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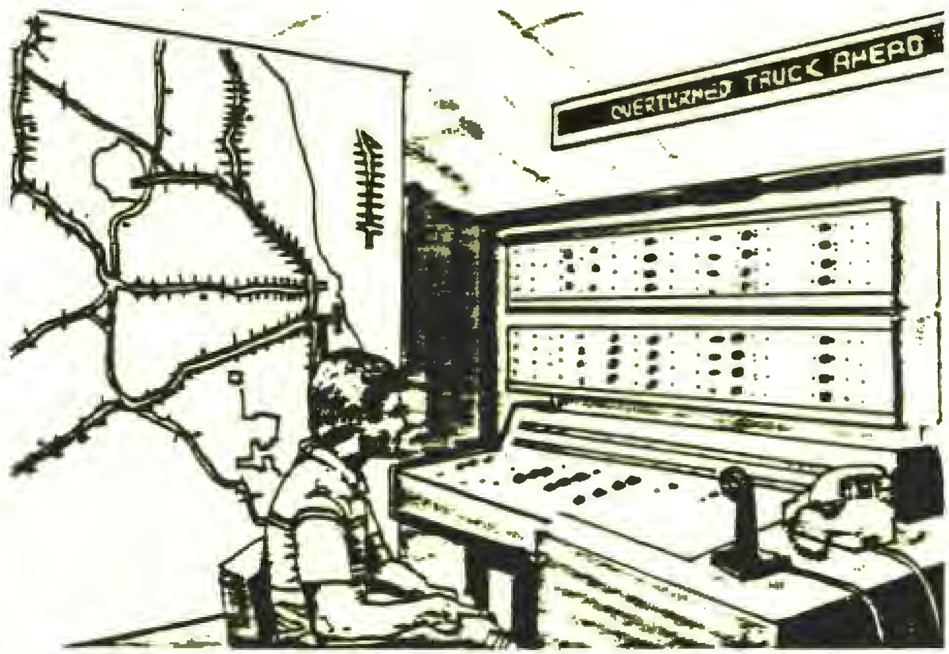
Prepared For
Federal Highway Administration

U.S. Department of Transportation

A Freeway Management Handbook



Volume 1: Overview

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Volume 2: Planning & Design
Volume 3: Operations & Maintenance
Volume 4: Annotated Bibliography

May 1983

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16. Abstract

Freeway Managment can be defined as the control, guidance and warning of traffic in order to improve the flow of people and goods on these limited access facilities. This handbook has been designed to provide potential users with a set of guidelines for the planning, design, operation, and maintenance of the various components of Freeway Management systems. The topics that are addressed in the handbook include:

- Problem Identification and Analysis
- Ramp Metering
- Priority Treatments for High Occupancy Vehicles
- Incident Detection
- Organization of Incident Response
- Driver Information Systems
- Evaluation of alternative Improvements
- Use of Simulation Models
- Implementation Issues
- Surveillance Operations
- Management of Traffic Operations
- Selection and Maintenance of System Components

This volume is aimed at managers, policymakers, and administrators. In addition, it is designed to provide an overview of freeway management systems for other professionals without getting too involved with technical details. It discusses the problems and solutions of freeway management with emphasis on those aspects that involve administrative, political, and financial decisions.

Volume 1 — Overview
Volume 2 — Planning and Design
Volume 3 — Operations and Maintenance
Volume 4 — Annotated Bibliography

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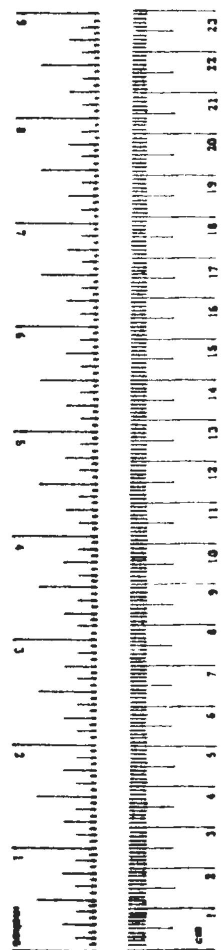
METRIC CONVERSION FACTORS

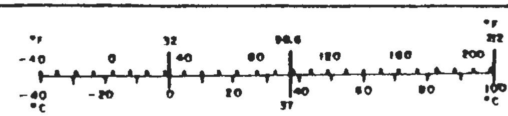
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



A FREEWAY MANAGEMENT HANDBOOK

VOLUME 1: OVERVIEW

Prepared for

FEDERAL HIGHWAY ADMINISTRATION

by

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1500 Planning Research Drive
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May 1983

PREFACE

This handbook is a compendium of new material and material from prior reports, too numerous to mention individually, which are cited in the chapter references. We would, however, like to call special attention to "Urban Freeway Surveillance and Control: The State of the Art" and the "Traffic Control Systems Handbook" which have provided the major contribution to this document.

We would also like to thank the review panel of FHWA personnel, Mr. Walter Dunn, and Mr. David Roper for their suggestions which have enriched this handbook.

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Existing Systems	8. Review of Existing Systems

CHAPTER 1. INTRODUCTION

In 1956 Congress authorized the construction of a national system of interstate and defense highways. This freeway system was planned and designed to provide a high-speed and high-volume road facility that would satisfy the need to move goods and people between the principal cities in the United States. The urban section of the freeway and interstate road system is now over 11,000 miles long. Although in urban areas this is only 2 percent of the total road system, it carries 28 percent of the traffic. Thus, taking the large view, freeways can be seen as a considerable success. This success is exhibited in the form of greater personal mobility and the efficient movement of goods. Freeways are also the safest type of road and their construction has resulted in an overall reduction of the number of accidents per vehicle mile. They have relieved congestion in most areas and have led to suburban growth as accessibility increased.

Unfortunately, freeways have not been a total success. In urban areas, freeways are subject to a considerable amount of congestion during peak periods. Why does this occur when freeways are designed to accommodate future traffic flow and land use? The answer is that, to an extent, freeways create the problem. In urban areas, land is expensive and thus freeway construction has often been made to cope only with existing, or short-term, future traffic volumes. The construction of freeways has also made dramatic changes in the land-use patterns surrounding cities. As the trip times to downtown areas are reduced and vehicle ownership rises, freeways have made the use of land in suburban/rural areas feasible for residential development. Furthermore, the lower price of land on fringe areas of cities is attractive to industrial developers who are able to build factories and offices more economically. They also have access to a large source of labor that can use freeways to commute.

Another aspect which has led to the underdesign of freeways in urban areas is the unpredictability of the number of induced trips. By constructing residential development adjacent to freeways, residents are given greater access to social and leisure facilities; thus, the number of trips per household increases. Over the past two decades these changes and uncertainties have resulted in traffic levels that were beyond the predictions of the freeway planners.

Apart from some outstanding scheduled improvements still to be completed, the construction of freeways in urban areas has effectively been finished. Under a constrained economic climate, attention must be paid to making the most out of these existing highways, as the construction of new facilities is not economically feasible. The problem of congestion on urban freeways has been the subject of investigation and research for the past 20 years, much money has been spent, and mistakes have been made. However, there have been successes, and a variety of freeway management techniques have evolved to tackle the congestion problem.

Freeway management can be defined as the surveillance of vehicles in order to control traffic flow and provide assistance to motorists, resulting in the improved flow of people and goods on limited-access facilities.

CURRENT STATUS

Programs to improve the capacity and efficiency of urban freeways are not new. As early as 1955, the City of Detroit im-

Freeway Linking Suburban Areas with Central Business District
Houston, Texas

plemented a project on the John Lodge Expressway that used closed-circuit television for freeway surveillance. Chicago, Detroit, Houston, Los Angeles, and Dallas pioneered the application of freeway surveillance and control in the early 1960's. New York applied the technology to increase the flow of traffic through the Hudson River tunnels. Based on the success and experience of these early experiments, freeway surveillance and control systems are now being developed and placed in operation in a number of urban areas throughout the world. Figure 1.1 shows those areas in the United States where some form of freeway management and control is currently used or being implemented.

Initially, projects focused primarily on the hardware aspects of surveillance and control, but experience soon showed that other elements were equally important: development of good relations with the public, the press, and concerned political jurisdictions; participation of police, fire, and maintenance organizations; development of operating procedures and control logic; and staff considerations. It was also found that freeway traffic management need not involve major commitments of staff and money. Installations of automated traffic control systems can often provide significant benefits for a relatively small investment. This is particularly true where limited installations are required for controls, such as ramp-metering devices.

Freeway surveillance and control can be a highly reliable and valuable management tool. Research conducted during the past 25 years has demonstrated that improved operations will provide tangible benefits to freeway users. However, relatively few freeway management systems are in operation today. One reason is that many highway administrators anticipate that the design, implementation, and operation of a freeway control system is too complex an undertaking. For this reason, it is important that every highway administrator become familiar with the concepts and benefits of freeway management systems so that they can promote the application of techniques for improving safety and mobility for people in urban areas.

ORGANIZATION OF THIS HANDBOOK

This is volume 1 of a four-volume document. The topics covered in each volume overlap as each is directed toward a specific audience—this volume is aimed at managers, policymakers, and administrators. In addition, it is designed to provide an overview of freeway management systems for other professionals without getting too involved with technical details. It discusses the problems and solutions of freeway management with emphasis on those aspects that involve administrative, political, and financial decisions.

Volume 2, "Planning and Design," is aimed principally at engineers. It is designed to enable engineers to analyze the performance of existing freeway systems and gives instructions on how various proposed strategies can be evaluated. By quantifying the benefits of a range of potential solutions, the engineer using volume 2 will be directed toward the most viable technique.

Volume 3, "Operations and Maintenance," has been written for engineers, technicians, police, and emergency crews. It is designed to provide information on the installation, operation, maintenance, and monitoring of freeway management systems.

Volume 4 is an annotated bibliography with a subject index that provides a source document for further reading. An abstract of each referenced report is included.

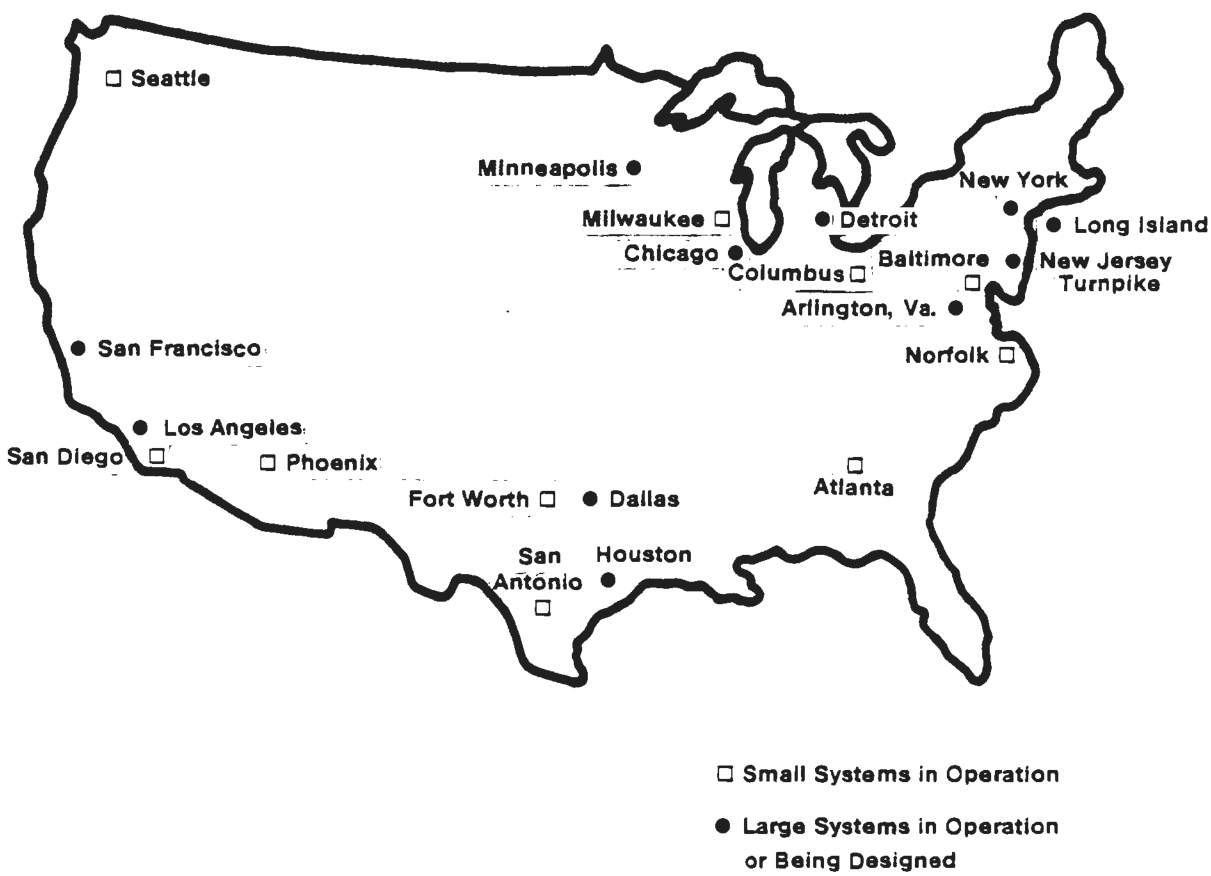

Figure 1.1. Location of Freeway Traffic Management Systems

URBAN FREEWAY PROBLEMS

Congestion is typified by undesirably slow travel speeds, erratic stop-and-go driving, unpredictable traveltimes, increased operating costs, higher accident frequencies, energy waste, air pollution, and many other frustrating conditions. It is attributed to overloaded facilities when traffic demand exceeds capacity; in other words, when too much traffic is attempting to use the same facility. Undesired delay, increased pollutants, and a waste of scarce resources are the resulting impacts.

While numerous factors contribute to congestion, most can be placed in one of the following general categories:

- Recurring excessive demand
- Non-recurring temporary capacity reductions (incidents), such as accidents or highway maintenance

The term, "recurring problem," is used to describe congestion when it routinely occurs at certain locations and during specific time periods. The term "non-recurring problem" is used to describe congestion when it is due to random events such as accidents or other extraordinary events.

Recurring Problems

The most common cause of recurring congestion is excessive demand, the basic overloading of a facility. Under ideal conditions, the capacity of a freeway is approximately 1,800 passenger cars per lane per hour. When the travel demand exceeds this number, an operational bottleneck will develop.

Conditions that give rise to delay are illustrated in figure 2.1. The solid line

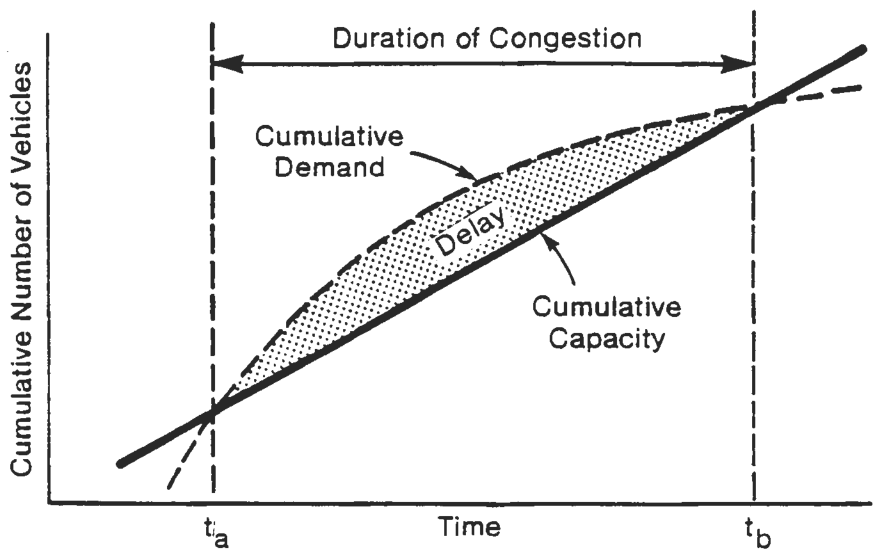

Figure 2.1. Relationship Between Demand, Capacity, and Delay

Recurring Congestion
Phoenix, Arizona

represents the cumulative capacity of a point on a section of freeway. The dashed line reflects the cumulative demand. As long as the traffic demand is less than or equal to the capacity of that section of freeway, there is no congestion. However, once the arrival rate begins to exceed the capacity (at time t_a), a bottleneck is formed and vehicles begin to accumulate upstream until the time when all of the accumulated vehicles being delayed pass the bottleneck and free flow is resumed. The amount of delay, represented by the shaded area between the demand and capacity lines, cannot be changed unless either demand or capacity is altered.

An example is congestion associated with unrestrained ramp access. If the combined volume of a freeway on-ramp and the main freeway lanes creates a demand that exceeds the capacity of the section where these lanes merge together, congestion will develop on the main lanes of the freeway, and this will result in queuing upstream of this bottleneck. The time and location of this type of congestion can be predicted fairly accurately.

Another cause of recurring congestion is the reduced capacity created by a geometric deficiency (such as a 'lane drop" where a through lane ends). The capacity of these sections, called geometric bottlenecks, is lower than that of adjacent sections along the freeway. When the demand upstream of the bottleneck exceeds the capacity of the bottleneck, congestion develops and queuing occurs on the upstream freeway lanes. The bottlenecks exhibit some of the same characteristics as the excessive demand bottlenecks. Likewise, the resulting congestion can also be predicted fairly accurately, after repeated observations of the congestion.

Lane drops, short weaving sections, narrow cross-sections, inadequate signing, sight restrictions, and non-standard interchanges are the most common causes of geometric bottlenecks. An active program of redesign and reconstruction of existing facilities could eliminate many of these geometric deficiencies. However, since these improvements tend to be very expensive, this type of problem will continue to be a source of congestion on many urban freeway facilities.

Non-Recurring Problems (Incidents)

Delay and hazards caused by random events constitute another, and usually equally serious, freeway congestion problem. Referred to as temporary hazards or freeway incidents, they can vary significantly in character. Included in this category is any unusual event that causes congestion and delay. Usually the effect of non-recurring problems is the reduction of traffic flow either by blocking a lane or lanes, or by causing some other impediment to traffic flow that reduces the capacity of a section of freeway. The most common types encountered on urban freeways include:

- Traffic accidents
- Disabled vehicles
- Spilled loads
- Adverse weather conditions
- Gawking or "rubbernecking"

Because neither the location nor time of these random events is predictable, the resulting congestion cannot readily be dealt with by routinely controlling demand or increasing capacity—strategies typically used to alleviate recurring congestion problems. Experience has shown that non-recurring problems happen frequently in day-to-day freeway operation and can create considerable congestion, especially if they occur early in peak demand periods.

Incident
Los Angeles, California

SEVERITY OF THE PROBLEM

Different freeway congestion problems have different impact severities; however, the severity of a particular problem is generally dependent on time of day, place of occurrence, and duration. A typical incident frequency would be 200 incidents per million vehicle-miles. On a dual four-lane freeway under heavy traffic conditions, this is equivalent to one incident per mile per hour. (Evaluation of the severity of an incident is contained in volume 2). Severity also depends on whether the different types of problems occur simultaneously or independently of one another. For example, a temporary hazard such as a disabled vehicle on the shoulder of a freeway may have only negligible impact on delay during off-peak conditions. But the same incident during a peak period, when freeway traffic is approaching capacity, may result in severe congestion.

Many studies have been conducted to determine the extent and magnitude of freeway problems. Although it is difficult to generalize the results because of the variety of problems encountered, it is possible to use statistics from a few of the studies to exemplify the magnitude of the overall freeway congestion problem.

DELAYS DUE TO INCIDENTS

Delays due to incidents may be as great or greater than those caused by recurring congestion. One study reports that at least one lane in a typical urban freeway network is likely to be blocked 7.2 percent of the time due to accidents and 6.7 percent of the time because of stalled vehicles or breakdowns. Such blockage of freeway lanes has severe impact. Research has shown that on one direction of a three-lane freeway, a one-lane blockage caused by a minor accident actually reduced the capacity of a freeway section by 50 percent even though the physical reduction was only loss of one lane (or a 33 percent reduction in capacity).

