1173

TRANSPORTATION RESEARCH RECORD

Urban Freeway Operations

TRANSPORTATION RESEARCH BOARD
NATIONAL RESEARCH COUNCIL
WASHINGTON, D.C. 1988

Transportation Research Record 1173
Price: $7.50
Editor: Ruth Sochard Pitt
Production: Lucinda Reeder

mode
1 highway transportation

subject area
54 operations and traffic control

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Printed in the United States of America

Library of Congress Cataloging-in-Publication Data
National Research Council. Transportation Research Board.

Urban freeway operations.
(Transportation research record, ISSN 0361-1981 ; 1173)
ISBN 0-309-04711-0
1. Express highways—United States. I. National Research Council (U.S.). Transportation Research Board. II. Series.
TE7.H5 no. 1173 380.5 s [388.4'11] 89-3110
[HE355]

Sponsorship of Transportation Research Record 1173

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Contents

Foreword

Urban freeways have become the vital arteries of modern cities, but without proper management, they can also be major sources of irritation to those who use them and those who are responsible for them. The papers included in this Record explore techniques for managing urban expressways so that they may be used more efficiently. The methods range from more effective physical facilities and management procedures to improved public relations practices.

Accident investigation sites are the subject of two papers by Dudek et al. First, the administrative and legal aspects of designated sites for investigation of noninjury accidents are discussed. Then the physical factors, such as location and design, are considered. The authors conclude that accident investigation sites can help prevent freeway traffic jams, but that care must be taken in planning and implementing the sites.

High-occupancy vehicle (HOV) lanes are becoming a popular solution to urban freeway congestion, especially during peak hours. Newman et al. evaluate the designs of the HOV lanes used on various California expressways and conclude that some designs are safer and more efficient than others.

Construction that will eventually improve freeways usually results in immediate delays and congestion. Effective public information systems can help alleviate the public's irritation in these cases. Turnbull describes the evolution of one such system, a hot line that provides users with up-to-date reports on topics such as lane closings, construction schedules, and bus routes.

The ramp metering systems that have been installed on many urban expressways can need adjustments to accommodate changes that occur in the traffic flow. Banks examines performance measurement techniques used in the San Diego area to allow effective adjustment of these systems.

The physical geometry of any roadway can affect its performance. On a high-speed, high-volume expressway, consideration of this factor is especially vital. Persaud and Hall investigate the effect of grade on the relationship between flow and occupancy on freeways. They conclude that it is possible to model the relationship for traffic management purposes.

Multiple aspects of traffic management, including ramp metering and a HOV lane, are examined in Nihan's case study of an urban freeway in Washington state. The planning and results of a complete traffic management system are presented, and it is clear that the multipart plan was effective in reducing freeway congestion and related negative impacts in nearby neighborhoods.

Promotional Issues Related to Accident Investigation Sites in Urban Freeway Corridors

CONRAD L. DUDEK, W. R. MCCASLAND, AND E. NELS BURNS

In this paper, a study of administrative, legal, and insurance issues concerning Accident Investigation Sites (AISs) in urban freeway corridors is described. The issues were identified through (a) a literature review; (b) contact with a limited number of individuals, organizations, and agencies involved in the coordination or administration of legal and insurance matters as related to traffic accidents; (c) interviews with urban freeway corridor traffic management teams; (d) contact with highway operations personnel from selected urban freeway surveillance and control systems; and (e) experiences of the authors. AISs are low-cost, specially designated and signed areas off the freeway where damaged vehicles can be moved, motorists can exchange information, and police and motorists can complete the necessary accident forms. These areas are located so that the motorists involved in the accident, the investigating police, and the tow truck operators are out of view of freeway drivers. "Rubbernecking" (and, consequently, freeway congestion) is thus reduced. Freeway congestion is also reduced because the motorists involved in property-damage-only accidents have a place where they can move their vehicles while waiting for the police investigators to arrive. Experiences with AISs in Houston, Texas, resulted in a benefit-cost ratio of 28:1 during the first year of operation. Data indicated that the potential benefit-cost ratio could be as high as 35:1, that is, $35 return for every $1 invested. The AIS concept is applicable for a variety of metropolitan area traffic management strategies. The administrative, legal, and insurance issues that must be addressed by highway and police agencies to implement and operate AISs successfully are identified and discussed.

Accident Investigation Sites (AISs) are specially designated and signed areas off the freeway where damaged vehicles can be moved, motorists can exchange information, and police and motorists can complete the necessary accident forms. These areas are located so that the motorists involved in the accident, the investigating police, and tow truck operators are out of view of freeway drivers. This reduces "rubbernecking," which is a major cause of congestion at freeway accident scenes. The AISs are may be located under a freeway overpass, on a side street or parallel frontage road, or in a shopping center parking lot out of view of freeway traffic.

The research reported in this paper was sponsored by FHWA (*1*) and involved a review of legal and insurance issues related to AISs through library searches and contact with a limited number of individuals, organizations, and agencies involved in the coordination or administration of legal and insurance matters related to traffic accidents. In addition, the literature on the use of AISs was reviewed. Guidelines for locating, designing, and operating AISs are presented elsewhere (see companion paper by Dudek et al. in this Record).

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BACKGROUND

Characteristics and Effects of Freeway Incidents

The frequency of incidents on urban freeways and their subsequent adverse effects in terms of congestion, delays, and secondary accidents have been well documented by several authors and summarized by Dudek (*2*). The consequences of accidents and other incidents are congestion, delay, shock waves in the traffic stream, secondary accidents, and other adverse effects.

Accidents that require police or wrecker assistance, as well as minor accidents in which the drivers refuse to move their vehicles off the freeway lanes until the police arrive, often block traffic for a considerable time. Studies conducted by the Texas Transportation Institute (TTI), for example, indicated that an average accident requiring (or waiting for) police assistance blocks one or more freeway lanes for an average of 19 min (*2*). An additional 25 min is required to complete the accident investigation.

Solution Approach

From a traffic management viewpoint, when an accident or other incident occurs on an urban freeway, the vehicles, debris, or both must be removed as quickly as possible. Approaching freeway traffic (demand) should be intercepted before it reaches the reduced capacity area caused by the incident and then redirected to routes with excess capacity. In addition, drivers must be warned of the slowed traffic ahead.

Freeway incident management (FIM) systems are frequently employed by highway and police agencies to combat congestion and safety problems resulting from accidents. These systems involve a coordinated and preplanned approach that uses human and mechanical resources to restore freeway traffic to normal operation after an incident has occurred. The approach involves a systematic process for

- Detecting any incident,

- Identifying the scope (i.e., number of vehicles involved, number of lanes affected, severity of the accident, anticipated time of the lane closures, etc.) and needs (e.g., police, fire department, wrecker and maintenance equipment and personnel) of the incident, and
- Providing appropriate responses to aid the motorists involved and to minimize the adverse effects of the incident by clearing the incident as quickly as possible.

Minimizing the Effects of Freeway Accidents

There are two ways to minimize the adverse effects of freeway accidents. First, the severity and duration of the reduction in freeway capacity should be reduced by clearing the vehicles involved in the accident from the traveled lanes as soon as possible, and second, the distractions (accident, police and wrecker vehicles) should be removed from the roadside.

One major low-cost approach to minimizing the adverse effects of freeway accidents is the use of AISs. The first AIS system was installed along the Gulf Freeway in Houston, Texas, in 1971 (*3*). The benefit/cost ratio for the first year of AIS operation in Houston was 28:1. Data indicated that the potential benefit/cost ratio could be as high as 35:1, that is, $35 return for every $1 invested in AISs.

STUDY METHODOLOGY

Interviews were conducted with the following individuals or representatives from organizations and agencies:

- City attorney from a large city;
- Chief justice, district supreme court of appeals;
- Assistant attorney general and former judge, municipal court;
- Automobile club representative;
- Insurance association representative;
- Insurance company representative;
- Representative of a private company with a large fleet of vehicles;
- Representatives of urban freeway traffic management centers in two states (New York and Virginia); and
- Representatives of traffic (corridor) management teams from five cities in Texas.

The traffic management centers and teams normally included members of the traffic engineering and planning divisions of the city or state transportation departments, local transit authority, and city or state police.

IMPLEMENTATION OF ACCIDENT INVESTIGATION SITES

Experiences with AISs in Texas

Houston

Initial Program As mentioned previously, the first AIS system was installed in Houston, Texas, in 1971 (*3*). The Texas State Department of Highways and Public Transportation (SDHPT) and TTI developed and implemented an AIS system adjacent to the I-45 Gulf Freeway in Houston in conjunction with a corridor traffic management system. The purpose of the AIS system was to provide a place out of view of the freeway motorists where police officers could investigate accidents and where motorists could exchange information. Texas law requires police investigation only for injury and fatality accidents, although drivers must complete and submit accident report forms for other accidents.

SDHPT and TTI installed 16 AISs within a 6-mi section of the freeway. Eight of the sites were located on city streets adjacent to the freeway, two were located on city streets under the freeway, one was located off a city street on freeway right-of-way, and five were on previously unused space under freeway structures. Two or more guide signs were erected on the frontage road and city street approaches to the sites to direct the motorists and to identify the AIS locations by number. No signs were placed adjacent to the traveled lanes of the freeway.

The Houston AIS system was designed so that the Houston Police Department could direct the motorists involved in a minor accident to drive to the nearest site at which the investigation would be completed. The police were provided with booklets containing maps detailing all of the site locations and with directions on how to exit the freeway to reach the closest site.

During the initial media releases, members of the public were advised to drive to the closest AIS if their vehicles were operational. Motorists, however, were reluctant to move their vehicles from the accident scene without being directed to do so by the police. No telephones were installed with the AIS system.

Records kept as part of the Gulf Freeway Surveillance Project revealed that the AIS system was used extensively by the police during the first 2 years. During the first year of operation, the AIS system was used for accident reporting for 40 percent of the 851 accidents reported in the study area. In addition, another 176 investigations (21 percent) were conducted at other off-freeway locations.

Benefits of the AIS system during the first year included $203,000 savings due to delay reductions because freeway congestion cleared faster when accidents were out of sight and $25,000 savings attributed to a reduction in secondary accidents. The annual cost for installation and maintenance of the sites was estimated to be $8,000, resulting in a benefit/cost ratio of 28:1 (*3*).

Even though the AIS system was very successful during the first year, accident records indicate that an additional 25 percent of all accidents could have been moved to the AIS system or to other off-freeway locations. These data suggest that the potential benefit/cost ratio may be as high as 35:1.

The success of the AIS system during the early months of operation was due to a number of factors. The system was well designed by the staff of the Gulf Freeway Surveillance Project, which included representatives of the Houston Police Department in addition to staffers from SDHPT and TTI. The Gulf Freeway was monitored electronically by vehicle detectors and a closed circuit television system. When an incident occurred on the freeway, a police officer in the control center could call a police patrol unit by telephone or radio, provide information on the location and nature of the incident, and suggest an AIS for the accident investigation. Even without the central control officer's reports, the surveillance project was well known to the police department.

The surveillance staff had requested and received cooperation and assistance from the police in the collection of data on many projects for several years. Thus the procedure for collecting data from the police accident investigators to assess the effectiveness of the AIS system was also instrumental in maintaining a high level of usage by the police.

The forms used to record the use and nonuse of the AIS system (*2*) were collected and analyzed weekly by the surveillance project staff, and the results were forwarded to the Chief of the Traffic Bureau of the Houston Police Department. The monitoring process continued for 2 years, until 1973, when the first phase of a major freeway rehabilitation project began on the Gulf Freeway. The Surveillance and Control Project was then shut down, and the record keeping on AIS usage was discontinued.

During Construction and in the Future During the next 7 years, the redesign and reconstruction of the Gulf Freeway changed the access patterns to and from the frontage roads. The original AIS design was keyed to the exit ramps for quick and direct movement from the freeway shoulders. Some of the sites, located under the freeway, served both directions of freeway traffic flow, whereas the others, on the adjacent streets, served only one direction.

Even though the construction activities severely restricted movement in the area, the AIS system was never officially taken out of service. However, as the reconstruction work progressed, most of the sites became inoperative. The few that were unaffected by the construction were not maintained, and the signs and pavement markings were not replaced when they deteriorated or were destroyed. The map booklets that were provided to the police were not updated or replaced. In general. the original AIS system was allowed to phase out by attrition (Table 1).

Some of the AIS system has been included in current plans for the reconstruction of the Gulf Freeway. One site under the freeway was redesigned and reconstructed when an interchange was improved. An innovative design combined the AIS parking area with the roadway for a U-turn. Another special site under the freeway has been preserved during the reconstruction and will be put back into service as soon as the freeway construction is completed. The other special sites under the freeway have been taken out of service and are not scheduled to be replaced because of a lack of access.

The SDHPT Houston District Office will not reinstate the full AIS system described by Pitten and Loutzenheiser (*3*) because some of the locations are no longer functional. Plans are underway, however, to replace the signs for all existing AIS locations, to upgrade one of the existing parking areas, and to construct new sites.

SDHPT is committed to the AIS concept. It is a low-cost, high-benefit strategy. However, AIS must be supported by the local policing agency to receive the type of maintenance by SDHPT that the system requires. To get the active support of the police, formal requests for AIS use and periodic reviews of the usage rates are required. The supervisors of the accident investigation section of the police department must also be supportive of the AIS concept. In Houston, this type of support is expected, and the system should be back in full operation as soon as the construction on the Gulf Freeway is completed in 1988. Other Houston freeways that are now being reconstructed will also have AIS systems installed.

San Antonio

In 1980, the SDHPT San Antonio District, working closely with the San Antonio Police Department, identified 13 candidate locations on the freeway system that had high accident experience. Four AISs were installed at the more accessible locations. Each AIS site had telephones with direct lines to the police dispatchers.

The objective of the AIS System in San Antonio was to get the motorists involved in minor accidents to drive to the AIS, place a call to the police department for assistance, and then

TABLE 1 STATUS OF THE ORIGINAL HOUSTON ACCIDENT INVESTIGATION SITE SYSTEM

Site Number	Site Type[a]	Direction Served	Status of Location	Status of Signs[b]
1	1	North	Removed from service	Removed
2	1	North and south	Closed temporarily	Removed (TBR)
3	1	North and south	Closed temporarily	Removed (TBR)
4	2	North	Closed temporarily	Removed (TBR)
5	2	South	Removed from service	Removed
6	2	North	Closed temporarily	Removed (TBR)
7	2	South	Closed temporarily	Removed (TBR)
8	2	North	In service	Needs repair (TBR)
9	2	South	Closed temporarily	Removed (TBR)
10	2	North	Removed from service	Removed
11	1	South	Removed from service	Removed
12	1	North and south	Closed temporarily	Removed (TBR)
13	1	North and south	In service (new)	Removed (TBR)
14	2	South	Closed temporarily	Removed (TBR)
15	2	North	In service	Needs repair (TBR)
16	2	South	In service	Needs repair (TBR)

[a]Type 1: specially constructed site. Type 2: existing parking areas.
[b]TBR: Signs to be replaced after the AIS is placed back in service.

wait at the site for the investigator to arrive. A media campaign, newspaper articles, and television and radio announcements were used to inform the public about the new AISs. SDHPT representatives appeared on talk shows to explain the operation and to answer questions. In addition, directional guide signs were erected on the freeway.

In spite of these efforts, the system was not used by the public because

- motorists did not become familiar with the system even though a media campaign had been conducted;
- motorists were unwilling to move their vehicles before the police arrived; and
- motorists were concerned that by moving their vehicles, they would lose their insurance coverage.

Also, the system was not always used by the police after they arrived at the scene of an accident. Some accident investigators preferred to use the shoulder and outer separation near the accident scene instead of removing the vehicles to an AIS.

