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STATE-OF-THE-PRACTICE

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16. Abstract

This paper focuses on the proactive management of freeway facilities to balance the capacity of the transportation system and the prevailing demands, and response to out-of-the-ordinary conditions (e.g., incidents, adverse weather, work zones, special events, and emergency evacuations). This paper will benefit all that are involved with highway traffic operations and freeway management, including; State DOT, tollway and toll authority traffic operations managers, and the people who directly support them.

Specifically, this document summarizes the state-of-the-practice in freeway management and operations in order to provide a basis for recommending actions that will address gaps between the state-of-the-practice and state-of-the-art. The paper will help those involved with the operation and management of highways providing them with the opportunity to:

- Determine if parts of their system can be considered state-of-the-art or state-of-the-practice.
- Develop ideas for what would be needed to move to state-of-the-art or state-of-the-practice.
- Develop ideas of activities needed to close the gap between state-of-the-art and state-of-the-practice nationally.

This white paper is inter-related to, and can be considered a companion document with, the new Freeway Management and Operations Handbook (FMOH). The FMOH is intended to be an introductory manual – a resource document that provides an overview of the various institutional and technical issues associated with the planning, design, operation, and management of a freeway network. It is intended to provide the user with a better understanding of the life-cycle considerations for the freeway network (in the context of the overall surface transportation network) and the associated freeway operations and management strategies, including ITS components.

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FOREWORD

This document is intended for individuals responsible for the operation and management of freeway systems and those who support them. The document provides a focused discussion on the management and operation of freeways, expressways, and toll roads. Specifically, this paper provides guidance on how to manage and operate the freeway transportation system assets to get the most out of them. As such, the document summarizes the state-of-the-practice in freeway management and operations in order to provide a basis for recommending actions that will address gaps between the state-of-the-practice and state-of-the-art.

Freeway managers and operators who read this document may benefit by understanding approaches to better manage freeway facilities in an overall effort to minimize the effects of congestion, incidents and other events with a potentially adverse effects. Additionally, managers and operators will be able to perform the following tasks:

- Determine if parts of their system can be considered state-of-the-art or state-of-the-practice.
- Develop ideas for what would be needed to move to state-of-the-art or state-of-the-practice.
- Develop ideas of activities needed to close the gap between state-of-the-art and state-of-the-practice nationally.

This white paper is inter-related to, and can be considered a companion document with, the new Freeway Management and Operations Handbook (FMOH). The FMOH is intended to be an introductory manual – a resource document that provides an overview of the various institutional and technical issues associated with the planning, design, operation, and management of a freeway network.

TABLE OF CONTENTS

1 INTRODUCTION AND PURPOSE 1-1

1.1 PURPOSE AND FOCUS 1-1
1.2 PROBLEM STATEMENT 1-2

2 BACKGROUND 2-1

2.1 INSTITUTIONAL ARRANGEMENTS 2-1
2.2 ORGANIZATIONAL ASPECTS 2-2
2.3 FREEWAY MANAGEMENT SYSTEM FUNCTIONS 2-2
2.4 BENEFITS 2-4
2.4.1 Ramp Metering 2-5
2.4.2 Dynamic Message Signs 2-7
2.4.3 Electronic Toll Collection 2-7
2.4.4 Traffic Incident Management 2-8

3 STATE-OF-THE-PRACTICE 3-1

3.1 INSTITUTIONAL ARRANGEMENTS 3-1
3.2 ORGANIZATIONAL ASPECTS 3-2
3.2.1 Funding and Organizational Culture 3-2
3.2.2 Procurement 3-2
3.2.3 Staffing 3-3
3.3 SYSTEM FUNCTIONS 3-3
3.3.1 Freeway Management Systems 3-3
3.3.2 Corridor Traffic Management 3-4
3.3.3 Electronic Toll and Traffic Management 3-5
3.3.4 Decision-Support Systems 3-5
3.3.5 Traveler Information 3-6
3.3.6 Traffic Incident Management 3-6
3.3.7 Special Events Management 3-8
3.3.8 Communication Systems 3-8

4 STATE-OF-THE-ART 4-1

4.1 INSTITUTIONAL ARRANGEMENTS 4-1
4.2 ORGANIZATIONAL ASPECTS 4-2
4.2.1 Funding and Organizational Culture 4-2
4.2.2 Procurement 4-3
4.2.3 Staffing 4-3
4.3 SYSTEM FUNCTIONS 4-4
4.3.1 Freeway Management Systems 4-4
4.3.2 Corridor Traffic Management 4-5
4.3.3 Electronic Toll and Traffic Management 4-5
4.3.4 Decision-Support Systems 4-6
4.3.5 Traveler Information 4-7

4.3.6 Traffic Incident Management 4-8
4.3.7 Special Events Management 4-8
4.3.8 Communication Systems...4-9

5 GAP BETWEEN THE STATE-OF-THE-ART AND STATE-OF-THE-PRACTICE 5-1

5.1 INSTITUTIONAL 5-1
5.2 ORGANIZATIONAL...5-1
5.3 SYSTEM FUNCTIONS 5-2
5.3.1 Freeway Management Systems 5-2
5.3.2 Corridor Traffic Management...5-3
5.3.3 Electronic Toll and Traffic Management 5-3
5.3.4 Decision-Support Systems...5-3
5.3.5 Traveler Information 5-4
5.3.6 Traffic Incident Management 5-4
5.3.7 Special Events Management 5-4
5.3.8 Communication Systems...5-4

6 RECOMMENDED ACTIONS 6-1

6.1 INSTITUTIONAL 6-1
6.2 ORGANIZATIONAL...6-2
6.3 SYSTEM FUNCTIONS 6-2

1 INTRODUCTION AND PURPOSE

According to a Federal Highway Administration (FHWA) paper on reauthorizing legislation[1], providing effective highway-based transportation consists of three component parts:

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

The FHWA paper likens highway transportation to a three-legged stool that cannot effectively serve customer needs if any one of these three legs is missing or is underemphasized (too short) relative to the others. This paper focuses on the "operations leg" – proactively managing freeway facilities to balance the capacity of the system and the prevailing demands, and responding to out of the ordinary conditions (e.g., incidents, adverse weather, work zones, special events, emergency evacuations).

1.1 Purpose and Focus

The over-riding objective of freeway management programs is to minimize congestion and its side effects. The TRB Freeway Operations Committee's Millennium paper states:

> Freeway operations, in its broadest context, entails a program to combat congestion and its damaging effects: driver delay, inconvenience and frustration, reduced safety, and deteriorated air quality.

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

This paper focuses on management and operation of freeways, expressways, and toll roads. Its primary intended audiences are:

> *State DOT, tollway and toll authority traffic operations managers, and the people who directly support them.*

Specifically, this paper describes system management, operations, performance monitoring, and effective application of available tools. The critical idea is to manage and operate the freeway transportation system assets to get the most out of them. For instance, actions need to be taken to quickly identify where incidents are most likely to occur and devise a set of operational plans to prevent delays from occurring.

[1] "Operating the Highway System for Safety, Reliability and Security: TEA-21 Reauthorization Proposal" Jeff Lindley Federal Highway Administration, 2002

This document summarizes the state-of-the-practice in freeway management and operations in order to provide a basis for recommending actions that will address gaps between the state-of-the-practice and state-of-the-art.

For the purposes of this paper, the state-of-the-practice is defined as:

> *The proven practices in common use and the effective application of technologies commonly installed and operated in the freeway management and operations disciplines.*

For example, the state-of-the-practice in operating a data warehouse would include storing and disseminating historical and real-time transportation and traveler information.

By comparison, the state-of-the-art is defined as:

> *Innovative and effective practices and the application of leading edge technologies that are ready for deployment in terms of operating accurately and efficiently, but are not fully accepted and deployed by practitioners.*

For example, the state-of-the-art in operating a data warehouse would include dissemination of predictive data based on historical and real-time information.

This white paper is inter-related to, and can be considered a companion document with, the new Freeway Management and Operations Handbook (FMOH). The FMOH is intended to be an introductory manual – a resource document that provides an overview of the various institutional and technical issues associated with the planning, design, operation, and management of a freeway network. It is intended to provide the user with a better understanding of the life-cycle considerations for the freeway network (in the context of the overall surface transportation network) and the associated freeway operations and management strategies, including ITS components.

The intended audience of the revised Handbook is similar to that of this paper. Specifically, the intended audience for the FMOH is transportation professionals that may be involved with or responsible for any phase in the life cycle of a freeway network. Specific distinctions between the state-of-the-practice and state-of-the-art are not addressed in the FMOH. Emerging trends are identified, however. Moreover, experience, lessons learned, and examples are provided in many instances.

The FMOH provides much more in-depth discussion of freeway management practices than this paper does. Taken together, this paper and the FMOH provides extensive background in and description of freeway management systems and practices and identifies where improvements in the body of practice and knowledge can be made.

1.2 Problem Statement

Freeway operators and motorists continually face increased levels of freeway congestion and operational inefficiencies. The major contributors are population growth and increased vehicle use, combined with the inadequate growth (if any) in capacity. Transportation officials are struggling to keep up with the increases in freeway demand, but have thus far been unsuccessful. Transportation officials often must overcome political and economical barriers when implementing freeway improvements. Funding for transportation improvements has not historically matched the growing transportation system improvement needs. Funding resources have shown little increase while traffic demands have grown tremendously. For example, in Washington State investment in transportation in 1980, was $342 million, while in 2000 the investment level, stated in 1980 constant dollars, was $361 million, an increase of under 6 percent. During the same 20 year period, vehicle miles of travel in Washington State increase 88 percent.[2] It seems unlikely that this trend will change. Funding is likely to continue to lag behind the growth in demand.

