantage over regular-use lanes to be attractive to travelers using the freeway. In terms of this example, it may be appropriate to allow some level of congestion in the regular-use lanes in order to achieve the best overall operation of the freeway system.

WHAT IS A FREEWAY MANAGEMENT SYSTEM?

In general terms, a system is defined as a set of components or elements that could be seen as working together for the overall objective of the whole.(7) These components or elements can be many different things, depending on the perspective of the person who defines the system. System components can be objects, concepts, processes, or even people. A system has a set of boundaries that define the interactions between system components and the environment. The environment consists of all those factors external to the system that influence the behavior of the system, but which cannot be controlled. There are interfaces between the components of the system which control how they interact with each other. Finally, the components themselves can be subsystems consisting of smaller elements or components.

A freeway management system, then, consists of the infrastructure elements utilized to accomplish the goals and objectives of freeway management. These things (components) include field hardware (cameras, variable message signs, electronic toll tag readers, etc.), communications equipment, a traffic management center (with associated hardware and software), the people who staff the center, and the policies and procedures established to deal with various transportation-related events that impact the freeway system. The freeway management system comprises several infrastructure subsystems (the motorist information system, the ramp metering system, etc.) that interface with each other to accomplish specific objectives as the need for them arises.

It is important to recognize that each freeway management system is a unique consolidation of components and interfaces that reflect the location-specific freeway, geographic, and political characteristics and needs of the region. However, most systems can be described in terms of which of the possible functions of freeway traffic management they perform. The following section presents a brief overview of these functions.

OBJECTIVES OF A FREEWAY MANAGEMENT SYSTEM

The goals and objectives of any one freeway management system are specific to the social and political desires of the community; however, there are goals and objectives for freeway management systems that are universal across all systems. These include the following:(8)

- To reduce the impacts and occurrence of recurring congestions on the freeway system.
- To minimize the duration and effects of nonrecurring congestion on the freeway system.
- To maximize the operational safety and efficiency of the traveling public while using the freeway system.
- To 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.
- To provide a means of aiding users who have encountered problems (crashes, breakdowns, confusion, etc.) while traveling on the freeway system.

HISTORY OF FREEWAY MANAGEMENT

Pioneering efforts in "freeway surveillance and control" as systems were generally known, took place in Detroit, Chicago, Houston, Los Angeles, Seattle, and Dallas. Highlights of some these early efforts are listed below:[9]

- **1960 Chicago** - Freeway service patrols.
- **1960 Detroit** - CCTV on freeways.
- **1962 Detroit** - Freeway lane control signs and variable speed signs.
- **1962 Chicago** - Surveillance by freeway loop detectors.
- **1963 Chicago** - Demand-capacity / occupancy metering.
- **1965 Houston** - Demand-capacity / gap-acceptance metering and surveillance by closed-circuit television and freeway loops.
- **1967 Los Angeles** - Fixed time metering and ramp closure.
- **1967 Seattle** - Reversible roadway control and closed circuit television surveillance.
- **1971 Dallas** - Corridor control integrating ramp metering, frontage road and arterial intersection control with preferential treatment for buses at ramps and intersections.
- **1972 Minneapolis** - Bus bypass ramps at metered ramps.
- **1990** - Intelligent Vehicle/Highway (IVHS) concept introduced including freeway management and related systems.
- **1992** - Intelligent Transportation Systems (ITS) succeeds IVHS, broadening scope of concept.
- **1993** - National ITS Architecture Initiative begun to address common interfaces and protocols for ITS systems.

As systems were upgraded and expanded, they began to be more properly termed "Freeway Management Systems." New and upgraded systems have incorporated many of the basic techniques developed on those earlier systems. The phenomenal developments in computer and communications technology have further enhanced capabilities for various freeway management tasks.

Functions of Freeway Management

Freeway management systems combine personnel, operational strategies and technologies together to control and manage traffic on the freeway more effectively. Figure 1-4 highlights the basic functions of freeway management. The functions that can be performed by a freeway management system include the following:

- Surveillance and incident detection.
- Lane use control.
- Ramp control.
- Priority treatment and control for high-occupancy vehicles.
- Information dissemination.
- Incident management.