Currently, two of the four AIS sites in San Antonio have already been removed, and a third site is scheduled to be removed from service because of freeway reconstruction. All of the telephones were removed because of vandalism. SDHPT considers the remaining locations to be operational. The signs, pavement, and lighting are being maintained. However, the San Antonio Police Department does not consider the system to be operational.

The concept of voluntary removal of vehicles from the freeway by the drivers before the police arrive has not worked well at any of the cities in Texas. The lack of support by the San Antonio Police can be traced to three factors:

- When the AIS system was installed, the police captain in charge of accident investigation was in favor of the program. When he was promoted, his successor did not encourage the staff to use the sites.
- Personnel changes at the SDHPT San Antonio District Office further reduced the level of support. The cause was a lack of communication rather than a lack of interest among the new personnel.
- There was no formal reporting or feedback mechanism on AIS system use, so the usage rate continued to fall.

There are current plans to install a few AISs at other locations that have good access and visibility (to discourage vandalism and to enhance motorist safety). These sites will be located with the assistance of the police department, and SDHPT anticipates increased participation by the police accident investigators.

Dallas

In May 1981, the city of Dallas installed an AIS system on the North Central Expressway (US 75). The system consisted of 10 sites located on the streets adjacent to the freeway. Signs were erected on the freeway, frontage road, and side streets to direct the motorists to the sites and to identify the locations by number.

The AIS system was designed to be used by the Dallas Police Department to direct the motorists off the freeway to the sites to exchange information and to complete the investigations. Guide signs were placed on the shoulders of the main lanes of the freeway to remind the police of the AIS system. Guide signs were also placed at the exit ramps, intersections, and curb sites.

To date, use of the system has been less than expected. Usage has not been strongly emphasized within the Dallas Police Department. There are no monitoring or evaluation processes to determine the benefits of the system. Police and city transportation officials place the usage rate at 10 to 15 percent of the accidents that could be moved.

The North Central Expressway is scheduled for reconstruction during the next 5 years. Traffic control plans call for most of the emergency shoulders to be removed for travel lanes during reconstruction. The AIS system, or some form of quick incident removal procedures, will be implemented while the freeway is being upgraded. SDHPT will include some form of AIS use in the traffic control plan.

El Paso

In June 1986 the SDHPT El Paso District installed an AIS system on I-10 east of the central business district. The system consists of 10 sites, located on the eastbound frontage road, between the frontage road and the right-of-way line. These locations, although not completely out of sight of the freeway motorists, are far enough removed to lessen the impact of incident scenes on freeway traffic capacity.

The sites are well designed to provide a safe area for the vehicles and the occupants. Signs were not erected on the freeway but were placed on the frontage roads and at the sites. Guide signs were placed at the frontage road intersections to direct traffic from the westbound lanes to the AISs by way of U-turn lanes. The sites are in well lighted areas, downstream of freeway exit ramps, and near public telephones. Signs at the AISs provide telephone numbers for contacting the police department and the AIS identification number.

An intensive media campaign was conducted by the El Paso Police Department when the sites were opened. There is no formal procedure underway at this time to monitor the use of the system, but SDHPT officials plan to make a survey of their usage and the benefits to justify the expansion of the system.

Summary of Knowledge Gained from Texas Experiences

Experiences in Texas have indicated that AISs are low-cost highway improvements that result in significant benefits to motorists. The benefit/cost ratio for an AIS system in Houston, for example, was 28:1. Data suggest that the potential benefit/cost ratio may be as high as 35:1.

The Texas experiences have also highlighted the need for effective management techniques. Recommendations based on the Texas experiences are incorporated into AIS administrative, location, design, and operation issues discussed in the next section.

CURRENT AIS ADMINISTRATIVE ISSUES

Lead Agency

The traffic and transportation agencies of cities, counties, and states have the authority to design, construct, and maintain AISs on their property and to acquire the rights (through agreements) to use private commercial parking areas for these purposes. To develop an effective AIS system in an urban area, the involved agencies should include, as a minimum, the department of transportation and the policing agencies that will use the AIS system. Also, a lead agency (usually the state department of transportation) should be designated to be responsible for the design and implementation of the AIS system for the entire freeway network. One approach to the successful development and operation of an AIS system is through a local traffic management team.

Traffic Management Teams

A traffic management team brings together professionals from the various traffic-related agencies in the area and helps them to work together to solve the area's traffic problems (*4*). The team improves the overall traffic operation and safety in the freeway corridors by coordinating the activities of the principal operational agencies in the urban area. The communication, coordination, and cooperation that can be realized through working side by side on the team are essential to its successful operation. Because of these relationships and activities, the traffic management team is a logical focal group for the administration, design, implementation, and operation of an AIS system.

The state of Texas provides an example of the success of traffic management teams. The first traffic management team in Texas was officially formed in 1975. Currently, 12 teams are operating in the state. These teams cover the seven largest metropolitan areas and the nine largest cities, as well as other, smaller areas. The rapid spread of the team concept and its wide acceptance among the large cities in Texas indicates that it is very beneficial. The need for the team approach was recently reemphasized by several governmental agencies during a national conference, "Corridor Traffic Management for Major Highway Reconstruction," which was held in Chicago, Ill., September 28–October 1, 1986.

The identification of specific agencies that should be represented on a local traffic management team is difficult because different cities have different situations. However, some agencies are almost always included on the team. These include the city and state traffic engineering offices, city and state law enforcement agencies, and the local transit authority. Other agencies and divisions should be included if they are significantly involved in the operation of the freeway corridor or corridors.

Distribution of Responsibilities

The responsibilities that each agency assumes in the day-to-day operation of AISs will be based on the organizational structures of each agency and the interagency operational structure within the city. In addition, specific interests of individuals and agencies will be influential in determining responsibilities.

Expected Benefits and Advantages of AISs

The monetary value of AISs fall into five categories:

- Reduced delay to freeway motorists,
- Reduced vehicle operating costs (e.g., gasoline consumption),
- Reduced secondary accidents,
- Reduced pedestrian accidents, and
- More efficient use of public agency personnel.

Delay and Operating Costs

AISs reduce delay time of freeway motorists and vehicle operating costs through the early removal of incidents from the traffic lanes and the removal of the vehicles from the sight of freeway motorists, particularly during the peak traffic periods. Examples of the reduced delay benefits of removing incidents occurring during the peak period to AISs were presented previously.

Monetary benefits of AISs resulting from reduced delay and vehicle operating costs are determined by computing the estimated delay and operating costs that would be expected if AISs did not exist and comparing them with the delay and operating costs calculated by assuming that AISs do exist. Analytical procedures and simplified computer programs are available to assist highway agencies in evaluating the delay and vehicle operating cost reductions and the monetary values of the reductions on the basis of the time of day that the incidents occur and length of time that they affected freeway traffic. For example, an analytical procedure for estimating freeway traffic congestion and calculating delay was published by Morales (*5*). A microcomputer program using an interactive Lotus 1-2-3 spreadsheet was also developed and is available for general use. Memmott and Dudek (*6*) developed a computer program called QUEWZ for determining delay and road user costs associated with delay and vehicle speed changes caused by stop-and-go driving in congested traffic. The program was developed for evaluating the effects of lane closures at freeway construction and maintenance work zones, but it can also be used for evaluating the effects of freeway incidents. Two major advantages of this computer program are that the information necessary to run the program can be easily obtained by highway agencies and that road user costs are automatically calculated.

Another approach to estimating the delay associated with freeway lane blockages is to use simple arithmetic. Subtracting the estimated traffic volume moving through the lane blockage section of the freeway from the estimated demand volume each hour gives an estimate of the number of vehicles trapped in the stop-and-go traffic during the hour. Multiplying the number of vehicles in the congestion by a time factor produces an estimate of vehicle-hours of delay.

Acceptable monetary values of time that can be applied to the computations of delay already exist. For example, in Texas as of August 1985, the average value of time for passenger vehicles was \$10.55 per vehicle-hour; that for trucks was \$19.25 per vehicle-hour (*7*). The value of time is affected by the composition of traffic and by changes in the monetary value of the dollar. These values must therefore be adjusted regularly.

An example of detailed analyses of the value of vehicle travel time can be found elsewhere (*7*).

Secondary Accidents

Each freeway incident has the possibility of causing a secondary accident, that is, an accident involving a stopped, parked, or disabled vehicle. Information about the number of secondary accidents that occur on a given section of freeway is difficult to obtain. It may therefore be necessary to make an estimate on the basis of experiences elsewhere. Because the monetary benefits of reducing secondary accidents will probably be relatively small in comparison to reduced delay and vehicle operating costs, the error associated with this estimating procedure may not be too critical. Fambro et al. (*8*) estimated that in 1973, 144 secondary accidents occurred in a 64-mi freeway network in Houston.

Monetary values can be placed on the cost of accidents. Accident cost statistics can be found in reports produced by the National Highway Traffic Safety Administration (*9*) and National Safety Council (*10*). In addition, highway agencies and research organizations periodically publish reports summarizing accident costs (*11*). Rollins and McFarland estimated that the costs for rural accidents as of July 1985 were $1,151,100 per fatal accident, $13,900 per injury accident, and $1,700 per PDO accident. For urban areas the estimated costs per accident were $1,077,700 for fatal accidents, $11,400 for injury accidents, and $2,000 for PDO accidents (*11*).

Pedestrian Accidents

AISs may also reduce pedestrian accidents. A California study (*12*) concluded that 43 percent of all the pedestrians struck on freeways were on the facility because their vehicles were either disabled or involved in a prior accident. In the absence of similar data in the local area, the California percentage can be used to estimate the potential reduction in the number of pedestrian accidents that occurred by using the number of total pedestrian accidents on the freeways to be serviced by AISs.

Efficient Use of Personnel

AISs can benefit local and state agencies by allowing a more efficient use of personnel. For example, by providing a refuge for motorists involved in accidents, encouraging them to move their vehicles to AISs before the police arrive, and providing telephone communications at the AISs, police will have additional time to attend to other responsibilities. Therefore savings might be realized by reducing human resources requirements.

CURRENT AIS LEGAL AND INSURANCE ISSUES

Ideally, for effective freeway incident management, vehicles involved in PDO accidents should be moved off the freeway lanes as soon as possible, even before the police arrive, to minimize the adverse effects of the lane blockages. However, interviews with highway and police agencies, insurance companies and an insurance association, an automobile club, lawyers, and judges revealed an obstacle that must be overcome. These agencies, organizations, and individuals reported that a majority of the motorists believe that it is illegal to move their vehicles before the police arrive, even if the distance traveled is a few feet to the shoulder of the roadway. In addition, it was reported that most motorists believe that it is necessary to wait for the police to arrive before moving the vehicles so that the insurance requirements would be satisfied.

Moving a vehicle before a police officer arrives is not normally a violation of the law in most states. In fact, the opposite may be true. Laws in some states explicitly require that vehicles involved in noninjury (PDO) accidents be moved so that the stopped vehicles will not interfere with traffic on the traveled way. In contrast, traffic laws in other states are not explicit on the issue. An assistant attorney general in Texas stated that because PDO accidents seldom go to trial, there is no reason for not moving minor accidents from the roadway before the police arrive. However, misperceptions about legal and insurance requirements and the specific requirements of several private and public fleet operators cause motorists involved in PDO accidents to take actions that are in conflict with freeway incident management objectives.

This section summarizes the legal and insurance issues that affect (a) motorists' moving their vehicles off the travelway before the police arrive, and (b) motorists' moving the vehicles to an AIS to conduct the accident investigation and to complete the necessary accident forms. The conflicts that result from the policies of private and public fleet operators and from insurance company instructions are also discussed.

Traffic Laws and Ordinances

Most states and municipalities use the *Uniform Vehicle Code* and the *Model Traffic Ordinance* as guides to setting up traffic laws and ordinances (*13, 14*). These publications were prepared and are periodically updated by the National Committee on Uniform Traffic Laws and Ordinances. The *Uniform Vehicle Code* is a set of motor vehicle laws that is supposed to reflect the best local, state, and federal laws and regulations, as judged by the National Committee, and is a guide for states in preparing and updating motor vehicle laws. The *Model Traffic Ordinance* is a companion document that contains a set of motor vehicle ordinances for municipalities. It provides a comprehensive guide or standard for cities and counties to follow in reviewing and revising their traffic ordinances. Section 10-103, "Accidents Involving Damage to Vehicle or Property," of the *Uniform Vehicle Code* addresses the issue of minimizing the adverse effect of accident vehicles to traffic. The section states that

> The driver of any vehicle involved in an accident resulting only in damage to a vehicle or other property which is driven or attended by any person shall immediately stop such vehicle at the scene of such accident or as close as possible, but shall forthwith return to and in every event shall remain at the scene of such accident until he has fulfilled the requirements of [Section] 10-104. *Every such stop shall be made without obstructing traffic more than is necessary* [emphasis added]. Any person failing to stop or comply with said requirements under such circumstances shall be guilty of a misdemeanor and, upon conviction, shall be punished as provided in [Section] 17-101.

The provision that "Every such stop shall be made without obstructing traffic more than is necessary" has been part of the national code since 1934. However, as of 1983, the following 19 jurisdictions did not have the requirement in their codes: Alaska, California, Connecticut, Delaware, Kentucky, Louisiana, Maine, Massachusetts, Missouri, Nebraska, New Hampshire, New York, North Carolina, Ohio, South Dakota, Vermont, Washington, Wisconsin, and the District of Columbia (*13, 14*). At least two states, Texas and Georgia, expand on the requirement to minimize the adverse effects of accidents on traffic flow.

Texas is the only state that specifically addresses the use of AISs (*13*). The *Texas Motor Vehicle Laws* specifies the following provision for PDO accidents (*15*):

> ...when an accident occurs on a mainlane, ramp, shoulder, median, or adjacent area of a freeway in a metropolitan area and each vehicle involved can be normally and safely driven, each driver shall move his vehicle as soon as possible off the freeway main lanes, ramps, shoulders, medians, and adjacent areas to designated accident investigation site, if available, a location on the frontage road, the nearest suitable cross street, or other suitable location to complete the requirements of Section 40, so as to minimize interference with the freeway traffic. Any person failing to stop or comply with said requirements under such circumstances shall be guilty of a misdemeanor.

"Metropolitan area" is defined as "an area that contains at least one city with a population of one hundred thousand (100,000) or more, according to latest federal census, and includes the adjacent incorporated cities and unincorporated urban districts."

Georgia adopted a law stating that when accidents occur on expressways in metropolitan areas, drivers or occupants with licenses must remove the vehicles from the roadway into a safe refuge on the shoulder, emergency lane, or median when the vehicle can be normally and safely driven without further damage or hazard. A person who moves a vehicle in compliance with this law is not regarded as being at fault merely because he moved it (*15*).

Large cities have also taken measures to reduce the impact of accident vehicles on freeways. For example, Houston enacted an ordinance in 1978 because (*16*) "vehicles left standing or parked on main-travelled portions of freeways constitute a grave and undue hazard to the travelling public and impede the flow of traffic." The ordinance, in part, reads (*16*):

> ... Any commissioned police officer of the City is hereby authorized to remove, or cause to be removed any vehicle: (1) parked or standing in or on any portion of a main-travelled lane or ramp of any freeway within the city limits...

Such ordinances give the police added, written authority to take actions necessary to minimize the adverse impacts of disabled vehicles on the main lanes.

Removing Vehicles: An Old Problem

In spite of the laws on removing vehicles from freeway lanes, observations indicate that many drivers wait until police officers arrive at the scene before moving their vehicles. This problem is not new to freeway operators.