During a ramp control experiment in Los Angeles, it was found that freeway volumes increased, waiting times at ramps decreased, and average speed on the freeway increased from 25 to 52 mph.

BENEFITS OF FREEWAY MANAGEMENT

In an analysis of incidents using data from a Detroit study, it was calculated that delay-causing incidents on a 10-mile freeway segment would produce 550,000 annual vehicle-hours of delay, resulting in excessive hydrocarbon pollutants and a waste of more than 360,000 gallons of gasoline. The Los Angeles program of early detection and rapid removal of unusual incidents noted that non-recurring congestion could be reduced by as much as 65 percent with an incident-management program.

Another of the major beneficial effects of freeway management systems is reduced accidents. By metering traffic at ramps, there are fewer merging conflicts and the traffic on the mainline of the freeway is less erratic in its flow patterns, reducing rear-end collisions. On the Eisenhower Expressway in Chicago, improved traffic flows reduced expressway and ramp accidents by 17 percent in the peak period.

It was estimated that the freeway management system in Los Angeles contributes to annual savings of more than 220,000 vehicle-hours (vehicle-hours is the number of vehicles on the system multiplied by the time they take to travel). This is equivalent to an annual net benefit of nearly $675,000. In Detroit, where ramp metering was installed to combat recurring congestion problems, it was estimated that 225,000 annual vehicle-hours were saved as a result of this

Two Lane Ramp Metering in Los Angeles, California

control. A similar savings in travel time has been reported for the outbound lanes of the Eisenhower Expressway in Chicago.

COST OF SYSTEM

There are no national figures indicating the total costs associated with freeway congestion, but it has been estimated that these costs constitute a multimillion dollar annual burden.

The costs associated with freeway management systems can vary greatly with the system size and sophistication. On the I-35E system in St. Paul, six controlled ramps were installed for approximately $70,000; speeds increased by 16 percent, and accidents were reduced by 37 percent. By contrast, the Chicago system mentioned earlier, which covers 110 miles of freeway, required a capital investment of $8 million and an annual maintenance cost of $1 million.

SUMMARY

The two major causes of freeway congestion are recurring excessive demand and non-recurring temporary reductions in capacity, such as accidents. The severity of the non-recurring congestion is dependent on accident severity, time of day, location, and duration. Freeway management programs in several U.S. cities have resulted in reduced congestion, increased average speeds, fewer accidents, and substantial gasoline savings.

Defining Problems	1. Introduction 2. Problem Statement
Proposing Solutions	3. Management Strategies
Implementing and Evaluating Projects	4. Development of a Freeway Management System 5. Economic Analysis 6. Staged Construction and Financial Planning 7. Intragency Cooperation
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CHAPTER 3. MANAGEMENT STRATEGIES

A wide range of options is available to minimize congestion and control the level of service provided to motorists on urban freeways. These options deal with both recurring and non-recurring problems.

MANAGEMENT OF RECURRING PROBLEMS

Although management of recurring problems can take a variety of forms, the following are usually involved: managing vehicular demand, increasing capacity through geometric improvements, or managing of travel demand. Figure 3.1 shows the general techniques that can be used to manage recurring problems.

Management of Vehicular Demand

Vehicular demand is managed by various freeway operation control techniques—control of traffic at entrance ramps, control of traffic on the freeway mainline, priority control, and corridor control.

Entrance Ramp Controls — Entrance ramp control is the most widely used method of managing vehicular demand. Its basic objective is to reduce the number of vehicles entering the freeway so that freeway traffic can move in the most efficient range of traffic density—i.e., the optimum density to achieve the maximum flow. This type of control provides for a higher and more predictable level of

FIGURE 3.1. MANAGEMENT STRATEGIES FOR RECURRING PROBLEMS

Management of Vehicular Demand

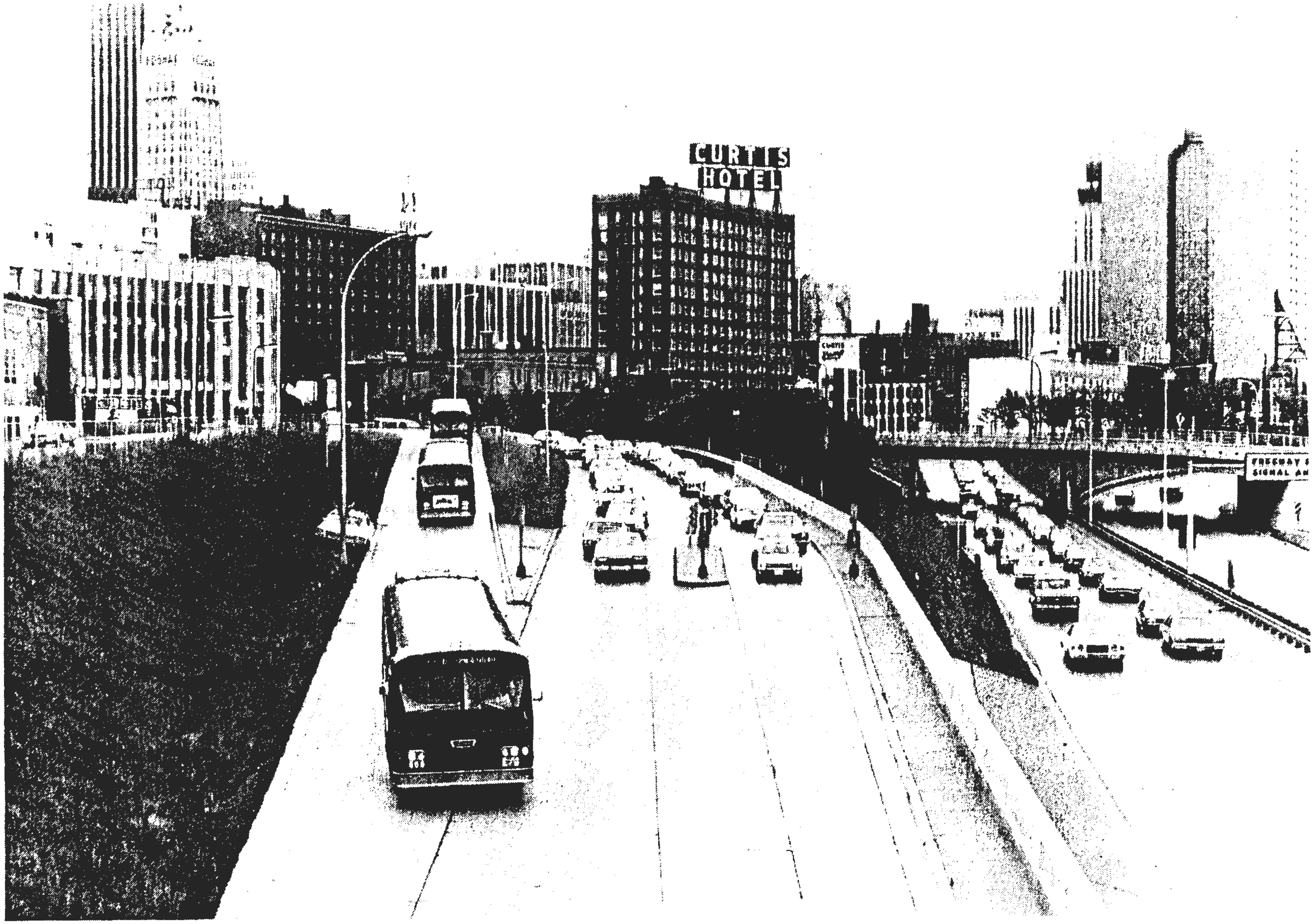
- Entrance Ramp Controls
  - Ramp Closure
  - Ramp Metering
  - Integrated Ramp Control
- Freeway Mainline Control
  - Variable Speed Control
  - Driver Information Systems
  - Priority Control
  - Corridor Control

Geometric Improvements

- Restriping to Add Lanes
- Reconstruction

Management of Travel Demand

- Work Rescheduling
  - Staggered Hours
  - Flexi-Time
- Ridesharing
  - Carpools
  - Vanpools
  - Subscription Bus Service
- Park and Ride Facilities
- Transit Service Improvements



Metered Ramp with Exclusive Bus Bypass Lane
Minneapolis, Minnesota

service on the freeway and, at the same time, improves the overall safety of operation, reduces air pollution, and conserves energy. Ramp closure and ramp metering are the most frequently used forms of entrance ramp controls.

Ramp closure consists of physically closing the ramp to traffic on either a permanent or a short-term basis. Because of the abrupt nature of this type of control, it is normally used only at selected locations. Such locations include facilities with inadequate storage at the entrance ramp (to prevent disruption to surface street traffic due to vehicles waiting to enter the freeway), facilities where the freeway is running at capacity on the section before the entrance ramp, and facilities where the ramp (even when controlled) does not allow traffic to merge into the freeway traffic stream without considerable hazard or disruption.

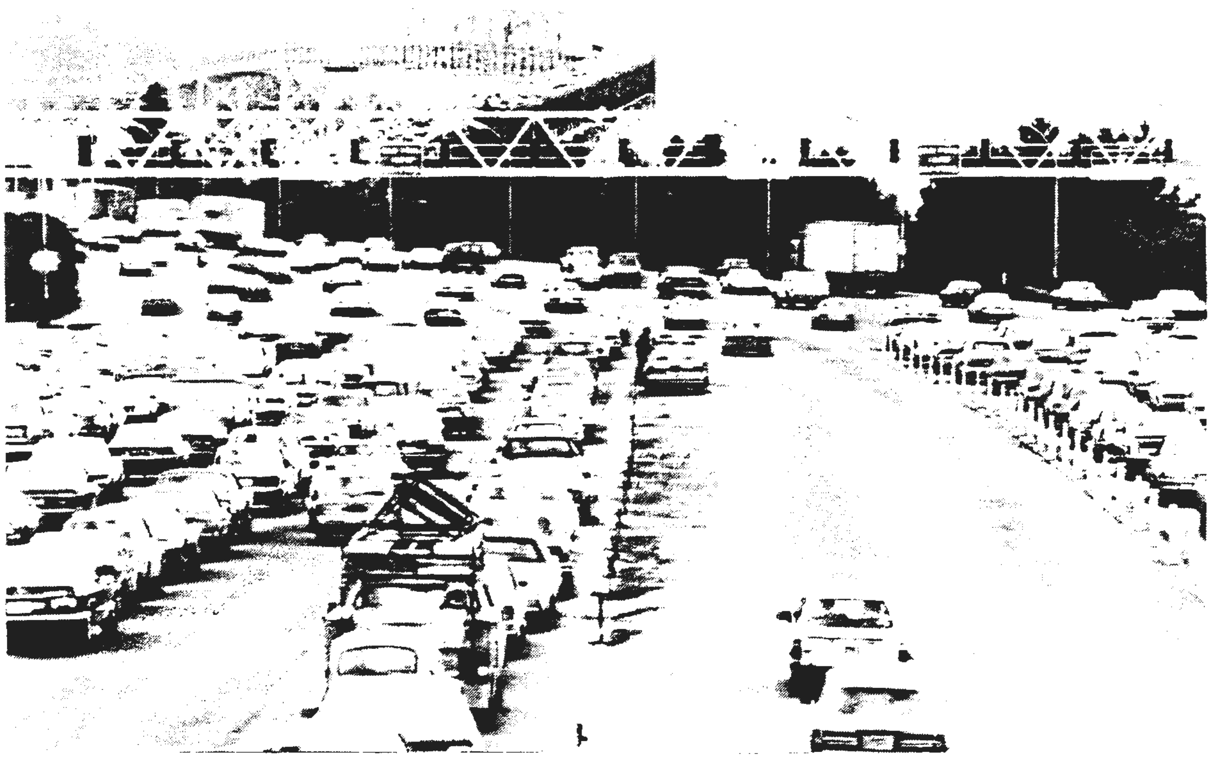
Ramp metering, the most common technique for controlling vehicular demand, limits the rate at which traffic can enter the freeway, thus allowing the freeway to operate at a higher level of service. A traffic signal is used on the ramp to control the flow of traffic.

Integrated ramp control is a refinement that has been planned for the Dallas system. With this technique, ramp metering rates are based on total system operation and not on traffic flow just immediately upstream and downstream of a ramp. The control system monitors level of service performance at all access points to the freeway and, from this measurement, establishes an allowable ramp flow that will achieve a desired level of service for the entire system. By controlling the level of service in the system, overall higher flows can be achieved throughout the length of the freeway. Integrated ramp control is a complex operation that requires both sophisticated control strategies and centralized computer control. However, such a system can be responsive to individual variations in traffic demands and can be especially useful in responding to incidents that occur within the control section.

Freeway Mainline Control — Control of traffic on the freeway mainline involves regulation and guidance of freeway traffic with the intent of achieving more uniform and stable traffic flow as demand for the facility approaches capacity. Although freeway mainline control has not been used extensively in operating systems, there is considerable interest in the concept, and it is likely there will be more emphasis on research and demonstration projects in the future. The most common mainline control techniques include variable speed control, driver information systems, and mainline metering.

Variable speed control is intended to control the speed of traffic on a freeway to a level that achieves a uniformity of speeds and stable traffic flow. The theory is that, as the peak-flow demand on a facility increases, speed control can help improve the stability of flow and thus reduce interaction between vehicles in the traffic streams. This assumes, of course, that drivers are responsive to speed increase opportunities and thereby maintain minimum headways. When this is not true, speed control is not a viable concept for preventing congestion. However, improving the uniformity of speeds reduces the occurrence of rear-end collisions as congestion develops. Variable speed control can also be used during off-peak periods to alert motorists to a traffic hazard.

Experience with variable speed control has been limited, and results have been somewhat mixed. In Detroit, motorists considered variable speed limits advisory rather than regulatory and thus did not decrease speeds to the posted limit unless



Mainline Metering
Oakland Bay Bridge, California

there was an apparent reason to do so. It was also found that the control was not successful in increasing flow at critical bottlenecks. Many European countries have found that variable speed signs on freeways are effective and produce favorable results in terms of improving speed distribution and reducing the frequency and severity of accidents. The success of these signs is attributed primarily to the fact that they contain information on the reason for the recommended speed.

Driver information systems are used in mainline control to advise motorists of freeway conditions so that appropriate actions can be taken by the driver to enhance the efficiency and safety of operations. The philosophy is to inform the driver (usually through signing or by radio) of impending conditions with up-to-date information. This enables the driver to decide what actions should be taken; i.e., whether to divert from the freeway or continue on the planned route under some form of control.

Single-message signs—those capable of conveying only one message—are used to warn drivers of a closed lane, congestion, or a particular hazardous condition such as weather or environmental conditions. Since they are used only when a particular hazard occurs, these signs are limited. However, they can be very useful at locations where a hazard is well defined and occurs periodically.

Variable message signs are able to convey a variety of information, which makes them more effective in presenting current information on changing traffic conditions. A number of these sign systems are currently installed on freeways and feature some of the principal systems discussed in table 3.1.

Commercial radio is a common means of communicating freeway traffic information. Local broadcast stations in all major urban areas provide information on a routine basis during the peak periods of traffic flow; however, because much of

TABLE 3.1. SUMMARY OF FEATURES OF SOME VARIABLE MESSAGE SIGN SYSTEMS

Location	Type of Sign	Number of Displays	Type of Information
Los Angeles, California	Lamp Matrix*	21	Freeway Condition
Denver, Colorado	Lamp Matrix	4	Freeway Condition
New Jersey Turnpike	Drum (95) Neon (41)	136	Alternate Route
Cincinnati, Ohio	Lamp Matrix	19	

*A lamp matrix is the type of sign consisting of a grid of bulbs, any pattern of which can be lighted to form letters and numerals.

Mobile Variable Message Sign
Los Angeles, California

the information broadcast by the local stations is not accurate, timely, or reliable, its effectiveness often is lost. Several urban areas have solved this problem by creating cooperative arrangements between radio stations and freeway operating agencies. Hence, detailed traffic information is furnished to the stations at regular intervals by a freeway management agency and the stations are notified almost immediately of traffic problems resulting from accidents or other major incidents. This increased cooperation has resulted in a much more reliable system for providing real-time driver information.

Priority Control — Priority control provides preferential treatment for buses, carpools and other priority vehicles using the freeway. The basic intent is to encourage use of more high-occupancy vehicles and thus reduce the total vehicle demand on the freeway. The major types of priority control used on freeways are separated facilities, reserved lanes, and priority access control.

Separated facilities are limited-access roadways specifically constructed for the exclusive use of high-occupancy vehicles. They are used to provide express service between outlying areas and activity centers or to act as short bypasses at major freeway bottlenecks. In most cases, the separated roadways are located in the median of an existing freeway with some type of barrier to provide a physical separation from the main freeway lanes. The advantages of this technique are that priority vehicles can operate safely at high speeds, existing freeway efficiency is not reduced, and enforcement of priority control is more manageable. Some disadvantages are high capital costs and lack of use during off-peak periods. However, separated facilities have the potential to provide long-term benefits, and often this is justification for the high initial capital costs.

Reserved freeway lanes have two configurations: concurrent-flow lanes for priority vehicles moving in the same direction and on the same side of the median as the main stream of traffic; contraflow lanes on the opposite side of the median where priority traffic moves against the flow of traffic.

Use of contraflow lanes seems to be preferred due to the difficulty of removing one lane from the primary flow direction. In this technique, an off-peak-direction lane is used for peak-direction traffic. Movable barriers normally delineate the lane, and access is limited to specific slip ramps or cross-over points at the beginning of the system.

Implementation of this technique usually relies on highly directional peak-period traffic flow with sufficient excess capacity in the off-peak direction. Many of the facilities in operation today are reserved exclusively for buses, but some also permit carpools. Advantages of contraflow lanes include increased capacity in the peak direction. Also, contraflow lanes can be implemented in a short time at relatively low cost. The disadvantages are high operating costs as often the labor required to cone off a lane can be extensive, potential for serious head-on collisions (although the safety record has been good), and the need for handling breakdowns in the reserved lane.

A concurrent-flow reserved lane is a normal-flow lane with signs and markings designating that priority vehicles have exclusive access to the lane. One concept of this technique is to create a preferential lane by taking one freeway lane out of existing service and dedicating it to the use of high-occupancy vehicles (buses and carpools). An alternative concept is to physically add a lane to the freeway for the use of high-occupancy vehicles. The advantages of such a system are that the high-occupancy vehicles are given a

Contra-flow Bus Lane
Lincoln Tunnel, New Jersey

distinct traveltime advantage and when properly planned, there are no adverse effects on the other traffic. The disadvantages are the potential hazards created by having a high differential in speed between the priority vehicles and traffic in the non-reserved lanes along with the increased weaving required for vehicles getting to and from the reserved lane. Enforcement is also difficult, and the overall effectiveness is likely to be negated in the event of an incident. Table 3.2 summarizes operational experience on three concurrent-flow reserved lane projects.