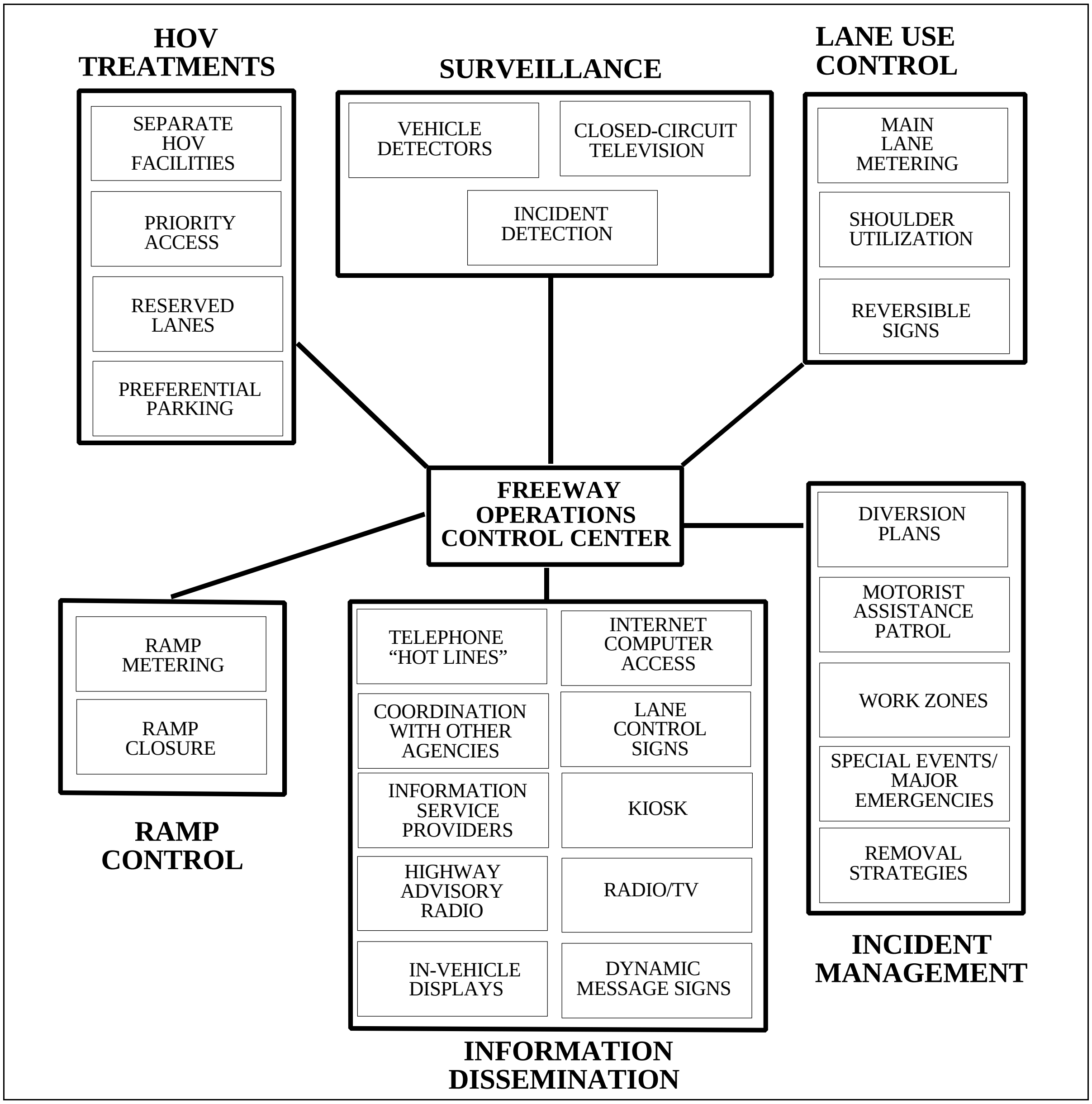

Figure 1-4. Functions and Elements of a Freeway Management System.

A brief review of each of these functions is provided below. A more detailed discussion of the pertinent issues affecting planning, design, operations, and maintenance is provided in subsequent modules.