In the early 1960s, Lynch and Keese (*17*), concerned that most drivers did not remove their vehicles from the freeway lanes after an accident, contacted various police departments. In the survey of 33 cities throughout the nation, 27 reported having no ordinance prohibiting a driver from removing a damaged vehicle from the freeway traffic lane before the police arrived.

Lynch and Keese then asked accident investigating officers of four Texas city police departments to furnish information on all freeway accidents for the following questions:

- Did the operator drive the vehicle to the freeway shoulder after the accident but before the police arrived?
- Could the operator have driven to the freeway shoulder after the accident but did not?

The results revealed that in the cities that did not require the vehicles to remain in place before investigators arrived, 50 percent of those vehicles able to move remained in place. Reasons given by the drivers were usually either fear of violation of law or possible loss of insurance claims.

From all indications, the drivers were not fully educated about what action they could or should take. In view of the results of the more recent interviews for the study reported in this paper, the problem has not changed in more than 25 years. Therefore encouraging motorists to move their vehicles off the travelway before the police arrive is a formidable challenge.

Fleet Operators

Government Agency and Private Company Policies and Procedures

Government agency and private company policies and procedures for operating their own fleet vehicles are often counterproductive to both the AIS concept and efficient traffic management. Therefore government and private policies and procedures should be evaluated at the local level, and measures should be taken to change them if conflicts exist.

For example, the policies of several cities and states specify that government fleet vehicles involved in accidents should not be moved before an on-site investigation and report conducted and prepared by the police. Some states require that the investigation be conducted by the state police and not by the local police. The policies do not actually discourage employees from using AISs, but they require that employees leave the vehicles on the roadway for extended periods of time until the police arrive. Another example of government conflict with FIM objectives can be found in local or state police fleet vehicle policies. Many police departments require a department representative to photograph or videotape the police vehicles involved in accidents before the vehicles are removed from the travelway.

Reporting procedures required by private companies with fleet vehicles are usually more stringent than the local and state motor vehicle laws. The reasons for these extensive procedures are to protect the organization in case of legal action, to be accountable to the taxpayers or owners of the organization in the use of the equipment, and to provide a measure of employee or departmental performance.

The public welfare would be better served if government agencies and private companies were encouraged to amend their accident reporting procedures by requesting their employees to remove vehicles involved in PDO accidents from the travelway as quickly as possible. In particular, governmental agencies that are responsible for the safe operation of streets and highways should have fleet vehicle accident procedures that are consistent with efficient traffic management objectives.

Government Agency Accident Reporting Information Guides

Most state and city agencies place brochures or checklists in fleet vehicles to remind their employees of the procedures to follow after an accident. Procedures can also be found in departmental or employee office handbooks. However, information from selected states and cities reviewed by the research team indicates that state and city agencies are not explicit enough about moving fleet vehicles involved in PDO accidents from the freeway lanes before the police arrive. Information guides do little to encourage employees to move their vehicles. In fact, the brochures and checklists from some states and cities—even those with state or city codes that require removal—appear to suggest that the vehicles should be left on the freeway until the police arrive. Consequently, many state and city employees—like the average driver—are not aware that they might need to move the vehicles off the lanes. The government representatives interviewed by the research team thought that most government employees would leave their vehicles on the main lanes until the police arrived.

City and state agency brochures, checklists, and handbooks should be examined and revised, if necessary, to ensure that employees have explicit instructions about the removal of vehicles from the travelway. In addition, information concerning the use of AISs should also be incorporated into the procedures.

Insurance Agencies

Insurance Agency Policies

Representatives from three insurance agencies interviewed by the research team agreed that most motorists believe that they should not remove their vehicles from the travelway until the police arrive, regardless of the type of accident. They also said that no insurance company policies would be violated if a policy holder's vehicle that had been involved in a PDO accident were removed from the freeway to an AIS before the police arrived.

Insurance Company Advice and Printed Information

Although each insurance agency interviewed stated that no insurance company policies would be violated by the removal of a policy holder's vehicle to an AIS, the insurance companies do little to encourage their policy holders to move their driveable vehicles from the freeway travelway after PDO accidents. Verbal advice is generally contrary to company policy. In addition, the examples of brochures and written instructions furnished to policy holders do not include explicit instructions to remove vehicles from freeway lanes after PDO-type accidents.

The primary obstacles appear to be the high priority placed in the written instructions on contacting the appropriate police agency and the high priority that drivers give to avoidance of accepting fault for the accident, which is thought to be a consequence of removing the vehicle without authorization from the investigating police officer. In response to questions about how insurance adjusters view the use of an AIS (removal of a vehicle) before an investigation and report by a police officer, the general opinion was that the best procedure is not to move the vehicle because moving the vehicle can have an adverse effect on the outcome of adjustments.

Insurance agencies appear to be most protective concerning the welfare and optimum protection against possible fault (responsibility) of their insured. This is only natural because of the potential problems of payment of damages and resulting insurance rate increases for policy holders. One concern expressed by insurance agency representatives that may be an underlying cause for caution in use of an AIS is the indefinite description of criteria or clear definition of what type of accident involves property damage only, which is the type of accident to which the AIS concept applies. It may be difficult for a motorist to rationally define or assess a PDO accident without assuming great risk (fault or possible lawsuit) if there is an injury that is not apparent to those involved in making the decision to remove a vehicle from a freeway lane.

Police Response to Accidents

Because of other pressing priorities, police agencies are changing their modus operandi for accident response and investigation. These changes can have both positive and negative effects on the implementation and use of AISs. Police in many large cities, for example, do not issue tickets for PDO accidents, but they do issue citations for no driver's license or no insurance card. Also, many state and city police agencies no longer respond to most PDO accidents, particularly during emergency conditions (e.g., severe inclement weather). For example, of six large cities in Texas, only one police department (San Antonio) responds to all PDO accidents.

In March 1986, the city of Austin joined Beaumont, Dallas, and Fort Worth in establishing policies to limit their response to accidents involving injuries or vehicles requiring special assistance. The intent was to allow police to concentrate on crimes against people and serious collisions. In 1985, Austin had more than 33,000 collisions. Police who responded to accidents involving minor damage and no injuries spent a minimum of 30 min taking information and writing a report (*18*). Austin police officers are dispatched to collisions to check for proper licenses, injuries, or criminal violations. If an officer finds no injuries or criminal violations, the drivers are given the "blue form" to fill out. The drivers must mail their reports to the Department of Public Safety.

The trend toward eliminating police response to PDO accidents and non-issuance of traffic violations after an accident reinforces the need to encourage motorists to move their vehicles off the freeway lanes and in particular, off the freeway to AISs when these facilities exist.

Initial Accident Information Collection Before Vehicle Removal

Some of the law enforcement officers interviewed expressed concern that encouraging motorists to move their vehicles to an

AIS before the police arrive may give some motorists greater opportunities to leave the area completely instead of moving to an AIS. Some law enforcement officers fear that AISs may increase the already high frequency of hit-and-run accidents. For example, of the 22,095 accidents that occurred in Fort Worth during 1985, 4,203 (25 percent) were hit-and-run.

To minimize the potential for hit-and-run situations, motorists could be instructed to exchange some basic information before moving the vehicles off the freeway lanes. Basic information (e.g., names, addresses, telephone numbers, license plate numbers, insurance companies, etc.) could be exchanged within a few minutes before moving the vehicles to an AIS. Instructions advising this initial information exchange could be made available through the media and through the materials distributed to motorists by state motor vehicle agencies and insurance companies.

Additional Accident Information Collection After Removal to AIS

More complete information can be exchanged and collected at the AIS, when the drivers and vehicles are not exposed to traffic. This includes information necessary for accident forms and insurance purposes.

Opinions of Judge, Attorney, and Police

In the opinions of a chief justice of a district supreme court of appeals, an assistant state attorney general, and police in New York, Texas, and Virginia (all interviewed by the research team), there are no legal or insurance requirements that prevent the movement of vehicles involved in PDO accidents from the travelway to a shoulder or to an AIS location, even if the vehicles must be pushed off the lanes. All the information for purposes of establishing traffic violations can be obtained after the vehicles are moved from the freeway. Police from one city stated that most freeway accidents during the peak hours are rear-end type, and violations are not that difficult to determine in most cases.

Insurance Agency Opinions

The three insurance agencies interviewed said that for PDO accidents, all the necessary information for insurance purposes can be obtained *after* the accident vehicles are moved from the freeway and that no insurance company policies are violated by removing the vehicles before police arrive at the scene. They added, however, that it would be a good practice for motorists to exchange basic information before the vehicles are moved off the freeway.

Effect of PDO Accident Severity on Removal

After PDO accidents, if the involved vehicles can be driven, the vehicles should be moved to the shoulder or an AIS as soon as possible to minimize the adverse safety and congestion impacts of the other motorists on the freeway. A major PDO accident may prevent one or more vehicles from moving under its own power, and therefore the motorists must wait for a push or for towing assistance.

Vehicle Pushing by Police or Highway Agency

A city's operations, according to the state assistant attorney general interviewed, can be classified into two basic functions: governmental and proprietary. These functions can be further classified into the following:

Governmental

- Police
- Fire
- Traffic control

Proprietary

- Street construction
- Maintenance
- Water treatment and so on

A city would not be held liable for damages caused by functions that are classified as governmental. According to the state assistant attorney general, if the city performed the act of pushing a vehicle from the roadway, even with a police vehicle with special bumpers, this could be judged to be a proprietary function, and the city could be liable for damages caused by the removal of the vehicle (legal reference: Shilling vs. the City of Houston). Also, for PDO accidents, there are no legal or insurance requirements that prevent the motorists from being pushed from the travelway to a shoulder or to an AIS location. If further damage or injury results from the action of being pushed, there is a question of liability. This could be construed as a proprietary function, and the person or agency involved in the clearance procedure may be liable.

Police interviewed from six jurisdictions in New York, Texas, and Virginia said that there have been no specific legal problems as a result of pushing disabled vehicles off the freeway travelway with special push bumpers. The gain in reduced motorist delay and increased safety by removing the disabled vehicles off the travelway, according to the police, far outweighs any potential damage that may be caused to a vehicle while it is being pushed. However, the city attorney interviewed in a large Midwest city said that the city has no vehicles equipped to push disabled vehicles and has no intention of pushing disabled vehicles because of liability elements.

Removal Methodology and Towing Fees

Perhaps the most critical issue about private enterprise that concerned the insurance agencies, judges, attorneys, transportation officials, and private fleet operators interviewed was related to towing. The primary concern was towing fees. If a vehicle is to be towed from the freeway to an AIS, the intermediate stop by a wrecker at an AIS may be perceived as the end of one tow, and moving the vehicle from the AIS to an automobile service center may be thought of as a second tow with an additional charge. The questions that must be resolved deal with the amount and payment of what is potentially two tows and with the waiting time involved at the AIS.

Procedures and pay schedules may also need to be evaluated to account for the additional time required by wrecker operators to wait for the drivers, police, or both to complete their discussions, investigations, and reports at the AISs before towing vehicles to a service center.

Fleet operators, both public and private, and automobile club members may have their own agreements with tow truck operators for on-call service. These agreements may complicate the procedures for towing and would need to be evaluated when local towing ordinances are being developed.

The importance of good wrecker service in metropolitan areas is well recognized. One major city, for example, indicated that 38 percent of all reported accidents require a wrecker. Most people interviewed agreed that private enterprise should handle the towing service. However, city codes to regulate towing services must be developed and enforced.

AIS IMPLEMENTATION

The AIS concept is applicable to a variety of traffic management system strategies in metropolitan areas. Traffic management strategies can range from very basic low-cost systems to sophisticated electronic traffic surveillance and control systems. The important thing to consider is that use of AISs in all cases will reduce both the time that incidents are blocking lanes on the freeway and the time that vehicles and motorists involved in accidents are in the view of freeway motorists. Thus the normal adverse effects of freeway accidents on congestion, delay, energy consumption, air pollution, and so on can be minimized.

Three broad categories of situations in which AISs might be implemented are as follows:

- No electronic freeway surveillance and control traffic management system exists, but AISs can be implemented. Examples in Texas include Houston, San Antonio, Beaumont, and El Paso.
- An agency is planning to implement an electronic freeway surveillance and control traffic management system, and AISs can be included as part of the overall system. An example is Fort Worth, Texas.
- There are already urban freeway networks that have operating electronic surveillance and control traffic management systems. In these cases, AISs could be added to the existing systems. Examples include Chicago, Illinois; Dallas, Texas; Denver, Colorado; Detroit, Michigan; Long Island (the Integrated Motorists' Information System) in New York; Los Angeles, California; Minneapolis, Minnesota; the New Jersey Turnpike; Tampa, Florida; San Diego, California; Seattle, Washington; and Northern Virginia.

It would be desirable for the AIS system to be installed and operated as part of a citywide freeway incident management program involving traffic engineers and law enforcement personnel. Without an incident management program, the AIS emphasis could become a "one-shot" effort that is forgotten as personnel change and everyone gets involved in other activities.

ACKNOWLEDGMENTS

This research was conducted as part of a FHWA-sponsored project, "Promotional Issues Related to Off-Site Accident Investigation." Gratitude is expressed to Merton J. Rosenbaum, Jr., who served as the FHWA contracting officer technical representative. The authors also thank the many individuals and organizations interviewed for their time and for the information that they provided for this research project.

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Location, Design, and Operation of Accident Investigation Sites in Urban Freeway Corridors

CONRAD L. DUDEK, W. R. MCCASLAND, AND E. NELS BURNS

In this paper, current recommendations for locating, designing, and operating Accident Investigation Sites (AISs) in urban freeway corridors are summarized. The recommendations are based on (a) interviews with freeway corridor traffic management teams in Texas who have had experience with AISs and (b) experiences of the authors. Some of the guidelines can be summarized as follows: The AIS locations must be easily accessible from the freeway. The most desirable location is within one block of the freeway exit ramp terminals. Because the freeway patrol officers are essential to a successful system, local police should be involved in locating and designing AISs. An AIS should be paved, illuminated, have a minimum of 1,000 ft^2, and be equipped with some form of telephone communications system. Police officers must understand and be convinced of the merits of AISs. A public campaign is essential to inform the motoring public about the system. In addition, a formalized process of feedback from the patrol officers concerning any problems with the sites, followed by a reply, action, or both by the highway agency, is important. Although AISs can provide considerable benefits without formalized freeway incident management approaches, it is better to install AISs as part of a citywide freeway incident management program involving traffic engineers and law enforcement personnel.

Accident Investigation Sites (AISs) are specially designated and signed areas off the freeway where damaged vehicles can be moved, motorists can exchange information, and police and motorists can complete the necessary accident forms. These areas are located so that the motorists involved in the accident, investigating police, and tow truck operators are out of view of freeway drivers. This reduces "rubbernecking," which is a major cause of congestion at a freeway accident scene.

General guidelines for the design of AISs were presented in 1972 by Pittman and Loutzenhieser of the Texas Transportation Institute (*1*). In this paper, current recommendations for the design and operation of AISs are summarized. These recommendations are based on interviews with freeway corridor traffic management teams in Texas who have had experience with designing, implementing, and operating AISs and on the experiences of the authors (*2*). Promotional issues related to AISs are discussed elsewhere (see companion paper by Dudek et al. in this Record).

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AIS LOCATION AND DESIGN

Access and Distance

AIS locations must be easily accessible from the freeway. There must be a minimum number of turns and distance to travel after leaving the freeway. The most desirable location is within one block of the freeway exit ramp terminals.

Location Alternatives

The following four alternatives for locations of AISs have been used:

- Alternative 1: Specially constructed sites on the freeway right-of-way out of the view of freeway traffic. These sites may be located under bridge structures (Figure 1) or in the outer separation of the freeway.