Transportation officials need to make the most efficient use of the infrastructure that is in place and they need to continue to investigate new, low-cost alternatives to major new freeway construction. They also need to focus on the operations of the transportation system, to modify their perspective from a construction mindset to an improvement in operations mindset. In other words, instead of determining the best construction projects in which to invest capital funding, transportation officials need to determine how best to allocate their resources to provide an operational system that best meets the needs of the users of that system. Freeways can have greater levels of operational efficiency through improved freeway management and operation. Investing in properly designed and operated freeway management systems will help meet the needs of the traveling public and will help get the most efficiency out of the existing freeway infrastructure. Specifically these systems help reduce congestion in an effort to improve traffic flow and safety without having to add additional capacity (i.e., more lanes).

It is important to note that freeway management alone will not solve all the congestion problems transportation officials face today. However, investment in freeway management will provide better ways to cope with congestion, reducing the level of congestion compared to not investing in freeway management, and provide the infrastructure necessary to measure the performance of the system as a whole.

In order to manage the system effectively, appropriate technologies need to be deployed, integrated, and actively managed, so performance of the transportation system can be measured, information shared with appropriate interests, and actions taken in response to changing conditions.

Effective freeway management system operation is critical to the effective operation of the transportation network. Automated control and decision-support systems can greatly reduce the load on freeway management staffing. However, in order to operate at peak efficiency, well-trained staff are needed to:

- Actively manage and monitor decision-support systems,
- Adjust system operation as needed, and
- Take actions beyond the capability of automated actions of the computer systems (such as communicating with appropriate field personnel and emergency responders and coordinating with partner agencies).

It is important not only to have effective technologies and systems deployed, but also to have the needed resources available and staff trained to monitor and control the system. System operators need to understand how freeway management systems function and how

[2] Key Facts: A Summary of Transportation Information for Washington State. Washington State DOT. 2002

they can be adjusted, in order for them to be most effective and operated at their peak efficiency.

Operators need technological support if they are going to effectively operate the freeway system over the wide range of conditions that occur on the network. Freeway management agencies should have a knowledgeable support staff, available at all times, that understands the technologies employed. Sufficient technology support is key to the success of freeway management system operation.

Coordination and collaboration among operating agencies is also a key success factor. System operators also need to know how other related disciplines and related agencies operate. Interaction with and knowledge of public safety agencies is particularly important. Systems that bring representatives of various agencies together for operations provide a catalyst for this coordination.

2 BACKGROUND

Since the 1960s, population growth and economic prosperity, among other factors, have led to a steady increase in the number of vehicles using freeways across the United States. This increase in demand has unfortunately resulted in more turbulent traffic conditions, increased congestion and more frequent and longer traffic delays. Increased turbulence and increased vehicle demand leads to more conflicts and collisions. Today, the demand for freeway facilities is overwhelming, and problems have grown to epidemic proportion in some metropolitan areas. In a perfect world, these problems would dissolve with increases in capacity (i.e., adding more lanes, and new facilities). Increasing capacity, however, introduces significant economic and political challenges, many of which cannot be overcome. Moreover, increased capacity usually creates additional demand. Alternatively less expensive and more practical approaches to address the freeway congestion problem have emerged. One such approach focuses on managing and operating freeways more effectively.

In general terms, freeway management and operation is the monitoring, control, sensing, guidance, and dissemination of information to improve traffic flow. Freeway management should be implemented on a regional basis and encompass all the activities typically undertaken to operate a freeway corridor. This includes arterial street, transit, and freight operations. Depending on regional needs and freeway management goals, the extent to which freeway management is performed may vary from region to region.

2.1 Institutional Arrangements

Institutional arrangements are either formal (written) or informal, and can address operations, maintenance and funding. Written agreements are always required when multi-agency funding or other resource exchange is involved.

There are three levels of multi-agency coordination.

1. Level One: Involves minimal coordination between agencies, mainly voice communications. This level is state-of-the-practice.
2. Level Two: Involves sharing data (video, signal timing, incident and accident reports, weather information, construction information, etc.) and some level of turning control over to other agencies under pre-specified and agreed upon conditions (after hours, major incidents or events, etc.). This level is state-of-the-art.
3. Level Three: Involves integrating regional traffic management in a single centralized or distributed system that monitors and/or controls all traffic in all joining agencies. This level is rarely achieved in the United States. The jointly operated regional TMCs in Houston (TranStar) and San Antonio (TransGuide) are examples of this level. It is the leading edge of multi-agency coordination.)

Multi-agency operations coordination includes coordinating with multiple systems or agencies including local agencies, traffic signal systems, the enforcement community, emergency responders, transit operators, the CVO community and new security operations.

2.2 Organizational Aspects

Organizational aspects that have a direct impact on freeway operations include funding, procurement rules and laws, staffing, training and staff development, and succession planning. Transportation agencies, especially at the state level, traditionally have been organized to plan, design, and construct new facilities. The organizations and their support structures developed to carry out this primary function. As more emphasis is placed on managing and operating the transportation network, these organizational structures and their support systems need to evolve to support management and operations, including freeway management and operations.

2.3 Freeway Management System Functions

A freeway management system consists of a set of resources (e.g., electronic systems, people, objects, and strategies) that are used to accomplish a set of goals to improve the operation of the freeway network. These resources are typically housed or operated from a TMC, although they can also be operated over a communication network without the need a formal center. In systems that include a TMC, it serves as the information "nerve center" for regional operations. At a minimum, a freeway management system often incorporates the following functions to manage and control traffic more effectively.

Ramp Management – A process that controls the amount of traffic that can enter or exit the freeway, in an effort to maintain operational efficiency. Ramp control is exercised through ramp metering and ramp closure. Ramp metering controls the rate at which vehicles from a ramp enter the mainline. This reduces turbulence on the mainline by smoothing out the flow of vehicles entering the traffic stream. Ramp closure is rarely used as a long-term solution, but can be implemented when the capacity of an entrance or exit ramp is exceeded and the resulting queues jeopardize safety. Ramp closure is the only exit ramp control strategy in use.

Lane Use Management – A process used to maximize benefits and use of existing pavement, and improve the safety and efficiency of freeway operations. Lane use management is typically exercised through use of signs (static and dynamic), temporary traffic control devices, economic incentives and disincentives, and law enforcement. Lane use management includes designating certain lanes for the use by a particular class of vehicles (e.g., buses, carpools), the use of shoulders as a traveled lane during peak periods, contra-flow lanes, reversible lane control, and lane use control.

Lane use control uses dynamic signing to indicate whether a lane is open (green arrow pointing down over a lane), closed (red "X" over a lane), or is closed ahead (a diagonal arrow over the lane). Lane use control is typically used to increase traffic flow stability in order to improve safety. It also can provide secondary benefits in reducing congestion. Lane use control is not in widespread use in the United States. In Europe, the Netherlands and the United Kingdom use lane use control in conjunction with variable speed limits to smooth traffic flow approaching congestion and as work zone traffic control measures. The combination of lane use control and variable speed limits is termed motorway control in the Netherlands.

Information Dissemination – Provides the necessary information travelers need to effectively plan their trip prior to departure, and when en-route, to avoid incidents and adjust driving behavior. Pre-trip information is typically disseminated to the public via websites, media broadcasts, and mobile communication devices (e.g., personal digital assistants, pagers, and cell phones). En-route traveler information has traditionally been disseminated via commercial radio, dynamic message signs (DMS) and highway advisory radio (HAR). With the emergence of wireless communication technologies, en-route traveler information can also be disseminated through wireless phones, web-enable wireless phones, and a variety of personal digital assistants (PDA) equipped with wireless communication capabilities.

Traffic Incident Management – An operational approach that employs all of the available resources, including human and technological, to identify, manage, and clear incidents from a freeway in a quick and effective manner. Traffic incident management entails a very broad and complex set of activities and disciplines. One portion of those activities and disciplines are housed or controlled from the traffic management center (TMC) and utilize the freeway management system most directly. In the TMC, operators utilize networks of closed circuit television cameras, vehicle detection sensors, incoming 911 reports, incoming media reports, and mobile reports (from service patrols, police, maintenance personnel, and motorists) to monitor, verify, and determine the scope of incidents to notify the public, other agencies, or field personnel of incident conditions and impacts. In some systems, operators in the TMC may dispatch DOT operated service patrols or incident response teams to incident sites. Operators, in some systems, may also communicate directly with emergency response personnel and systems to receive current incident information. After field personnel arrive at the incident scene, TMC operators continue to monitor the incident and conditions surrounding the incident to inform travelers of traffic conditions via roadside equipment (e.g., highway advisory radio, dynamic message signs), personal computing devices (e.g., internet, cell phones, personal digital assistants, pagers) and/or media reports.

This paper focuses on the impact freeway management systems and traffic management center operators have on traffic incident management activities. The traffic information collected by freeway management systems is a key to effective traffic incident management. Quick identification and verification of incidents makes it possible for emergency agencies to respond more rapidly, and with the proper personnel and equipment.

There are equipment and systems that support these functions. These include:

Surveillance and Detection Systems – collect data on traffic flow and performance through sensor technology and allow operators to monitor conditions on the freeway system using sensors and video monitoring systems. The data collected feeds the control and information dissemination functions mentioned above, and allow operators to intervene when appropriate in those functions. Sensor technology also allows the system to monitor roadway and environmental conditions, such as pavement temperature and weather. Roadway and environmental condition information are often used in deciding how best to allocate resources for functions such as snow and ice control.

Data is also gathered from other agencies. In some systems, data is shared between public safety agencies and transportation agencies, as well as among transportation agency. The primary method of detecting incidents is through mobile 911 calls. A few freeway management systems, such as those in Salt Lake City, Seattle, and San Francisco, have access to computer-aided dispatch (CAD) systems that display incident information to TMC operators nearly as soon as the public safety agency knows about the incident.

Communication Systems – The effective operation of all of the functions mentioned in this section require communication of data, voice, or both. Communication systems transmit data from the field to a TMC or central location, transmit commands from the TMC or central location to the field equipment, transmits information among agencies, distributes traveler information to the systems that disseminate it, and allows personnel at any distance to communicate with one another.