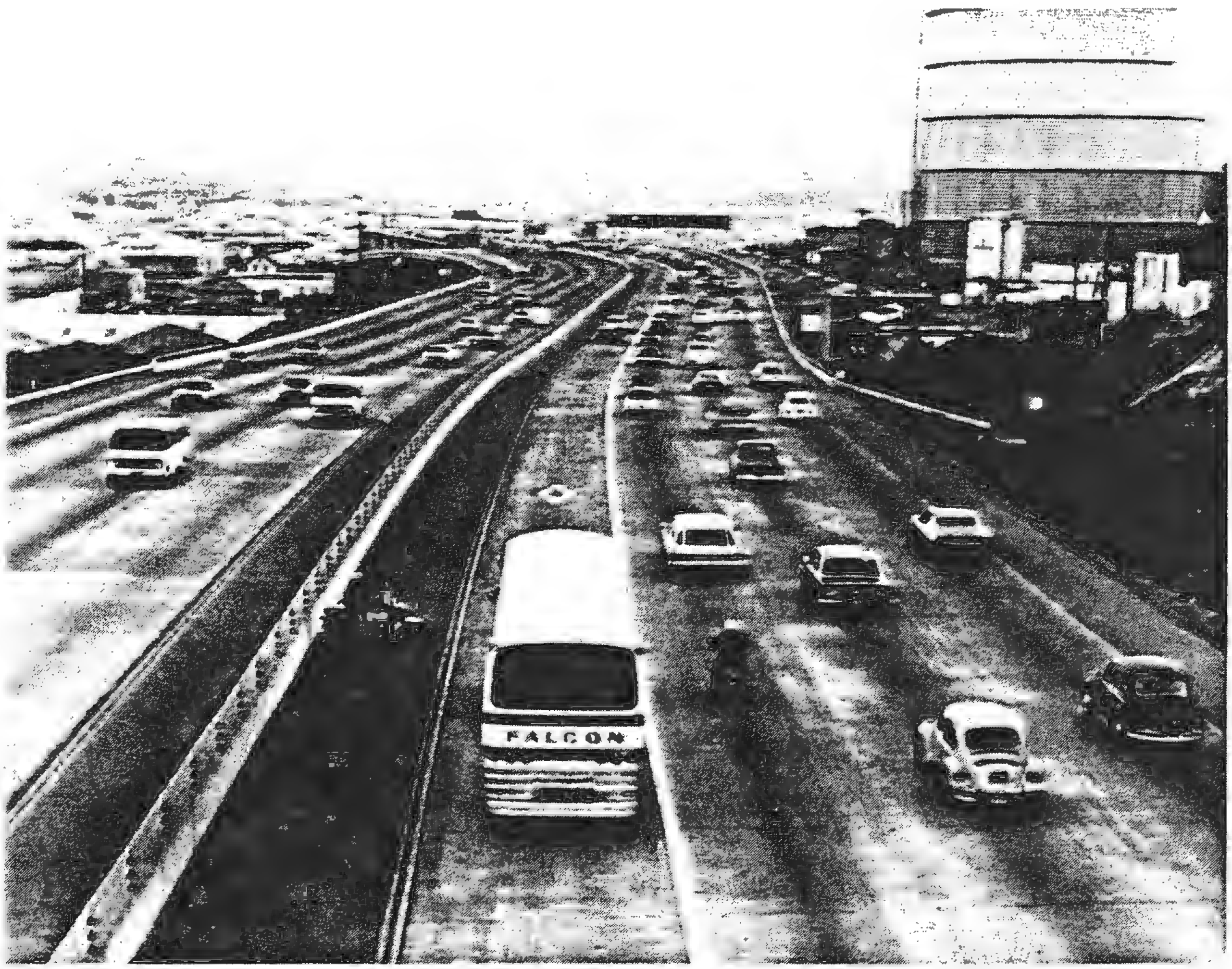
Other concurrent-flow reserved lane projects are similar except that a reserved lane was designated at the same time a lane was added to the freeway. The added lane was provided either by widening or by restriping and using a portion of the shoulder. In most of these projects there was a significant increase in carpools but the safety of operation still remains a concern of the operating agencies.

Priority access control is another technique used to improve the level of service for high-occupancy vehicles. This type of control, used in conjunction with freeway ramp metering controls, either gives high-occupancy vehicles priority access to a ramp bypass lane or designates exclusive ramps for their use. The concept is that the high-occupancy vehicles can avoid the delay caused by the ramp metering and can enter an uncongested freeway with minimum disruption. Priority entry can be installed and operated at relatively moderate cost and can provide a significant increase in the people-moving capacity of a freeway, without the degree of enforcement and accident problems associated with reserved lanes.

Corridor Control — In freeway management terms, a corridor is defined as the freeway and adjacent arterial streets running parallel to the freeway. The objective of corridor control is to obtain an optimum balance between traffic demand and capacity through the coordination of various control and driver information

TABLE 3.2. CHARACTERISTICS OF FOUR CONCURRENT-FLOW RESERVED LANE PROJECTS

	Miami, Florida North-South Freeway I-95	Los Angeles, California Santa Monica Freeway	Marin County, California Redwood Highway
Date of Operation	December 1975 to Present	March 1976 to August 1976	December 1974 to Present
Length in Miles	7.5 Miles	12.5 Miles	4 Miles
Number of Users	40 Buses Peak Period, 334 Carpools Peak Hour	170 Buses and 4,592 Carpools Daily	90 Buses and 475 Carpools Peak Hour
Time Savings	7 to 10 Minutes	4 Minutes EB 6.5 Minutes WB	3 to 6 Minutes
Hours of Operation	6:30-10:00 a.m. 3:00- 7:00 p.m.	6:30-9:30 a.m. 3:00-7:00 p.m.	6:00-9:00 a.m. 4:00-7:00 p.m.



Concurrent Flow HOV Lane
Los Angeles, California

systems. This facilitates the total movement of traffic on the freeway and adjacent urban arterial streets. The basic concept is to monitor all routes in the corridor and divert traffic from overloaded facilities to those with excess capacity. Inherent in this type of system is the requirement for traffic-responsive capabilities and the ability to implement operational control strategies that will optimize traffic flow within the corridor.

Most corridor control strategies, such as the Dallas Corridor Control Project, are still in the research stage and have not advanced to the point that they can fully take into account all of the variables of freeway and urban street control. At this time there is no fully operational corridor control system in daily operation in the United States. However, the Centrally Integrated Traffic Control System in Glasgow, Scotland was introduced in 1980 and has proven successful.

Geometric Improvements

Another approach to the management of recurring freeway problems is improving freeway capacity at bottleneck locations. A basic solution is to add lanes, either by restriping the pavement and shoulder or by reconstruction of the entire cross-section. The restriping is least costly, but it requires some sacrifice in design standards. In most instances, restriping is generally regarded as a temporary solution with an intent to provide improved geometrics at some later date.

The major disadvantage of either solution is that provision of additional capacity may attract more traffic and increase demand to use the freeway, which results in demand approaching the new capacity. Therefore, when geometric capacity improvements are made, it is often desirable to implement management techniques, such as driver information systems, at the same time to ensure that the benefits of the geometric design can be fully realized.

Often, a major problem in implementing geometric design improvements at bottleneck locations is the lack of downstream capacity to absorb increased volumes. Any improvement should be part of a complete system or the problem could move to another bottleneck location downstream. For this reason, it is important that geometric improvements be planned on a systematic basis. Analyis and implementation of improvements should consider the effects on all sections of the freeway. This avoids a major expenditure that only transfers the congestion problem to a new location.

Experience in improving freeway capacity through the use of restriping has been good. In Los Angeles, four 12-foot lanes and a 10-foot shoulder were converted into five 11-foot lanes and a 3-foot shoulder. This resulted in an 18 percent capacity increase with no adverse safety effects. Other projects have reported similar results, and many agencies are now adopting this technique as policy.

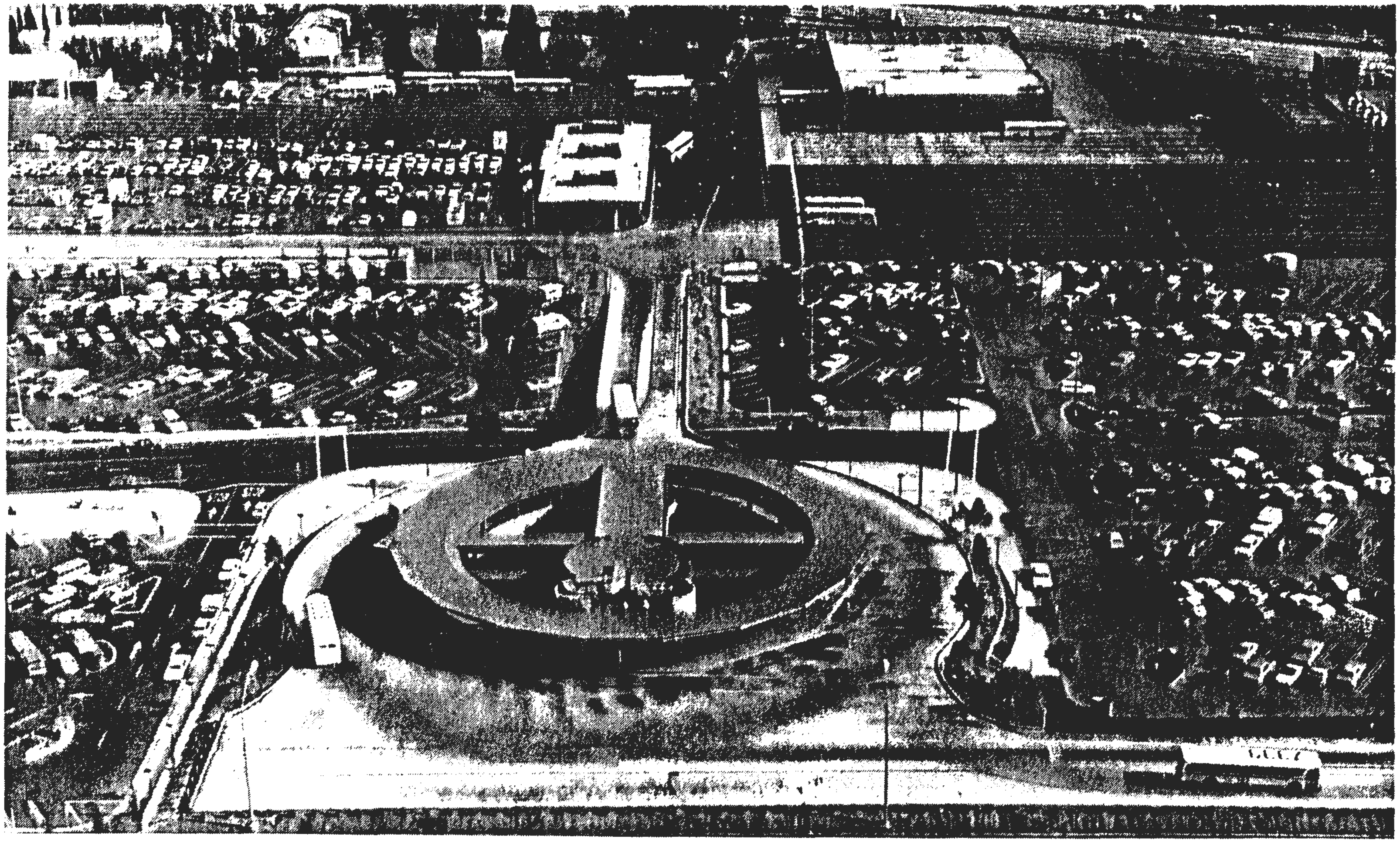
Management of Travel Demand

A third approach is to reduce peak-period travel demand by placing greater emphasis on:

- Using fewer vehicles
- Encouraging off-peak use of the facility

Techniques include work rescheduling, ridesharing, park-and-ride, and transit service improvements.

Work Rescheduling — The peak concentrations of work trips during the commuting hours are an evident cause of congestion. Thus, the main thrust of work rescheduling is an attempt to reduce con-



Park and Ride Terminal
Los Angeles, California

gestion by spreading out the peak (i.e., increasing the total time during which commuting occurs, decreasing the percentage of commuter travel during the busiest period).

The basic alternative forms of work rescheduling are:

- Staggered hours, in which changes in fixed schedules of starting and quitting times are implemented either for all employees or groups of employees within an employment location

- Flexi-time, in which employees are permitted freedom to adjust their own working hours within certain limits

Numerous cities have undertaken comprehensive variable work-hour programs. Experience has shown that, when coordinated with the transit system, work rescheduling has resulted in significant improvements in transit system operating efficiency, even to the point of increasing ridership. It has also been demonstrated that while work rescheduling strategies are not likely to produce significant changes in vehicle-miles of travel, they can produce improvements in freeway levels of service during peak periods.

Ridesharing — Increased use of ridesharing has the potential for reducing total vehicular travel on urban freeways. By increasing vehicle occupancy, ridesharing reduces the number of vehicles used for commuting. Carpools are the most popular, but use of vanpooling and subscription bus service is increasing. Carpools are easier to organize as fewer riders are required to share similar origins and destinations. Many data banks have been organized to put carpool users in contact with each other.

Ridesharing is most commonly used where a long trip is involved and public transit is either inconvenient or non-existent. It is most effective when both origins and destinations are concentrated within relatively small areas and arrival and departure times of the participants are similar. While ridesharing programs can be carried out as an isolated technique, experience has shown that they are more effective in achieving widespread participation if they are conducted in conjunction with other programs such as park-and-ride, priority control, and parking management.

Many of the more successful ridesharing programs have been developed by large employers who are located in relatively isolated situations and draw their labor force from residential communities some distance away. The critical element in attracting riders seems to hinge on the type of service offered. Users will be attracted to direct, easily accessible, comfortable service that is not significantly more expensive than competing modes.

Many employer programs have resulted in dramatic increases in ridesharing among their employees. For example, the Tennessee Valley Authority in Knoxville has:

- Increased carpool use from 30 percent to 41 percent of employees

- Increased vanpooling from 0 percent to 7 percent of employees

- Reduced "drive alone" commuters from 65 percent to 18 percent of employees

Since ridesharing programs benefit from standardized work-hour patterns, however, ridesharing and work scheduling programs implemented together may create conflicts and work at cross purposes.

HOV Advertising
Miami, Florida

Park-and-Ride Facilities — Provision of park-and-ride facilities to encourage transit and ridesharing is another technique used to increase the efficiency of a freeway corridor. Park-and-ride lots located at strategic points along a freeway corridor can serve as convenient collection points where users are subsequently shuttled to their destination by express bus or some other form of ridesharing. This encourages the use of fewer vehicles.

Park-and-ride service is becoming increasingly common in the United States, particularly in urban freeway corridors. Los Angeles has developed a park-and-ride program that consists of 16 such facilities along the extensive freeway system. Most of the lots are shared-use facilities (i.e., drive-in theaters, shopping centers, etc.). A survey showed that 50 percent of the users of these park-and-ride facilities shifted from driving alone to riding the bus. Similar results are being reported in other major urban areas.

The advantages of park-and-ride facilities are that they shift the parking from dense activity centers to outlying areas and, when coupled with good service that normally includes other incentives such as priority measures, they can result in considerable commuter time savings. This makes park-and-ride an unusually attractive alternative to private auto travel.

Transit Service Improvements — Maximizing the use of bus transit is another technique to achieve more efficient flow along an urban freeway corridor. Its aim is to make transit more competitive with the private auto. Complementary measures such as park-and-ride facilities, reduced fares, and reserved lanes also provide additional incentives to transit use.

The effectiveness of transit service improvements in reducing peak-period congestion on freeways is dependent on the ability to provide improved traffic flow along the freeway and, in turn, on the number of peak-period drivers that can be diverted to the transit system. For example, bus lanes on the Shirley Highway in Virginia caused patronage to rise by 68 percent. The time savings on this project varied between 12 and 23 minutes.

The most recent experience with a program of this type was the Santa Monica Freeway Diamond Lane Project. Transit service in the corridor improved significantly with four new express routes that more than doubled the number of CBD workers living within walking distance of the route. In response to both the reserved lane and the significant increase in transit routes and service frequency, daily bus ridership in the corridor more than tripled, increasing from 1,171 riders per day to 3,793 riders per day. Survey results indicated that 96 percent of the trips were to and from work; of those interviewed, 39 percent previously drove alone, 8.5 percent carpooled, 36 percent rode the bus, and 16.5 percent did not previously make the trip. It was estimated that at least 700 former drivers switched to riding the bus following the project's implementation.

MANAGEMENT OF NON-RECURRING PROBLEMS

Non-recurring problems are somewhat more difficult to manage. Their locations and times are not predictable, and the impact of their occurrence can be either significant, as in the case of a major lane-blocking incident, or somewhat insignificant, such as a disabled vehicle on the shoulder. Delay-causing incidents are a main concern since they are the most disruptive to traffic flow.

In the case of the delay-causing incidents where reduced capacity is encountered,

Mainline Loop Detectors
Los Angeles, California

the major requirement is to eliminate or prevent the cause, manage the demand that is approaching the incident, and restore the freeway to its normal service volume as quickly as possible. Thus, management of these problems requires a fairly extensive system of surveillance, services, and information.

Surveillance is required to detect and evaluate the nature of the problem and determine the appropriate action to be taken. The services function provides the response in terms of incident removal or motorist aid and includes the resources needed to restore normal conditions. The information system provides the motorists with information that will enable them to select and follow the best course of action (i.e., slow down, divert, etc.). Figure 3.2 illustrates management strategies for non-recurring problems.

FIGURE 3.2. MANAGEMENT STRATEGIES FOR NON-RECURRING PROBLEMS

- Surveillance Systems
  - Detector-Based
  - Closed-Circuit Television
  - Aerial Survey
- Incident Servicing
- Motorist Information

<u>Surveillance Systems</u>

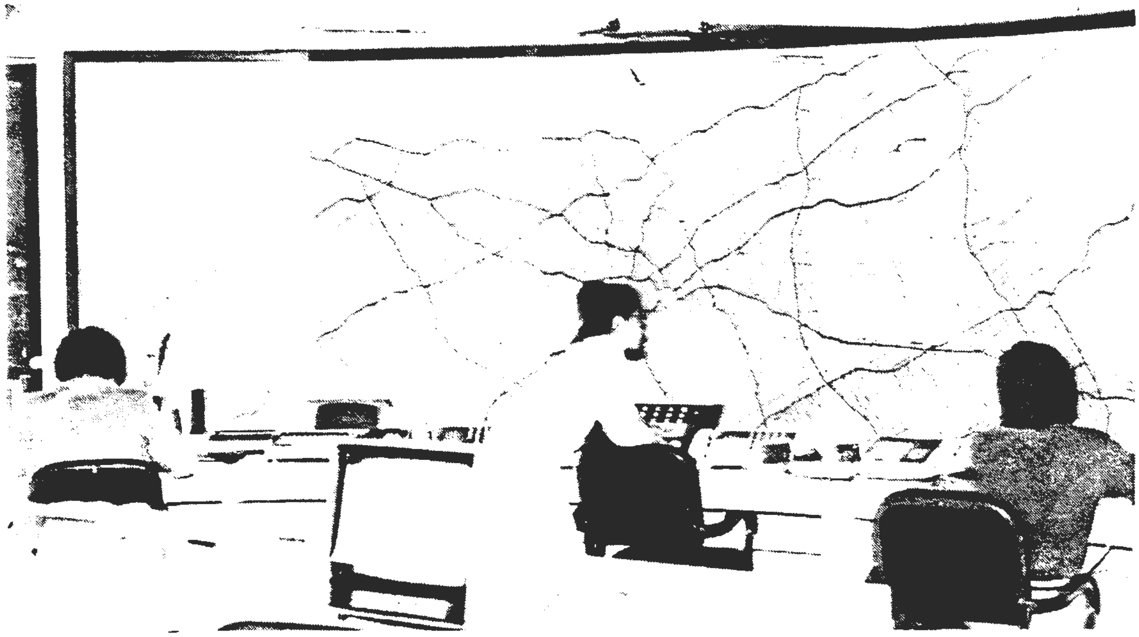
Various surveillance systems are used for incident detection. Some systems convey information concerning the type of response required to remedy the problem that has been detected. In most cases, however, the detection process is an independent operation, and some form of follow-up is required to ascertain the nature and extent of the incident and the type of response required.

<u>Detector-based Surveillance</u> — Incident detection by electronic surveillance is real-time monitoring of traffic data through use of detectors installed at critical locations along the freeway. When a delay-causing incident occurs, the capacity of the freeway is reduced at the point of occurrence. If capacity is reduced to less than the existing demand, the traffic flow upstream of the incident will be affected. If the changes in traffic flow are greater than some predetermined value, it is likely that an incident has occurred. In this manner, incidents are detected by logically evaluating the variations in flow characteristics.