FIGURE 1 AIS under bridge structure.

- Alternative 2: Specially constructed sites between the frontage road and the right-of-way line.
- Alternative 3: Existing parking facilities on private commercial property abutting the freeway right-of-way (Figure 2).
- Alternative 4: Public curb parking spaces on local streets (Figure 3) or frontage roads in the vicinity of the freeway.

FIGURE 2 AIS on private commercial property.

FIGURE 3 AIS on city street.

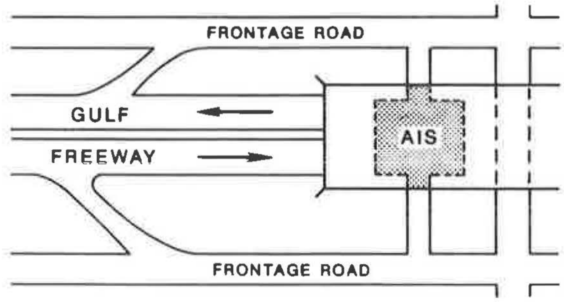

FIGURE 4 AIS under overpass.

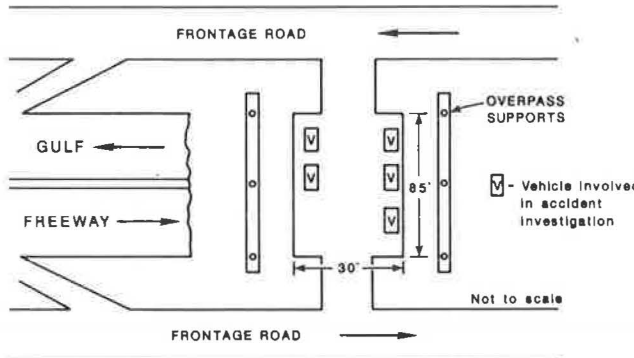

FIGURE 5 AIS schematic.

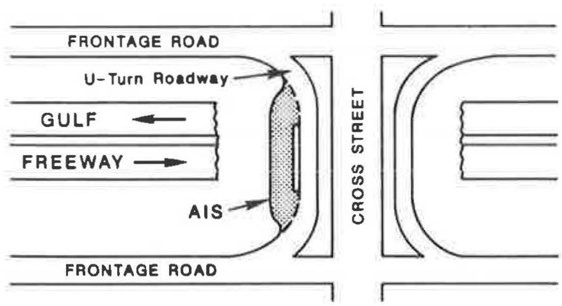

FIGURE 6 AIS combined with U-turn roadway.

As examples, the location and layout for a site out of view of freeway motorists that was constructed in Houston on the Gulf Freeway right-of-way are presented in Figures 4 and 5. The access to the site and the drainage are simplified with this design, and the 85 × 30–ft (26 × 9–m) parking area is more than adequate. An innovative design that combines an AIS with a U-turn lane constructed under a bridge structure is shown in Figure 6.

The advantages of locating AISs in the outer separation of the freeway are that there is direct access from the main lanes (and the frontage roads, when available) and the potential locations are not dependent on the location of the exit ramps. When AISs are located in the outer separation, they should be shielded by some type of screen to keep the accident and emergency vehicles out of sight of freeway motorists. The screens can be constructed of natural or artificial materials. A disadvantage of using the outer separation is that the sites may not provide as much protection from traffic as the other, alternative locations, but the outer separations offer benefits over the normal shoulders for accident investigation. In addition, representatives of one state noted a potential problem with using screens to hide accident vehicles: the AISs could be very susceptible to collecting debris.

Alternative locations 2, 3, and 4 may not always be completely out of sight of freeway traffic. Even if they are visible, however, the disruption factor is significantly reduced when the accident scene is removed by some 50–100 ft (15.2–30.5 m) from the traveled lanes.

The need for cooperation with local jurisdictions and private property owners during installation and operation of AISs cannot be overemphasized. It is rare that all AISs can be located on state- or city-owned right-of-way.

Police Involvement in Site Location and Design

Because the freeway patrol officers are essential to a successful system, local police should be involved in locating and designing AISs. Because of their intimate knowledge of the freeway corridor and their experience with accident investigations, the patrol officers are in the best position to help select locations that will optimize the use of AISs. Police inputs to design will enable the highway agencies to include features that will also enhance the probability of AIS usage.

AIS System Continuity

Because of the experimental nature of previous AIS systems, AISs previously were installed on only a small segment of the metropolitan freeway system of the cities in which they were implemented. Experience has indicated that although AISs are beneficial, an incomplete system can sometimes have an adverse effect on the use of AISs by motorists. Having an accident on a freeway, let alone on a given section of freeway in which AISs may be located, is a rare event for most motorists, and therefore motorists may not have too many opportunities to use AISs. Thus motorists are inclined to forget about the existence of the AISs that are located on a small segment of the freeway system.

Installing a complete system of AISs throughout a metropolitan area within a relatively short time frame may not always be possible because of constraints such as funding. However, it may be possible to install AISs selectively along the freeway sections in which accident frequencies are the highest. Frequent advertisements and public information announcements are necessary in these cases, in addition to the normal AIS signing along the freeway to remind motorists of the specific segments of the freeways on which AISs are located.

Size

An AIS should have space for parking a minimum of five vehicles (one police car, two damaged vehicles, and two wreckers). Additional space is desirable to accommodate multivehicle accidents and additional wreckers, but provisions can be made for emergency parking on streets for these situations. Therefore a typical specially constructed site or private parking area (off street) should have a minimum of 1,000 ft^2 (304.8 m^2) of parking space, and curb parking sites should be a minimum of 100 ft (30.5 m) in length.

Signing and Marking

Signs can be placed on the freeway ahead of the exit ramp (Figure 7) and on the frontage roads (Figure 8) and local streets (Figure 9) as required to guide drivers to the AISs. These signs also serve as reminders to the public and police of the AIS system. The sites should be identified on the signs by a number. "No Parking" signs should also be placed at the sites to lessen the misuse of the sites as parking areas. Supplemental pavement markings may be required on private parking areas and curb parking.

FIGURE 7 AIS signing on freeway.

FIGURE 8 AIS signing on frontage road.

Communications from AISs

If motorists are to use the AIS system before an accident investigator arrives, some form of telephone communications must be provided. For the sites within the freeway right-of-way, a dedicated telephone system to the police dispatcher's office should be provided (Figure 10). On the private parking areas or local streets, public telephones may be provided within walking distance of the site. Public telephones could also be provided at the sites on the freeway right-of-way to allow motorists to contact other sources of help or to make personal or business calls.

FIGURE 9 AIS signing on local street.

FIGURE 10 Telephone to police dispatcher.

Security

Concern for the personal safety of motorists who use the out-of-the-way parking areas must be considered in the design and location of the sites. High-risk areas should be avoided if possible. The sites should have paved surfaces and good illumination for night usage. Street lights and telephones promote safety. Other techniques that can be used to improve security are as follows:

- Have the sites checked regularly by police, highway maintenance crews, and emergency service crews.
- Park emergency and maintenance vehicles in or near the sites when they are not on patrol or in service (e.g., during lunch).
- Place the sites near locations that will have high volumes of vehicle and pedestrian traffic (e.g., near a bus stop).

OPERATION

Selling the Concept to Individual Police Officers

One of the first steps to ensure successful use of AISs is to make sure individual police officers understand the benefits of AISs and will support the use of the AIS system. Accident investigation is not a favored function of many police departments. Some police officers complain that it consumes substantial time and human resources in the field and in the courtroom. Positive efforts by highway and police supervisors are essential in overcoming a problem that exists with some accident investigators. These investigators prefer to complete reports at or near the scene of the accident because they believe that this reduces the time needed to complete the paperwork and enhances the accuracy of the report and possible court testimony. Positive efforts are also necessary to overcome some investigators' preferences to move several vehicles to the shoulder of the freeway instead of to a site several hundred feet off the freeway. These officers believe that it is more hazardous to lead a platoon of vehicles from the freeway than it is to conduct the investigation adjacent to a lane of moving traffic. The operations agency must change these attitudes if the AIS system is to be successful.

Formalized Instruction and Information

To obtain high AIS usage rates, the freeway police patrols and accident investigation units must be convinced of the merits of the AIS system and provided with

- A description of the AIS system and instructions on how and when to use the sites,
- A map of AIS locations and a description of the use of the sites (short forms could also be made available for distribution to motorists involved in accidents), and
- A procedure for monitoring the use of the AIS system.

Public Information

As previously noted, information concerning the location and use of AISs must be given to the motoring public. All sources of information transfer should be used (e.g., radio, television, newspaper, etc.). In addition to special brochures for distribution to the public, press release packages should be prepared for the media so that they have all the information necessary for dissemination to the public via all media modes. Motorists and media must be made aware of the AIS system during the early phases of development (i.e., planning and design phases) so that they are able to provide input if necessary. Motorists must be reminded of the AIS system periodically so that they become familiar with the locations of the sites and so that they have appropriate expectations about the use of the sites and the overall improvements to freeway traffic. This news release, which was used in Houston, Texas, is an example of the kind of media communication that might be used:

> The Texas Highway Department in cooperation with the City of Houston Police Department and the Department of Traffic

> and Transportation recently constructed 16 sites along a section of the Gulf Freeway for accident investigation purposes. These sites, constructed along the freeway between Dowling Street and Broadway Boulevard, are to be placed into operation by the Houston Police Department on Monday, June 12, 1971.
>
> Studies conducted by the Texas Transportation Institute and the Highway Department have indicated that an average minor accident on Freeways directly affects traffic for some 41 minutes. The removal of an accident to a location out of view of the freeway would have the net effect of screening the accident and removing the "gapers block" for an average of 25 minutes. This in turn would result in renewed flow on the freeway and reduced secondary collisions.
>
> The Police Department advises that motorists involved in minor accidents where their cars are driveable should move to one of these sites before calling the police. The sites, accessible from the frontage roads, are marked by blue signs and are constructed under grade separations or on existing city streets.
>
> By quick removal of the accident to these sites, traffic flow along the freeway can recover, minimizing the usual stop-and-go operation on the freeway.
>
> The City of Houston and the Texas Highway Department solicit your cooperation in the use of these sites. The sites, now termed experimental, will become permanent and expanded if good results are obtained.

A videotape demonstrating the intended use of the AISs would also be helpful in enhancing public understanding and encouraging motorists to use the sites.

Monitoring and Feedback

The chances are that in spite of careful planning and the direct involvement of the police in designing and locating the AISs, certain sites or site characteristics may be found to be less than acceptable after a period of use. A formalized process of feedback from the patrol officers about any problems with the sites, followed by a reply, action, or both from the highway agency, is very important if the sites are to be regularly used by the police investigators.

To determine the effectiveness and benefits of the AIS systems, information on the frequency and usage rate of the sites is needed. The police officers who respond to accident scenes are the best source for this information. Although police in general and accident investigators in particular are opposed to any additional paperwork, a brief form can be devised that should take no more than 2 or 3 min to complete. The form used for the Houston Surveillance Project is shown in Figure 11. It is important that each patrol vehicle be supplied with the forms. These forms may be combined with the booklet and maps that are provided to the police to explain the location and use of the AIS system.

The completed forms should be collected by the AIS manager at frequent intervals and the results reviewed with the supervisor of the traffic investigation section. To obtain information on the rate of usage, the number of total accidents in the same area as the AIS must be obtained. For those systems that attempt to get the motorists to move voluntarily from the freeway to the AIS before notifying the police, the remarks

Complete For ALL accidents Investigated On Freeways

1. Freeway (name)____________________

2. Date__________ Time ________ AM___ PM___

3. Accident Investigation Site No. __________ (if used)

4. Approximate Location of Accident: Block No. ________

5. Location of Investigation

   ___ Shoulder   ___ Accident Investigation Site

   ___ Frontage Road   ___ Median

   ___ City Street   ___ Other ________

6. In View of Traffic?

   ___ Yes   ___ No

7. How Long Did Investigation Take?

   _____ Minutes

8. Remarks ____________________

Signed ____________

Investigating Officer

FIGURE 11 Houston Police Department supplemental freeway accident report form.

section should include the motorists' reasons for moving or not moving to the AIS system.

These forms will also be helpful in monitoring the operations of the police investigators and determining their reasons for not using the AIS system. The most common reasons cited by the field investigators are as follows:

- The length of investigation was too short to justify moving the vehicles.
- Because of the prevailing conditions, the officer determined that the investigation could be conducted more safely adjacent to the freeway main lanes.
- The accident investigator forgot about the AIS system or did not know where the nearest site was located.

Most of these reasons can and should be answered by the supervisor of the accident investigators. First, no investigation should be so short that it should not be removed from the freeway and freeway shoulder as soon as possible. Second, the AIS system's major advantage is that it puts the officer and motorists into a situation that is safer than remaining in the area adjacent to the moving lanes of a freeway. Third, the purposes of the signs, bulletins, and maps are to remind the police of the location of the sites. Frequent reminders to new and old investigators could be provided in various forms.

An alternative to having a special short form for recording AIS usage would be to include statements on the potential use of an AIS site on the normal accident report form. If the report form can be modified to include a specific question concerning AIS usage, this would provide a constant reminder to the investigator of the system. In the absence of a modified form, investigators could be told to include the required information on use or nonuse of the AIS system in the remarks section for location of the accident. This second approach will not be as successful as the use of the special form because it does not immediately call attention to the need for using the AIS system.

A third method for monitoring the use of the AIS system would be to use personal contacts with the officers involved with accident investigation and to use an interview method at frequent intervals to obtain the information. This is obviously less desirable for several reasons, but often it is the only method to get information.

If motorists are to be induced to use the AIS system before the police investigator arrives, they must be informed of the system's existence and the actions that they should take. The administrators of most of the projects issue news releases when the systems are first opened. However, project personnel frequently fail to follow up with subsequent public relations actions to remind the public of the use and benefits of the AIS system.

Freeway Incident Management

AISs can provide considerable benefits even without formalized freeway incident management approaches. Significant benefits in reduced delays and increased safety can be gained merely by having the AISs available for accident investigations. Sophisticated electronic surveillance systems are not required for a jurisdiction to benefit significantly from AISs.

However, the primary consideration in reducing the congestion and safety impacts of accidents and other incidents is to remove the involved vehicles from the freeway lanes as soon as possible and to move them out of sight of freeway motorists. Consequently, one issue is to encourage motorists involved in PDO accidents to move their vehicles off the freeway as quickly as possible instead of waiting for the police to arrive before the vehicles are removed. Ideally, the vehicles should be moved to AISs. If efforts to encourage motorists to move off the freeway lanes are unsuccessful, then surveillance approaches to detect incidents may be necessary to reduce the delays and safety problems associated with PDO accidents on freeways.