Surveillance and Incident Detection

Traditionally, one of the primary functions of most freeway management systems is to provide traffic surveillance.[10] With surveillance, traffic conditions can be monitored and the location and causes of any operational problems that occur can be pinpointed. As traffic management systems have become increasingly multijurisdictional and multimodal, the surveillance function has expanded to include such things as transit and emergency fleet vehicle locations, weather and pavement conditions, and parking lot status.

Lane Use Control

The function of lane use control is to maximize the efficient use of existing pavement within the right-of-way. Mainline metering, temporary shoulder utilization, reversible lane operations, and large truck restrictions are all examples of lane use control.

Ramp Control

Managing the amount of traffic that can enter or exit the freeway is another function of freeway management systems. Both ramp metering and temporary ramp closures (during peak periods, for instance) are examples of the ramp control function. Controlling freeway access and egress reduces turbulence in freeway flow near the ramps and improves overall freeway operations.

High-Occupancy Vehicle (HOV) Priority Treatments

Another function of freeway management is to provide preferential treatment to buses, carpools, and vanpools on a freeway to generate a travel time advantage for the vehicle occupants and review the number of vehicles on the roadways. These treatments can include special lanes, priority access ramp controls for HOV vehicles, special surveillance of lanes to detect and remove incidents quickly, and occupant restriction enforcement.

Information Dissemination

From a traveler's perspective, information dissemination is one of the most important functions of freeway management. Research and experience have shown that travelers want and use real-time information about traffic conditions on the freeway and alternative routes; adverse weather and driving conditions; construction and maintenance activities; and special lane use and roadway control measures that are enacted. With current and accurate information, travelers are better able to make mode, departure time, and route choice decisions. A number of existing and emerging technologies are available to facilitate information transfer to travelers.

Freeway Management System

A freeway management system is generally the common interface for multiple transportation agencies in a given region. ITS infrastructure includes a "regional multimodal traveler information" element. This may be co-housed with the freeway management center. In that case, the freeway management center is the focal point for receiving, processing, and transferring various types of traffic and transportation data, including digital, video, and voice. Regional multiagency coordination will logically take place in the freeway management center.

Incident Management

Of all the major freeway management functions, incident management probably offers the greatest potential operational and safety benefit to freeway motorists.[5] Incident management requires the coordinated operation and preplanned use of human and technological resources to restore the freeway to full capacity quickly and efficiently after an incident occurs. Typically, incident management includes other freeway management functions such as the following:

- Control center operation.
- Surveillance.
- Information dissemination.

- Freeway service patrols.
- Ramp control.
- Decisions process control strategies.
- Lane use control signals.

Elements of a Freeway Management System

Each of the functions of a freeway management system requires one or more elements in order to successfully carry out that function. A number of these elements are pieces of hardware that must be in place, whereas others are procedures and strategies that are enacted. Generally, these elements can be categorized as existing or occurring either in the field, as part of the communication linkage, or within the control center.

Field Elements

A number of different technologies can be utilized in the field to monitor traffic conditions, control traffic access and lane utilization, manage incidents, and communicate with motorists. Most of the major field elements are illustrated in figure 1-4 (within each major freeway management function). Within certain elements, a variety of hardware technologies can be employed. For example, vehicle detection within the surveillance function can be accomplished through inductive loop detection, microwave or radar sensors, video imaging, automatic vehicle identification or location, or other technologies, depending on the type of data desired. Similar alternatives exist for information dissemination, lane use control, and incident management functions.

Communications Element

Communications can be thought of as the backbone of freeway management.[11] The communications element transfers information from the field elements back to the traffic control center. In some cases, instructions and other data are transferred out from the center to the field elements. Reliability and performance are critical issues related to communications system design.

The communications element consists of a number of hardware components and supporting software. Again, a number of hardware technologies are available upon which to base communications. The two basic categories that exist are buried or aerial cable (fiberoptic, coaxial, twisted pair) or airwave transmission (microwave, radio [including narrow band or spread spectrum], cellular telephone, and citizen-band radio).