Computer Systems and Systems Integration – Freeway management systems are dependent upon the computer systems on which they operate. Selecting the right computer platforms for the desired functions, developing or selecting the right software, integrating the software and hardware systems into a complete system, and maintaining the complete system is a critical element of providing effective freeway management systems. The on-going maintenance of these systems and the continuing integration of new features are often not well understood by traditional transportation engineers, planners, and practitioners. Discussing the state-of-the-art in software development, computer hardware, and system integration is beyond the scope of this paper. However, it is extremely important for transportation practitioners involved in freeway management systems to be aware of these issues and have personnel available with the knowledge and training needed to address these issues.

2.4 Benefits

Since the time of their inception in the 1960s, freeway management systems have had a positive effect on freeway operations. Effective management and operation of freeway facilities can lead to several benefits, some of which include:

- Improved Safety.
- Reliable Travel Times.
- Reduced Congestion and Delay.
- Reduced Emissions.
- Reduced Operations and Maintenance Costs.

Besides benefiting the general public, these systems have a positive indirect effect on the regional economy through improved movement of goods and services from origin to destination. Examples of measured benefits of freeway management are provided in Table

1. (These benefits were derived from a variety of studies and documents without a common set of measures used. The lack of consistency in measuring and reporting benefits makes it difficult to compare benefits from one study to another or accumulate benefits over the entire nation.)

Table 1: Measured Benefits of Freeway Management

Measure	Benefit
Travel Time[3]	Decrease 20% to 48%
Incident Duration	23 minute average reduction[4]*
	Decrease in incident duration time by 50%[5]
Travel Speed**Error! Bookmark not defined.**	Increase 16% to 62%
Freeway Capacity**Error! Bookmark not defined.**	Increase 17%to 25%
Crashes**Error! Bookmark not defined.**	Decrease 15% to 50%
Fuel Consumption**Error! Bookmark not defined.**	Decrease of 41% in congested areas
Emissions**Error! Bookmark not defined.**	Decrease HC emissions 1400 tons annually
	Decrease NOx emissions 1200 tons annually

*reduction observed on six sections of I-75 and I-85 in Georgia and includes the effects of operators, incident detection system, highway emergency response operators, and cameras

Benefits of specific traffic management strategies and technologies are descried below.

2.4.1 Ramp Metering

Ramp metering controls the rate at which traffic arrives at the freeway by holding traffic on the entrance ramp and releasing vehicles at a rate that the freeway can better absorb. Ramp metering breaks up platoons of vehicles, making it easier and safer for each entering vehicle to find a gap in the traffic stream to enter.

Documented ramp metering benefits include:

[3] http://www.its.dot.gov/tcomm/itibeedoc/fms.htm
[4] http://www.georgia-navigator.com/benefits/summary.html
[5] http://www.dot.state.wi.us/dtd/hdist2/monitor/projects.htm

- Reductions in total crashes from 15% to 50%
- Increase in mainline speeds from 8% to 60%
- Increase in vehicle throughput from 8% to 22%

In perhaps the most comprehensive assessment of ramp metering benefits, the Minnesota Department of Transportation (Mn/DOT) showed that ramp metering produces significant benefits in reducing crashes and delays and increasing speeds. Ramp metering has been an important element of Mn/DOT's traffic management efforts. However, some members of the public and legislature questioned the effectiveness of the strategy and a bill in the 2000 legislative session required Mn/DOT to turn the meters off and conduct an evaluation of the system.

Mn/DOT formed an evaluation team and began the study in Fall 2000. The goals of the effort included:

- Determining whether the benefits of ramp metering outweigh the negative impacts and associated costs;
- Identifying ramp metering impacts on surface streets and transit operations;
- Assessing public attitudes toward ramp metering; and
- Comparing the Twin Cities' system against ramp meter systems in other regions.[6]

The performance measures and results of the study, as reported in 2001, are listed below:[7]

Traffic Volumes and Throughput: After the meters were turned off, there was an average nine percent traffic volume reduction on freeways and no significant traffic volume change on parallel arterials included in the study. Also, during peak traffic conditions, freeway mainline throughput declined by an average of 14 percent in the "without meters" condition.

Travel Time*:* Without meters, the decline in travel speeds on freeway facilities more than offsets the elimination of ramp delays. This results in annual systemwide savings of 25,121 hours of travel time with meters.

Travel Time Reliability: Without ramp metering, freeway travel time is almost twice as unpredictable as with ramp metering. The ramp metering system produces an annual reduction of 2.6 million hours of unexpected delay.

Safety: In the absence of metering and after accounting for seasonal variations, peak period crashes on previously metered freeways and ramps increased by 26 percent. Ramp metering results in annual reduction of 1,041 crashes or approximately four crashes per day.

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[6] Twin Cities Ramp Meter Evaluation: Executive Summary; Cambridge Systematics, February 1, 2001

[7] Twin Cities Ramp Meter Evaluation: Executive Summary; Cambridge Systematics, February 1, 2001

Emissions: Ramp metering results in a net annual reduction of 1,160 tons of emissions.

Fuel Consumption: Ramp metering results in an annual increase of 5.5 million gallons of fuel consumed. This was the only criteria category which was worsened by ramp metering.

Benefit/Cost Analysis: Ramp metering results in annual savings of approximately $40 million to the Twin Cities traveling public. The benefits of ramp metering outweigh the costs by a significant margin and result in a net benefit of $32 to $37 million dollars per year. The benefit/cost ratio indicates that benefits are approximately five times greater than the cost of the entire congestion management system and over 15 times greater than the cost of the ramp metering system alone.

Facilities at ramps may also be implemented to give priority to transit and high occupancy vehicles.

2.4.2 Dynamic Message Signs

Dynamic message signs are beneficial from the standpoint of providing information to motorist en-route. Signs can be operated to warn of incidents and adverse weather conditions, and to re-route motorists around incidents or construction, and. According to the FHWA ITS benefits website, documented benefits of DMS include[8] an 8% decrease in network travel times.

2.4.3 Electronic Toll Collection

Toll agencies have found benefits from implementing electronic toll collection (ETC). ETC provides a means of collecting tolls without vehicles stopping to exchange money at a toll booth. An ETC system is typically comprised of:

- A transponder, or “tag”, that identifies the account from which tolls will be taken. Each vehicle participating in electronic toll collection has a transponder.
- Antennae and readers at toll collection points. These devices read transponders to determine the accounts from which the toll charges will be taken.
- The accounting, or “back-office”, systems that handle the transfer of funds and track the charges on each account.
- The communication system that ties all of this together.

Some of the types of benefits that may be attained through electronic toll collection include:

Increase Capacity - Electronic toll collection systems can increase toll facility capacity by allowing traffic to pay tolls without stopping. Compared to manual toll collection, this significantly increases tollway throughput, without adding additional lanes.

[8] http://www.itsdocs.fhwa.dot.gov/JPODOCS/REPTS_TE/13463.pdf

Reduced Operating Costs – Costs incurred by the operating toll agency can be reduced after installation of an electronic toll collection system. Costs associated with handling cash from tolls can be reduced. Additional capacity at toll plazas can be added without the addition of toll taker staff. (However, the cost of maintaining the required electronic equipment, communication, and computer systems are largely new costs that can at least partially offset the other operating cost reductions.)

Reduced Delays – Electronic toll collection can eliminate or greatly reduce the typical wait times endured at toll booths. This is a particular benefit to commercial vehicle operators meeting delivery deadlines, allowing goods to be delivered more expeditiously.

The New Jersey Turnpike experienced an 85% reduction in vehicle delay after Electronic Toll Collection was implemented. Table 2 shows other benefits from ETC.[9]

Table 2: Measured Benefits of Electronic Toll Collection[10]

Measure	Benefit
Operating Expenses	Decreases of up to 90%
Capacity	Increases of up to 250%
Fuel Consumption	Decrease range of 6% to 12%
Emissions	Decrease in HC emissions up to 83% per affected mile Decrease in NOx emissions up to 45% per affected mile

2.4.4 Traffic Incident Management

Traffic incident management provides significant benefits. When incidents block traffic lanes, the resulting loss of capacity is greater than the proportion of the lanes taken out of service. For example, when one lane is blocked on a three-lane facility, the capacity drops by about half.

The Traffic Incident Management Handbook[11] presents some of the quantitative benefits attributed to traffic incident management:

[9] www.benefitcost.its.dot.gov
[10] http://www.its.dot.gov/tcomm/itibeedoc/etcs.htm
[11] Traffic Incident Management Handbook; FHWA Office of Travel Management, November 2000

Gowanus Expressway/Prospect Expressway – Brooklyn, New York

- 66 percent reduction in the time required to respond to all incidents
- 19 minute reduction in the time required to aid motorists with vehicles that have broken down [12].

Traffic and Incident Management System (TIMS) - Philadelphia, Pennsylvania

- 40 percent decrease in freeway incidents,
- 55 percent reduction in freeway closure time
- 8 percent reduction in incident severity rate[13].

TransGuide – San Antonio, Texas

- 35 percent reduction in total crashes, including a 30 percent reduction in secondary crashes
- 20 percent reduction in incident response time.[14]

CHART – Baltimore, Maryland/Washington, DC

An evaluation of the initial operation of this system shows a benefit/cost ratio of 5.6:1. A majority of the benefits that are associated with this system result from a 5 percent (2 million vehicle-hours per year) decrease in delay associated with non-recurrent congestion[15].

Highway Helper, Minneapolis – St. Paul Minnesota

- 8 minute reduction in the duration of stalled vehicle incidents. (Stalled vehicles represent 84 percent of the calls to which Highway Helper service patrol vehicles respond.)
- $1.4 million annual benefits due to reduced delay, while operating costs are only $600,000 a year[16].

[12] Samartin, Kevin, "*Under Detection*," ITS: intelligent transport systems, May/June 1997.
[13] Taylor, Steven T., feature article, ITS World, Jan/Feb 1997
[14] Henk, Russell H. et al, "*Before-and-After analysis of the San Antonio TransGuide System*," Texas Transportation Institute, Third World Congress on Intelligent Transportation Systems, July 1996.
[15] COMSIS Corporation, "*CHART Incident Response Evaluation Final Report*," Silver Spring, MD, May 1996.
[16] Minnesota Department of Transportation, "*Highway Helper Summary Report - Twin Cities Metro Area*," Report # TMC 07450-0394, July 1994.