Surveillance systems are effective in detecting accidents and other incidents rapidly. This rapid detection reduces the overall adverse effects of these incidents because police and other emergency vehicles can be dispatched to the incident scene promptly. There are a number of surveillance options that can be used to detect accidents and incidents. These can be used either individually or in combination, each with different degrees of cost and effectiveness (*3*). The key issue to be considered is the time that it would take to detect accidents by using one or more of the surveillance techniques. The options are as follows (*4*):

- *Increased Police Patrol Frequency:* Increasing the number of patrolling vehicles during periods when an incident would cause significant delay.
- *Peak Period Motorcycle Patrol:* As the previous option but using motorcycles (which have greater mobility than patrol cars for traveling through congestion) to obtain the additional patrol frequency during peak periods.
- *CB Radio Monitoring:* Capturing the freeway incident information by monitoring the CB radio and ensuring that the information obtained is forwarded to the proper response service.
- *Service Patrol:* Increasing the existing patrol frequency with publicly or privately operated service vehicle patrols or tow trucks.
- *Stationary Response Vehicle:* Strategically placing response vehicles, such as tow trucks, along the freeway at vantage points so that the driver can detect incidents and respond immediately.
- *Aircraft:* Using public (police) or private (radio station) aircraft to patrol and detect incidents.
- *Call Boxes:* Installing roadside communication devices that motorists can use to alert the proper authority that an incident has occurred and that a response is required. Two systems are available: coded push-button or two-way voice. The two-way voice systems (special telephones or commercial telephones) have proven to be more effective than the push-button systems.
- *Closed Circuit Television (CCTV):* Using CCTV to detect incidents. This is considered a low-cost FIM technique only on bridges, in tunnels, or at high-accident locations.
- *Loop Detectors:* Employing sensors buried in the roadway to detect incidents. These sensors are usually installed as part of a more sophisticated electronic surveillance and control system.
- *Volunteer Observers:* Using individuals at vantage points to detect incidents in critical locations and to report to the appropriate agency.
- *Cellular Telephones:* Urban areas with the 911 emergency number system can promote use (without charge to individual motorists) of the mobile telephones.

It would be desirable for the AISs to be installed and operated as part of a citywide freeway incident management program involving traffic engineers and law enforcement personnel. With such a program, the law enforcement personnel will continue to be trained and encouraged to use the AISs. Also, the engineers will keep the AIS system in mind and continually remind and inform the public. Without such a program, the AIS emphasis could be a "one-shot" effort that is forgotten as personnel changes occur and individuals get involved in other activities.

ACKNOWLEDGMENTS

This research was conducted as part of a FHWA-sponsored project, "Promotional Issues Related to Off-Site Accident Investigation." Gratitude is expressed to Merton J. Rosenbaum, Jr., who served as the FHWA Contracting Officer Technical Representative. The authors also thank the many individuals and organizations for the time and information that they provided for this research project.

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Operational and Safety Experience with Freeway HOV Facilities in California

LEONARD NEWMAN, CORNELIUS NUWORSOO, AND ADOLF D. MAY

Highlights of a technical investigation conducted to evaluate various designs of HOV lanes currently in use on freeways in California are presented. Operational efficiency and safety were the measures of effectiveness examined. None of the currently operating facilities was found to contain severe operational or accident problems. All three of the broad design types identified in the state and studied were found to be operating relatively smoothly. Although statistically reliable conclusions could not be made, it did appear that certain designs were better than others. The physically separated facility appears to be the safest type because interaction of HOV lane vehicles and mixed flow vehicles is virtually eliminated. Of the facilities that were not physically separated (which were the primary focus of the study), the wide buffer (full lane width) facility was clearly superior to the contiguous types. The study was unable to differentiate between the various contiguous designs, which were categorized by whether they restrict intermediate access or not.

In this paper, the major findings of a 14-month study aimed at investigating the operational and safety experience of HOV facilities on freeways in California are abstracted. The full report is available from the Institute of Transportation Studies (University of California, Berkeley) on request (*1*). The objectives of the study, which was sponsored by the California Department of Transportation (Caltrans), were to evaluate HOV lane effectiveness in terms of both safety and operational efficiency and to recommend the most appropriate design for specific circumstances.

Although similar facilities nationwide were surveyed in the study, only the pertinent results from an analysis of California facilities are presented in this study. In 1986, there were about 73 directional miles of freeway HOV facilities of various designs operating in California, all in the Los Angeles and San Francisco areas. However, most of these facilities have only been in operation for a short time. It was evident that the available operational data and accident experience were not adequate to provide reliable conclusions on the relative benefits of the various designs under specific operating conditions. Certain conclusions have been drawn, however, on the basis of data obtained in the study, together with the experience and opinions of the project investigators. It is believed that the information presented will be of interest.

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BACKGROUND

In recent years, growth of suburbanization and commuter travel in metropolitan areas has continued to increase at a steady rate, while both the economic and environmental costs of providing highway facilities have been increasing at an even faster rate. There is little chance that enough freeway capacity can be constructed to satisfy traffic demands. Recent emphasis has therefore been on making the existing transportation corridors more efficient in terms of passenger-carrying capacity.

One of the strategies used is high-occupancy vehicle lanes (HOVL). This general term covers transitways, busways, carpool lanes, and so on. Essentially, an HOVL is a facility designated for use by a specific class of vehicles, giving them a time advantage over mixed-flow traffic. Caltrans has been engaged in developing HOV facilities since the early 1970s, and the state is considered a U.S. leader in their use. There are 73 directional miles of freeway HOV lanes in California alone as of 1986, compared to 190 directional miles in seven other states.

Currently, many different designs are being used for freeway main-line HOV lanes. In particular, these designs differ from one another in regard to their separation from mixed flow lanes. The HOVL may be broadly categorized into three design types (Figures 1–4):

- physically separated facilities (8 mi total),
- buffer-separated facilities (13-ft-wide buffers; 11 mi total); and
- essentially contiguous facilities with various types of separation, striping, and access control.

There are 54 mi of this last type of design, with separations varying from a normal lane line to a 2-ft-wide buffer. Striping ranges from broken white stripe through broad (8-in.-wide) solid white stripes to double yellow lines (barrier striping). The double yellow lines are intended to restrict access between the HOV and mixed flow lanes to specified areas only. Table 1 presents a summary of existing freeway HOV facilities in California, including their design characteristics.

As more jurisdictions adopted the HOV concept, the state realized that an evaluation of the design characteristics of existing facilities was necessary. The state also decided that it might be desirable to determine the most effective designs in terms of both operational efficiency and safety, thereby resolving some of the design issues currently being debated within the state. The primary concern was the design of facilities that

FIGURE 1 Physically separated HOVL. Barrier is visible at left center, with westbound HOVL immediately to the right and the eastbound HOVL at far right.

FIGURE 2 HOVL separated from regular lanes by a wide, traversable buffer (center).

FIGURE 3 HOVL separated by double yellow stripe indicating restricted access (stripe visible starting at bottom left).

are not physically separated. The major design issues addressed are as follows:

- Where an HOV lane cannot be physically separated, should it be separated with a traversable buffer or should it be contiguous with the mixed flow lanes?
- Should the HOV facility be operative full time or part time?

FIGURE 4 HOVL with unrestricted access. In this case, the HOVL is marked by signage.

- If the facility is operative part time, how should the lane be used during the nonoperative hours?
- How should the facility start and end?
- How should any intermediate access be provided?
- What provisions for enforcement should be included in the design?

PROCEDURE AND ACCIDENT ANALYSIS

The main portion of the general investigative process was an attempt to relate operational and accident data. The intent was to determine measures of effectiveness of each major design type and then to compare them under identical operating conditions. The comparison was carried out via a matrix. The operating characteristics considered were speed differentials and HOV lane utilization. It was hypothesized that entries in each cell of the matrix belonged to one design, and these entries were treated as a sampling from that design. The cells with identical operating characteristics were then compared to determine whether differences in accident rates were statistically significant.

Two types of accident data were used in the analysis. First, inferences were made about HOV lanes by using accident data from entire freeways. Second, the relative safety levels of different HOV lanes were determined more directly by using data from HOV lane-related accidents.

Peak Freeway Accident Rates

Accident data were obtained and rates calculated for six of the eight HOV facilities currently operating on freeways in California (Table 1). The remaining two facilities were only put into operation very recently. Of the six, Ala 80 (the approach to the Bay Bridge) was considered too unique to be fairly compared with the others. Thus five facilities (LA 10, LA 91, Ora 55, Mrn 101, and SF 280) were put to critical analysis.

The source of the accident data was the state's Traffic Accident Surveillance and Analysis System (TASAS). Accident reporting levels in this system can vary among different areas. Although it is generally accepted that less than half of

TABLE 1 FREEWAY HOV FACILITIES IN CALIFORNIA AS OF 1986

FACILITY(1)	INBOUND MILES	INBOUND OPER HRS	OUTBOUND MILES	OUTBOUND OPER HRS	HOVL/dir	Mix Ln/dir	Type (2)	Sep. (3)	Spd Dif(4)	HOVL Vol (5)	HOV Def	Acc/mvm	% Viol(6)	REMARKS
1a LA I-10 BUSWAY	4.0 WB	24 HR	4.0 EB	24 HR	1	4	C	P	varies from section to sect.	b	3+		highly variable : 5 - 30 %	
1b LA I-10	6.1 WB	24 HR	5.3 EB	24 HR	1	4	C	B		c	3+	0.90		facility has 3 different designs
1c LA I-10	0.7 WB	24 HR	2.5 EB	24 HR	1	4	C	L		c	3+	0.90		
2 LA RTE 91	no facility		8.6 EB	2-7p	1	4	C	L		c	2+	1.05		
3 MRN US 101	3.7 SB	6-9a	3.7 NB	4-7p	1	3	C	L		a	3+	1.06		hrs changed in 1987 to 6:30-8:30am 4:30-7:00pm
4 ORA RTE 55	10.9 SB	24 HR	11.9 NB	24 HR	1	3	C	L		c	2+	1.27		
5 SF I-280	1.9 SB	24 HR	no facility		1	3	C	L		a	3+	0.5		
6 ALA I-80 SFOBB	0.6 WB	6-9a	no facility		3	16	C	L		b	3+			
	WB	3-9p	no facility		3	16	C	L		a	3+	7.72		
7 MRN US 101	no facility		3.0 NB	4-7p	1	3	C	L		–	3+	–		new facility north of San Rafael hrs changed in 1987 to 4:30-7:00pm
8 SCL US 101	2.8 NB	5-9a	3.3 SB	5-9a	1	3	C	L		b	2+	.90		inbound considered towards S.F.
	NB	3-7p	SB	3-7p	1	3	C	L		c	2+	.90		
TOTAL	30.7		42.3											

1. Information is for 1986 conditions
2. Types of HOVL: R=Reversible; C=Concurrent; F=Contra-Flow
3. The separation is between the HOV lanes and mixed flow lanes. forms: P=Physical; B=Buffer; L=Normal Lane Line
4. This is the estimated difference in speeds between HOV and mixed flow vehicles during the peak hour. Categories: 1 = 0-10; 2 = 10-20; 3 = >20 (mph).
5. HOVL Utilization -- 3 groups: a = <500; b = 500-1000; c = >1000 veh.
6. These are approximations and are the % of all vehicles in HOVL that are violators

TABLE 2 MATRIX OF DESIGN TYPES BY OPERATING CONDITIONS

SPEED DIFFERENTIAL	I. < 10 MPH		II. 10-20 MPH		III. > 20 MPH	
HOVL UTILIZATION (PK HR)	LOW (<500)	HIGH (>1000)	LOW (<500)	HIGH (>1000)	LOW (<500)	HIGH (>1000)
S E P A R A T I O N	SEC ACC ! INJ !	SEC ACC INJ	SEC ACC INJ	SEC ACC INJ	SEC ACC INJ	SEC ACC INJ
A) CONTIGUOUS UNRESTRICTED ACCESS	101S-2 1.23 0.50 101N-1 2.50 0.06 280S-1 0.66 0.19 280S-2 1.38 0.57 * AVG = 1.44 ** SD = 0.67	10E-6 2.32 0.91 10W.4 0.93 0.55 55N-1 3.19 1.67 55S-1 0.36 0.18 55S-6 1.00 0.29 55N-6 1.14 0.29 AVG = 1.49 SD = 0.96	101S-1 0.52 0.19 101N-2 5.36 1.57 101N-3 7.13 0.41 AVG = 4.34 SD = 2.79		10E-1 1.85 0.98 10E-2 5.53 1.82 AVG = 3.69 SD = 1.84	
B) CONTIGUOUS RESTRICTED ACCESS		55S-2 1.08 0.39 55S-5 2.08 0.25 91E-1 1.08 0.36 91E-5 2.22 1.03 AVG = 1.62 SD = 0.54		55N-3 4.45 0.75 55N-5 1.44 0.21 55S-4 3.92 0.78 91E-4 1.62 0.45 AVG = 2.86 SD = 1.34		55N-2 8.18 2.37 55N-4 3.48 1.14 55S-3 3.3 0.27 91E-2 2.97 1.15 91E-3 2.3 0.56 AVG = 4.05 SD = 2.11
C) BUFFER		10E-5 2.49 0.91 10W-1 0.49 0.16 AVG = 1.49 SD = 1.00		10E-4 1.42 0.52 10W-2 1.45 0.51 10W-3 1.75 0.20 AVG = 1.54 SD = 0.15		10E-3 1.37 0.36 AVG = 1.37 SD = 0

* AVG = AVERAGE OF TOTAL PEAK PERIOD ACCIDENT RATES
** SD = STANDARD DEVIATION OF SAME
! ACC = PEAK PERIOD TOTAL ACCIDENT RATE
! INJ = PEAK PERIOD INJURY RATE

accidents involving property damage only (PDO) are reported, as many as 90 percent of accidents involving injury are reported. Thus an analysis based on the rate of injury accidents would appear to provide a more accurate perspective of safety conditions than one based on PDO. However, to obtain a reasonable sample size and uniformity in coding, rates were calculated for total accidents (PDOs, injuries, and fatalities) and then separate rates were calculated for injuries. The injury rates were used in cross checking abnormalities or extremities that might become apparent in rates for various facilities.

The physically separated HOV facility was excluded from detailed analysis. The only existing case is a 4-mi section of the San Bernardino Freeway "Busway." This section, which operates 24 hr/day with a 4,000 ADT rate (two-way), had just five recorded accidents in a 4-year period (1983–1986), including one fatal accident.

Each HOV facility was divided into study sections primarily on the basis of differences in design and secondarily on the basis of estimated differences in operating conditions. All the study sections were then grouped by various peak period operating conditions and typical designs. Table 2 is a matrix of the groupings. Three basic designs were used:

- full buffer,
- contiguous (no separation) with unrestricted access and without differentiation as to type of line separation, and

- contiguous with sections of barrier stripe buffer.

The operating conditions were in terms of speed differential and HOVL use. There are 18 possible combinations, or "cells." Unfortunately, there were many cells with no examples, and some with just one or two.

The primary points indicated by the matrix are that when there is no significant speed differential (less than 10 mph), the peak period accident rates were about 1.5 per mvm, regardless of design type. When speed differentials increase, the contiguous design accident rates went up, but the buffer design accident rates stayed the same. Two conclusions may be drawn. The first is that when speed differential is low or nonexistent, the HOV lane design characteristics do not really matter. The second is that the buffer-separated design is likely to be superior to other types, even under varied operating conditions. Consideration of this latter conclusion, however, should include the fact that the buffer-separated facility is used on only one freeway. It is also worth noting that no left shoulder is available in the contiguous designs studied, and thus the total space for evasive action in case of sudden moves is less than on the buffer design. A section of contiguous design with a full left shoulder is currently in operation but has not been active long enough for evaluation.

Figure 5 is a plot of individual study sections against ADT and peak period accident rates. The plot indicates no correlation between the variables: increasing ADT appears to have no impact on peak period accident rates. However, the results generally reflect the same conditions indicated by the matrix. The buffer design sections had low rates and variability in comparison to the other design types. The total peak period accident rate for all I-10 sections, as indicated in the figure, was 1.77 per mvm. If the contiguous sections were not included, then the rate for only the buffer sections would be 1.58 per mvm.

Figure 6 is a plot for weekday peak period injury accidents. The rates are naturally much lower, but the same general pattern is indicated. The injury rate for Ora 55 is 0.63 per mvm. The injury rate for the buffer sections of I-10 alone is 0.52 per mvm. The rate given in the figure for all of I-10 is 0.69 per mvm.