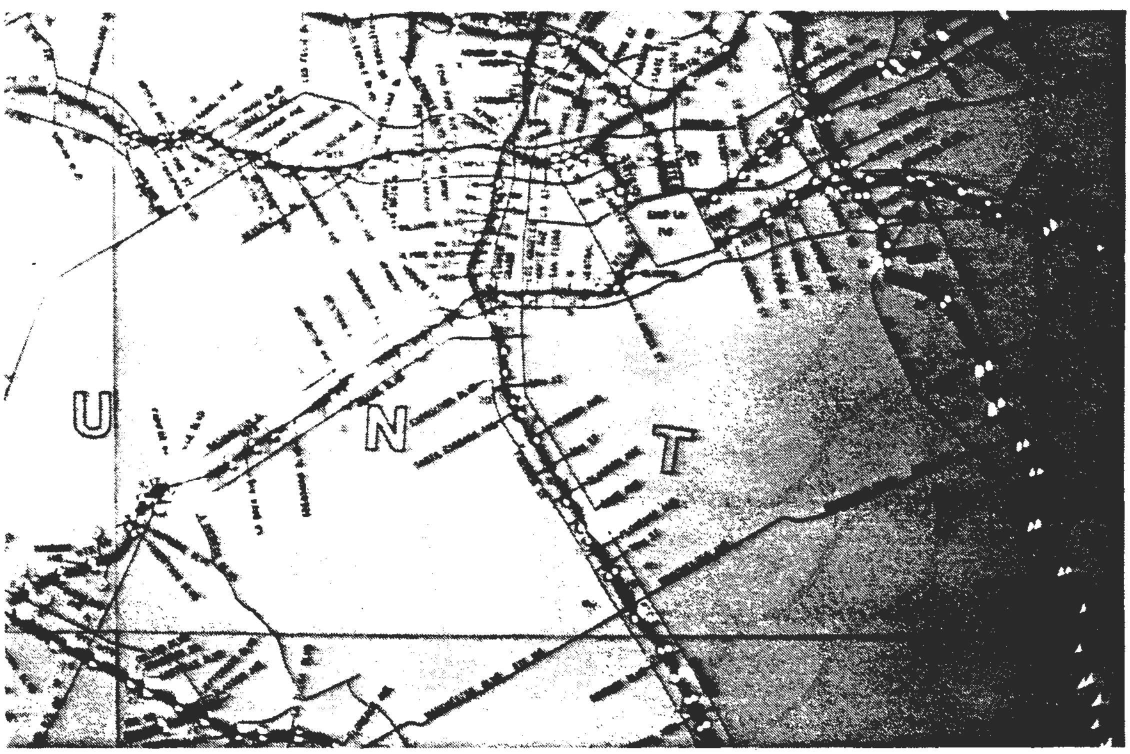
In the Los Angeles Freeway Surveillance and Control Project, changes in the percentage of time that vehicles spend above a detector (lane occupancy) are used to sense congestion and indicate that an incident has occurred. A computer calculates the difference in occupancy between adjacent detector stations (in this case, spaced at 1/2-mile intervals). When the difference between the occupancy at the upstream and downstream detectors exceeds a certain value, an alert is signaled automatically by the computer. Additional information on traffic conditions immediately upstream of the incident is then obtained, and decisions are made as to what response is needed.

The main advantage of detector-based surveillance is that it provides a continuous network-wide monitoring capability at a relatively low operating cost. It can also be used for many other tasks such as establishing metering rates for traffic-responsive ramp-metering systems. Its main disadvantage is that the nature of the incident cannot be readily identified, and some follow-up surveillance is often required to determine what response is needed.

<u>Closed-Circuit Television</u> — Incident detection by closed-circuit television is per-



Control Room
Los Angeles, California



Close-up of Wall Map,
Indicator Lights Change Color to Show Congestion
Los Angeles, California

formed using operators in a central control room who monitor traffic conditions using television cameras placed at critical locations on the freeway. When an incident occurs, the operator determines the nature of the incident and the type of response likely to be required. In general application, closed-circuit television is limited to those locations where delay-causing incidents are a chronic problem and fast response is essential. In this use, the television normally serves to confirm electronic surveillance where incidents are detected automatically and an alarm is used to alert the operators. It also provides information on the nature of the incident.

The major advantage of closed-circuit television is that it provides a full view of a section of freeway. The major disadvantages are:

- It is expensive to install and maintain. However, recent technological developments may alleviate this problem as the costs of video cameras fall and communication systems become more reliable.

- It is often difficult and expensive to obtain good pictures under adverse weather conditions and after dark. However, new technology has resulted in provision of much better pictures under such conditions.

- Monitoring of the TV screen is a tedious task. Without an automatic alarm in a detector-based surveillance system, operators tend to lose interest and consequently fail to notice incidents immediately.

- Continuous monitoring of TV screens by qualified operators is expensive.

<u>Aerial Surveillance</u> — This type of surveillance is primarily used by police and commercial radio stations to get a general overview of traffic in a particular area or corridor. Through the use of light planes or helicopters, they observe where the bottlenecks are occurring and determine whether they have been caused by incidents. Advisories of this information are then broadcast to motorists, and assistance is dispatched to the scene of the incident. Due to the expense of this type of surveillance, usually a wide geographical area must be covered. Consequently, there often is considerable time delay in identification and removal of incidents.

In general, it has never been conclusively demonstrated that aerial surveillance is a cost-effective technique for incident detection. The equipment and the labor requirements of the system are expensive and its effectiveness is sometimes limited by weather conditions.

<u>Motorist Call Systems</u> — One of the earliest incident detection systems used motorist call boxes or emergency telephones. Motorists experiencing, or witnessing, an incident used the nearest call box or telephone to inform the operating agency of the nature of the incident. Telephones are generally preferred because voice communication gives the motorist an opportunity to explain exactly what services are required. However, the call box with coded message buttons is less costly than a telephone requiring voice transmission.

The major advantage of a motorist call system is that it is an efficient system for signaling a motorist's need for service. A major disadvantage is the delay associated with the motorist's determining that an incident has occurred, determining that the proper action involves using the call box, locating the nearest call box, and then proceeding safely to the call box to inform the operating agency. This delay can be quite significant. Another major disadvantage is the large number of

Motorist Call Box
Los Angeles, California

"gone-on-arrival" calls that are generated (i.e., the motorist remedies his problem through some other means and when the servicing agency arrives the disabled vehicle is no longer there).

Citizens Band Radio — Another way freeway incidents can be detected is through use of citizens band (CB) radio. Drivers of vehicles equipped with a CB radio observed incidents to a central monitoring center which in turn transmits the information to the appropriate agency for dispatch of the required assistance. The key elements of this system are motorists who are knowledgeable about the system and willing to report the incidents they observe. Signs informing the motorists which CB channels are monitored are necessary. Because of this volunteer aspect, the detection capability of the system is always a function of the number of motorists on the freeway who have the necessary CB equipment and are willing to provide their cooperation. With the growing number of CB-equipped vehicles, this type of system has considerable potential. This system has been working well in Detroit where remote CB units are used to monitor calls. These remote units are called up over telephone lines when an incident is detected and the broadcast is then monitored to provide additional information on the nature of the incident. In Minneapolis, two remote CB units are continuously monitored and initial results show that one in six incidents were detected over the CB radio before they were detected by the automatic incident detection system.

Police and Service Patrols — Various patrol systems have been used on urban freeways to provide incident detection. The most common is the use of police patrols that circulate in the traffic stream and have as their primary objective the identification of incidents, determination of the nature and extent of the incident, and dispatch of the type of response needed. The major advantage of police patrols is that detection and dispatch of response is one function. The major disadvantage is the large number of patrols required to effectively cover a freeway system and the high costs involved.

Another system used to provide incident detection is the service patrol. This system involves the use of light-duty service vehicles and, similar to the police patrols, provides for detection of incidents. It also provides minor services such as fuel, oil, water, and minor mechanical repairs. As with the police patrols, this system is relatively expensive because of the large number of patrols required. The patrol vehicles in regular use in Chicago have assisted over 1 million motorists in the past 20 years.

Since surveillance techniques are complementary, most operational surveillance systems utilize more than one concept to achieve a cost-effective surveillance and control system.

Incident Servicing

Once an incident is detected, the key to minimizing non-recurrent congestion is the speed with which the incident is removed. The longer the duration of response, the more severe the resulting congestion and delay for a given level of demand. Consequently, an effective incident management program must include service facilities which, upon location of an incident, allow for rapid removal of that incident.

Experience has shown that much of the congestion caused by an incident can be alleviated if operational procedures provide for the removal of disabled vehicles to a location off the freeway as rapidly as possible. Such a program involving accident investigation has been implemented

Police Tow Truck
Lincoln Tunnel, New Jersey

with significant benefits on a 6-mile section of the Gulf Freeway in Houston.

Three operational incident management systems that have effective incident servicing are the Chicago Area Emergency Traffic Patrol, the Los Angeles Area Freeway Surveillance and Control Project, and the traffic management system for the Holland and Lincoln Tunnels in New York.

The major elements of the Chicago Emergency Traffic Patrol include:

- A special radio-equipped fleet of trucks continuously patrolling to promote freeway safety and to maintain good traffic flow
- Illinois DOT Communication Center coordinates all incoming reports of incidents and directs nearest patrol unit to respond
- Expressway Surveillance Project; an electronic surveillance network that detects traffic flow disruptions, troubled expressway sections and notifies IDOT Communication Center

The major elements of the Los Angeles Area Freeway Surveillance and Control project include:

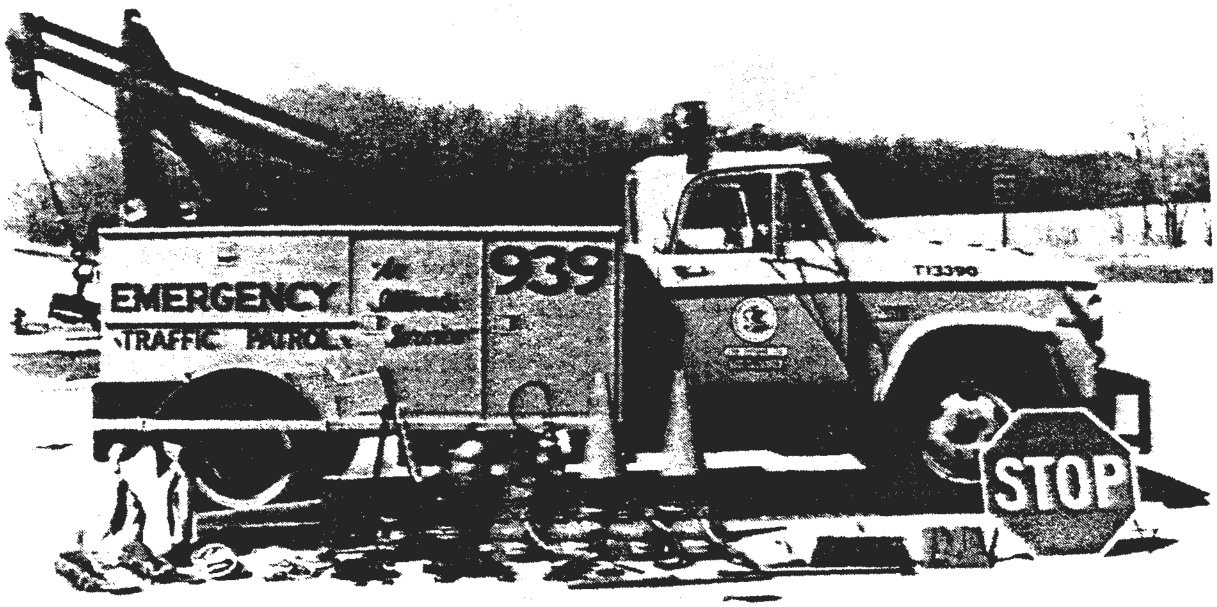
- An incident management team representing the disciplines of police, maintenance, and traffic engineering
- A control center where a three-man team has access to incident detection information and communication facilities to dispatch services required for rapid incident removal
- A freeway electronic surveillance system that detects incidents, enabling dispatch of a tow truck to confirm the incident and determine its nature and extent; the control center team is notified and determines response
- A helicopter equipped with a closed-circuit TV camera to monitor major incidents (used about twice a week)

This system reduced incident-related delay by more than 50 percent.

The major elements of the traffic management system in the New York tunnels include:

- An automatic surveillance and control system with vehicle detectors, minicomputers, alarms indicating when and where a stoppage has occurred, and changeable-message signs at each tunnel entrance to meter traffic ("Pause Here Then Go") when necessary to prevent congestion in the tunnels
- Closed-circuit television and monitor screens at the police desk enable an evaluation of the stoppage alarms
- Two-way radio communication among all police assigned to tunnel operations
- A vehicle designed to operate on the catwalks to allow rapid police movement in the tunnels
- Rescue tractors capable of coping with all emergencies and removing obstructions rapidly

Intensive surveillance is provided 24 hours a day, 7 days a week. When traffic flow, measured by the electronic surveillance system, deteriorates to a point that it meets predetermined criteria, an alarm is signaled. This alarm continues until the police acknowledge it or the computer determines normal traffic flow has resumed. Through use of the closed-circuit TV, the police determine the probable cause of



Service Patrol Truck with Ancillary Equipment
Chicago, Illinois

the alarm and assure that the necessary responses are implemented.

A most important element of the system is its high reliability, combined with low operating cost. The surveillance system operates unattended, and TV monitoring is required only when an alarm is sounded. This system has contributed significantly to increasing the transportation service provided by the tunnels.

SUMMARY

The technical solutions to freeway problems cover a range from relatively simple techniques, such as monitoring CB radio, up to a fully computerized ramp control and incident detection system with closed-circuit television.

When planning a freeway management system, managers and policymakers should be aware that there exists a range of solutions that vary greatly in cost. Furthermore, it is possible, and often desirable, to implement the less-expensive solutions initially as these can be expanded and made more sophisticated in later years as local staff become more knowledgeable and finances are available.

Defining Problems	1. Introduction 2. Problem Statement
Proposing Solutions	3. Management Strategies
Implementing and Evaluating Projects	4. Development of a Freeway Management System 5. Economic Analysis 6. Staged Construction and Financial Planning 7. Intragency Cooperation
Existing Systems	8. Review of Existing Systems

CHAPTER 4. DEVELOPMENT OF A FREEWAY MANAGEMENT SYSTEM

For many highway administrators, freeway traffic management is somewhat of a mystery. Consequently, common misconceptions portray a freeway management system as a multimillion dollar expenditure for elaborate computer facilities, expensive data collection systems, and a continuing monetary commitment of unknown magnitude.

Freeway controls are similar to those used on a standard urban arterial. For example, each intersection on a major urban arterial is signalized only as it becomes necessary. The traffic engineer installs the equipment needed for the control — detectors, signal displays, and controllers — and then monitors the intersection's operation after the system is working. Eventually, as more intersections are signalized, the system may require some form of central monitoring or control.

Freeway management systems can evolve just as gradually — entrance ramp by entrance ramp. Eventually, a series of entrance ramps can be regulated and controlled, much like a network of signalized intersections. Incident detection can also have a staged approach starting with CB monitoring, then adding some patrols, and finally being expanded to a full electronic detection system with service patrols and closed-circuit television. The components employed in the control of individual entrance ramps are the same as those needed for control of the entire freeway. Thus, freeway traffic control can consist of a very sophisticated system with centralized traffic-responsive control or it can be as simple as the installation of a few pretimed ramp metering controls. The type of system selected will depend on the specific problems to be solved and available resources.

ANALYSIS OF SOLUTIONS

To identify solutions to freeway operational problems:

- Establish freeway management goals
- Locate and evaluate problem(s)
- Define alternative solutions
- Select the best solution

Establish Goals

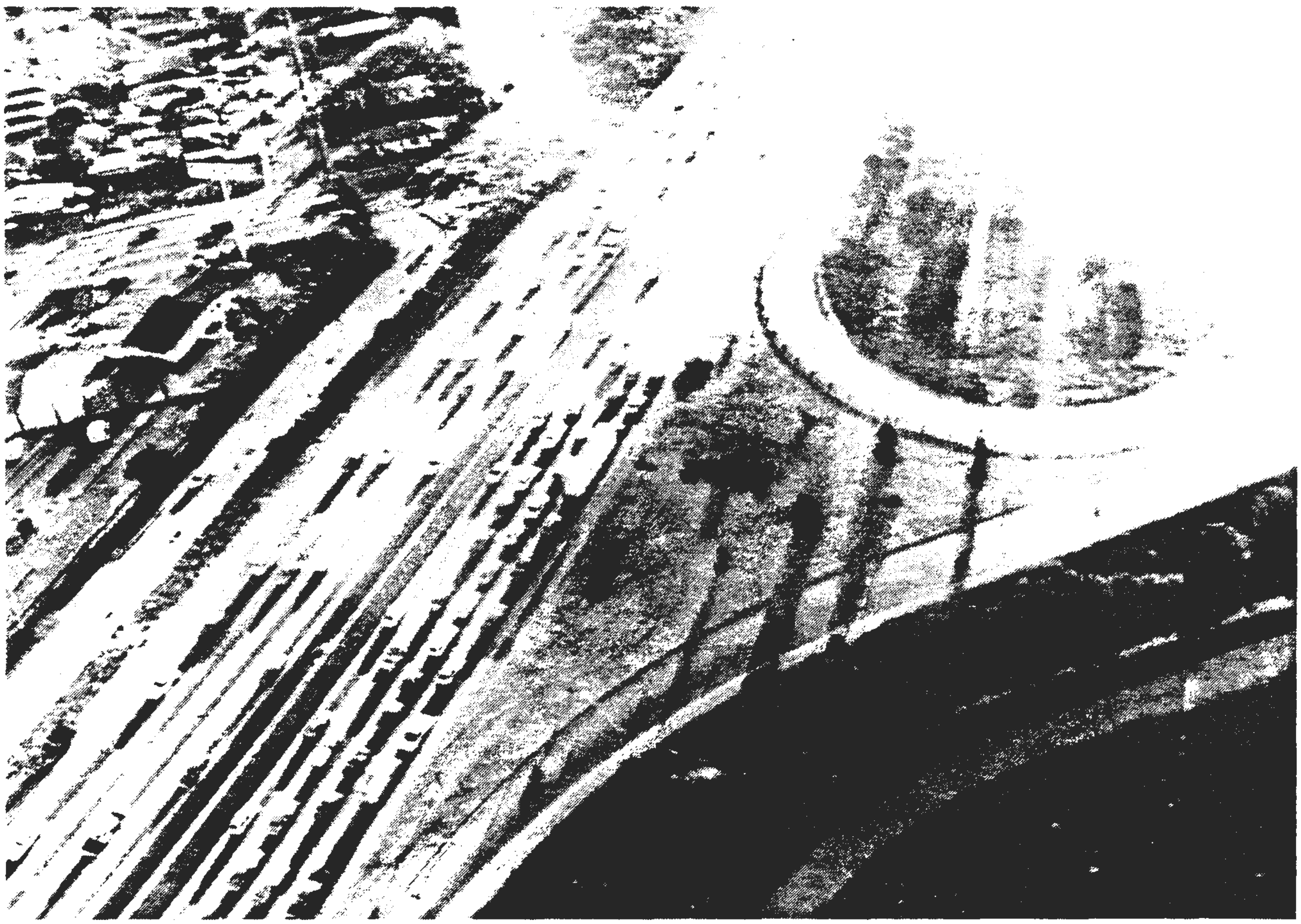
The first step in the analysis of potential solutions to freeway problems is to establish goals. Typical goals might include the following:

- Reduce recurring freeway congestion
- Minimize the affects of non-recurring problems
- Maximize safety of operation
- Provide drivers with information on freeway conditions
- Provide aid to those who have encountered freeway problems (i.e., accidents, breakdowns, etc.)

Once goals are established, problem situations will be revealed that can then be analyzed. For example, if reducing recurring freeway congestion is a goal, then it becomes obvious that bottlenecks are one problem that needs to be addressed.

Locate and Evaluate Problem(s)

The next step is to define the problem areas. In the case of recurring congestion, the methods of locating bottlenecks are fairly straightforward. They include:



Incident Causing Upstream Congestion

- Ground observation of traffic conditions using direct and remote survey techniques
- Aerial surveillance of the system
- Complaints from system users

This provides for identification of the major bottlenecks requiring detailed studies of traffic characteristics.

Once the recurring problems or bottlenecks have been located, the magnitude of the problem must be determined. This will provide a definition of the detailed characteristics of the bottlenecks, an estimate of traffic demands, and an estimate of delay in quantitative terms.