3 STATE-OF-THE-PRACTICE

This section presents institutional, organizational, and technical aspects of freeway management systems that will illustrate the state-of-the-practice in freeway management and operations.

3.1 Institutional Arrangements

Currently, most multi-agency coordination in place relates to arterial signal coordination across jurisdictional boundaries to improve arterial progression. Coordinated time-of-day signal plans are loaded in each signal system. Time clocks are synchronized in any of three methods:

- Synchronization pulses are sent to the coordinated systems from a single local master (via a hard-wire connection) to ensure time clocks remain synchronized.
- System clocks are synchronized by sharing time among the systems.
- All system clocks use universal time. These systems receive time broadcast by the WWV system.

Freeway/arterial coordination also takes several forms. Many agencies coordinate ramp meter controllers with intersection signal controllers to mitigate ramp queuing. On a broader scale, a handful of locations, including Oakland County, MI, and several locations within California (e.g., the Santa Monica SMART Corridor), have operated freeways and arterials as a coordinated corridor. has been . In California and Michigan, the approach involves implementing traffic responsive traffic signal systems that can implement plans supportive of diversion from the freeway during incidents. In Boston, information on parallel arterial travel time is provided to drivers so they may select their preferred route. For each of these systems, agreeing on the operation of arterials in concert with freeways takes a significant effort and is often more challenging than implementing the coordinated technical solution.

Private companies can provide the mechanism for collecting information across jurisdictional boundaries. There are several examples of traffic reporting companies (e.g., Metro Traffic and SmartRoutes) that gather information across an entire region and provide it to the public in a consolidated single report. These companies can serve as a catalyst in getting agencies to coordinate data sharing among themselves as well.

Data exchange among agencies is another level of institutional coordination. Efforts to develop a shared data archive user system may serve as the catalyst for institutional integration and cooperation. Regional integration of freeway management, arterial management, transit operations and emergency response agencies is becoming more common. Data uses include:

- Regional multi-modal traveler information, has been implemented in the TravInfo system in San Francisco.
- Traffic incident management with emergency response agencies sharing real-time, computer-aided dispatch system information on incidents with freeway management agencies and freeway management agencies sharing their

congestion maps and CCTV images with emergency response agencies, as is done in Utah, California, and Washington state.

Voice communication among agencies is common for coordination during emergencies and special events.

Some multi-agency entities/forums have been established for the purpose of gathering and disseminating information to improve regional operations (see the discussion of state-of-the-art in Section 4). However, for the most part, agencies can provide resources only for systems under their own jurisdiction, and cannot rely on resources from other agencies. This is one of the barriers to multi-agency regional operations and information sharing. Typically a single agency (usually the State DOT) takes on the burden of gathering, synthesizing and disseminating multi-agency traveler information.

3.2 Organizational Aspects

3.2.1 Funding and Organizational Culture

Current funding practice typically favors building new or rehabilitating existing transportation facilities over operational improvements, such as freeway management systems. A key reason is that many agencies do not consider operations as a distinct line item in their budget. Freeway management systems require both capital and maintenance funding. This topic has been under discussion for several years, and few agencies have been willing to attempt new approaches. See section 4.2 for one new approach to funding operational and technology improvements.

The City of Bellevue, Washington established a sinking fund to ensure their traffic management components can be replaced as needed. This is a process that is commonly used for large asset purchases such as vehicle fleets. Each year, the City places funds in an account to be used to replace these components when they wear out or need to be upgraded. The City updates their upgrade and replacement schedule each year, and establishes the annual funding necessary to support required controller replacements, component upgrades, and other related items.

3.2.2 Procurement

Agencies often procure design services, equipment, and construction services for freeway management. Traditional procurement is fixed price, low bid. The software and new technology aspects of freeway management systems do not fit well into traditional procurement rules. However, the momentum in most agencies is to fixed price, low bid for systems.

The most effective agencies have approached technology projects in new ways including design/build for field devices, procurement based on qualifications for software, using task order agreements, and purchasing equipment based on best value. The state-of-the-practice is somewhere between using fixed price, low bid only to these more effective practices.

3.2.3 Staffing

This includes internal staff and any contractors or contract employees. Contract employees are most frequently used for meeting operational, maintenance, and training needs. Some of the core issues related to staffing include training/development and staff retention. Even though the most effective agencies have been able to establish positions for electrical, systems and software engineers, the state-of-the-practice still emphasizes hiring civil engineers and transportation planners in transportation agencies.

Training remains a difficult task. Compared to the traditional civil engineering discipline required for highway design, there is a broad set of disciplines needed to successfully design, implement, operate, and maintain a freeway management system. Training in some of these disciplines is not available through the mechanisms most transportation agencies use for their training programs. Most training in a transportation agency's training program is geared toward mainstream agency positions, like roadway design, or general supervisory and management skills. The training required for freeway management positions needs to include both the mainstream agency training programs to preserve employees' ability to progress in the agency, and training in other technical disciplines such as telecommunication, software development, and systems engineering. Therefore, there is a need for more training than that required for other traditional positions at a DOT. Training budgets for freeway management organizations need to take these needs into account.

The state-of-the-practice in transportation agencies is to provide on-the-job training for technology specific tasks and positions and to supplement that with periodic training that is made available through the FHWA and the National Highway Institute.

3.3 System Functions

This section describes the functions of effective freeway management and operations systems that are commonly in place. The discussion does not cover specific technologies because technologies evolve very rapidly and what was on the cutting edge of technology yesterday may be the state-of-the-art today and the state-of-the practice tomorrow. Instead, this paper discusses the **functions** of systems to illustrate how the needs of systems evolve and how practitioners meet those needs.

3.3.1 Freeway Management Systems

Monitoring Traffic Conditions – A basic requirement of freeway management systems is to monitor the state of the freeway network. Electronic data collection and visual surveillance are methods of monitoring conditions. The systems can detect the onset of congestion and alert operators to take action. These methods allow systems and operators to identify recurring and non-recurring bottlenecks and to detect and verify incidents. Bottleneck locations represent typical congested and incident prone areas. Staff uses this information to develop mitigation strategies and direct their resources, including capital projects, most effectively. The state-of-the-practice for electronic data collection is to measure traffic flow characteristics at discrete points throughout the network. Visual surveillance is typically performed via field-located cameras that are viewed by operators at a TMC. The most common method of detecting incidents is through motorists calling 911 or a specific call-in number set up for this purpose. Operators at a TMC generally use their traffic monitoring capabilities, especially visual surveillance, to verify incidents. Emergency responders, when on the scene, provide the best verification of incidents and the response needed.

A variety of automated incident detection algorithms have been implemented at a variety of locations. However, as stated earlier, most incidents are "detected" by mobile 911 calls. Incident detection algorithms analyze data from electronic data collection systems to identify anomalies in traffic flow that are characteristic of an incident. Practitioners have not universally accepted any of the algorithms developed to date. Although these algorithms reliably detect anomalies in traffic flow that could be incidents, it is not possible to completely eliminate the occurrence of false alarms while maintaining a favorable time to detect. The advantage of detection algorithms is that they provide a more precise incident location, whereas information from mobile phone calls is less reliable due to the difficulty a normal driver has reporting a location on a highway.

Traffic Control Strategies – Ramp metering has been tested and proven to be effective when properly deployed, and therefore is a common freeway traffic control strategy. Ramp metering has the potential to shift delay from the freeway to local streets, and therefore needs to be engineered with care and concern for the total mobility of a corridor in which it is used. Measures that benefit the freeway mainline only can raise local public concerns if there is a perception of inequity or misunderstanding of the purpose of the meters. In areas where metering has been properly designed and operated, public opposition has been moderate and can be effectively addressed through education and measured results.

Ramp metering strategies are typically either developed off-line and implemented on a time-of-day basis or ramp metering rates are determined by local conditions only. The state-of-the-practice in large, congested areas has moved to system or corridor level algorithms that adjust metering rates automatically on the basis of conditions throughout the system or corridor.

Providing En-Route Travel Condition Information – Most freeway management systems communicate directly to motorists using dynamic message signs and/or highway advisory radio systems. Messages are usually directed to alert motorists of unusual downstream conditions. The state-of-the-practice in freeway management in large metropolitan areas has evolved to include providing traveler information over the world wide web and via telephone call-in systems, often in a partnership with private information service providers (ISPs). Freeway management systems use the information obtained from traffic monitoring systems to provide congestion and incident information to interested travelers. Other systems provide information to motorists at large trip generators like at Chicago's O'Hare Airport where signs will be eventually used to provide information to travelers in the airport's baggage claim area. This system provides traveler information and train arrival times to give travelers the option of selecting the most appropriate travel mode. Finally, most freeway management systems provide this same information to private sector ISPs.

3.3.2 Corridor Traffic Management

Corridor traffic management is intended to coordinate and integrate the operation of the freeway with the surface streets and arterials that surround it. Corridor traffic management utilizes freeway management concepts and systems and arterial management concepts and systems to better manage the entire freeway and street network. The components of freeway management are discussed above.

Arterial traffic management focuses on signal control systems. Signal control systems adjust and coordinate traffic signals to improve arterial traffic flow. Individual traffic signal timing plans are stored in the control system and are adjusted based on current demand, through use of traffic management software algorithms.

The state-of-the-practice, in terms of signal control systems, is coordination among different agencies. For example a local arterial network may be coordinated with a State's freeway network (ramp meters) to alleviate congestion on or near a freeway.

The state-of-the-practice in corridor traffic management is to manage the freeway and arterial systems separately and to coordinate the operation through the operators of the two separate systems.

3.3.3 Electronic Toll and Traffic Management

Most toll authorities are implementing electronic toll collection systems but have yet to use this equipment for other purposes. Electronic toll collection may provide the following functions.