Communications infrastructures (and continuing system operational and maintenance costs) are typically the most expensive part of a freeway management system. FMS functional design must include the communications system concurrently with field devices and central control elements to ensure compatibility and economies of system deployment.

Control Center Elements

The traffic control center is the hub or nerve center of a freeway management system. It is where information about the freeway system is collected, processed, and collated. It can also be the location where decisions about control strategies are made, coordinated with other agencies, and implemented. Information dissemination is also typically coordinated and implemented from the center.

The major elements of the control center are the display and control interfaces that link the center to the various field elements through the communications element. The other major elements of a center are the human operators who monitor conditions and make the adjustments in control and management strategies needed to maximize the efficiency of the freeway system. Ultimately, the degree to which a traffic control center meets the objectives of the freeway management system depends on how well the human operators are able to interface with the system devices.(12)

Toll Roads Versus Freeways

It is important to note that any of the elements of a freeway management system can also be applied to the toll roads. Toll roads exhibit many of the same design features and operating characteristics as freeways. For example, access to both types of facilities is controlled. Both try to achieve high operating speeds. Both need to communicate trouble locations to users of the facilities.

The primary operating difference between toll facilities and freeways is the presence of toll booths. Toll booths are necessary interruptions to the free flow of vehicles on the facility, and need to be considered in developing control strategies.

Relation to National ITS Architecture

It is beyond the scope of this handbook to describe the National ITS Architecture initiative. However, the reader is directed to the extensive documentation that has been developed under that FHWA sponsored project. Quoting from the *1996 ITS Architecture Executive Summary*:

> *The National ITS Architecture provides a common structure for the design of intelligent transportation systems. It is not a system design nor is it a design concept.*

Agencies should seek to ensure that Freeway Management System design is compliant with the National ITS Architecture and applicable National Traffic Control/ITS Protocol.

Growing out of the National ITS Architecture development is the concept of Intelligent Transportation System infrastructure. The term "infrastructure" has been in common use for a number of years to describe the supporting roadways, bridges, water and sewer lines, and other public works structural items that allow movement of persons and goods. It is not the truck or car; it is the roadway and bridge. It is not the water; it is the pipes or conduits that carry the water. A logical extension of the infrastructure terminology is its application to flow and delivery of information in Intelligent Transportation Systems.

Many of the functions needed for ITS implementation are already being provided or supported by a broad variety of ITS infrastructure features, which can serve as the building blocks of a full ITS implementation. ITS infrastructure refers to those portions of ITS-related hardware, software, etc. that today, and increasingly in the future will manage and support the transportation-related activities. This is typically happening first in the metropolitan areas, but is expanding to include commercial vehicle and rural needs.(13)

An intregrated transportation management system contains two or more of the following nine components:

- Traffic Signal Control.

- Freeway Management.
- Transit Management.
- Incident Management.
- Electronic Fare Payment.
- Electronic Toll Collection.
- Railroad Grade Crossings.
- Emergency Services.
- Regional Multimodal Traveler Information.

Although freeway management and incident management are the components included in this handbook, the other components are often noted as they relate to those two components.

Freeway Management

Real-time information describing flow conditions is essential to managing the freeway system. Such information is repackaged for dissemination to the traveler, and is also used to make control decisions such as in-ramp metering or lane use control. Deployment objectives for the freeway management element of an ITS infrastructure are as follows:[(13)]

- Provide critical information to travelers through infrastructure-based dissemination methods such as variable message signs and highway advisory radio.
- Monitor traffic and other environmental conditions on the freeway system.
- Identify recurring and nonrecurring impediments so that short-term and long-term actions can be taken to alleviate congestion.
- Implement various control and management strategies (such as ramp metering and/or lane control, or traffic diversion).
- Use probe vehicles for additional sensors for collecting real-time traffic information.

Incident Management

Rapid detection, response, clearing the roadway, and restoring capacity are the essential elements of incident management. Reduction of secondary accidents and delays to the traveler are the result of an efficient incident management program. Deployment objectives for the freeway management element of an intelligent transportation management system are as follows:[(13)]

- Coordinate incident management across regional boundaries to ensure efficient and sufficient response.
- Use traffic management capabilities to improve response times.
- Use onboard moving map route guidance equipment to assist incident response vehicles (e.g., ambulances and tow trucks).
- Reduce traveler delay due to incidents.