Identification of non-recurring problem locations is more difficult. The choice of methods for identifying non-recurring problems depends on the extent of incident management goals. If motorists are to be advised of incidents and congestion, a very sophisticated system will be needed (such as an automatic detection system or a closed-circuit television system). However, if it is only necessary to provide aid to those who encounter problems on the freeway, some method of communicating with only these stranded drivers is adequate.

When dealing with non-recurring problems, determining the frequency of their occurrence, quantifying the reduction in capacity caused by various types of incidents, and estimating the effect that incidents have on the overall accident rate, is often more difficult than identifying problems.

Common measures of traffic characteristics used for evaluating the magnitude of freeway operational problems are:

- Traffic volume
- Speed and traveltime
- Density
- Lane occupancy
- Capacity

When collecting traffic flow data, it is important to know the operating conditions throughout the peak period as well as the manner in which congestion develops. This is particularly important since delay during the peak period is generally quite variable. Congestion build-up forms the basis for estimating traffic demand, which is an estimate of the number of vehicles attempting to pass a point compared to the number that actually do.

Data Collection Techniques

Techniques for collecting traffic flow data have been well developed; the methodology depends on the types of data needed. Some of the more commonly used methods are:

- Manual counting
- Automatic detection
- Floating-car speed surveys
- Aerial photography

Other techniques that are useful for obtaining freeway traffic operational data include: time-lapse photography or closed-circuit television for studies limited to a small geographical area such as a freeway ramp or a critical bottleneck area; origin-destination surveys to obtain the travel patterns of vehicles using a section of a freeway; input-output studies to obtain a more definitive description of

Table 4.1. Methods of Measuring Freeway Traffic Characteristics

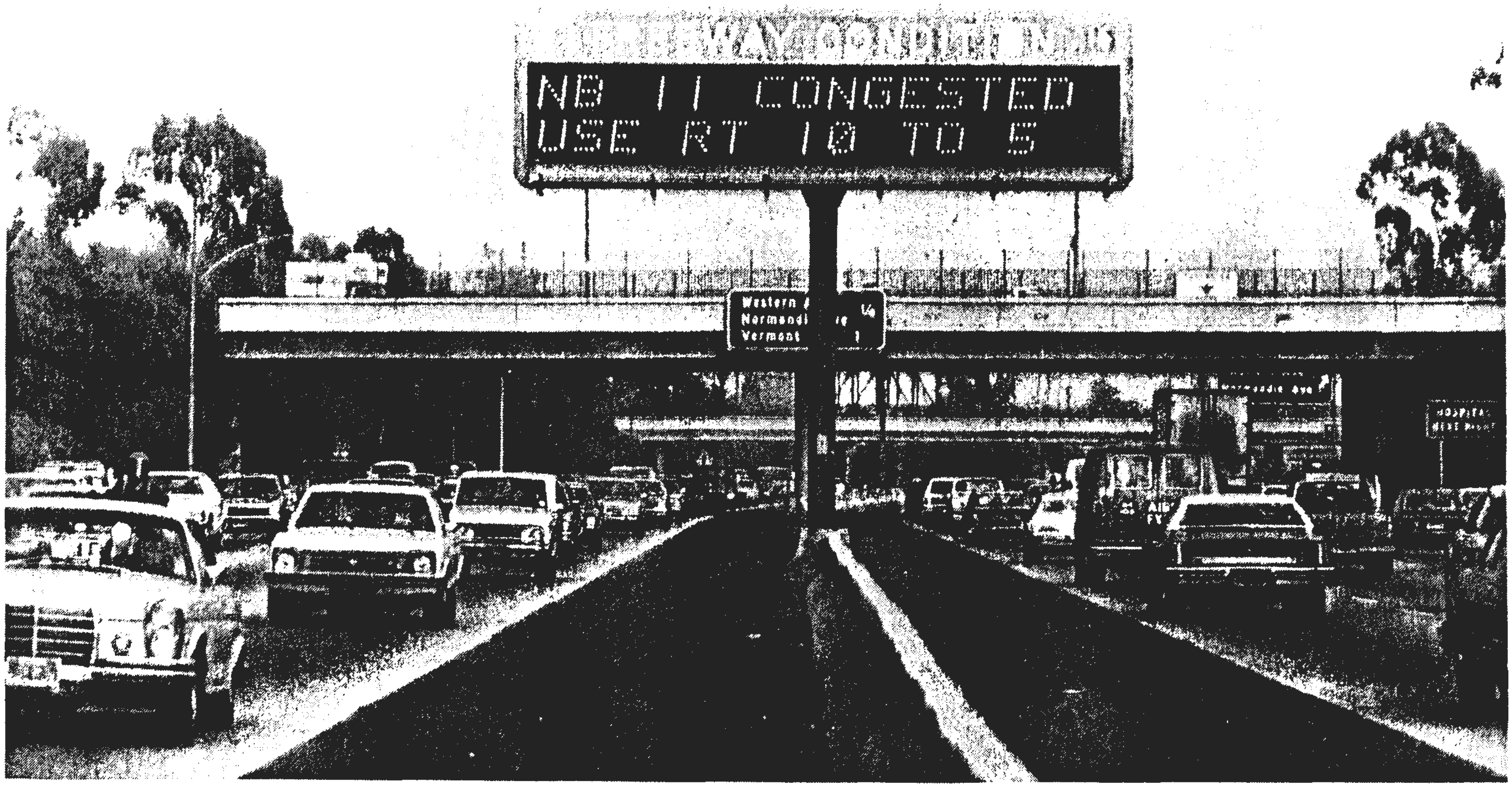
Method	Measure							
	Volume	Capacity	Speed & Travel Time	Density & Occupancy	Speed Changes	Headways	Gap Acceptance	Queues
Manual Counts	●	●				●		●
Automatic Detectors	●	●	●	●	●	●		●
Moving Vehicles			●		●			●
Aerial Photography	●	●	●	●	●	●	●	●
Time-Lapse Photography	●	●	●	●	●	●	●	●
Closed-Circuit TV	●		●	●	●	●	●	●
Input-Output Studies	●	●	●	●		●		●
Origin-Destination Studies			●					

traffic flow within a section of freeway; and accident studies either at spot locations or along a section of freeway to establish performance measures. Table 4.1 summarizes these different methods of measurement and lists the measure that each method is capable of determining.

Define Alternative Solutions

Once the problem(s) are defined, the next logical steps are to establish specific objectives for the traffic control system and select specific actions that will achieve these objectives. Figure 3.1 and the discussions in chapter 3 identify the various actions that can be implemented. Since each possible action will have a different impact on traffic performance, it is necessary to identify a combination of actions that, when implemented as a group, will make up a total system. For example, one freeway management project (the I-35W project in Minneapolis) established the following system objectives:

- Improve the freeway corridor level of service
- Increase the transit modal split in the corridor
- Improve the reliability of the freeway operation
- Improve the transit system performance in the corridor
- Obtain user acceptance of the freeway control system
- Obtain a positive environmental impact



Bulb Matrix Variable Message Sign
Los Angeles, California

- Implement the freeway management system in a cost-effective manner

To accomplish these objectives, a system of five functional elements was implemented, including:

- A real-time freeway surveillance, command, and control system
- A freeway ramp metering system
- Extensive express bus service in the corridor
- Priority access to the freeway via express or priority ramps
- Provision of certain amenities (park-and-ride facilities, bus shelters, signs) in the corridor

Select the Best Solution

The selection of the best solution to a particular set of freeway management problems is performed through an economic analysis of the benefits and costs of these alternatives. The procedures that are used in this type of analysis are discussed in the next chapter.

HARDWARE AND EQUIPMENT NEEDS

In implementing freeway management control systems, decisions must be made with regard to the type of hardware needed. For simpler systems (i.e., isolated ramp controls), the hardware components are generally limited to the equipment needed for the control of traffic at a specific location. For systemwide surveillance and control systems, however, the hardware components generally consist of detectors, information and control displays in the field, communications links to and from a control center, and computer and display equipment in the control center.

Detection

All freeway control systems require some form of data base. These data may be acquired either manually or through automatic detection. The most common data collection method involves automatic detection, which senses individual vehicles in the system. Three types of detectors have been used for freeways — ultrasonic, magnetometer, and inductive loop. Of these, the inductive loop is considered the best detector currently available for freeway control applications.

Ramp Metering Equipment

As a result of years of field experience, standards have been developed for the installation and use of ramp metering equipment.

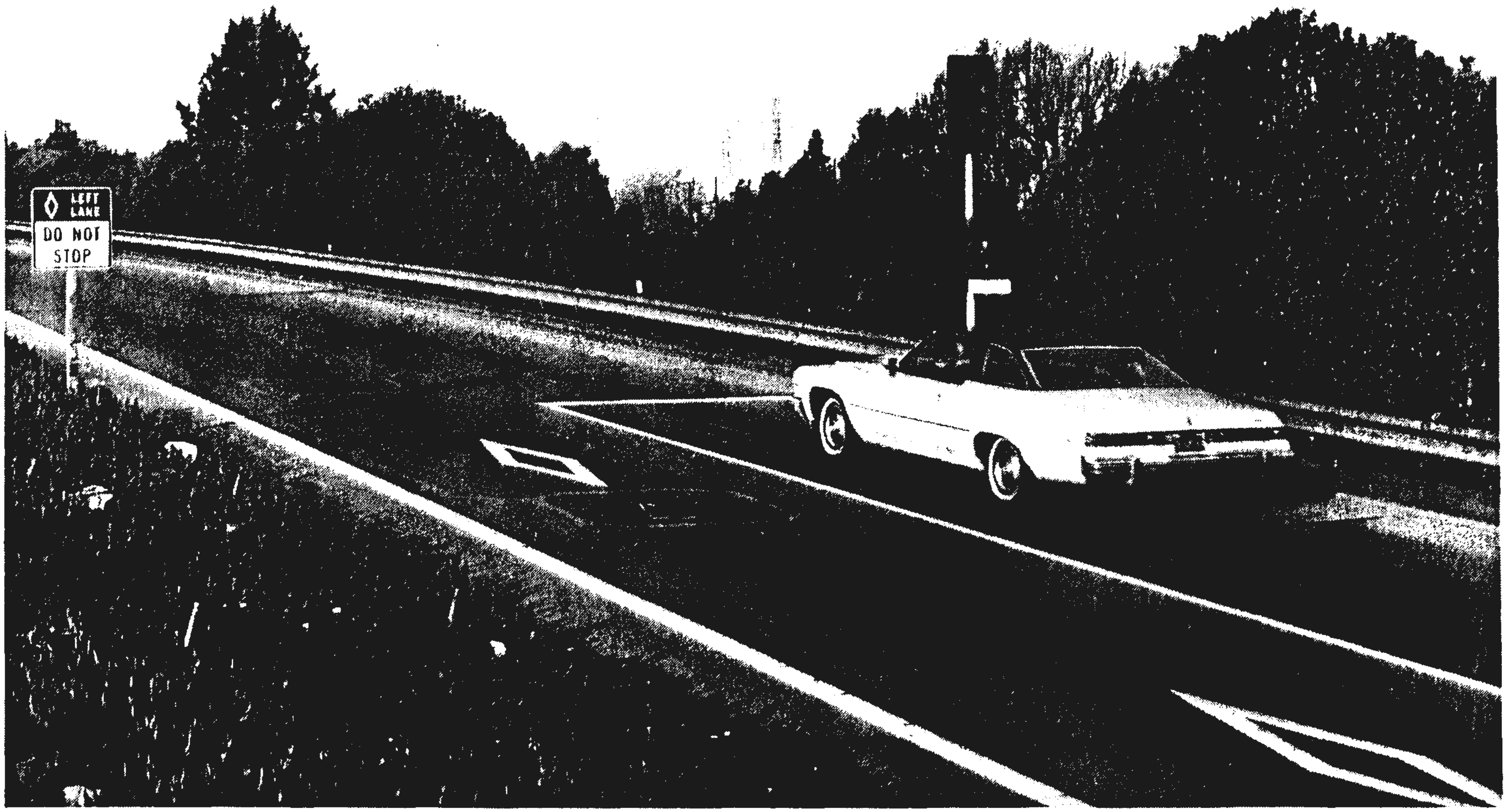
(For further information, the reader should refer to the most recent update of the Institute of Transportation Engineers "Tentative ITE Recommended Practice.")

There are three basic types can be used for ramp metering control:

- Pretimed controllers
- Centrally located controllers
- Locally actuated controllers

The pretimed controller is the simplest of the three and often consists of a one-to three-dial controller operated by a time clock. The metering rates are pre-programmed, based on historical traffic data. Although this is the lowest cost system, the limitation of not being able to be responsive to changing flow conditions is a major disadvantage.

Centrally located controller functions are incorporated within a central computer and the need for controller hardware at the ramp site is virtually eliminated. This



Metered Ramp with HOV Bypass Lane
Los Angeles, California

system offers considerable flexibility since almost limitless timing plans can be stored in the computer memory and timing changes can be easily achieved. One disadvantage of this type of controller is the requirement for a fairly elaborate communication system between the field and the central control center. Another disadvantage is the need for a back-up pretimed controller that is used in the event of computer failure.

Locally actuated controllers are basically small computers located in the field. They operate in a stand-alone fashion by selecting metering rates based on real-time information gathered from ramp and mainline detectors. They offer a great deal of flexibility and can serve as the basis for a centrally controlled system.

Communication

All freeway traffic control systems require some form of data transmission system. The type of system used generally depends on the type of control and the information to be transmitted. With local control, simple direct communication methods are often used because the distances between the detectors, controllers, and displays are small. Direct wire connections are commonly used with central control. The distances over which the data must be transmitted are generally large and different methods of communication (data transmission) must be considered.

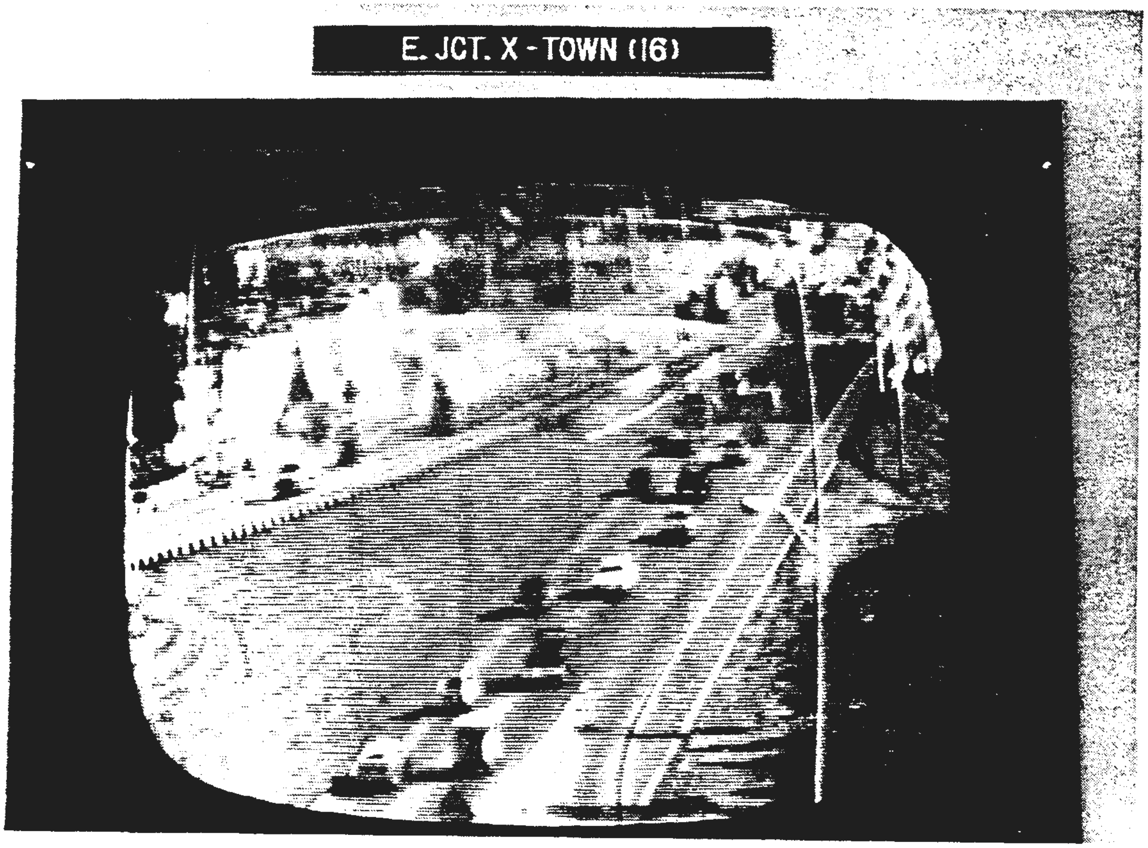
These long-distance data transmissions often use cable facilities that are either leased from the telephone company or owned by the operating agency. The major factors considered in a trade-off analysis between these two alternatives are cost, reliability, and ease of incremental systems expansion. Maintenance capability and special conditions of utility franchises are also considerations. Leased wire systems, however, are subject to increasing rental cost which should be accounted for when deciding on a communication system. The owned cable system has a higher reliability but the leased wire system in most instances is initially less expensive and can be expanded more easily.

Control Center Equipment

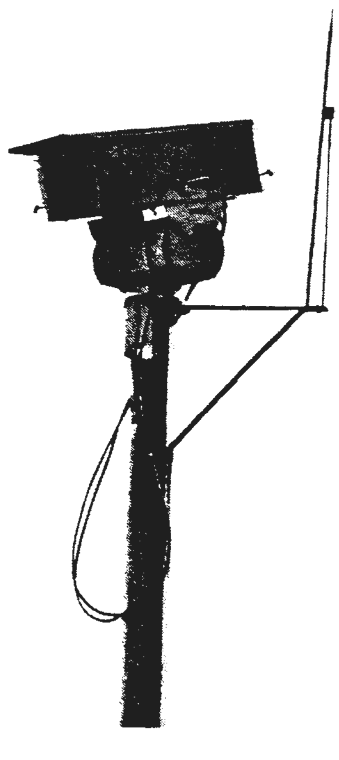
The control center is the focal point for all communications and control in a large-scale freeway management control system. At the control center, information concerning traffic is received, analyzed, and evaluated, and decisions are made regarding the type of control to be used. The equipment normally found in a control center consists of the computer and related peripheral equipment, communication console(s), display components, and equipment for dispatching emergency and maintenance vehicles to the problem locations.

The computer is the nucleus of most centralized freeway management control systems. It normally:

- Performs various functions according to a pre-established order
- Gathers information, calculating parameters, making decisions, and outputting control commands
- Operates in real-time so that events, as they occur, initiate pre-established priority-level programs
- Operates automatically on a continuing basis
- Records system performance and outputs the performance in printed form for permanent records, as well as in display form to allow operator interaction with the system



Traffic Flow Surveillance
St. Paul, Minnesota



Closed Circuit TV Camera
in Environmental Housing

- Controls various kinds of systems, including signing and television subsystems, by turning on, turning off, or selecting equipment, based on previously programmed control and decision logic

- Performs technical analysis when the control system is in off-line mode

The peripheral equipment used in freeway control systems also includes interactive peripherals and storage devices. The interactive peripherals provide a means of obtaining information as well as inputting commands or altering performance. They generally include a teletype, a cathode ray tube (CRT) display terminal, and a display map.

A display map is often a scaled replica of the freeway control system with colored lights used to show the degree of congestion on the freeway. It is a valuable tool enabling the operator to visualize congested sections and identify incidents. Because of its easy-to-understand visual format, the display map can also be a valuable public relations tool.

Storage devices are magnetic recording devices (tapes or disks) used for storing large quantities of data on system operations and programs.