Electronic Payment - Electronic toll collection systems allow traffic to pay tolls without stopping. Compared to manual toll collection, this significantly increases freeway throughput, without adding additional lanes.

Vehicle Identification – The transponders associated with electronic toll collection may be used to track the movements of vehicles, providing valuable travel time information. This information can be used for traveler information and can greatly benefit the planning process and may be used to determine where funding may best be allocated.

3.3.4 Decision-Support Systems

Decision support systems use information from a variety of sources to organize, analyze, and present information to help staff make decisions and take action. These systems improve the effectiveness of agency staff. Decision support systems analyze and present information, which is often stored in an archived data system, in an organized way to provide the most pertinent information to staff at the time they need to make decisions. Decision support systems commonly in use for freeway and highway management purposes include roadway weather information systems, event reporting systems, and maintenance management systems.

Roadway Weather Information Systems (RWIS) – RWIS are traditionally deployed to help staff make snow and ice control decisions. RWIS analyzes data about current and forecast weather and pavement conditions and provides information to snow and ice control decision-makers to help them deploy equipment and personnel to locations and, at times, to most effectively treat pavement and plow roadways.

Event Reporting Systems – Event reporting systems allow state, regional, and local agencies to collect and share weather, construction, incident, and other traffic related information and data. Some of these packages utilize a GIS database so information can be entered and graphically displayed for quick viewing. The information entered can be viewed by regional agencies instantly, reducing the time needed to disseminate the data.

Maintenance Management Systems – These systems are used to track inventory (make, model, serial number, and location), log specific maintenance activities (sometimes only trouble reports and repairs and sometimes including preventative maintenance activities), and track failure history for each piece of equipment. Reports can be generated to determine the reliability (mean time between failures) of specific pieces of equipment, specific models, or specific manufacturers. The difficulty in repairing equipment can be tracked (mean time for repair) as well. Some maintenance management systems can use geo-location to pinpoint equipment in the field. Others rely on address or route and milepost.

3.3.5 Traveler Information

Traveler information is disseminated two ways: en-route and pre-trip. Over the years, motorists have benefited from both types. Over the last few years, however, most advances have occurred in the dissemination of pre-trip information.

Public vs Private Applications - More now than in the past, private agencies are a valuable source of traveler information. From the public's perspective, private agency traveler information is beneficial for several reasons. First, many private companies provide traveler information that can be customized to the daily travel habits of a unique user, for a minimal cost, usually monthly subscription. For example, a user may request that his or her pager ring when there is a delay to the specific bus route he or she uses. Private agency data is usually more comprehensive than single data sources. Private agencies usually pull data from multiple sources, integrating it into a single package where it can be obtained at once.

511 Program – 511 is an abbreviated dialing number for callers to access traveler information. The 511 program ties together a variety of automated traveler information telephone services within a region or across the country. Before 511, regions with similar services usually designed a telephone number that differed from numbers in adjoining areas. As travelers crossed from one region to another, these numbers would change often making it difficult to remember any areas specific number. Adding to this problem, numbers were often not easy to remember affecting the effectiveness of these systems. 511 is easy to remember and is designed to replace existing services.

The state-of-the-practice in 511 systems is to provide highway condition and traffic congestion or incident information using a traditional touch-tone based telephone interface.

3.3.6 Traffic Incident Management

The traffic information collected by freeway management systems can contribute to effective traffic incident management. This section describes the state of the practice in freeway management systems supporting traffic incident management.

Identifying and Verifying Incidents – The state-of-the-practice in detecting incidents, as mentioned above, is through motorists reporting them with their mobile phones. After an incident is detected, operators verify the location and identify the type of incident so they can determine their proper response. By the time TMC operators know about an incident, emergency responders are usually or their way to the scene or at the scene. TMC operator response often involves modifying ramp control or other traffic control systems, providing travelers with information about the incident and monitoring the incident as conditions change. TMC incident monitoring is primarily completed through use of a CCTV system. The CCTV system is used to remotely view, verify, and determine the nature of an incident. Often a CCTV system is beneficial when reports of an incident are received through public safety agencies from mobile phone users. For identifying and verifying minor incidents, Freeway Service Patrols and other roving patrols are often the most effective.

Reference markers are also used to quickly and accurately identify the location of an incident. Reference markers are usually posted a pre-determined distance apart and are used to obtain the specific location of an incident. Since the location of the reference markers are fixed there is no confusion where an incident may have occurred, as often happens when relying on a motorist's description of where the incident occurred. The Ohio Department of Transportation has a statewide program in the eight major metropolitan areas to install freeway reference markers every 2/10ths of mile on the mainline. These markers are accompanied by at least one marker at each interchange ramp.

In Europe, the state-of-the-practice is to detect congestion, or traffic jams, without trying to infer the existence of incidents per se. Once a traffic jam is detected, motorway control systems, as described in Section 2, automatically engage the variable speed limit system and reduce speed limits approaching the back of the traffic jam.

Communication to Responders - Freeway management system functions can support emergency response personnel en-route to or at an incident scene. Analysis of CCTV images can determine the extent and exact location of the incident and provide input to determining the response equipment, supplies, and personnel needed to treat injured persons and remove disabled vehicles from the roadway. It will almost always require on scene emergency responders to determine the full complement of equipment needed to respond to an incident. However, TMC operators, if properly trained, or emergency response dispatchers, if CCTV images are shared with response agency dispatch centers, can play a significant role in the early identification of some of the specialized response equipment needed. TMC operators, in some locations, can also dispatch service patrols to assist and clean-up minor incidents.

Although TMC functions play an important role in emergency response, there is a clear difference between these functions and those that occur at the scene of an incident. Decisions made at the scene of the incident will be those made by emergency response personnel. These personnel have more information pertaining to the incident and are therefore better prepared to make a quick, appropriate decision.

Disseminating Information/Data to Other Agencies and the Public – The TMC serves as the focal point for communications and coordination among multiple agencies for traffic incident management. Operators at the TMC provide updated information about the progress of clearing the incident to partner agencies and the public. Media outlets often use DOT generated real-time video feeds of traffic flow and incident information. TMCs can also disseminate information through the Internet, kiosks, special telephone lines, 511, and pagers. Although any single method may only reach a small number of motorists, cumulative effects can be substantial.

3.3.7 Special Events Management

Special events management is the management of traffic around events where large crowds gather such as at sporting events, festivals, and concert halls. Functional capabilities of special events management includes:

Reduced Congestion - Special event management can significantly reduce local congestion near a major event by establishing special event traffic management plans and encouraging use of alternate routes and travel modes, such as transit, shuttles, and car pools.

Reduced Road and Parking Requirements - Since special events management encourages use of alternate modes of transportation, parking requirements for automobiles is significantly reduced. Often special events management is implemented where demand exceeds existing parking capacity. It can also provide considerable safety benefits by reducing potential vehicle/pedestrian conflicts.

The state-of-the-practice in special event management is to utilize fixed freeway management infrastructure to monitor and manage traffic approaching and at the special event venue and to provide traveler information about the event through available means, such as fixed dynamic message signs, portable dynamic message signs, trailblazer signs, websites, and through the media. Traffic monitoring is accomplished through existing detection and video systems or through personnel in the field observing conditions. If a central system or TMC does not cover the area in which the venue is located, personnel in the field often implement the traffic management plans manually. If a central system or TMC does cover the area in which the venue is located, many elements of the plans, such as signal timing plans and dynamic sign messages, can be implemented remotely.

3.3.8 Communication Systems

Communication systems are key to the overall operation of a freeway management system. All of the system functions mentioned above rely on communications. Both data and voice need to be transmitted from one location to another. The state-of-the-practice in freeway management systems is to use wireline communication (copper or fiber optic cable) to transmit data or voice between fixed locations, such as from field equipment to a TMC, and wireless communication (radio systems or mobile phones) to transmit voice to or between personnel in the field. In some systems, the agencies own their own communication infrastructure (wireline or wireless), and in others, agencies lease the communication bandwidth they need from telecommunication providers. Fiber optic cable installations are fast replacing copper wire as the communications medium of choice, one of many steps taken by jurisdictions to adopt standards and deploy NTCIP compliant systems in the future.

4 STATE-OF-THE-ART

This section covers the state-of-the-art in freeway management and operations. The intention is to discuss how systems can use the latest concepts to most effectively manage and operate freeways, expressways, and corridors.

4.1 Institutional Arrangements

Successful, cutting edge, multi-agency, institutional arrangements can provide more efficient use of resources across jurisdictional boundaries, improve operations on portions of the network where agency jurisdiction overlaps, and provide cross-training and joint operation opportunities. Examples of these arrangements include:

Multi-Agency Integrated Systems - These include systems where multiple agencies share a single management center, such as San Antonio TransGuide and Houston TranStar, and systems that share a data and communications network in order to share data and facilitate control decisions. Examples of the latter include; TransCom, the I-95 Corridor Coalition, the Gary-Chicago-Milwaukee Corridor, and the Atlanta system. TransCom is notable among these examples, because it is a separate agency, funded jointly by the operating agencies that supply and receive data from it, rather than a consortium of organizations that share staff.

Regional Initiatives that Foster Improved Operations, Coordination, and Cooperation - The Southeastern Wisconsin Traffic Incident Management Program, TransCom and the I-95 Corridor Coalition are also examples of this type of program or initiative, but there are a number of others that range from multiple states cooperating (such as the Gary-Chicago-Milwaukee Corridor) to multiple agencies cooperating within a region.

Multi-Agency Resource Sharing - Many regions have arrangements to cede the operation of signal systems under their jurisdiction to another agency. Some go beyond this to share resources. An example of resource sharing is in the area of snow operation and control. Some agencies, in real-time, communicate with one another about where resources of the agencies are located. Decisions are made to assign snow operations to the highest priority facilities based on location of the resources and not the agency for which they work. In this system, a state snow plow may plow a city or a county road and a county snow plow may plow a city street or state route without having the on-going responsibility to maintain that section of roadway. The ARTIC system in Minnesota is designed to support this type of resource sharing.