Integration with Other ITS Infrastructure Components

As shown in Figure 1-5, freeway management is just one component of an integrated transportation management system. Freeway management, along with traffic signal control, form the hub of an

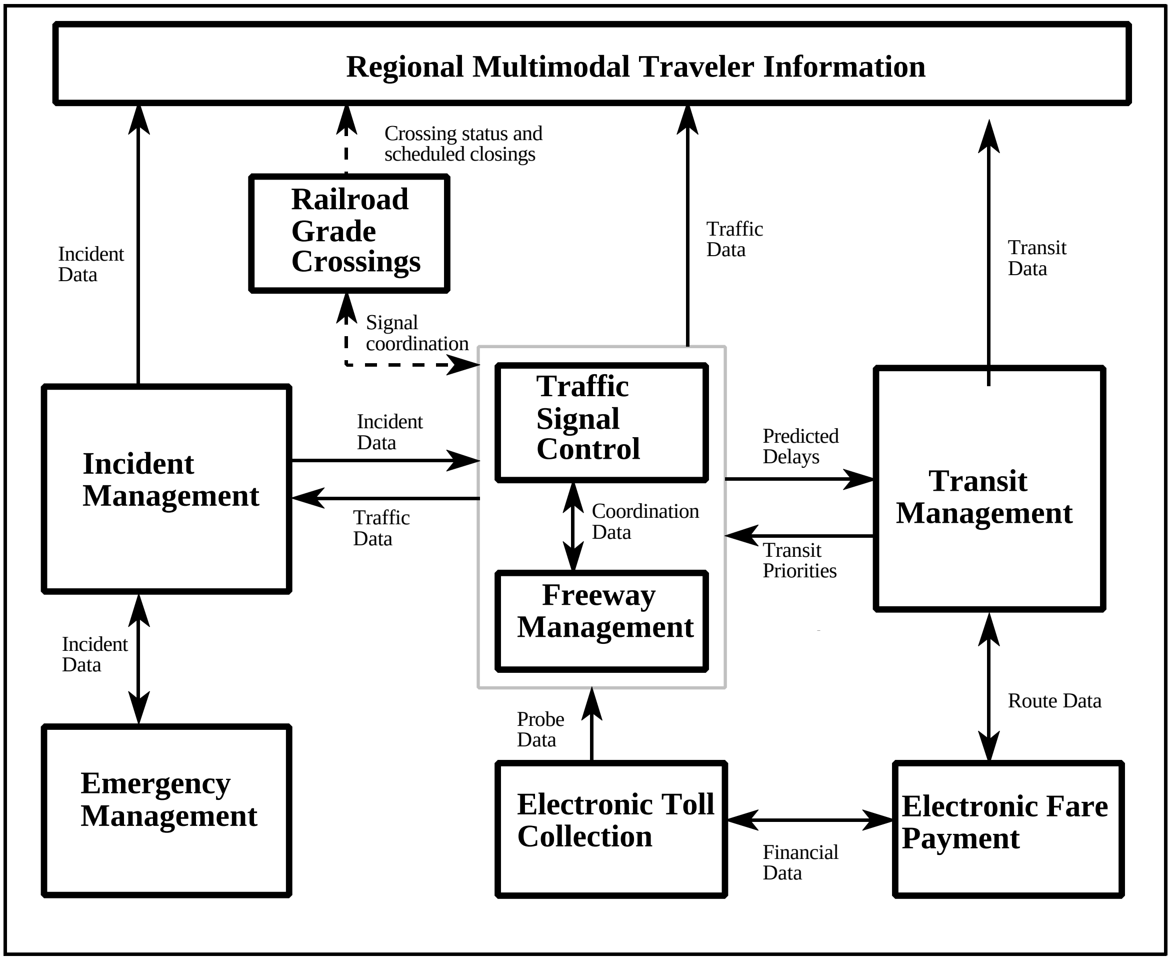

Figure 1-5. Freeway Management as Part of an Integrated Intelligent Transportation System. [14]

integrated transportation system. As shown inside the larger box, the traffic signal control and freeway management components exchange data with each other, allowing the traffic management strategies on the freeways, the freeway entrance ramps, and the surface street network to act as an integrated system. These data define the actions to be taken by the system when a particular signal timing plan is in effect on the road network, and when a particular sign plan is in effect on the highways. For example, ramp meter timings and traffic signal controls can be coordinated to ensure that queues do not back into intersections. When traffic is diverted off the freeway to bypass an incident, the traffic signals timings can be adjusted to handle the increased flow on the arterials. At the same time, dynamic message signs can be updated along the arterials to give directions on how to return to the freeway beyond the incident location.