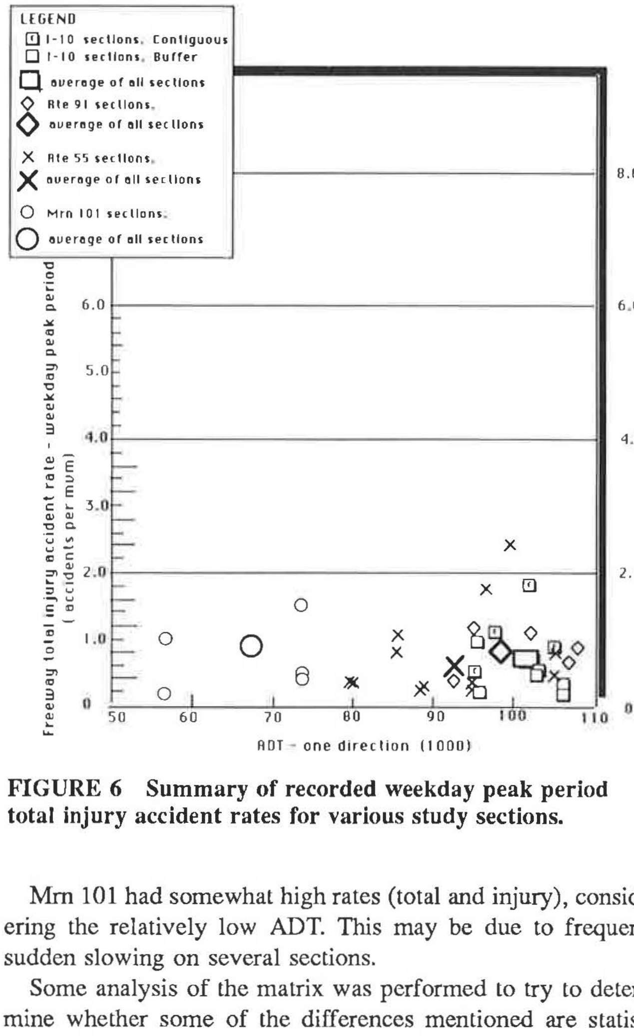

FIGURE 6 Summary of recorded weekday peak period total injury accident rates for various study sections.

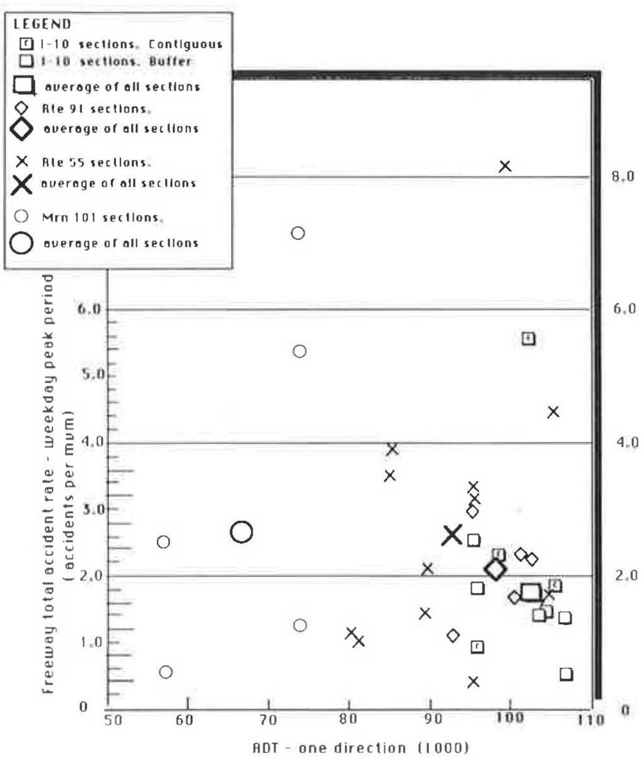

FIGURE 5 Summary of recorded weekday peak period total accident rates for various study sections.

Mrn 101 had somewhat high rates (total and injury), considering the relatively low ADT. This may be due to frequent sudden slowing on several sections.

Some analysis of the matrix was performed to try to determine whether some of the differences mentioned are statistically significant. An analysis of variance was performed as an attempt to compare the mean rates computed for entries within each cell. Because the main concern is the type of design, the tests of significance conducted were directed at groups of cells that are comparable vertically instead of horizontally. Vertically comparable cells are two or more cells with exactly the same operating characteristics but different designs.

Five cells were determined to be comparable. For low speed differential (less than 10 mph) and high HOV lane utilization, all three design types have entries that are comparable. Also, for medium speed differential (10–20 mph) and high HOV lane utilization, the buffer and the restricted designs are comparable. At the 5-percent level, the differences in mean accident rates between various designs are not statistically significant for either total accident or injury rates.

Next, all cells for each type of design were lumped together, and the test was applied between various designs. Analysis of variance indicates that the differences in means between various designs were again not significant for either total accident rates or injury rates. These results are interesting for two reasons. First, on the basis of available data, one result confirms an earlier opinion, that contiguous HOV lanes were basically the same in safety and effectiveness irrespective of limitations placed or not placed on intermediate access. Second, the results (on the basis of available data) could not indicate conclusively that a wide buffer–separated facility is superior to the contiguous types.

Off-Peak Period Freeway Accident Rates

One of the design issues considered in this study is how the facility should be used during off-peak periods. There is considerable pressure to use the lanes during off-peaks for mixed flow traffic. For barrier- or buffer-separated designs, this type of use would be difficult operationally, although it is easy for contiguous designs. In both cases, signing is even more complicated.

At locations where HOV facilities operate 24 hr/day, there is usually no significant speed differential and no significant congestion in any of the lanes during off-peak periods. However, from a safety viewpoint there is still a question about what type of operation will provide the best level of safety. Caltrans has already gathered a large amount of data indicating that, for a given ADT, the greater the number of lanes (and thus the lower the densities), the lower the accident rate.

In this study, the related data are limited in this regard. Figure 7 is a plot of off-peak accident rates related to 24-hr ADT for the various study sites. Mrn 101, LA 91, and LA 10 all have average accident rates of roughly 0.75 per mvm. During off-peak periods, each of these freeways has four mixed lanes and, in the case of LA 10, one HOVL (with approximately 4,000 ADT). ADT per mixed lane varies from about 17,000 (Mrn 101) to 24,000 (LA 91 and LA 10).

Ora 55 has an average off-peak accident rate of slightly over 1.0 per mvm. This section has three mixed lanes plus an HOVL (with 10,000 ADT). The mixed lanes averaged about 27,000 ADT per lane. If the HOVL were opened to mixed traffic during off-peak periods, the average would be about 23,000 per lane, with a likelihood of reduced accident rates.

HOV Lane–Related Accidents

For each of the study locations, all accident reports were examined for varying periods, and any accident that appeared to involve HOVL operation or design was read and summarized. In a few cases, certain individual accidents that were not considered to have any bearing on HOV design or operation were not selected.

The predominant type of accident was multivehicle and involved or was caused by a vehicle entering or exiting the HOVL. The movement could be voluntary, involuntary, legal, or illegal. It is possible that other accidents noted as "rearenders" in the HOVL or lane 1 (the lane next to the HOVL) could have actually been caused by vehicles entering or exiting the HOVL, causing a queue that ultimately caused the rearender.

Figure 8 plots the peak period accident frequency involving vehicles entering or exiting the HOVL at different locations

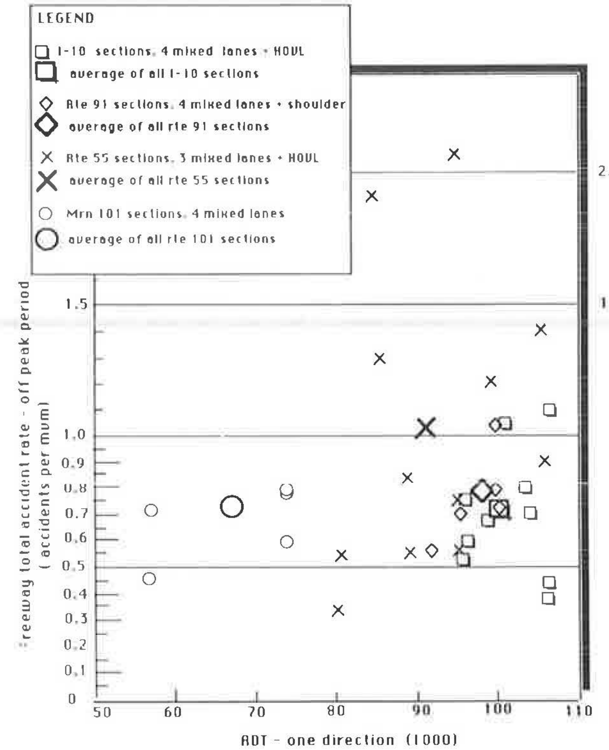

FIGURE 7 Summary of recorded off-peak total accident rates for various study sections.

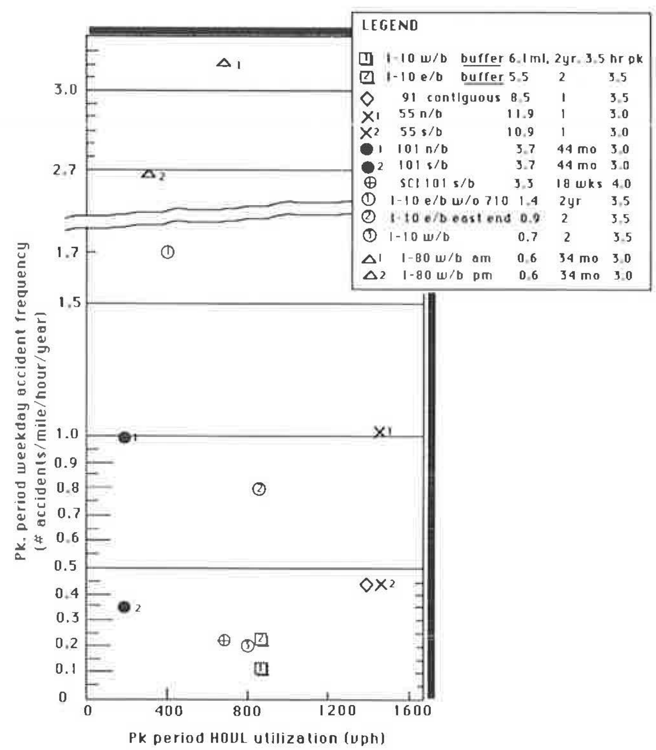

FIGURE 8 Summary of recorded HOVL-related accidents involving vehicles entering or exiting the HOVL.

against the peak period HOVL utilization. One rather surprising result is that the utilization of the HOVL does not appear to have a direct relationship to accident frequency. It had been hypothesized that increased usage of the lane would cause more exposure to accidents. Apparently, when the lane is crowded, drivers are less likely to make a sudden move into it, whereas if the lane is moderately used, sudden maneuvers are more likely to be attempted.

A significant point is that, again, the full buffer design has lower accident frequencies than the contiguous designs do. The peak period average of the I-10 buffer sections is about 0.17 accidents/mi/hr/yr, compared to about 0.75 for contiguous sections (excluding I-80, a special case). In aggregate terms, this means that in a 5-mi buffer section (one direction) for a 3-hr peak (typical), about 2.5 accidents per year are likely to occur. For a similar contiguous design there are likely to be about 11 accidents per year—a 440-percent increase. In both instances, most of the accidents would be of the property damage–only (PDO) type.

SUMMARY

Results from the investigation of California facilities for various issues are described next. As noted, experience and accident sample size was very limited, and the remarks made should be considered in this context.

Separation

The physically separated design virtually eliminates interaction of HOVL and mixed flow vehicles except at designated access points. This design generally provides optimum operation, even if it does not provide maximum HOVL utilization. Where it is feasible, this is the preferable design

The accident analysis indicated that the 13-ft buffer section on I-10 had significantly fewer accidents involving entry and exit maneuvers than sections without buffers. The data indicate, for example, that for a 3-hr peak period a 5-mi one-way section with a 13-ft buffer could expect 2.5 multivehicle accidents per year involving vehicles entering or exiting the facility. Sections without buffers could expect, on average, about 11 accidents per year. In both cases, most of the accidents would be PDO accidents.

The accident analysis could not differentiate between the various nonbuffer designs. A nonbuffer design with a full left shoulder may have different accident characteristics. However, the one example—SCl 101 (Santa Clara County, south of San Francisco)—has not been in operation long enough to allow any conclusions.

On Ora 55 and LA 91 the separation includes barrier striping (a marking for no crossing) with yellow stripes 1 ft apart on Ora 55 and 2 ft apart on LA 91. On both routes, intermediate access between the start and end points of the HOV lane was desired at points where the highway passed crossing freeways and relatively high-volume ramps. In terms of location of entry or exit to the HOVL, by far the highest-rate (per mile) locations used were the designated entry and exit locations. This is because these locations were carefully selected in terms of demand for access (and were revised for Ora 55) and presumably because most people try to obey the law.

However, significant numbers of drivers cross the barrier stripe, and because the length of the nondesignated sections is much greater than the length of the designated intermediate access locations, probably as many vehicles enter or exit across the barrier stripe as at the designated locations. The impacts of this, as noted, cannot be quantified. However, it is the opinion of the project investigators that these crossings are beneficial, given the assumption that all the crossings are going to be made somewhere. The belief is that these nondesignated crossings reduce the concentration and give drivers more opportunity to select gaps because the geometry at designated access locations is not different from that at the nondesignated locations.

HOVL Utilization and Speeds

Peak hour usage of the various facilities varied from about 200–300 vehicles to 1,600–1,700 vehicles. On a single-lane HOV facility of substantial length (no passing), some slowing can occur at flow rates of 1,300 vehicles per hour (vph). Indications are that capacity is probably about 1,800 passenger automobiles per hour. There were instances of stoppages at flow rates of 1,500 to 1,700 vph, probably caused by merging or diverging movements downstream of the stoppage.

No clear trends for HOV speed were detected. In some cases, speeds remained high (>50 mph), even with slow speeds in the mixed flow lanes. In other cases, with apparently the same circumstances, HOV speed was less.

When there is no significant speed differential between HOV and mixed flow vehicles (i.e., differential of <10 mph), there are no apparent operational problems related to the HOV facility. A moderate speed differential (10–20 mph) appears to cause as many operational problems as a high differential (>20 mph). The high differential usually indicates severe congestion in the mixed flow lanes, whereas the moderate differential usually indicates that the mixed flow lanes are operating at very high flows and are subject to frequent shock waves and sudden queues. This may result in more frequent and sudden changes involving the HOVL.

The utilization of an HOVL does not appear to have a direct relationship to the rate of HOVL-related accidents involving vehicles suddenly entering or exiting the lane. This somewhat surprising condition may result from the discouraging effect that a crowded HOVL has on these movements, whereas more of these maneuvers may be attempted on a moderately used facility.

Part-Time Use

There are indications that for contiguous HOVL designs, opening HOV lanes to mixed flow traffic during off-peak periods (including weekends) might reduce accident rates through the lowering of average lane density. Off-peak use of the HOVL as a shoulder may also be considered. However, in 1986, the LA 91 part-time shoulder facility did have several accidents during shoulder use in which drivers said that they thought the shoulder was a lane. This is still an unresolved issue, and appropriate signing and striping needs to be determined before part-time use can be considered a viable strategy.