In addition, resource sharing can include communications infrastructure and private interests. Telecommunication shared resource programs include utility accommodation policies, data sharing, and financial transactions where improvements to operations are funded in exchange for access to rights-of-way to install and operate telecommunication infrastructure.

Independent Performance Monitoring and Research Support. Several regions allow universities to access real-time freeway performance data for performance monitoring and research activities. Examples include the University of Washington, the University of

Virginia, Virginia Tech, the University of Central Florida, the Texas Transportation Institute, the University of Wisconsin, and the University of California.

4.2 Organizational Aspects

Successful, new or non-traditional organizational structures and actions have proven effective in supporting an operations and management oriented organization. Included in this discussion are programs, initiatives, and other related issues that support integrating management and operations into the organization and culture of an agency. In addition, the idea of becoming more operations oriented is becoming more commonly accepted, as agencies realize that they simply cannot build their way out of transportation problems. Examples of the organizational structures and actions include:

4.2.1 Funding and Organizational Culture

A key approach to improved funding for freeway management is to reduce the preference toward traditional infrastructure projects that is common in most agencies today. One approach is to emphasize the operation and performance of the transportation network. This emphasis can lead to "mainstreaming" freeway management and operations activities, creating a culture where these efforts are equally weighted and equally important as traditional infrastructure projects.

Mainstreaming Operations and Management in an Agency's Organizational Structure – Most traffic management organizations in general and freeway management organizations in particular, are either small, lower level sections, or stand-alone, isolated mid-level sections within an agency. In both cases, operating budgets are relatively small and the sections have little overall impact on their agencies' overall direction.

As some agencies progress toward an operating, as opposed to construction mindset, traffic management and operations organizations are becoming more central to the overall effort of an agency. The organizations are becoming more a part of the mainstream of the agency, instead of being isolated from the mainstream. With this trend, traffic operations and management organizations influence the culture of the agency more and are more likely to reverse the bias against funding management and operations activities and projects.

Mainstreaming Operations and Management into Decision Making Processes – As operations and management become a greater part of the culture of an agency, decisions are made to emphasize the importance of improving the operation of the transportation network. Examples include:

- Commitment to improved operation in strategic planning.
- Capital programming processes that have project selection criteria based on improvement of the overall operation of the system.
- Policy development that reflects the need to operate the transportation network efficiently.

Commitment to Monitor Performance – An essential step in incorporating operations and management concepts in an agency is to commit to monitor system performance. Monitoring programs focus attention on elements of the system that have experienced improved performance and those that need improvement. A wide array of solutions can be suggested and evaluated to mitigate performance problems if performance can be measured, analyzed, and understood. Freeway management systems provide much of the infrastructure needed to measure performance of the network. Performance monitoring in turn provides much of the information needed to justify mainstreaming management and operations. The state-of-the-art in freeway management is moving to include performance monitoring as an integral part of a freeway management system.

As an example, Ohio DOT is instituting Quality Assurance Reviews (QAR) for freeway management systems. The QAR process involves establishing areas to be monitored (for example, DMS message content and use, field device status, staffing, data accuracy, cost containment, information dissemination) and criteria with which to measure compliance. The criteria normally are derived from current polices and procedures established for freeway management system operations on a statewide basis.

4.2.2 Procurement

Non-Traditional Contracting – As discussed in Section 3, the most effective agencies have approached procurement in technology projects in new ways including design/build for field devices, procurement based on qualifications for software, using task order agreements, and purchasing equipment based on best value. These approaches, however, are still more state-of-the-art than state-of-the-practice.

Performance-Based Contracting - Some agencies contract for operations and maintenance of Intelligent Transportation Systems (ITS). These contracts have been difficult to assess for value, as they have been traditionally structured as “pay for hours”. A new approach to these types of contracts is performance-based contracting. For example, the contractor pay is tied to the operational performance of the procured system. Instead of simply paying a fixed price or a price per hour or activity, the contractor’s pay is at least partially determined by the percentage of time that system components are in full working order.

4.2.3 Staffing

The state-of-the-art in staffing in transportation agencies is to establish positions for electrical, systems, and software engineers. Unfortunately, these staff have little ability to advance within the broader DOT organization as most higher level positions still require a professional engineering registration.

Recruiting staff is also a challenge in the relatively obscure world of freeway management and the somewhat broader ITS world. Washington State DOT and Mn/DOT both use college students (master’s degree candidates as well as undergraduates) to staff their respective TMCs. They have found that the students are of the highest caliber, and that this program is a means to identify high-quality staff candidates for the DOT. Additionally, as different technologies are selected for deployment, organizations must have or hire staff with knowledge of the system and how to maintain it.

Training – Some agencies are developing specific knowledge, skills, and abilities matrices for freeway management and ITS positions. By identifying what knowledge, skills, and abilities are needed for each classification, training needs can better be identified and obtained. The state-of-the-art in training is to develop specific training programs for these classifications and to utilize the full range of training opportunities available, especially training in communication and computer technology that is offered by the information technology sector.

4.3 System Functions

This section describes state-of-the-art functions in freeway management systems. Technologies are not specifically called out, however the functions use technology and tools to successfully implement technology. Once in place, the technology and tools can facilitate the continuing migration from one generation of technology to the next with a minimum of disruption and cost.

One note on equipment and technology is warranted. Standards development organizations, the Federal government, and a large number of transportation organizations have expended tremendous effort and resource in developing ITS standards. Many of these standards are applicable to freeway management systems, especially National Transportation Communications for ITS Protocol (NTCIP), Traffic Management Data Dictionary, Traffic Incident Management Data Dictionary, and Advanced Traveler Information System (ATIS) standards. State-of-the-art freeway management systems being designed and implemented use these standards whenever possible.

4.3.1 Freeway Management Systems

Monitoring Traffic Conditions – The state-of-the-art in monitoring traffic conditions merges infrastructure based point detection techniques with a variety of newer techniques, including the use of probe vehicles to monitor conditions. The most common way of incorporating probe vehicles is by making use of toll tag technology. By installing tag readers at locations throughout the freeway system, travel times can be directly measured. Travel times represent a user-based measure of network conditions.

Some state-of-the-art TMCs are deployed with detector algorithms that can determine where significant congestion exists and trigger the video system to display the proper video camera. This cues the operator to begin monitoring the situation and simplifies the operators' tasks when incidents occur by automatically displaying the appropriate camera for monitoring the incident or congested condition. An emerging concept uses a variety of modeling or computational methods to predict when traffic congestion is likely to occur. This reduces the delay in informing drivers of congestion so they can change to routes that better serve their travel needs.

There are some technologies that are emerging for use in detection and monitoring. Cellular-based Geolocation and Geographic Positioning System (GPS)-based technologies are state-of-the-art technologies that some systems are using to monitor roadway conditions in real-time. Cellular-based Geolocation and GPS-based technologies may also be beneficial for tracking the movements of vehicles for planning purposes and for identifying the specific location of an incident. These two types of technologies may be beneficial for all roadways, not just tollways and other roadways where toll-tag readers are implemented. Another promising technology with limited implementation is the use of remotely controlled, or drone, airplanes equipped with video cameras. Operators control these planes to fly over freeways and images from the cameras are transmitted to the local TMC.

Although there continues to be developments in automated incident detection algorithms, the state-of-the-art is not much different than the state-of-the-practice. Improvements in detection technologies and the implementation of probe vehicle technologies for monitoring traffic conditions also provide the potential to update and improve upon incident detection algorithms. These are primarily still in the development stages, however, and have not been implemented broadly and successfully enough to be considered state-of-the-art.

Traffic Control Strategies – The state-of-the-art in ramp metering incorporates advanced system control concepts in the algorithms mentioned in Section 3.3.1 that adjust metering rates automatically on the basis of conditions throughout the system or corridor. Many of the advanced control concepts come from process control theories as opposed to traditional traffic flow optimization theories.

4.3.2 Corridor Traffic Management

The state-of-the-art in corridor traffic management is to incorporate the state-of-the-art in freeway and arterial systems into a coordinated, integrated system. The state-of-the-art in freeway management systems is discussed above.

The state-of-the-art for arterial management systems is to utilize many of the freeway management components on arterial streets. Video surveillance and advanced sensor technologies have been deployed on some arterials to provide better real-time traffic monitoring and traffic incident management capabilities. Dynamic message signs have been implemented on some arterials to provide motorists with information on traffic conditions, slowdowns, and, sometimes, alternate routes. The state-of-the-art in signal control merges traditional traffic control systems with improved means of collecting the data needed to update signal timing plans, simplified ways to update timing plans, and better traffic signal system monitoring features. For some conditions, especially those that are unpredictable, adaptive signal control is being merged with other, more traditional signal control strategies, such as time of day and traffic responsive control, in state-of-the-art in traffic signal control systems. Adaptive control can also automatically adjust for queuing conditions approaching freeway entrances or for providing additional timing on an arterial when there is an incident on the freeway.

The state-of-the-art in corridor traffic management integrates the operation and control of freeway and arterial traffic management systems. The conditions on the arterials provide input into the operation of the freeway management system and the conditions on the freeway provide input into the operation of the arterial traffic management systems. One unique component of state–of-the-art corridor traffic management is electronic trailblazer signs that direct traffic that has exited the freeway because of an incident on how to get back to the freeway downstream of the incident.

4.3.3 Electronic Toll and Traffic Management

Electronic Toll and Traffic Management – The state-of-the-art developments in electronic toll collection focus on coordination between both public and private entities. In the Northeastern United States, several toll agencies have integrated separate toll systems, and as such, have made it easier for motorists to pay tolls when traveling between adjoining states. This also bodes well for cost savings as toll agencies can enter into agreements to share costs of the system, such as maintenance.