In addition, both the freeway management and traffic signal control components can provide critical information to other components of the transportation system. Both the freeway management and traffic signal control components are responsible for the surveillance, monitoring, device control, and management of the road network. These components provide information on the status of the roadway system, including link travel times, traffic volumes, and speeds currently flowing on the road and highway network. These data can be passed to the other components in the overall transportation system, such as the incident management and transit management components, and information from these other systems can be channeled through the freeway management and traffic control components. Traffic data can also be output to a regional traveler information system for dissemination to the public for trip planning and other purposes. Because the freeway management and traffic signal control components are monitoring traffic conditions on the roadways, information about predicted delays and incidents can be passed to the transit management component, which in turn can use the information to establish transit priorities and operating strategies, which are implemented by the freeway management and traffic signal control components.

Although it may be possible for some transportation management subsystems to operate in an isolated or independent manner, their operation and functions will affect and be affected by the other transportation subsystems. This will be particularly evident in an urban environment. For optimal efficiency, the various transportation subsystems must operate in a cohesive, integrated manner. Multiple agencies must maintain open communication and cooperation to achieve the goal of a truly integrated transportation system.

For a description of the other infrastructure components and further information on the intelligent transportation infrastructure requirements for freeway management and incident management, the reader is referred to *Building the ITI: Putting the National Architecture into Action* and *Operation TimeSaver-Building the Intelligent Transportation Infrastructure.* [13, 14]

OBJECTIVE OF THE HANDBOOK

The objectives of this handbook are as follows:

- Define the process of planning, designing, operating, and maintaining a freeway management system.
- Provide an overview of the techniques and technologies available for accomplishing the functions of a freeway management system.
- Identify critical issues associated with planning, designing, operating, and maintaining a freeway management system.
- Provide guidance in developing a freeway management system that is compliant with the ITS National Architecture and applicable NTCIP and national standards.
- Identify points in the design development process where integration and interface with other systems should take place.

SCOPE OF THE HANDBOOK

This handbook is intended to be a "How To" manual for planning, designing, operating, and maintaining a freeway management system. This manual is directed at a mid-level administrator or engineer for a State or local agency that is responsible for planning, designing, operating, or maintaining all or portions of a freeway management system. As a result, it primarily focuses on the issues associated with each element of a freeway management system. For many of the elements and functions, there are excellent reference materials that provide detailed information about the technologies and techniques. For example, the *Communications Handbook for Traffic*

Control Devices and the *Freeway Incident Management Handbook* provide many technical details on communications and incident management systems, respectively.[5,11] In those cases where there are other manuals and reference materials to provide technical details, the details have not been reproduced in this manual. Instead, the reader has been provided with references to these materials as a source of more detailed information than that presented in this handbook is desired.

STRUCTURE OF THE HANDBOOK

A modular approach has been used to prepare this manual. Each functional element of a freeway management system is covered in a separate module. Each module presents information specific to the planning, design, construction, operation, and maintenance of that particular functional element. This approach was used when preparing this handbook so that system designers and operators can turn to the modules of interest and find all the information pertinent to the planning, design, operation, and maintenance of those specific elements.

In addition, a decision process module has been provided. The decision process module describes the systems engineering approach that can be used to plan and design a freeway management system. The systems engineering approach can be used regardless of whether a system is being designed from scratch, modifications are being made to an existing system, or upgrades are being planned to an outdated system. The decision process module also serves as a model of each of the remaining modules.