INTERAGENCY COOPERATION

An element of considerable importance in implementing a freeway management system is the development of good interagency cooperation. No single agency is capable of handling every aspect of freeway traffic management. The disciplines most involved in freeway management are:

- Public relations, with news media primarily responsible for informing the public about real-time traffic conditions

- Law enforcement, with primary responsibilities for safety of the public

- Traffic engineering, with primary responsibilities for maintaining efficient traffic flows

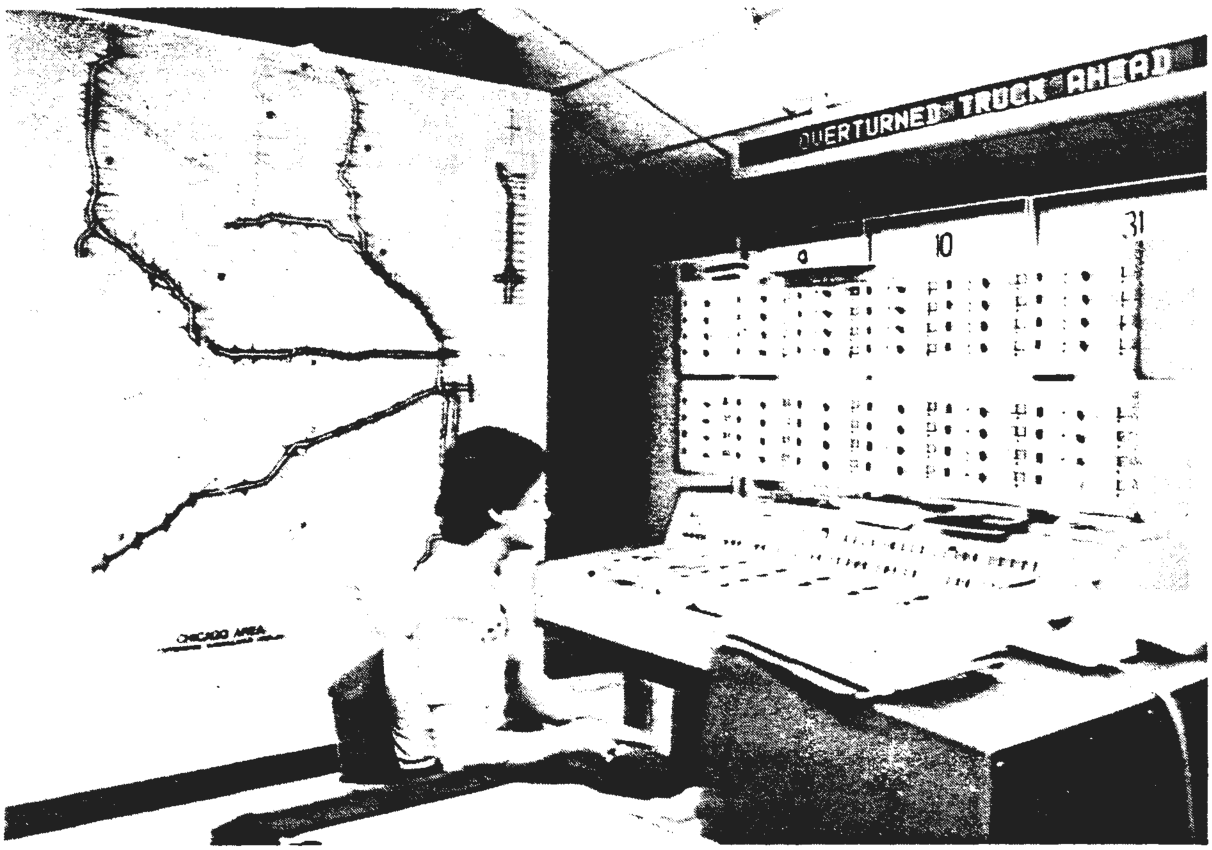
- Maintenance operations, with primary responsibilities for roadway repairs, incident removal, and general overall upkeep of the roadway facilities

- Transit operations, with primary responsibilities for providing public transportation services

It is essential that the agencies involved understand and appreciate their overlapping responsibilities and work harmoniously so that each agency can better fulfill its role.

Although traffic, enforcement, maintenance and transit are the primary disciplines involved in freeway management, there are other disciplines that also contribute to increasing system efficiency. Included are agencies such as fire departments, ambulance services, utility companies, automobile clubs, and towing service companies. These agencies are generally only called upon to handle special problems, but their importance cannot be overlooked.

Public acceptance and citizen support are also critical elements in freeway management programs. The public must be continually informed of project development through press releases, project newsletters, etc. There must also be a process whereby public input can be accomplished through public hearings, citizen committees, and forums. The public needs to know the projects to be introduced, the reason for the projects, and the expected benefits. At a different level, the motorist who uses the corridor needs to know



Traffic Control Center
Chicago, Illinois

what changes are taking place and how these changes may affect his daily travel patterns. Failure to recognize the importance of public involvement can lead to complete rejection of a freeway management program.

SYSTEM MONITORING

In monitoring a system, three levels are normally required. The first level involves policymakers and those who have various degrees of administrative responsiblity (i.e., traffic commissioner, state highway agency director, police chief, etc.). At this level, freeway management projects are evaluated on the basis of their overall impact on the public, their relationship to other projects in the region, and their long-range effect on the region's total transportation and traffic needs. The primary objective at this level is to evaluate the demand for facility use, the scope of needed improvements, and the year for future freeway improvements. The information input for this level of monitoring is usually in the form of summary reports from the freeway project staff; control is in the form of policy directives.

The second level of monitoring is at the engineering/technical level and involves those responsible for development and maintenance of operating procedures, traffic flow analyses, and performance evaluations. The primary objective at this level is to be responsive to changing traffic needs and to upgrade the system in response to those needs or because of technological advances that will permit a given function to be performed more efficiently. Input is obtained from operating reports, traffic surveillance statistics, traffic surveys, public relations, communications with other agencies, and special research and operational studies; control at this level is accomplished through exercise of adjustments in system parameters, control strategies, and operating procedures.

The primary objective of the third level of monitoring is the day-to-day operation of the system. An operator maintains a constant surveillance not only of the operating conditions on the freeway but also of the operating performance of the equipment. Information is obtained through computerized surveillance, television surveillance, police reports, private citizens, repair and maintenance notices, and computer alarms; control consists of some form of override or intervention based on operating procedures developed by the engineering/technical staff—i.e., the response to an alarm condition to ensure that proper action is taken or the implementation of an emergency strategy in response to a need to exercise more control.

PERFORMANCE EVALUATION

Justification for freeway management systems is made on the basis of some forecast of the benefits that may result. These benefits might be solutions to specific problems such as high accident rates or congestion in certain areas. An evaluation of a freeway management systems performance is required to provide information and data to administrators. Such an evaluation is also useful in identifying ways to increase the benefits further or to justify expansion or upgrading of the system.

This performance evaluation is an integral part of the system implementation; as such, the evaluation plan must be considered in the early stages of the development planning process. It involves identifying improvement objectives, determining what effectiveness measures are to be used, developing a data collection plan, and selecting an evaluation methodology.

Ramp Entrance Sign
Los Angeles, California

The evaluation plan must also take into consideration the changes in travel patterns that relate directly to the types of controls that are implemented. Some common changes that typically result from a freeway control system are: bottleneck shifting, time shifts in demand, localized operational problems, localized increase in demand, and a general redistribution of traffic. All these changes have to be carefully evaluated and the various control strategies have to be modified to match the actual traffic needs as they evolve and change over time.

Implementation Objectives

A group of typical goals for a freeway management system were listed at the beginning of this chapter. The implementation objectives for the system are a set of target values for these goals that will be achieved after some period of time.

The specific implementation objectives associated with these typical goals after 2 years of system operation might be:

- A 10 percent reduction in delay due to recurring congestion
- A 25 percent reduction in the duration of an incident
- A 5 percent reduction in peak-period accidents
- The operation of four motorist advisory signs at critical route diversion points
- A decrease in the heading of service patrols from 90 minutes to 50 mintues

Effectiveness Measures

In general, four basic measures of effectiveness can be used in evaluating the performance of a freeway management control system. These are:

- Changes in congestion levels reflected through traffic measures such as volume, total traveltime, total travel speed, and duration of congestion
- Changes in system costs, both to the user and to the system operator
- Changes in safety, using factors such as decreased accidents or decreased accident rates
- Changes in accessibility as indicated by decreased delays in the system

Additional criteria, such as reduction of air pollution, decrease of fuel consumption, and increase of driver satisfaction, are measures of effectiveness that may also be warranted in an evaluation. However, these measures are often considerably more difficult to quantify and, when used, are normally derived from basic traffic flow measurements.

Data Collection and Methods for Evaluation

After the implementation objectives and measures of effectiveness are selected, the data collection plan and evaluation methodology can be determined. The data collection plan will specify: the agency responsible for data collection; the traffic characteristics to be collected; the locations at which this data will be gathered; the times of day and, in the case of some studies, the interval between collection of before and after data; and the data collection procedures and the ability of the freeway management system to provide this data automatically. Common data collection pitfalls are to collect more data than needed, to collect data on an ad hoc basis without knowing how the data will be used, or to fail to clearly document conditions prior to implementation of the improvement program.

SYSTEM MAINTENANCE

The ability of a freeway management control system to perform its functions with optimum effectiveness is highly dependent on the quality and level of maintenance provided. The consequences of a breakdown or malfunctioning of system equipment include disruptions in traffic flow, increases in accident potential and, often, loss of credibility with the motoring public. There is also a legal implication. If an injury or damage occurs because some element of the system fails, there could be a case of liability against the operating agency.

Development of a maintenance management program for a freeway control system will vary, depending on the type of system being used. For example, a centrally controlled system permits continuous monitoring of all system hardware (i.e., controllers, detectors, communication links, etc.). With this type of extensive monitoring, failures in equipment performance can be detected early and maintenance response can be almost immediate if necessary. Thus, preventive maintenance can be accomplished more efficiently. On the other hand, the noncentralized systems (such as an isolated ramp metering system) can create different types of maintenance management problems. In order to detect a malfunction or failure of these systems, frequent field checks are required. This testing tends to be expensive, and often takes place even when the system is functioning properly.

In the centrally controlled systems where digital computers are used, most agencies find that the most cost-effective practice is to use maintenance contracts in preference to adding specialized staff. Such contracts can be made with the computer manufacturer or an independent service firm. Typical contracts provide for both scheduled and unscheduled maintenance (including parts and labor), and the costs are always less than retaining full-time computer maintenance personnel.

An example of the distribution of maintenance time allocation and maintenance calls for the I-35W freeway management control system in Minneapolis is given in table 4.2. These numbers are directly

TABLE 4.2. DISTRIBUTION OF SYSTEM MAINTENANCE

System	Percentage of Calls	Maintenance Time Allocation (Percentage)			
		Adjusting	Field Repair	Shop Repair	Total
Closed-circuit TV	12.4	1.8	15.3	4.9	22.0
Detectors	42.7	13.7	16.9	5.4	36.0
Ramp Controls	7.7	0.3	3.8	0.4	4.5
Variable Message Signs	2.4	0.0	3.6	0.0	3.6
Lane Signals	0.7	0.0	0.2	0.0	0.2
Communications	29.0	0.7	24.0	6.4	31.1
Miscellaneous	5.1	0.5	1.4	0.7	2.6
Totals	100.0	17.0	65.2	17.8	100.0

related to a detector-based system with relatively limited closed-circuit TV and, therefore, are not applicable to all systems. However, they do give an indication of where most of the maintenance problems normally occur—in the detection and communication system.

FUNDING SOURCES

With the increasing costs of operating and maintaining transportation systems, the highway administrator is constantly challenged with the development of funding sources that will meet the needs of the various programs within his system. Because freeway management and control systems normally involve extensive capital improvement expenditures as well as a long-term commitment for operations, and because there are numerous competing programs, funding of freeway management control projects is always an issue.

The most common funding sources for freeway management control projects are Federal Highway Administration (FHWA) programs, authorized by the Federal-Aid Highway Act. Program funding varies from state to state and may be preempted by Congressional authorization. Therefore, for funding information in your state, contact your FHWA Regional Administration office.

SUMMARY

There are four steps in the identification of solutions for freeway operation problems: establishment of freeway management goals, location and evaluation of freeway problems, definition of alternative solutions, and selection of the best alternative. The evaluation of alternatives is made on the basis of its potential costs and benefits. The evaluation of the performance of the freeway management system is an important component and must be considered in the early stages of the planning process. The most common funding sources for freeway management control projects are Federal Highway Administration (FHWA) programs, authorized by the Federal-Aid Highway Act. Program funding varies from state to state and may be preempted by Congressional authorization. Therefore, for funding information in your state, contact your FHWA regional administration office.

CHAPTER 5. ECONOMIC ANALYSIS

The basis of any economic analysis is a comparison of benefits and costs. When a freeway management system is implemented, the benefits that can be anticipated are increased speeds and reduced delays, accidents, fuel consumption, and pollution. Because a freeway essentially is a service system, it can require significant operating and maintenance funds in addition to the capital funds required for construction. There are, however, low-cost systems that can reasonably address problems of limited scope. Every system, regardless of size, will require a thorough evaluation to screen the options that are available and select a set of components that respond to the needs and financial ability of the community.

BENEFITS

The benefits achieved through freeway controls have been documented in many freeway management projects. However, comparing benefits of different control system designs and for different locations can often be misleading. Because of the variations in the magnitude of the problems encountered and cost of the controls that were implemented, the results vary considerably. Similarly, the benefits for certain types of control systems may be comparable but the costs of one may be much less than for another.

Studies of benefits of some major freeway management projects have shown that as freeway efficiency is improved, average speeds increase, accident rates are reduced, and total traveltimes in the freeway system decrease.

- In Dallas, it was estimated that a freeway corridor control system on the North Central Expressway for a two-hour p.m. peak period resulted in a decrease of 477 vehicle-hours of delay (a 30 percent decrease in travel time), an increase of 23 percent in average speeds, and an 18 percent decrease in accidents.
- In Chicago, an analysis over a four-year period of a ramp control and electronic incident detection system demonstrated a significant change in the congestion patterns, reducing delays 19 to 29 percent. The four years of experience with the ramp metering system also indicated a 35 percent reduction in accidents related to freeway entrance ramps.
- In Minneapolis, the I-35W corridor control project significantly improved the general level of service for traffic in the corridor. Peak-period average speeds were increased from 44 mph to 50 mph northbound in the a.m. and from 36 mph to 46 mph southbound in the p.m. It is estimated that the control system is resulting in a daily peak-period savings of approximately 1,400 passenger-hours. In addition, safety was improved with a 58 percent reduction in a.m. peak-period accidents and an 18 percent reduction in p.m. peak-period accidents.
- In New York, the Northern Long Island Corridor feasibility study estimated that the Integrated Motorists Information System would result in annual benefits comprising 2,850,000 hours of vehicle delay savings, 2,736,000 gallons of fuel savings, a 6,000,000-pound reduction in pollutants, and 200 fewer accidents.

Separate HOV Facility
Los Angeles, California

- In Houston, a ramp metering system on a 6-mile section of the Gulf Freeway provided an increase in the average speed from 20 mph to 33 mph during the peak a.m. period, a 27 percent reduction in accidents, and a 25 percent decrease in total travel-time.

These are just a few examples of improved traffic flow and/or accident reduction that have resulted from freeway management projects. It should be noted that not all benefits are instantaneous. Often, the payoff may be years ahead it is difficult to relate the benefits to costs at the time of improvement. Also, many of the improvement benefits may be hidden, in the sense that they correct problems that have not yet become apparent.

COSTS

As with the case of benefits, generalization of costs for freeway management systems are extremely difficult to develop. This is due to the variables related to planning, construction, implementation, and operation of systems in widely scattered locations. In some systems the basic planning and system justification is highly formalized and the design and implementation are let to bid to private contractors as a complete system. Under these arrangements, costs are well documented. In other instances, the system is developed by in-house staff, over an extended period of time. In this process, costs are more difficult to define. The variability in labor and installation costs as well as the variability in salaries of professional, administrative, and technical staff are also factors that tend to obscure the costs of freeway management systems. There are, however, some general figures that have been developed for certain system costs. They are:

- <u>Ramp Control Systems</u> – The simplest form of ramp control is pretimed ramp metering. The equipment consists of a traffic signal, local controller, and the ancillary facilities such as signs and pavement markings. The most basic configuration costs approximately $2,500 per ramp.

  Another type of ramp control system is the locally actuated traffic-responsive system. This is more sophisticated than pretimed control, as it normally uses a microprocessor-based controller with inputs from both mainline and ramp detectors. The costs are approximately $5,500 per ramp, or about double those of the pretimed system.

  The centralized interconnected ramp control system represents the highest degree of sophistication in ramp control. If offers the full flexibility of normal control as well as incident-related control. Because of the wide variations in their configuration, it is difficult to develop a specific per-ramp cost for this type of system. However, some representative costs for a large-scale system capable of controlling up to 50 ramps are $150,000 for the central control system and approximately $5,500 for the items required at each ramp.

- <u>Busways</u> – Costs for busways range from $1 million to $5 million per mile and are generally governed by construction type and level of service desired. Busways using existing rights-of-ways generally fall in the $1 million-per-mile range, whereas busways requiring elevated construction or additional right-of-way average $3 to $5 million per mile.

- Reserved Lanes — The costs of implementing reserved lanes are generally minimal, but the maintenance and operational costs tend to be significant. Cost for the 2.5-mile reversible-lane operation on I-495 in the Lincoln Tunnel (New York) was approximately $700,000, of which $134,000 was for construction and the balance for traffic controls. Annual maintenance and operational costs are approximately $200,000, or $80,000 per mile. Costs for implementing the 2.0-mile Long Island Expressway contraflow bus lane were $25,000 per mile and the annual maintenance and operational costs are about $75,000 per mile. Costs for implementing the bus and carpool bypass lanes on the San Francisco-Oakland Bay Bridge were approximately $60,000 per mile and the maintenance and operational costs are approximately $150,000 per mile, annually.

- Incident Management — The costs of incident management systems are also quite variable, depending on the specific requirements of the system, the type of system used, geographical locale, and procedures used. The emergency traffic patrol in Chicago, which covers 192 miles of the Chicago area freeway system, has an annual cost of approximately $1.5 million or approximately $7,800 per mile. Freeway courtesy patrols in Houston, which provide emergency vehicle service on 64 miles of freeways, have an annual cost of approximately $230,000, or $3,600 per mile.

- Surveillance Systems — Experience has shown that the annual maintenance and operating costs of freeway surveillance systems are also quite variable, depending on the size of the system under control. In Chicago, the annual operating expenditures for the overall freeway surveillance and control systems average approximately 15 percent of the capital investment costs. In Minneapolis, the total system operating costs are $235,000 annually, or about 14 percent of the capital investment costs. Similar costs are being experienced in Los Angeles, and on Long Island it has been projected that the total annual maintenance and operation costs for the Integrated Motorist Information System (IMIS) in the Northern Long Island Corridor will be approximately 5 to 6 percent of the estimated capital costs.

All of these costs (the implementation as well as the annual maintenance and operating costs) must be viewed with some degree of caution inasmuch as they do not take into consideration the impact of continuing inflation.

LOW-COST ALTERNATIVES

It is possible to obtain fairly significant benefits to motorists without large expenditures. For example, if a fairly short section of a freeway is suffering from congestion due to excessive input flow at three or four on-ramps, the congestion can be reduced by installing fixed-time ramp control that will control input flow and reduce congestion. Another example of a low-cost technique could be section of freeway where vehicle breakdowns cause excessive delays to the freeway traffic. By increasing police patrols in this area and equipping patrol vehicles with the facility to push disabled vehicles off the road, the congestion problem will be reduced.

These low-cost techniques do provide significant benefits for relatively low capital expenditures. However, each one only tackles a specific problem and they do not provide the same improvements as those

Mobile Variable Message Sign
Los Angeles, California

associated with full freeway management systems. A series of such low-cost techniques can form the basis of a full system by adding components until all problems have been addressed.

EVALUATION

The major problem that the highway administrator faces is allocating a limited budget among the many competing needs. Recent inflation and a corresponding drop in revenues make it necessary to achieve an operating system that will provide the greatest benefits at minimum cost. Consequently, each freeway management option under consideration must be carefully evaluated. Although this evaluation will be conducted by engineers and planners, administrators should be familiar with the process.

Figure 5.1 outlines the procedure used for evaluating a series of options that may provide solutions to specific problems.

Select Possible Options

A selection of options to be evaluated must be identified. Many options may not be suitable for particular freeway systems. It might be necessary to evaluate some options for particular parts of a freeway system and other options for the remainder of the system. For example, closed-circuit television might be a suitable option for that part of a freeway system near the central business district, while call boxes would be a more viable option on suburban and rural sections of the freeway.