In addition to system integration, there are also possibilities for private company and transit agency involvement. In the case of private involvement, corporations such as McDonalds have expressed interest in adapting the “smart card” as a method of payment. Some transit agencies have implemented or are in the process of implementing smart cards as a fare payment medium. The smart card can be used in conjunction with a transponder to use the same payment media for toll collection, transit fare collection, parking charges, and retail transactions.

Vehicle Identification – The transponders associated with electronic toll collection may be used to provide origin and destination information to supplement the state-of-the-practice travel time data. O-D information from toll tags can be used in the planning process and electronic toll collection system transponders and readers can reduce the cost of collecting this information substantially.

4.3.4 Decision-Support Systems

Roadway-Weather Information Systems – The state-of-the-art in RWIS involves sharing weather and pavement condition information. RWIS information can provide valuable data to improve meso-scale weather forecasting done by a variety of weather services, both public and private. The improved, detailed weather forecasts, in turn, can provide better information for snow and ice control decisions.

RWIS information is also being combined with other weather information and presented to travelers to help in their trip planning and decision-making. The information is usually presented via websites and telephone call-in systems.

Event Reporting Systems – The state-of-the-art event reporting systems are incorporating emerging ITS standards.

Management Systems – Some maintenance management systems link the traffic management system with the maintenance work order development process within an agency to automatically issue maintenance work orders on field equipment.

The state-of-the-art in management systems incorporates managing systems operations and system assets with managing maintenance activities as described in Section 3.3.4. State-of-the-art management systems often utilize inter-agency archive data systems to store and retrieve information pertaining to the management activities. Examples of management systems include:

- Incorporating freeway management assets in **asset management systems**. Asset management is an emerging concept for public agencies. Asset management is geared toward optimizing resource allocation across transportation assets that are very broadly defined. It is generally viewed to provide improved decision making for investments in new capacity, improvements, preservation, and operations. Information is needed on a broad array of assets, but is usually focused on the roadway, structures, guardrail and barrier, signs, and other traditional roadway features. Asset management allows agencies to track the condition of their current system and the adequacy of their annual expenditures. Asset management systems are not specifically designed for electronic systems, but electronics can be entered into the system and tracked.

- Establishing **network management systems** for fiber optic and other telecommunication systems. Just as a system is needed to manage the maintenance of freeway management system components, a system is needed to manage the maintenance of the telecommunications network. These systems identify the devices that are attached to the telecommunication system, track the individual strands of fiber or pairs of twisted pair cable that are used by devices, and identify the specific telecommunications equipment included in the system.
- Utilizing **configuration management systems** to help freeway system managers locate and identify the current versions of software, documents, procedures and models of hardware and firmware in use in their system. These systems are focused on tracking components and documentation that are part of a central system, both those in the central location and those in remote locations. The systems track replacement and upgrades of equipment and the software resident in the equipment. The idea behind these systems is to know what may have changed if a systemic problem is uncovered. Very often, systems used to manage telecommunication networks are used for hardware configuration management. In fact, freeway management telecommunication systems should be included in the overall configuration management system. The network management systems mentioned above can facilitate this inclusion. System configuration management is a relatively new concept in transportation and is an outgrowth of the emphasis on software configuration management.

4.3.5 Traveler Information

Innovative Web Application Systems – These systems provide needed traveler information to motorists planning a trip or those en-route. The state-of-the-art in traveler information websites is moving from general information of interest to personalized information tailored to an individual or to an individual trip. This information includes conditions and travel times for a specific route or set of routes delivered at a specific time or on demand to a device of the subscriber’s choosing. These include personal data assistants and web enabled wireless telephones, pagers, e-mail, and the Internet.

511 Systems – 511 systems are evolving to natural speech applications instead of touch-tone based interaction. Natural speech applications allow callers to obtain the information they want by simply asking for it in a conversational way. These systems are less tied to a menu structure and callers don’t have to remember precise option numbers or specific responses. These systems can recognize a variety of caller responses for a given information request. For example, if a caller wants information on transit, the system could be programmed to recognize “bus”, “public transportation”, or a variety of other phrases as well as “transit”. Many of these systems allow direct shortcuts to popular information directly from the entry menu of the system.

The state-of-the-art in 511 systems is also evolving to provide multi-modal information instead of just highway and traffic information.

4.3.6 Traffic Incident Management

Traffic incident management systems are focusing more on coordinating among multiple agencies than ever before. State of the art systems incorporate data sharing techniques between transportation and public safety agencies. An emerging capability is to integrate CAD information into a freeway management system. This is beyond the state of the art currently, but CAD-TMC integration is being developed and field tested.

Automation of key traffic incident management activities is also being emphasized to reduce labor intensive operations such as CCTV monitoring being performed by TMC operators. Automation will also assist operators in quickly identifying incidents as the TMC's coverage area increases. Incident detection algorithms appear to provide the most promise in automating traffic incident management functions.

Traffic incident management concepts and systems are also being applied to emergency management. Large-scale natural disasters require all of the resources and strategies of traffic incident management across a large geographic area. Hurricanes and major earthquakes are examples of these large-scale disasters. Inter-agency coordination, communication, and cooperation is critical. Freeway management personnel and systems support these coordination and communication efforts.

Finally, freeway and traffic incident management systems are beginning to be applied to homeland security concerns. Transportation agency response to a large-scale terrorist act is similar to the response to a large-scale natural disaster and many of the same principles are being applied. In addition, CCTV systems can play a role in threat assessments and monitoring potentially vulnerable assets, like bridges. The same inter-agency communication systems that are used to manage major incidents can also be used in case of terrorist attacks.

4.3.7 Special Events Management

The state-of-the-art in special events management, in addition to using the state-of-the-art features available from other related system functions, focuses on utilizing mobile devices to help manage traffic during special events. The use of portable dynamic message signs for special events is relatively common practice. However, expanding that concept to other devices is more state-or-the-art than state-of-the-practice. Portable devices that have been used for special events management include portable CCTV cameras and detection devices to monitor conditions surrounding special event venues and the use of portable traffic signals to control intersections that don't require signals when these is no special event.

Instead of using portable devices, which often require site visits before and after the event, many jurisdictions are deploying trailblazer signs on arterials to direct event traffic more effectively after leaving the freeway or through traffic around congested areas.

If the special event venue is in an area not covered by a TMC, the state-of-the-art is to use a temporary or portable TMC specifically established for managing special event traffic.

Portable CCTV cameras and temporary detection systems transmit camera images and data to the portable or temporary TMC where operators can monitor conditions, take control and management actions, control portable or fixed dynamic message signs, and provide traveler information.

4.3.8 Communication Systems

The state-of-the-art in freeway management systems is to enhance the state-of-the-practice (fiber optic communication between fixed points) by transmitting data using wireless communication media where wireline communication is either too expensive or is not yet available.

5 GAP BETWEEN THE STATE-OF-THE-ART AND STATE-OF-THE-PRACTICE

This section discusses where the practice described in Section 3 falls short of the state-of-the-art described in Section 4. It identifies issues that contribute to the gap. Significant improvements to the surface transportation system could result in moving from the state-of-the-practice to the state-of-the-art.

5.1 Institutional

Agencies have traditionally focused only on their own jurisdiction to fulfill their mission. Planning and capital programming processes were developed that focus within a single jurisdiction rather than on the interactions and inter-dependencies among jurisdictions. Evolving from the single jurisdiction view to multiple agency data and control systems and multiple agency cooperation requires breaking the institutional momentum built up over generations.

Agencies traditionally have not been positioned to share resources. There are sometimes laws against one jurisdiction providing resources to a neighboring jurisdiction, which may have to be modified by legislative action.

Differences in technical capabilities between public and private agencies seem to be widening. Public agencies are increasingly becoming constrained by narrowing budgets, delaying the much needed upgrades and improvements to technical resources. Private agencies on the other hand, are less affected by narrowing budgets and thus have frequently upgraded and adopted new technological resources. Public agencies need to invest in newer technologies in order to move from the state-of-the-practice to the state-of-the-art.

5.2 Organizational

Operational responsibility is often fractured among several divisions within an agency. The focus is usually on delivering the capital program. Operations and ITS champions often struggle to get operations at the appropriate level of the organizational structure.

Transportation agencies, especially at the state level, traditionally have had missions focused on construction. Organizational structures within State DOTs were developed with this primary mission in mind. Operations, maintenance, and management were less important than designing and constructing new facilities. Operations was usually a second or third tier group within agencies' hierarchies. Now operations divisions are being more accepted, and are often being pushed to include additional activities, such as performance monitoring.

A majority of transportation capital budgets traditionally went to capacity development and improvement (new facilities). More recently, emphasis has been placed on rehabilitating and preserving existing facilities as well as constructing new ones. The historical funding categories and the criteria used for selecting projects have made it difficult to fund operational improvements and freeway management.

Many organizations rely on special Federal funding or earmarking for a majority of their ITS and operations improvements. There may be no other effective way to insert operational improvements and ITS projects in the planning and programming process. Often the selection criteria, developed before ITS and operational improvements were common, have no way to fairly assess these investments. The traditional planning process does not identify operational improvements or ITS projects. Organizations are slowly becoming aware of the need to integrate ITS into the traditional planning process and have just started working toward a solution.

Staffing levels traditionally were tied to the capital program and the size of the construction program. As operations, management, and maintenance are emphasized, the traditional staffing plans and mechanisms no longer fit the needs of the organization, but they are still in place.

Traditionally, transportation agencies were focused on civil engineering disciplines. Training programs emphasized how to develop professional civil engineers with civil engineering educations and skills. With the change in mindset toward operations, a more diverse skill set is needed, including computing and telecommunication technology, software development, and systems engineering. Training needs are greater, new courses and programs need to be developed, and training from a broader array of existing sources needs to be supported.

There are significant gaps in staff knowledge and training. It is difficult to keep up with changing technology. New disciplines coming into transportation because of the new technologies needed in effectively managing and operating the system require new actions and practices to be utilized. Lack of knowledge and in adequate training in technology and new practices is a major roadblock to effective use of technical tools. Employing contractors with the required skills may be one way to introduce a more diverse skill set, but agency staff will still need to understand at least the general concepts of these additional disciplines.