Start and End Treatments

It was not possible to relate the relatively small number of HOVL-related accidents to these specific design issues. In general, however, whenever the lane ended in a free-flow area, there were rarely any definable safety problems, whether the end of the HOVL was a merge or continuous. The eastbound merge at the end of the LA 10 facility did have a number of merging accidents and rear end accidents that were caused by merges. The merge endings on LA 91 and Ora 55 had fewer problems. The Mrn 101 facility ended as a mixed flow lane. The northbound direction, which had several accidents near the end, was a special case because a mixed flow queue often started right at the end of the HOVL. There were not enough data from which to draw any conclusions about capacity impacts of the end treatments.

The only facility that did not start as a new lane was on the I-80 approach to the San Francisco–Oakland Bay Bridge. Although the data did not indicate that this was a safety problem, visual observation indicated that many vehicles went past the starting point. This often disrupted HOVL operation when the vehicles exited, especially when there was a high speed differential, and reduced capacity of the HOVL.

Enforcement

None of the facilities except LA 91 had specific enforcement areas set up. Some had been constructed for Ora 55, but they were considered inadequate by the California Highway Patrol and are not used. In most cases, however, because of a lack of enforcement areas and left shoulders, the normal procedure is to escort a violator to the right shoulder.

Experience in other states indicated that violations in physically separated facilities are very low (less than 10 percent). In California, occupancy violations varied greatly at the different facilities (from 5 to 30 percent). It is difficult to relate this variance to design because it appears that violations are just as much a function of public acceptance as of enforcement effort. The violation percentage (as opposed to the actual number) is also affected by the utilization of the HOVL. For instance, if there are 1,000 legal carpools, the violation percentage will almost always be less than at a location where there are 400 legal carpools.

General

It is interesting (although not directly related to the study objectives) that at all locations where a.m. and p.m. data are available, freeway accident rates and HOVL-related accident frequencies are always less in the morning than in the afternoon. An explanation for this is that the early a.m. traffic stream is more homogeneous, consisting primarily of commuters, and presumably the drivers are more rested and alert. From this it might be assumed that installation of an HOV facility that is operative during the morning peak, even of an undesirable design, will cause fewer problems than an installation that operates in the afternoon.

ACKNOWLEDGMENTS

The authors wish to thank the California Department of Transportation both for sponsoring this investigation and for granting permission to have these results presented.

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Interstate 394 and the HELP-394 Information Number

KATHERINE F. TURNBULL

In this paper, the results of the first 2 years of use of the HELP-394 information number in Minneapolis–St. Paul, Minnesota, are presented. The HELP-394 information number has been an integral part of the overall marketing and information program being conducted in conjunction with the construction of I-394, the last segment of the Interstate highway system in the Twin Cities metropolitan area. The 11-mi facility, which runs from downtown Minneapolis west to Wayzata, is a total transportation system based on the concept of moving people, not vehicles. The facility will include regular traffic lanes, high-occupancy vehicle (HOV) lanes, ramp metering and HOV bypass lanes, two major transit stations, and three parking garages in downtown Minneapolis. These fixed facilities are being supported by improvements in the transit system and by an aggressive marketing and ridesharing program. The HELP-394 information number has been an important part of the marketing and information program supporting the I-394 project. This hot line has been used to provide current information on highway construction activities, lane closings and detours, bus routes and schedules, rideshare matching services, and a free parking program for carpoolers. This paper discusses the use and evolution of the HELP-394 information system over the first 2 years of operation, including development of the system, modifications, cost, and use.

I-394 is the last segment of the Interstate highway system that is being constructed in the Twin Cities metropolitan area. The 11-mi facility, scheduled for completion in 1992, runs from downtown Minneapolis west to Wayzata and is more than just a highway. I-394 is a transportation system based on the concept of moving people, not vehicles. The facility will include regular traffic lanes, high-occupancy vehicle (HOV) lanes, ramp metering and HOV bypass lanes, two major transit stations, and three parking garages on the western edge of downtown Minneapolis. These fixed facilities are being supported by a major restructuring of the bus system and the ridesharing program. All of these improvements are being supported by an aggressive marketing and public information program, including the latest approaches to consumer communication.

One of the major elements of the marketing and information program has been the use of a general-purpose information number, HELP-394. The HELP-394 hot line provides current information on highway construction activities, lane closings and detours, bus routes and schedules, rideshare matching services, and parking information for carpoolers. The use and evolution of the HELP-394 information system over the first 2 years of operation are discussed in this paper. The process of establishing the system is presented, along with a review of its use, modifications in operation, and costs. The benefits of the system are also presented, along with its drawbacks and limitations.

I-394 TRANSPORTATION SYSTEM

When it is completed in 1992, I-394 will provide a unique transportation system. The total system includes not only the construction of the I-394 freeway but also a complementary package of transit and parking elements. This approach, documented elsewhere (*1*), is the result of a coordinated approach by the Minnesota Department of Transportation (MnDOT), Metropolitan Council, Regional Transit Board (RTB), Hennepin County, Minnesota State Patrol, Metropolitan Transit Commission (MTC), Medicine Lake Lines, and Minnesota Rideshare.

The result is a transportation system that includes an 11-mi freeway with two lanes of mixed traffic in each direction; 3 mi of two-lane physically separated reversible HOV lanes; 8 mi of "diamond" HOV lanes; ramp metering and HOV bypass lanes; two transit stations; and 5,400 new parking spaces and transit facilities in three major parking garages in downtown Minneapolis. The HOV lanes and timed transfer bus system are being used for the first time in Minnesota as a result of this project.

I-394 is being constructed in the existing Highway 12 right-of-way. MnDOT has made a commitment to maintain traffic on Highway 12 during construction to reduce the effects on the traveling public and businesses in the corridor. This procedure has caused a longer construction period, accompanied by restrictions and delays for those using the facility.

To help manage traffic during the construction period and to introduce the use of HOV lanes to motorists, an interim HOV lane was designed, constructed, and opened in November 1985. The interim HOV lane, called the "Sane Lane," was constructed in the median of Highway 12 at strategic locations along the corridor. The Sane Lane consists of a 3-mi segment and a 1-mi segment that allow carpools, vanpools, and buses to bypass major congestion points along the facility. The Sane Lane still includes signalized intersections; however, the lights are timed to provide a smoother flow, and the vehicles bypass the longer queues in the mixed traffic lanes. Surveys have indicated that use of the Sane Lane results in a 5–10-min time savings over the regular traffic lanes.

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I-394 MARKETING AND PUBLIC INFORMATION PROGRAM

Because of the unique nature of the facility, need to introduce and promote the use of the Sane Lane, potential traffic disruptions caused by construction activities, and recent MnDOT experience with reconstruction of a major freeway segment, it was felt that a major marketing and public information program was critical. To identify the nature and focus of this program, a marketing research effort was undertaken in 1985. The result of this effort, which included a review of other HOV facilities throughout the country and formation of focus groups of I-394 corridor residents, was the development of a multifaceted marketing and public information program.

The marketing and public information program included a variety of mechanisms and media to communicate with the public. These included radio and newspaper advertising, public service announcements, billboards, signs on the sides of buses, a corridorwide newsletter and information brochure, and increased ridesharing and bus promotions. A major component of the program was the use of a highly publicized information number, HELP-394.

The major focus of the program was residents, commuters, and businesses in the I-394 corridor. This includes all or portions of five communities located along the corridor. The total population of this area is ~130,000. The newspaper advertisements were targeted at local papers and zoned editions of the metropolitan papers. A direct mail package was sent to 65,000 households in the corridor. This package included the "I-394 Commuter's Guide" brochure, the I-394 newsletter, new bus schedules, and carpool information. These households continue to receive the newsletter on a periodic basis.

A secondary focus was to provide information to the larger market area of communities to the west of the major corridor and the metropolitan area as a whole. Because the project represents the first use of HOV lanes in the Twin Cities area, it was considered important to educate the general public on the use and purpose of the Sane Lane. A general media approach was used for this metropolitan area program, including weekly press releases, a press kit and tour during the opening, and appearances by officials on public affairs programs.

HELP-394 INFORMATION NUMBER

Participants in the focus groups organized in 1985 indicated that current information about the status of the I-394 project was very important. A number of mechanisms were discussed, including the use of newsletters and brochures, radio updates, information along the highway, and a general information number. The use of a general information number was ranked highly by focus group participants. Subsequently, the marketing and information program was developed to highlight the use of the HELP-394 hot line number. Thus HELP-394 became a common thread throughout all the different marketing tools.

The purpose in developing the HELP-394 information number was to provide a central contact point for all information the public needed about the I-394 project. The objectives of the information number were to

- Provide general information on the nature and design of the completed I-394 system, as well as specific explanation and information on the use of the interim HOV lane;
- Provide current information about highway construction activities, including lane closings, access restrictions, detours, and alternate routes;
- Provide information on bus routes and schedules, rideshare matching, and the free parking program for carpools, as well as generate new leads for the ridesharing data base and promote transit use within the corridor; and
- Monitor public comments and concerns about I-394 and the effectiveness of different marketing and public relations material.

The use of telephone information services, both for information purposes and as a direct marketing and sales tool, has increased dramatically over the past few years. This trend reflects the growing view of consumers and businesses alike that service is a convenience item. Consumers are demanding quick, easy, and result-oriented access to goods and services. Businesses have responded to this trend with a variety of telemarketing techniques, including the use of toll-free numbers, local information numbers, and direct sales by telephone. The HELP-394 hot line number represents the use of some of these techniques by the public sector to provide important information on highway construction activities and to promote the use of the Sane Lane, ridesharing, and transit.

DESIGN AND DEVELOPMENT OF HELP-394

The HELP-394 information system was designed during summer and fall 1985 and began operation in November. A subgroup of the I-394 Corridor Management Team, the I-394 Marketing Committee, was responsible for development and implementation of the system. This group, consisting of staff from MnDOT and their consultants (Strgar-Roscoe-Fausch, Inc.), RTB, MTC, and Minnesota Rideshare, worked with Colle and McVoy, a local marketing firm, to establish the system.

The initial design of the HELP-394 information system is shown in Figure 1. The system was developed not only to provide information and answer questions but also to register callers with Minnesota Rideshare, provide direct mail follow-up materials, survey callers on their use of Highway 12/I-394, and promote interest in ridesharing and transit. Operators could also connect the caller directly to MnDOT, MTC, Minnesota Rideshare, or Medicine Lake Lines if more detailed information was desired or if the question concerned a topic (e.g., right-of-way acquisition) that the telephone operators had been instructed not to answer.

During the first 16 months of use, individual calls to HELP-394 were answered by a live operator. The nature of the call was ascertained by the operator and then answered by using detailed information on microcomputer screens. The information screens, which had been developed by the Marketing Committee, contained a series of questions and answers on the following topics:

- general Highway 12/I-394 design, construction activities, and schedules;

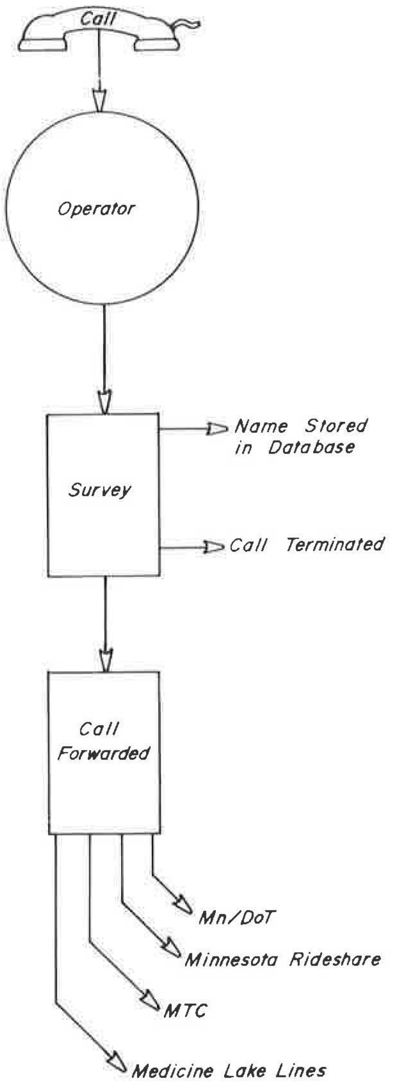

FIGURE 1 HELP-394 operation.

- use of the Sane Lane;
- bus routes and schedules;
- rideshare matching; and
- the free parking program for carpools and vanpools.

The normal sequence for calls to HELP-394 was as follows. The operator identified the nature of the caller's question and provided the answer on the basis of information programmed into the microcomputer screens. If the caller was seeking specific information, such as bus routes and schedules or ridesharing information, the operator would record the individual's name, address, and request on the data base. The requested information was then sent directly to the individual, and a copy of the data base summary was sent to the appropriate agency.

If additional detailed information was requested or if questions were asked that the operators had been instructed not to answer, the operator could connect the caller directly to the relevant agency. Questions or concerns that needed a written response were also captured on the data base and transmitted to the appropriate agencies for follow-up correspondence.

Before each call was terminated, regardless of its nature, the information screen defaulted to a short survey that was administered by the operator. The survey included questions on how the caller had heard of HELP-394 and whether the caller used Highway 12/I-394 regularly. The survey ended by asking if the caller would consider using the bus or carpooling and if the caller wanted more information on any of these. Thus the HELP-394 information system not only provided information but took the more proactive role of marketing ridesharing and bus use to those who called. The data base and survey information also provided valuable leads for additional marketing of these services and provided a good gauge of the individual perspective on I-394 and the different marketing techniques.

In February 1987, the HELP-394 system was changed from the use of live operators to a voice box with programmable recorded messages. As discussed later, this was done to reduce the cost of the system during a period of low call volumes. The redesigned system is shown in Figure 2. Calls were still answered by a live operator but were then directly connected to a voice box with a prerecorded message on the latest construction update. The voice box messages could be changed at any time by calling in a new message. If additional information was desired, the caller remained on the line, and the operator then transferred the call to MnDOT, MTC, or Minnesota Rideshare. The messages could be updated regularly to reflect the latest construction activities. The use of the voice box eliminated the options of direct mail follow-up, capturing names for the data base, and administering the surveys.

The operation of HELP-394 information number utilized a number of major system components. These included the telephone routing system, use of a commercial telephone center, and hardware and software to organize and manage the information provided and to maintain the data base. Existing businesses and technology were used to operate the system.

A commercial telephone information service, The Connection, formed the basis of the system. This service provided the live operators and voice box to answer the incoming calls. Initially, it was also possible to access the information number by computer modem.

HELP-394 calls were one of many information and commercial calls received by The Connection. The number of the incoming line allowed the operator to determine which general information to dispense. The Connection also collected and maintained the data base during the first phase of operation. This data base identified calls that required additional information (which was sent later by a mailing house firm) and those that required specific follow-up, which were directed to the appropriate agency for a formal response. Leads generated for ridesharing applications or bus information were forwarded to Minnesota Rideshare and the Metropolitan Transit Commission.