The same structure has been applied to each of the modules. Each module contains an overview section that provides some background into the nature of the functional elements, and the objectives and scope of the information presented in each module. Following the overview section, a section describes a system engineering process for planning, designing, and implementing the functional element within a freeway management system. Another section describes the techniques and technologies commonly used in each functional element. Each module also has a section devoted to covering any special issues that could not be adequately covered in the previous sections. Wherever possible, examples of state-of-the-art facilities are provided in each module. The module concludes with a section showing the references and suggested readings for the module.

A summary of the type of material to be covered in each of the proposed remaining modules is provided below.

Module 1. Freeway Management Concepts

This module provides an introduction to the handbook, including objectives, scope, and structure. Also included is an overview of freeway management concepts as a primer or preface to the 10 modules addressing technical issues and management issues.

Module 2. Decision Process

The second module is devoted to discussing the process for determining functions and technologies to be included in a freeway management system. It provides the steps to be taken for conducting a system engineering analysis for planning, designing, and implementing a freeway management system. This module focuses on the issues associated with integrating each of the functional elements to form a comprehensive freeway management system.

Module 3. Surveillance

This module contains information related to planning, designing, and implementing the surveillance subsystem of a freeway management system. Using the structure for the decision process discussed in Module 2, this module provides a process for determining the appropriate elements to be included in a surveillance subsystem. It provides an overview of the various technologies and techniques that are available for performing the surveillance functions in a freeway management system.

Module 4. Lane Use Control

This module focuses on the process for planning, designing, operating, and maintaining systems for controlling the use of the freeway main lanes. This module provides information related to the design and operations of freeway main lane meters, techniques for using the shoulder, and providing reversible lane control on the freeway. It also provides insight into the special issues related to operating and maintaining these control systems.

Module 5. Ramp Control

This module presents information needed to plan, design, operate, and maintain freeway ramp control systems. It provides an overview of the theory and principles of ramp control, including ramp metering and ramp closures. It also presents information on the different types of ramp metering strategies. The module concludes with a section on the special issues associated with ramp control systems, including maintenance, enforcement, and public perceptions and acceptance of various ramp control strategies.

Module 6. HOV Treatments

This module presents information needed to include high-occupancy vehicle (HOV) priority treatments in a freeway management system. It provides a summary of the planning, design, and operations issues associated with including an HOV treatment in a freeway management system. It also provides an overview of the decision process for determining which type of priority treatment is appropriate for a specific system. It also discusses some of the special design, operating, and maintenance issues associated with HOV treatments.

Module 7. Information Dissemination

This module describes the process for establishing a cohesive information dissemination subsystem in a freeway management system. It identifies the existing and emerging technologies available to facilitate information dissemination to travelers. It also illustrates how the information dissemination subsystem integrates with the other subsystems of a freeway management system.

Module 8. Incident Management

Module 8 presents information related to the planning, design, operations, and maintenance of an incident management subsystem in a freeway management system. It is intended to illustrate how to develop or enhance the incident management capabilities of a freeway management system. It also provides insight into the key factors and issues to be considered in planning, designing, and implementing an incident management subsystem. It is intended to complement the material already presented in the *Freeway Incident Management Handbook.*[5]

Module 9. Communications

This module provides insight into the issues associated with planning, designing, operating, and maintaining a communications subsystem in a freeway management system. It focuses on the decision process for determining the appropriate technologies and system architecture for specific freeway management systems. It also provides a summary of existing and emerging communications technologies. It is intended to complement the material already presented in the *Communications Handbook for Traffic Control Systems*.[11]

Module 10. Control Center

This module provides information related to planning, design, operations, and maintenance of the control center. It focuses on both the physical design and human factor elements associated with freeway management control centers. It also provides insight into how the functions of the freeway management system affect the design and operations of the control center. Special issues such as privatization of operator functions and multi-agency control centers are also discussed in this module.

Module 11. Economic Analysis

This module presents information on some of the economic analyses that can be used in planning and evaluating alternative designs of freeway management systems. Included in this module is step-by-step instruction on how to conduct a life-cycle cost evaluation, a benefit-cost evaluation, and other pertinent economic analyses.

This module also provides guidance to the reader on when it is appropriate to use the different types of economic analyses.

1.3 REFERENCES

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