5.3 System Functions

Gaps between the state-of-the-practice and state-of-the-art in system functions can be readily identified by comparing the discussion of state-of-the-practice functions in Section 3.3 and state-of-the-art functions in Section 4.3. In order for transportation systems to function closely with (or to be integrated with) public safety systems, those in transportation and public safety have to better understand each other's systems and each other's operations and operational requirements. The discussion below summarizes these gaps. The gaps can be characterized as primarily gaps in knowledge, gaps in breadth of perspective, or gaps in integration and coordination.

5.3.1 Freeway Management Systems

Monitoring Traffic Conditions – The primary difference between the state-or-the-art and state-of-the-practice deals with the perspective of the monitoring system. State-of-the-practice systems primarily monitor the transportation network at discrete points on the infrastructure. State-of-the-art systems also monitor the network at discrete points along the infrastructure and incorporate monitoring travel times to include a perspective of the individual trip instead of being infrastructure-centered only.

Practitioners and designers do not, however, have a single resource nationally that will aid them in the full range of design and implementation of a surveillance and monitoring systems. The Traffic Detector Handbook is an extremely valuable resource that describes various detector technologies and their strengths and weaknesses. However, an additional document that describes the requirements and best practices for designing and implementing CCTV, detection, and other monitoring systems would be helpful.

The cost of large-scale detection and monitoring systems is one of the biggest impediments to agencies implementing state-of-the-art (sometimes even state-of-the-practice) systems. The development of low-cost detection and monitoring capabilities would go a long way in narrowing the gap between state-of-the-art and state-of-the-practice.

Traffic Control Strategies – The gap between the state-of-the-art and state-of-the-practice in ramp metering strategies comes at two levels. One is a system-wide versus local condition gap. Although some state-of-the-practice systems incorporate a system-wide ramp metering algorithm, the state-of-the-art strategies all take a system view of the problem. The second is in the type strategy employed. State-of-the-art systems tend to incorporate process control concepts, not just optimization models.

5.3.2 Corridor Traffic Management

The primary gap between state-of-the-practice and state-or-the-art in corridor traffic management lies in the level of coordination between freeway management and signal control systems and the organizations that operate them. State-of-the-art corridor traffic management systems provide functions that provide enhanced methods to manage the freeway and arterials within a corridor in an integrated fashion. The state-of-the-practice systems require manual coordination.

An additional gap between state-of-the-art and state-of-the-practice lies in signal control. State-of-the-art signal systems provide the ability to incorporate multiple control strategies, such as adaptive control, time of day, and traffic responsive control.

5.3.3 Electronic Toll and Traffic Management

As with many of the gaps identified in this section, the primary gap between state-of-the-art and state-of-the-practice in electronic toll and traffic management systems is in the level of integration among systems. State-of-the-art-systems are well-integrated with neighboring toll systems.

5.3.4 Decision-Support Systems

Roadway Weather Information Systems (RWIS) – The gap in state-of-the-art and state-of-the-practice for RWIS involves information sharing. The state-of-the-practice systems use the information gathered primarily for snow and ice control decision making, whereas state-of-the-art systems share their information with a variety of stakeholders, including weather forecasters and the traveling public.

Management Systems – The state-of-the-art and state-of-the-practice management systems all are geared to inventory assets and track histories of those assets. The main differences are the degree to which the systems are integrated with other functions and the degree to which they are inclusive of agency assets.

5.3.5 Traveler Information

The gap between the state-of-the-art and state-of-the-practice in traveler information systems centers on user interfaces and levels of personalization. State-of-the-art systems focus on developing convenient user interfaces and personalized services. Private sector companies typically bundle information collected by public sector agencies to provide these services. However, reliance on the private sector may not always be viable. Therefore, if the dissemination of this information is needed, the public sector may need to step in and provide information that will meet customer needs.

5.3.6 Traffic Incident Management

Like many of the functions mentioned in this paper, state-of-the-art traffic incident management systems distinguish themselves by the degree of coordination, integration, and scope of events to which they can respond. State-of-the-practice systems are geared more toward responding to typical freeway incidents and coordination with traditional freeway management and response organizations. State-of-the-art systems can be applied to large-scale emergencies and homeland security involving many agencies with a command structure that incorporates appropriate decision-making of each.

The investigation of the difference between the state-of-the-practice and state-of-the-art also shows that there continues to be lack of a well-accepted incident detect algorithm. While this is not strictly speaking a gap between the state-of-the-art and state-of-the-practice, it does point to an area that deserves continued attention. Although incidents are detected relatively quickly and reliably through motorist use of mobile phones to report them, reliance on these calls presents some problems to operating agencies. For example, the location of an incident may not be reported accurately resulting in the dispatch of emergency personnel and equipment to another location. Agencies often receive multiple calls about the same incident, sometimes with differences in location. Agency personnel must sort through the information from the multiple calls and refer to CCTV images, if available, before they have an accurate and unambiguous picture of the incident. This takes time and resources that would not have to be expended if an accurate, reliable, and accepted incident detection algorithm was available.

5.3.7 Special Events Management

The state-of-the-art in special events management is distinguished from state-of-the-practice by the use of portable devices and portable or temporary TMCs to help manage traffic during special events.

5.3.8 Communication Systems

The state-of-the-art in freeway management communication systems differs from state-of-the-practice in the use of wireless communication media.

6 RECOMMENDED ACTIONS

This section identifies actions that can be taken to close the gaps identified in section 5. Some of the actions may be relatively stand-alone, such as the need to develop materials to raise awareness of some issues. There may also be major initiatives that need to be undertaken in order to address some issues. This section includes recommended actions in research (including field tests and deployment testing of innovative or developing methodologies and technologies), education, outreach, and awareness. Actions are categorized and further explained by the following headings:

- Institutional
- Organizational
- Technical

6.1 Institutional

The gaps between the state-of-the-practice and state-of-the-art with regard to institutional arrangements can be narrowed by completing a series of actions. These actions will help foster multi-agency coordination.

Research Actions – The need for research on an institutional level extends to technical guidance and best practice examples on a number of different topics. Key research areas include:

- Stakeholder Involvement – Research should focus on developing and distributing informational materials on freeway management and ITS for use by transportation professionals in presentations to the elected officials and the public. It is important to de-mystify freeway management for decision-makers in organizations that are important partners. This is particularly important in order for agencies to develop the trust needed to enter into arrangements to share their resources.
- Agency Operating Cultures – Research should focus on identifying agency differences, providing successful and unsuccessful practices related to multi-agency coordination.
- Performance Measures – Research should identify a common set of performance measures for freeway management and the set of network performance measures for which freeway management systems can gather data. Moreover, research should identify a common set of performance measures for freeway operations and maintenance activities.

Educational Actions – The success of a freeway management system depends heavily on changing the mindset of agencies from that of construction to operations. Therefore, educational materials and programs will be necessary to train, re-train, and cross-train existing personnel at all levels. Recruiting and retaining staff will also be very important.

Outreach Actions – Freeway management outreach, on the institutional level, must focus on developing multi-agency partnerships, bridging institutional gaps, and building new institutional arrangements. Outreach to policy makers will be key in building support and identifying champions.

6.2 Organizational

The gaps between the state-of-the-practice and state-of-the-art with regard to organizational structure can be narrowed by completing the actions described below. These actions will help incorporate operations and management concepts in the mainstream of transportation agencies

Research Actions– More research in the following areas needs to be undertaken to determine if an agency's organizational structure will support freeway management operations.

- Organizational and Program Structures – Research should determine the level of effort various organizational and program structures contribute to freeway management operations.
- Staffing – A synthesis report should be developed to identify the personnel and skills associated with state-of-the-art freeway management systems and to provide a sense of the difficulty in acquiring the needed personnel and skills in those systems. The report should also document successful approaches to providing the needed personnel and skills.

Education Action – A variety of educational actions are needed to close the gaps in organizational structure.

- Additional training resources should be dedicated to developing the skills needed for effectively operating and managing a state-of-the-art freeway management system.

Outreach Actions – A variety of outreach actions are needed to close the gaps in organizational structure.

- A program to share successful models of organizational structure is needed.
- A program of outreach is needed to explain the importance and benefits of mainstreaming operations and management to agency and political decision-makers.
- Within organizations, project champions need to be identified.

6.3 System Functions

The gaps between the state-of-the-practice and state-of-the-art with regard to system functions can be narrowed by completing a series of actions. These actions will help improve technology transfer to address gaps in knowledge and perspective and address the needs for integration and coordination.

Research – More research is required in the following areas:

- Use of the Systems Engineering Model – A synthesis report should focus on developing methods to apply the systems engineering approach to freeway management. The systems engineering approach fosters developing systems from a broad perspective, including functions in the design that need to be integrated.

- Control processes applied to transportation. Research should address ways to apply process control concepts in transportation control strategies.
- Security – Research should concentrate on the procedures for identifying risks and mitigation strategies for those risks.
- Technology transfer – A technology transfer program should focus on how to share successful applications of state-of-the-art freeway management among practitioners.
- Synthesis on detection requirements/guidance/best practices on designing surveillance.
- Research in detection technologies should include, perhaps even focus on, low cost sensor and detection systems that can be installed and operated in a short period of time.
- Incident detection algorithms should continue to be developed and tested in operating systems.

Education and Outreach – Technical education should focus on training employees on the basics of freeway management to improve knowledge, including integration issues. Similar efforts should focus on policy and decision making groups, top agency personnel, technical staff, and the general public.

Awareness – A variety of awareness efforts are needed.

- Additional efforts are needed to ensure that security issues are addressed in the appropriate manner in freeway management systems. Issues primarily evolve around non-authorized access to systems and physical threats to systems and infrastructure.
- A program is needed to raise awareness of the state-of-the-art practices and functions that are in place or being deployed.
- The content of this paper should be updated often to keep current with Freeway Management state-of-the-art practices. This effort should be coordinated with similar efforts associated with the Freeway Management Handbook.

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