During planning of a new freeway system or modification of an existing freeway, engineers and planners should select a series of options that would:

- Be locally acceptable
- Suit the existing or proposed system
- Provide a solution to an existing or potential problem

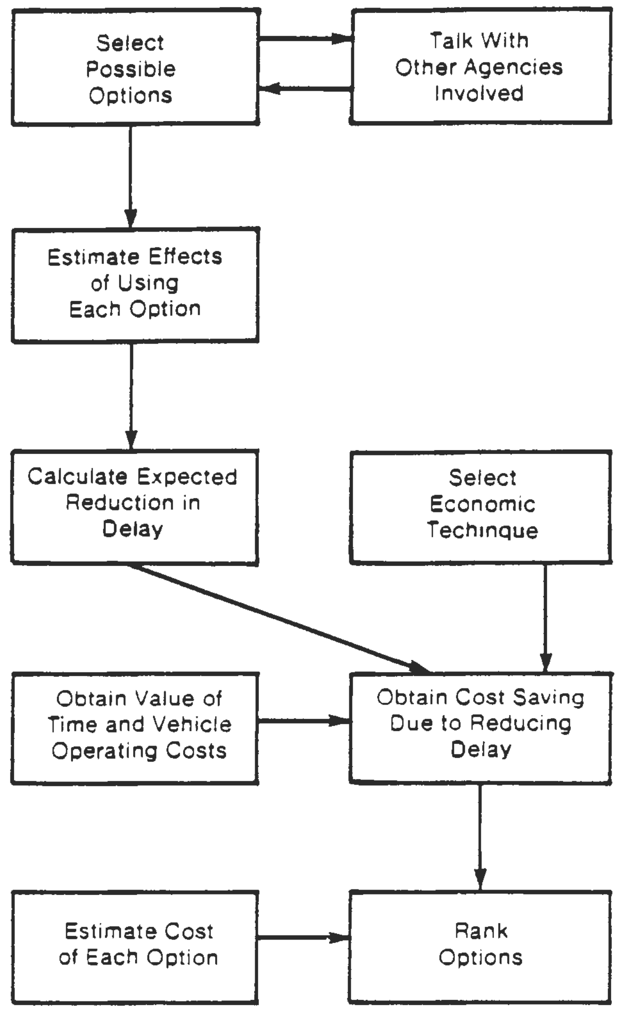


Figure 5.1. Evaluation Process

Talk With Other Agencies

Knowledge of local conditions provided by other agencies is an important part of this selection process. Many of the potential solutions to freeway problems involve the cooperation of other agencies, and it is advisable to discuss the types of solutions being considered with these agencies to obtain their opinions and, if possible, an esitmate of the extent and costs of their involvement. An example of this would be an option that increases the police patrol frequency on the sections of the freeway under management. It is likely that this option would require additional vehicles and radio equipment as well as a commitment from the police.

Estimate Effects of Using Each Option

In estimating the effects of a particular option, engineers and planners should refer to the relevant chapters in volumes 2 and 3 of this handbook, the published literature cited in volume 4, as well as their own judgment and experience with the facility.

To estimate the effects of each option being evaluated, specific information must be known and analyzed. For example, if a dedicated freeway patrol is the option under consideration, two factors must be known: the headway between patrols and the ability of patrols to detect incidents that have occurred in the other travel direction. Once identified, the time necessary for a dedicated patrol to detect an incident can be estimated.

Using an incident tree (shown in volume 2, chapter 2) and the number of vehicle-miles per mile on the freeway, the number of incidents can be estimated. This is the value required for delay computation. However, the engineer must also estimate the time duration of the incident for the existing conditions in order to fully evaluate the effects of the option. On existing freeway systems this is not difficult as incidents will be occurring and surveying procedures will provide the relevant information. On a proposed facility, the detection response and clearance times of existing freeway systems should be examined in order to make estimates.

Calculate Expected Reduction in Delay

Delay is one of the best and most common measures of congestion, because it is cumulative. Delays at differing points on the freeway can simply be added to provide a total number of vehicle-hours of delay for each option.

The calculation of the expected reduction in delay is determined using the basic principal of evaluating the results of excessive demand. These calculations are straight-forward for recurring congestion because the capacity of the location being analyzed remains constant. The calculation of delay for non-recurring congestion is more complex because the demand and capacity may both change, and the degree and duration of these periods of reduced capacity are dependent upon the type of incident, and the detection, response, and incident removal time of the freeway management system. Four generic types of equations have been developed to analyze various situations which cover: a simple reduction in capacity; a reduction in capacity and a period where all traffic is stopped to clear the incident; a reduction in capacity and a period when the capacity is between this reduced value and its normal value; and an incident in which the demand is decreased because of the diversion of traffic from the facility or the end of the peak period.

Obtain Value of Time and Vehicle Operating Costs

If the evaluation is to be performed in terms of vehicle-hours of delay alone, or it is an evaluation intended to reduce a specific problem (for example, accidents), then this step may be skipped. However, if the evaluation is to include a dollar value, the engineer must use a value of time and a vehicle operating cost. Vehicle operating costs can be obtained from the American Automobile Association and the American Trucking Association. Operating costs for 1981 were:

- Medium-sized autos: $0.25 per mile
- Trucks: $1.25 per mile

The values are subject to considerable fluctuation resulting from oil price changes and inflation. Thus, any values used should be current. The value of time is a contentious issue and there are many different techniques and methods used in its calculation. If any specific value has been used by the local agency, it would be reasonable to use this value. The 1980 value of time quoted by AASTO is $3.00 per hour. This value encompasses work and pleasure trips as well as allowing for the non-working sections of the population.

Select Economic Technique

Engineering economic textbooks use four differing procedures for comparing alternatives in monetary terms:

- Annual cost method
- Present worth method, in which comparison is made on a present worth basis of all present and future expenditures
- Rate of return method, which involves the determination of the interest rate at which the alternatives are equally attractive
- Benefit-cost ratio method, developed by civil engineers involved in public works expenditure

Obtain Cost Saving Due to Reducing Delay

This function involves taking the expected reduction in delay, separating the vehicle delay into truck and auto components, and then using vehicle operating costs and the value of time to put a dollar value on the savings due to reducing delay.

Estimate Cost of Each Option

The engineer and planner have to obtain the best estimate of the costs associated with the option under consideration. These, of course, depend upon the type of option and its degree of sophistication. Some of the options are very inexpensive as they merely involve initiating an agreement between two agencies. Others require administrative effort but no capital expenditure on hardware; an example of this would be the production of a hazardous materials manual.

Rank Options

The options may now be ranked and presented. The format of this presentation will, to a large extent, depend upon the cost evaluation technique involved.

In presenting a summary of freeway management operational options, costs and some traffic flow parameters should be included. Indeed, as mentioned earlier, if a specific problem is to be addressed, the evaluation can be limited to predicted before-and-after values and separate associated costs.

SUMMARY

The analysis of options that may be incorporated into a freeway management system involves a number of steps to evaluate their relevance, benefits, and costs. The major steps in this process are:

- Select possible options
- Talk with other agencies
- Estimate effects of using each option
- Calculate expected reduction in delay
- Obtain value of time and vehicle operating costs
- Select economic technique
- Obtain cost saving due to reducing delay
- Estimate cost of each option
- Rank options

If an analysis of a freeway's problems is performed and a series of solutions decided upon, it is likely that a highway agency's response will be that it cannot afford all of the necessary costs to obtain the large savings in delay. However, freeway management control systems, particularly the larger ones, have developed over many years from small beginnings and it has been demonstrated that this staged approach is effective and realistic.

FINANCIAL PLANNING

The Federal Highway Administration is authorized under the Federal Aid Highway Act to provide funds to specific projects. These funds are commonly used to provide the initial capital costs on many freeway management projects. From a financial control point of view there are many advantages associated with spreading expenditure over several years.

It is recommended that a freeway management program be developed for a 3- to 10-year implementation period. Financial control can be tied to the implementation program based upon the anticipated available funds. It provides a safety net against obligating more funds than will be available. Spasmodic decisions (such as adding or subtracting projects in a rushed manner) cause an inefficient use of work time and capital funds, and should be avoided.

Lead times are important. A long planning time affords time to give all actions thorough consideration, to reach agreements with cooperating agencies, and to prepare thoroughly and in detail good freeway control designs and construction cost estimates. Long lead time avoids the last minute rush to get the plans and specifications finished ahead of the letting dates.

The 3- to 10-year implementation program can be continually updated by project priority selections and can provide a financial base for keeping the whole project on an even keel. All units of the department may then work on their own programmed basis towards specific common goals. Employment levels become more uniform, the necessary skills can be made available, and each implementation project can be coordinated with others as desirable for engineering consistency, production efficiency, and budgetary constraints.

Implementation Program Requirements

The basic requirement for an effective implementation program consists of the following eight functions:

- Legislative Provisions — Definition of responsibilities and designation of defined areas as well as adequate legal provisions
- Executive Support — Recognition of the technical nature and complexity of freeway management and the cooperation of department heads
- Planning Surveys — Data collection, accident analysis, financial outlays and any specific needs such as passenger flow
- Budgetary Provisions — Definition of allocation and staffing resources that are available and those that will be required in the future

Carpool Lane which Bypasses Ramp Control in Los Angeles, California

- Construction Priorities — Setting of priorities such that the most needed aspects of the program are implemented before less essential tasks

- Coordination — Involves cooperation with other public bodies and agencies

- Scheduling — Provision of advance and flexible schedules so allowances can be made for unforeseen obstacles that commonly thwart planners

- Administrative Organization — Should be from a high level so that cooperation between design, construction, and maintenance departments can be achieved easily

STAGED CONSTRUCTION

The illustrative example given below outlines how a medium-sized freeway traffic management system can be built in stages to eventually form the final design. Imagine a freeway system that has congestion problems resulting from excessive demand and incidents. Following selection of the options available and evaluation of their effects, selection of the most economic candidates, and an agreement to cooperate from the participating agencies, the following freeway management requirements can be identified:

- Fifty miles of the freeway should have electronic surveillance and ramp control.

- A 10-mile section in the CBD needs 12 closed-circuit television (CCTV) cameras.

- The existing police patrols should be equipped to deal with minor incidents.

- Additional highway patrols will be provided; these will be operated by the highway agency.

- Forty-five ramps will have traffic-responsive control.

- CB radio monitoring will be used in the central control and agency vehicles, but not in the police vehicles.

Year 1 — Equip police vehicles (providing immediate saving at a minimum cost), write specifications and contract for cable ducting for future ramp control and CCTV. Select site for central control room. Install surveillance loops in CBD area.

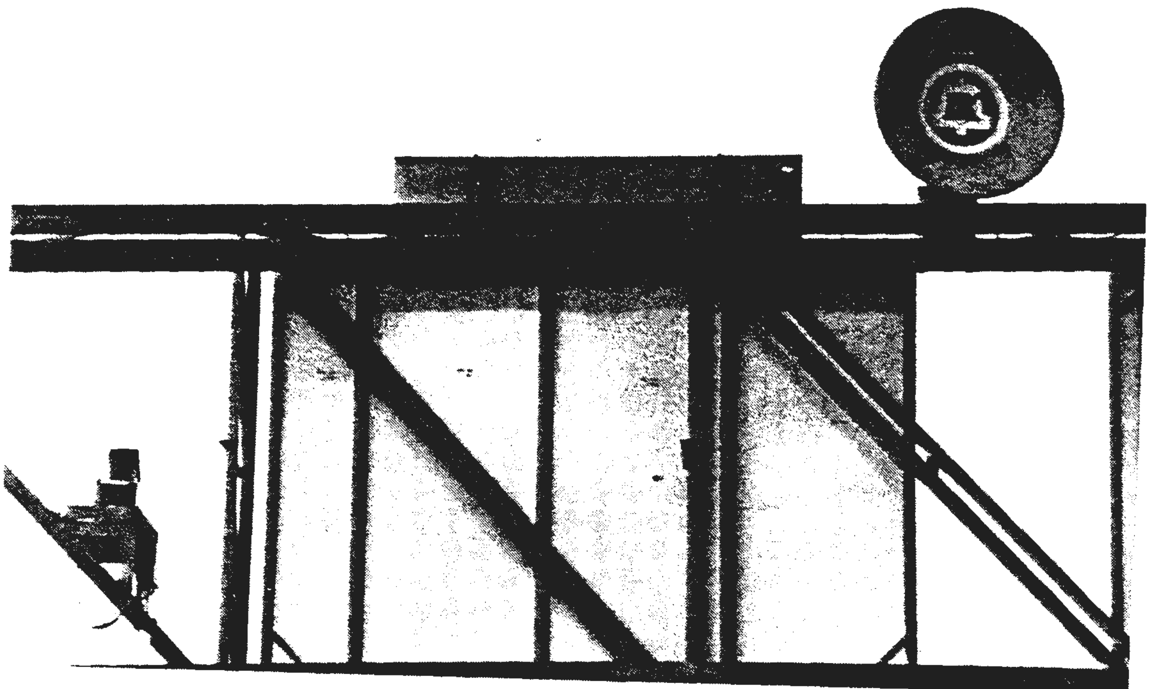
Year 2 — Order patrol vehicles and CB radio equipment. Award cabling contract, begin installation. Continue loop installation and add metering at the five most critical ramps. Acquire land for central control room and begin construction.

Year 3 — Install metering equipment at an additional eight ramps and continue loop installations. Start service patrol and CB monitoring of incidents. Continue cable ducting installation and control room construction. Write specifications for central control computer and its peripherals.

Year 4 — Install more loops and meter 10 more ramps. Expand service patrol. Finish control room construction, continue cable and ducting installation. Order computer and peripherals, write specifications for CCTV and data transmission equipment.

Year 5 — Install ramp metering equipment at an additional 11 ramps and expand loop installation. Take delivery of and test computer, its peripherals, and data transmission equipment. Finish cable ducting. Test CCTV equipment.

Year 6 — Install metering at the final 11 ramps and CCTV equipment. Change ramp control to traffic-responsive mode —turn computer on.



Closed Circuit Television Camera and Data Transmission Antenna
Los Angeles, California

SUMMARY

This hypothetical example is obviously oversimplified, but it does illustrate the staged construction approach. In the first year there will be small benefits from the equipping of police vehicles. In the second year, more reductions in delay can be made with the installation of ramp metering at the first ramps. As more ramps are included in the systems, the benefits increase until the sixth year when the entire planned system is operational.

CHAPTER 7. INTERAGENCY COOPERATION

An important consideration in an incident management system is the cooperation of the agencies responsible for providing the needed response. Often, more than one department, agency, or jurisdiction is involved. Because the priorities within each agency are often different, it can be difficult to achieve full cooperation. To overcome these differences it is sometimes necessary to create an incident management team composed of representatives of the major agencies and/or governmental entities. Responsibility for initiating and coordinating all incident management activities is given to this team.

The five incident management organizational options discussed in this chapter are:

- Police
- Police and Highway Department
- Highway Department
- Citizen Groups
- Incident Team

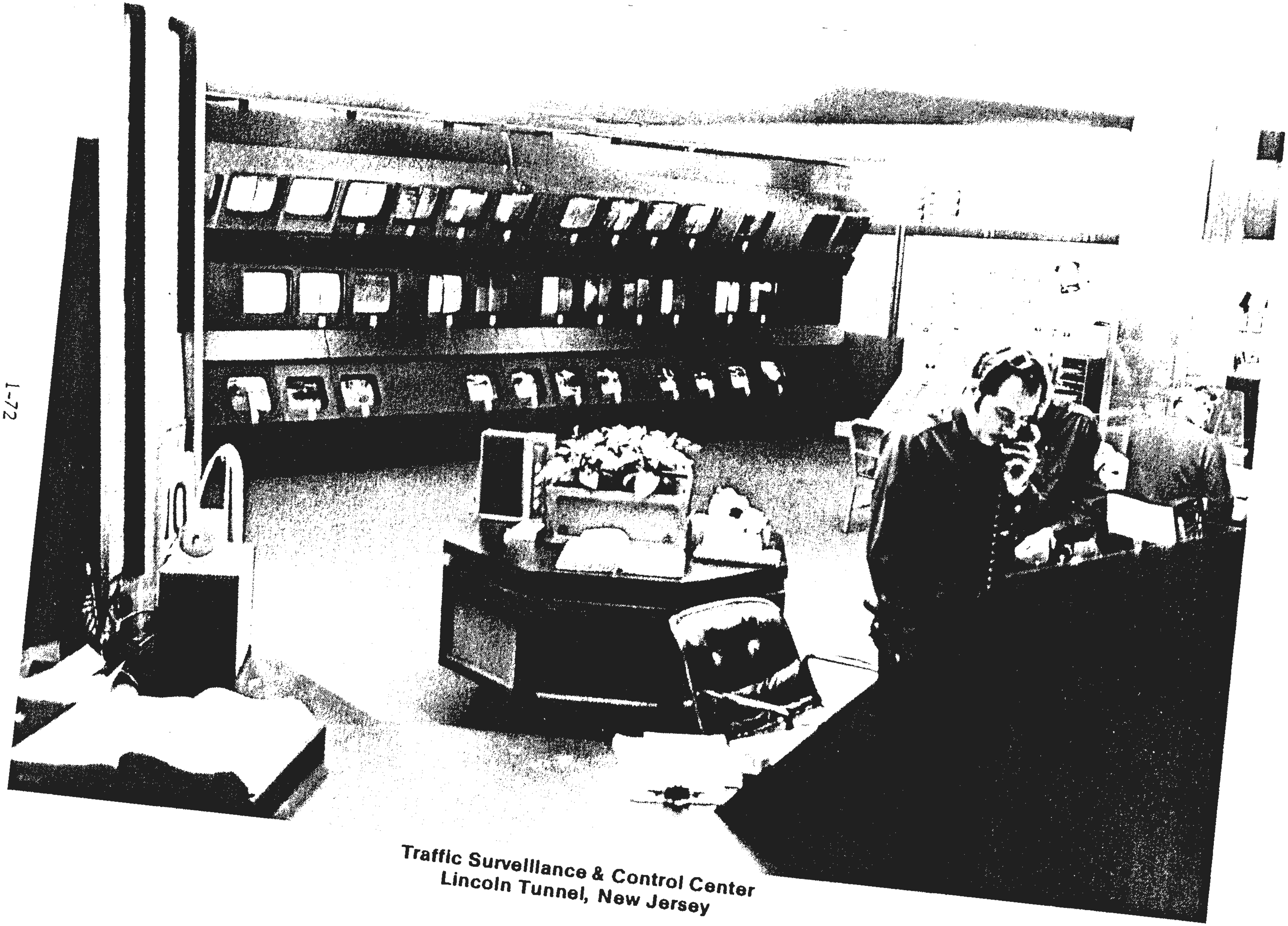
The discussion of these options is followed by a description of the skills (other than law enforcement) that are required.

In most cities, the state or local police agency has operational responsibility for the freeway system. This duty evolves quite naturally from traditional police concerns of traffic law enforcement, traffic control, and accident investigation. Some departments view it as control over the vehicles in the freeway environment, in contrast to highway department responsibility for the stationary elements. Given this high degree of involvement in freeway operations, many police agencies regard incident management as a logical extension of their existing responsibilities. Hence, police agencies tend to implement incident management techniques that build on their basic patrol functions.

A meaningful commitment, however, requires the assumption of a service role that may not be practical for some police agencies, due to limited experience or inadequate resources. Under such circumstances, incident management responsibility may fall on the next most logical public agency, a highway department or department of transportation (DOT).

The traditional construction and maintenance responsibilities of highway departments and DOT's have necessitated the acquisition of many of the vehicles and much of the equipment used for the clean-up and removal of freeway incidents. Maintenance and operational responsibilities may be divided among several jurisdictions. Furthermore, some DOT's have acquired an additional incident management role as a result of operating electronic surveillance and control systems. These activities provide a sound base upon which to build a more comprehensive incident management system under DOT control. Many of the potentially new incident management techniques, however, involve responsibilities that are usually those of police agencies. A DOT-sponsored incident management system can only be seriously considered with the approval and cooperation of the local police agency.

A DOT-sponsored incident management system can operate effectively under two different organizational configurations: as the joint responsibility of the DOT and



Traffic Surveillance & Control Center
Lincoln Tunnel, New Jersey

the police department, with each agency still performing its traditional role but having closer coordination with the other; or as the sole responsibility of the DOT, with the agency assuming what were previously police incident management responsibilities, such as providing aid to motorists or monitoring CB radio reports.

For bottleneck or point facilities such as bridges and tunnels, the operating authority is often the initiator of an incident management system. These facilities present special problems, since shoulders or emergency service lanes are usually nonexistent and diversion opportunities limited. Consequently, measures to reduce delay and congestion are of great importance to the authority, which, because of its operational experience, is the most logical group to oversee implementation. Furthermore, police agencies and highway departments generally play only supporting roles with respect to incident management on point facilities. Point facility incident management systems tend to emphasize their surveillance measures since detection over a short stretch of highway can be virtually instantaneous without being prohibitively expensive. This fact explains the low-cost classification of options using closed-circuit television and loop detectors for point facilities, even though their installation throughout an entire freeway system would require a large investment.

A citizen group may take the lead in implementing incident management options, particularly when it perceives official activities to be inadequate. Because of citizen groups' volunteer nature and limited resources, these incident management options tend to be labor-intensive and often consist of methods for improving the speed and quality of the incident-related information transmitted to public agencies and the media. Citizen involvement frequently develops out of existing organizations such as citizen band (CB) radio clubs and civic associations. It can then be easily broadened to include crime-reporting activities for the benefit of local law enforcement agencies.

The final incident management system, the freeway incident management team or authority, is considered to be the most effective due to the consolidation of all response and surveillance responsibilities into one administrative unit. This allows for the complete management of incidents by a single multidisciplinary team composed of police, highway, and other public agency personnel, with possible assistance by citizen volunteers. Such an authority is usually not available, so a team system is likely to require an intense, well planned organization and administrative effort at its inception. The potential benefit (i.e., elimination of the coordination and communication problems that reduce the effectiveness of other systems), however, makes the extra effort worthwhile. An additional advantage of the team system is that all incident management options are available to it, since it represents a combination of the other four systems.

Figure 7.1 shows the options available for incident management which are described in volume 2. The figure shows which agencies generally have the operational responsibilities for each of the options. These divisions are by no means rigid, as in specific locations one agency often takes on the responsibility for many of the options listed. In the case of point facilities at bridges or tunnels, the operating agency can be considered to perform similar functions to that of a highway department.

ADMINISTRATION AND STAFFING

Staffing requirements for a freeway management control system will vary with the size and complexity of the system. Some

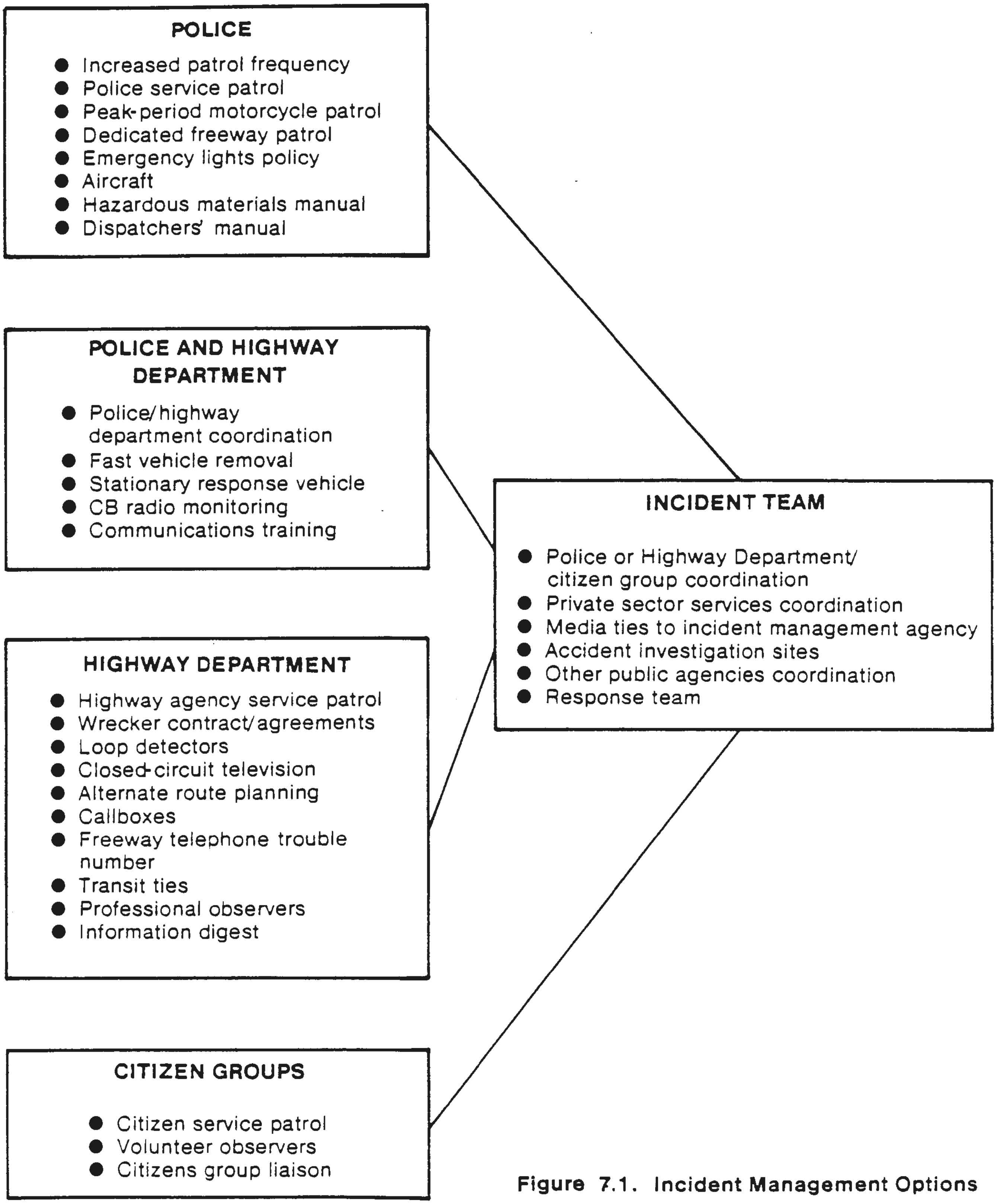


Figure 7.1. Incident Management Options

small systems (e.g., a four- or five-ramp metering system) require only the skills of an experienced traffic operations engineer. These skills include a knowledge of freeway traffic flow concepts, performance evaluation, and the ability to monitor the system's operation and make the modifications necessary to enhance performance of the system. In this mode of operation, the traffic operations engineer is responsible for the operation and maintenance of the system with part-time support from electronic technicians, maintenance staff, and data analysts. Support is also required from the police to ensure compliance at signals.

In the larger systems, the tasks or functions that need to be performed tend to be much broader in scope and, therefore, a team of individuals is usually required. Typical functions for these larger systems and the types of skills required are shown in table 7.1. Normally, one individual might possess two or more skills and can fill several functions in this matrix. For example, the traffic operations engineer could, and normally does, serve in the dual role of administrator and traffic analyst. He also assumes the responsibility for developing public relations and citizens information programs based on the

Table 7.2. Position and Functions of All Possible Staff

POSITION \ FUNCTION	Administration	Systems Planning	Performance Evaluation	Computer Programming	Computer Operation	Computer Maintenance	Equipment Maintenance	Public Relations	Documentation and Publication
Project Manager	●							●	●
Traffic Operations Engineer	●	●	●					●	●
Systems Analyst			●	●					●
Computer Programmer				●					●
Computer Operator					●				
Electronic Technician						●	●		
Engineering Technician							●		
Data Analyst			●						

Incident Removal by Contracted Towing Company
Los Angeles, California

operation and performance results of the control system.

In assessing staffing requirements it is most important to define clearly the tasks to be performed and the skills needed to perform these tasks. It is equally important to translate these needs into personnel equivalents, taking into consideration overlapping skills, cross utilization of personnel, and budgetary constraints. Administrators of freeway management systems have had problems in obtaining and keeping staff. This is due to low pay for engineers and software specialists who can often find better remuneration elsewhere.

SUMMARY

An important consideration in the planning of an incident management system is the cooperation of the agencies responsible for providing the needed response. The staffing requirements will vary with the size and complexity of the freeway management system. However, an integrated freeway management team composed of police, highway, and other public agency personnel is considered to be the most effective form of staffing. This assures a unified effort in operating, maintaining, and updating the system, and provides the opportunity for developing a skilled staff that can be increasingly responsive to system requirements.

Defining Problems	1. Introduction 2. Problem Statement
Proposing Solutions	3. Management Strategies
Implementing and Evaluating Projects	4. Development of a Freeway Management System 5. Economic Analysis 6. Staged Construction and Financial Planning 7. Intragency Cooperation
Existing Systems	8. Review of Existing Systems

CHAPTER 8. REVIEW OF EXISTING SYSTEMS

In general, the freeway management systems that have been built up over the past 25 years have demonstrated their ability to achieve significant benefits. The initial small experimental systems were prone to failure due to faulty equipment and a lack of existing techniques from which to draw experience. From these early beginnings, a number of freeway management systems have developed, becoming very extensive and sophisticated.

The Los Angeles system now has 462 directional miles of its freeway system under control with 611 ramps being used to meter traffic into the system. Some of the smallest systems have only a few ramps operating under pretimed control, yet still have been able to demonstrate significant reductions in congestion. Table 8.1 shows a summary of the majority of the freeway management systems in North America. As can be seen in this table, the type and functions of the systems are extremely variable. Many of the smaller systems have no central electronic surveillance and no variable message signs, but rely on ramp control only. By contrast, the New Jersey Turnpike system has no ramp control, but 136 variable message signs that give information on the conditions on the freeway and in certain locations advise drivers on alternative routes.

Differing strategies are obviously required to suit the needs of individual freeways. By careful planning and the use of evaluation exercises freeway management systems can slowly grow to meet the specific needs of cities. Both Chicago and Dallas can be cited as examples of how freeway management systems can develop.

CHICAGO

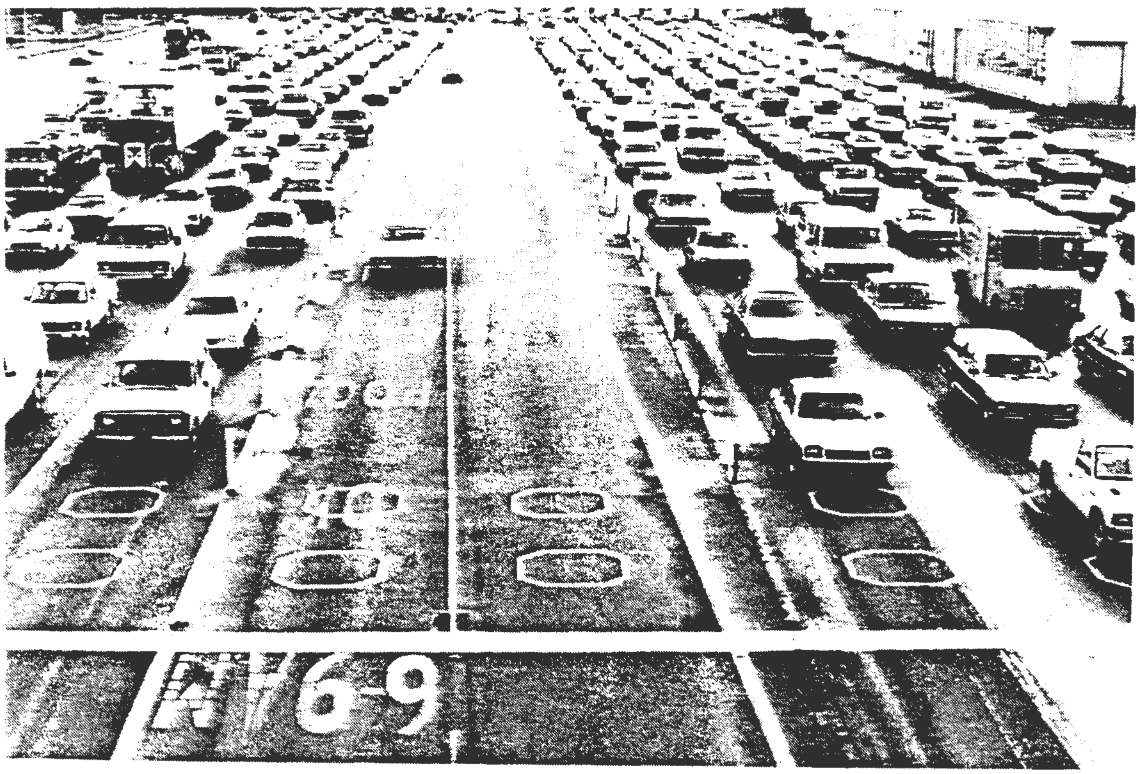
In 1961 a project was started in Chicago to improve network traffic flow by means of automatic control and information techniques. The initial efforts involved the installation of 25 detectors on a 5-mile section of the Eisenhower Expressway. These detectors provided basic traffic flow information. From these beginnings the system has grown to the point where, in 1982, 220 directional miles of freeway are under control, there are 1,700 loop detectors and 70 metered ramps. The system handles approximately 14 million vehicle-miles of travel per day and its service patrols, on an average day, assist more than 200 disabled motorists. More than 20 years after its inception, only now is the staff moving into a specially designed traffic systems building.

The Chicago system (as others) was not without controversy as residents in inner areas felt that the system provided priority to users in outer areas, which lead to their being excessively delayed. An effective countermeasure to this complaint is to reduce the flow onto an upstream ramp when the downstream becomes congested.

DALLAS

In the late 1960's, FHWA, the Texas State Highway Department, the City of Dallas, and the Texas Transportation Institute mutually agreed to install a freeway control system in the City of Dallas. The plan was to integrate the following seven components:

Ramp Metering in Oakland, California



Mainline Metering with Bypass Lanes for HOV Traffic
Oakland Bay Bridge, California

TABLE 8.1. SUMMARY OF EXISTING FREEWAY SYSTEMS

Location	Directional Miles of Controlled Freeway	Total Cost $000	Number of Metered Ramps	Number of Detectors	Variable Message Signs	Call Boxes	Detection Confirmation By
Los Angeles, California	462.0	Not Available	611	Approximately 6,500	21	Yes	Patrol
Detroit, Michigan	66.0	16,000	7	1,350	3	Yes	Patrol
Chicago, Illinois	220.0	11,000	70	1,700	1	No	Patrol
Baltimore, Maryland I-83	11.0	1,500	None	109	11	Yes	Patrol (aircraft in peak hour)
Minneapolis, Minnesota I-35/I-94/I-694	45.0	4,468	55	594	8	Yes	CCTV
New Jersey Turnpike	96.0	12,000	None	875	136	No	Patrol
Cincinnati, Ohio	2.5	1,000	None	90	19	No	CCTV
Phoenix, Arizona	20.0	800	18	206	None	No	None
Dallas, Texas	20.0	2,663	35	317	None	No	CCTV

Table 8.1, Continued

Location	Directional Miles of Controlled Freeway	Total Cost $000	Number of Metered Ramps	Number of Detectors	Variable Message Signs	Call Boxes	Detection Confirmation By
Houston, Texas	49.0	850	40 1.23	160	None	No	Not Applicable
Fort Worth, Texas	10.0	217	16 0.63	Not Available	None	No	Patrol
San Antonio, Texas	8.0	130	9 0.89	Not Available	None	No	Not Applicable
Hampton, Virginia I-64 Tunnel	14.0	7,800	None	76	80	No	CCTV; Patrols
Seattle, Washington	34.0	4,500	18 1.89	500	37	No	CCTV
Milwaukee, Wisconsin	18.0	317	21 0.86	Not Available	2	No	Patrols
Toronto, Canada	8.0	2,000	10 0.80	180	1	No	CCTV; Patrols

Note: Some of the freeway management systems shown in figure 1.1 are still in the design or construction phases and these data are not yet available.

- Freeway ramp control
- Freeway surveillance; CCTV
- Frontage road intersection control
- Arterial intersection control
- Bus priority signals
- Driver information systems
- Traffic control center

The current status of these components is outlined below.

Initially, 35 metered ramps were installed. However, in 1977 most of the mainline detectors were damaged when the expressway was textured to increase skid resistance. This resulted in a loss of real-time traffic data. Thus, ramp control was on a pretimed basis until 1979, when all of the loops were replaced.

The CCTV surveillance system was designed to have nine cameras. The coaxial cable to these cameras was laid on the surface of the median and was ruined by environmental conditions. Only one camera is still working and this is on the roof of the control building.

The minicomputers used for frontage road intersection control and surveillance are malfunctioning and replacements are unavailable. Many of these intersections are being converted to fixed time controllers.

The arterial control system is working well.

The driver information system had variable message signs and a dial-in telephone system. Since the surveillance system was inoperative, however, no meaningful information was available for transmission to drivers. Furthermore, two of the signs were in the path of an arterial that was to be widened and they were removed.

The experiences in Chicago and Dallas provide an example for those contemplating freeway management.

In order that potential freeway management planners can make the most of the experience of others, a list of contacts is contained in table 8.2.

SUMMARY

Freeway management has matured past the point of being theoretical research—it is now an effective tool for managing present traffic flow and controlling future travel demands. Much has been learned from the examination of existing systems, whether they have succeeded or failed.

The following points summarize the principal lessons learned.

- Carefully define all resource requirements for the project after weighing the available alternatives.
- Obtain formal commitments for staffing and funding from all involved organizations.
- Make sure the ultimate operating agency is involved from project initiation and is fully aware of the implications of implementing the control system.
- Assign a project coordinator committee to oversee the project.
- Balance research and operational needs to ensure that the system can be economically and effectively operated after the research phases are completed.

TABLE 8.2. FREEWAY MANAGEMENT CONTACTS

Freeway Location	Telephone	Address
Los Angeles, California	(213)620-3754	Traffic Operations, California Department of Transportation, 120 South Spring Street, Los Angeles, California 90012
Chicago, Illinois	(312)524-2146	Illinois Department of Transportation, 230 West Madison Street, Oak Park, Illinois 60302
Baltimore, Maryland I-83	(301)396-3029	Department of Transit and Traffic, 414 North Calvert Street, Baltimore, Maryland 21202
Minneapolis, Minnesota I-35/I-84	(612)341-7500	Traffic Management Center, 1101 Fourth Avenue, South, Minneapolis, Minnesota 55404
New Jersey Turnpike	(201)247-0900	Edwards and Kelcey, Inc., 70 South Orange Avenue, Livingston, New Jersey 07039
Cincinnati, Ohio I-75S	(614)466-5197	City Traffic Engineer, 801 Plum Street, Cincinnati, Ohio 45202
Dallas, Texas	(214)670-4538	City of Dallas, 2721 Municipal, Dallas, Texas 75215
Houston, Texas	(713)869-4571	State Department of Highways and Public Transportation, District 12, Post Office Box 1386, Houston, Texas 77001
Fort Worth, Texas	(817)292-6510	State Department of Highways and Public Transportation, Post Office Box 6868, Fort Worth, Texas 76115
San Antonio, Texas	(512)969-1110	State Department of Highways and Public Transportation, Post Office Box 29928, San Antonio, Texas 78284
Hampton, Virginia I-64 Tunnel	(804)723-0761	Virginia Department of Transportation, Tunnel and Toll Facilities, Post Office Box 3447, Hampton, Virginia 23663
Milwaukee, Wisconsin	(414)224-4625	Wisconsin Department of Transportation, 819 North Sixth Street, Milwaukee, Wisconsin 53203
Toronto, Canada	(416)248-7141	Control Systems Research, 1201 Wilson Avenue, Downsview, Ontario M3M 1J8 Canada

- Maximize use of off-the-shelf, tested technology.
- Implement ramp control and arterial signal systems as an effective means to improve traffic performance.
- Separate evaluation from the duties of the implementation contractor, but do <u>not</u> separate planning and implementation.
- Require complete documentation of all software and hardware components and assess the effectiveness of the system.