Calls are routed to HELP-394 through a telephone carrier. The right to use the desired number, HELP-394, had to be purchased for a nominal fee from its existing user. Because the number is a suburban exchange and The Connection's telephone center is in a Minneapolis exchange area that is served by a different telephone company, the calls have to be routed to Minneapolis. This required the initial purchase of the necessary

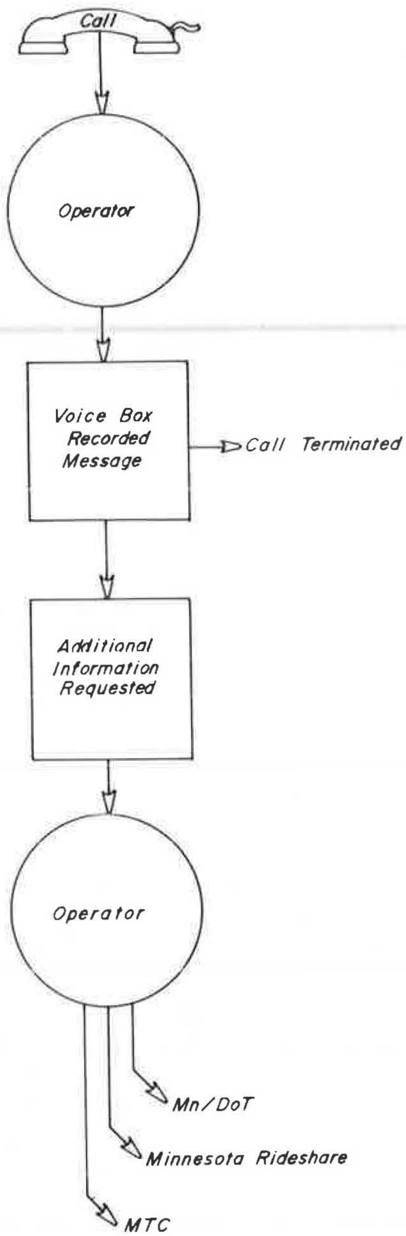

FIGURE 2 Revised HELP-394 operation.

rotary hardware to handle multiple calls. The ongoing monthly charges are slightly higher than if just one exchange were used.

COST OF HELP-394

The cost of the HELP-394 information number can be broken down into costs for three general stages: system development, first 16 months of operation with live operators, and last 8 months with the voice box. Development costs for the system were about $7,500. This included the different hardware needed to rotate multiple calls through the HELP-394 telephone number, development of the necessary software, and the marketing agency and information center time. The development of the information and survey questions was done by RTB and MnDOT staff, but the questions had to be entered into the system by The Connection. Operating costs during the first 16 months averaged ~$2,600 per month. During the first 13 months this included the live operator, completion of the survey, and an on-line data base. After the first year, the on-line data base and the survey were dropped to lower the cost. The change to the voice box reduced the monthly cost to ~$1,000.

USE OF HELP-394

The number of monthly calls to the HELP-394 information number is presented in Table 1. The largest number of calls was received in the first 3 months of operation; calls during October, November, and December 1985 were 942, 1,152, and 717, respectively. Call volumes dropped to 247 in January 1986 and averaged 150 calls per month from February through May. The number of calls increased during June and July 1986 before dropping off to below 100 during fall and winter 1986 and 1987. The call volume increased to an average of 150 calls per month in February–April 1987.

TABLE 1 HELP-394 INFORMATION NUMBER MONTHLY CALLS

Month	Number of Calls
1985	
October	942
November	1,152
December	717
1986	
January	247
February	153
March	157
April	148
May	174
June	431
July	294
August	194
September	106
October	79
November	71
December	82
1987	
January	56
February	136
March	198
April	141
May	97
June	76
July	54
August	71
September	57
October	27
November	26

The volume of calls directly reflects both the amount of marketing occurring and the construction activities. Call levels were highest during major marketing and information campaigns and when major construction activities were occurring. These two elements often coincided. The marketing and information program to introduce the Sane Lane began October 1985, and the lane opened in November. The HELP-394 information number was highly publicized during this time as one of the major mechanisms for communicating the use of the lane and promoting bus use and ridesharing. The highest daily call volume occurred during a December 1985 snowstorm, with 250 calls. The higher volumes in June and July 1986 reflected another marketing and information program that outlined the summer construction activities, including lane closings and detours. During periods of little marketing or construction activities, the call volumes dropped off.

During the first 13 months of operation, a short survey of HELP-394 information number callers was conducted. The results of this survey provided insight into the types of people calling and the information requested. Of all the people calling HELP-394, about 22 percent indicated that they used the Sane Lane. Of those who were not currently using the lane, some 37 percent indicated that they would consider using it by carpooling or bus travel. The majority of Sane Lane users indicated time savings of 5–10 minutes. Additional information on the free parking program was requested by 36 percent of the callers. Bus route and schedule information was requested by 18 percent of the callers, and ridesharing information was requested by 20 percent.

To help measure the effectiveness of the different marketing and information techniques, callers were asked how they first heard about HELP-394. Responses indicated that newspaper advertising was the most effective, followed by billboards, word of mouth, brochures or newsletters, and radio advertising.

EVALUATION AND CONCLUSIONS

The effectiveness of the HELP-394 information number can be measured in two general ways. The first is by the actual call volumes, whereas the second is by actual use of the Sane Lane and increases in ridesharing and bus use in the corridor. By both measures, the HELP-394 number has been a successful and important element of the overall I-394 marketing and information program. Additional insight has also been gained on how a telephone information system can be used most effectively.

The cost of the system, both start-up and ongoing, appears reasonable for the benefits received. Excluding the start-up cost, the average cost per call over the first 2 years was ~$6.50 a call. Given the wide difference in monthly volumes, however, the cost per call during months with high volumes was as low as $2.00 per call. The results of the use of the HELP-394 number indicate that a high volume of calls must be maintained to ensure that the system is cost effective.

The HELP-394 number generated new carpool leads and assisted with providing information to corridor residents on bus services. Some 500 new leads were generated for Minnesota Rideshare's carpool and free parking information. This increase in ridesharing is reflected in the use of the Sane Lane and in the increase in automobile occupancy rates for the corridor. Improvements in bus service to make use of the Sane Lane were implemented in January 1986. Increases in ridership, both on weekdays and weekends, followed these improvements. The HELP-394 information number fulfilled ~450 requests for bus information during the first year.

The use of the HELP-394 information number appears to have helped explain and promote the use of the Sane Lane during the first few months of operation. Initially, traffic volumes averaged ~430 vehicles during the morning peak hour. This increased to a high of 560 vehicles during the first year. Because of delays caused by construction on the facility, the use of the Sane Lane dropped off somewhat during summer 1987.

Thus it appears that the HELP-394 information number was an effective way to communicate with the general public. The HELP-394 hot line was used to obtain information on all facets of the I-394 project. The information number provided a cost-effective communication tool during periods of high call volumes. The use of the number was most effective during major construction periods and during marketing activities.

The use of an information hot line appears to be most applicable to major long-term projects for which there is a need to provide updated information to the public on an ongoing basis. The flexibility of using a voice box or other methods to reduce costs during periods of low call volumes is also important. As an example, the possibility of moving the hot line into MnDOT has been considered. This could reduce costs by allowing for the continued use of the information number during periods of little activity while maintaining the ability to change back during periods of high call volumes.

REFERENCE

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Abridgment

Performance Measurement for a Metered Freeway System

JAMES H. BANKS

Performance measures and data reduction techniques to quantify these measures from automatically collected data have been developed for the main-line freeway portions of the San Diego ramp metering system. These measures and techniques are primarily intended to allow detection of significant changes in the ongoing performance of the system. Performance indicators include speeds, volumes, flow rates, and occupancies for individual detector locations; throughputs, total travel times, and delays for freeway sections; and accident statistics. Current morning peak period conditions on the main-line freeway portions of the system were analyzed. Measures of freeway use, such as volumes and throughputs, display little variation from day to day. In contrast, measures of flow quality, such as travel time and delay, are highly variable. Most congestion appears to be the result of normal flow breakdown at fixed bottlenecks rather than incidents. Bottleneck capacities display considerable variation. There appears to be little relationship between daily use of the system, as represented by total morning peak period throughput in extended sections, and daily delay.

Ramp metering is a commonly used means of traffic control for freeways. Ramp metering systems often provide the potential for very flexible control, but to take full advantage of this potential, it must be possible to measure and evaluate the performance of the systems. The research described in this paper (*1*) was aimed at developing performance measures to be applied to the ramp metering system operated by the California Department of Transportation (Caltrans) in the San Diego area, as well as to similar systems elsewhere, and to use these to measure certain aspects of the performance of the San Diego system.

Most of the earlier evaluation studies on ramp metering have been before-and-after studies that compared conditions in the first few months after metering began with those on the uncontrolled freeway before metering (*2–4*). The most comprehensive and best-documented of these studies was that performed by the Texas Transportation Institute on the Gulf Freeway in Houston in the late 1960s (*2, 5, 6*). The current study was related to those cited in that it involved attempts to measure a variety of aspects of system performance. It differed from the earlier studies in that it was intended to evaluate the effects of relatively minor changes in an ongoing system.

Performance indicators chosen for the San Diego ramp metering system included spot speeds, flow rates, and occupancies at the controllers; travel time, delay, and throughput (or total travel, measured in vehicle miles) for sections; and accident statistics.

In the case of all measures other than accident statistics, initial data reduction involved aggregating the raw data, which consisted of 30-sec counts for each freeway lane, to produce 6-min average values for all lanes at a particular location or for an entire section. Throughput, travel time, and delay were used mostly as indicators of overall daily performance for basic sections or more extended portions of the freeway and were thus further aggregated over the entire peak period.

These performance measures were used to analyze several aspects of current freeway performance for the San Diego ramp metering system. The aspects considered included normal variations in the various performance measures, sources of congestion in the system, performance of bottlenecks, and the relationship between daily levels of system use and delay.

VARIATIONS IN PERFORMANCE MEASURES

Total peak period volumes and throughputs were found to be quite stable. Volume counts for June and July 1986 were analyzed. For main-line detector locations, coefficients of variation (standard deviation divided by mean, expressed as a percentage) ranged from about 1 to 3 percent. For ramp counts, coefficients of variation tended to be somewhat larger. In most cases, the coefficients were less than 10 percent, but they were occasionally higher for lightly used ramps.

Travel times and delays, on the other hand, proved quite variable. These measures were aggregated for segments immediately upstream of the three major morning peak bottlenecks for April and May 1987. Standard deviations for travel time and delay were virtually identical (as would be expected) and amounted to about 20–30 percent of the mean travel time. Distributions of these measures proved to be extremely one sided.

SOURCES OF CONGESTION

Variations in travel time in the San Diego system are the result of both normal flow breakdown at the bottlenecks and incidents. In an effort to determine the relative frequency of these two sources of congestion, space-time displays of speeds and flows for June through October 1986 were analyzed. All episodes of congestion that involved speeds of 30 mph or less were identified. The overwhelming majority of the 403 episodes thus identified occurred in the vicinity of the major fixed bottlenecks and did not appear to have been the result of

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incidents. When incidents were involved, however, they usually contributed to the delay. In particular, recorded accidents appear to have contributed significantly to congestion only in rare instances.

BOTTLENECK PERFORMANCE

Because most congestion in the San Diego ramp metering system appears to be related to the performance of the major bottlenecks, a preliminary investigation of the capacities of these bottlenecks was undertaken. In this study, consideration was given to the question of how to identify capacity flows. The usual assumption is that the existence of a queue upstream of the bottleneck indicates capacity flow. On the other hand, a considerable body of literature contends that maximum discharge rates from queues are lower than maximum free flow rates (*7–12*).

To account for the possibility of different free flow and forced flow capacities, 6-min average flow rates from detectors either immediately upstream or downstream of the bottlenecks were cross-classified with speeds just upstream of the bottlenecks on a monthly basis for the period June–November 1986. Table 1 presents an example of the distributions that resulted. Maximum flow rates were found to be similar for all upstream speeds greater than 30 mph. Because the cross-classifications indicated that maximum queue discharges were not significantly lower than maximum free flow rates, all 6-min flow rates coinciding with upstream speeds less than 50 mph were taken to be capacity flows for the conditions prevailing at the time that they occurred. It should be noted that this means that some low flows that were the results of incidents were included.

Distributions of these "capacity flows" were prepared from the cross-classification tables. Figure 1 shows a fairly typical histogram of one of the resulting monthly capacity flow distributions. Note that there appears to be considerable (and apparently random) variation in capacity flow. In all cases, the bulk of the distribution fell within an interval of about 20 percent of the average capacity. Table 2 summarizes means and coefficients of variation for the various capacity flow distributions. It should also be noted that the monthly mean capacities of all three bottlenecks are fairly high and that those at the College Avenue bottleneck on Interstate 8 are exceptionally high.

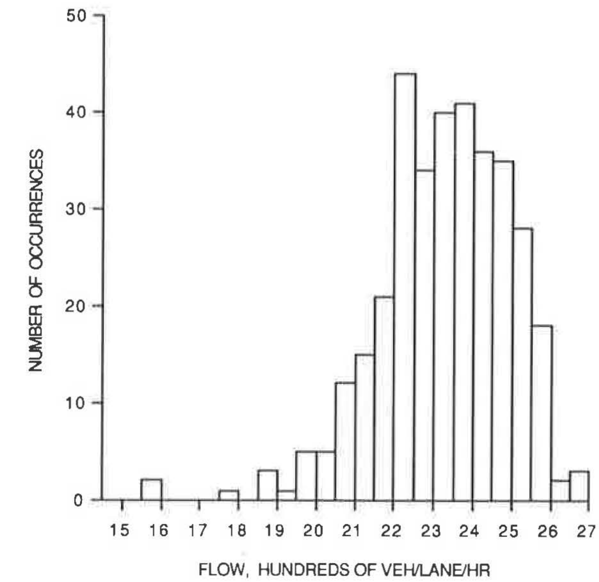

FIGURE 1 Histogram of 6-min flows through the College Avenue bottleneck on Interstate 8, with upstream speeds less than 50 mph, September 1986.

RELATIONSHIP BETWEEN DELAY AND THROUGHPUT

Relationships between throughput aggregated for the entire peak period and delay are not fully understood, although there has been some past discussion (*7, 13*). If bottleneck capacity remains constant and throughput in a section increases, delay should be expected to increase. If, on the other hand, variations in delay are primarily due to variations in bottleneck capacity—which they may be in this system (see the preceding section)—there should be little or no relationship between delay and throughput. The exception is that if drivers divert from the freeway when it is heavily congested, there may be a negative correlation.

Delays and throughputs aggregated over the entire morning peak period for the sections upstream of the major bottlenecks were plotted against one another for April and May 1987. Figure 2 shows an example of the resulting scatter plots. As can be observed, there is little correlation between throughput and delay. To the extent that there is a correlation, it is negative and appears to be due to diversion of traffic from the freeway system during the most severe delay-producing incidents.

TABLE 1 CROSS-CLASSIFICATION OF NUMBERS OF 6-MIN FLOW OCCURRENCES

Speed (mph)	Flow (hundreds of vehicles/lane/hr) 10–12	12–14	14–16	16–18	18–20	20–22	22–24	24–26	>26	Total
0–10	0	0	0	0	0	0	0	0	0	0
10–20	0	0	0	0	4	0	1	0	0	5
20–30	0	0	0	0	2	37	53	0	0	92
30–40	0	0	0	0	2	13	76	49	0	140
40–50	0	1	1	1	1	3	29	66	5	107
>50	0	5	16	33	72	58	54	43	2	283
Total	0	6	17	34	81	111	213	158	7	627

NOTE: Interstate 8 at Waring Road versus 6-min average speeds at College Avenue, September 1986.

TABLE 2 MEANS AND COEFFICIENTS OF VARIATION OF 6-MIN FLOW DISTRIBUTIONS

	Bottleneck					
	Rte 15		College Ave.		Grossmont Summit	
Month	Mean[a]	Cov (%)	Mean[a]	Cov (%)	Mean[a]	Cov (%)
June	2,088	6.09	2,343	10.81	2,026	11.17
July	2,014	8.26	2,305	8.83	2,000	9.71
August	1,970	11.97	2,344	6.73	2,003	9.33
September	2,031	9.79	2,322	7.37	2,037	7.67
October	2,033	8.59	2,305	6.58	1,990	10.48
November	2,053	8.76	2,321	5.88	2,032	9.75

NOTE: For bottlenecks with upstream speeds less than 50 mph.
[a]Means in vehicles per lane per hour.

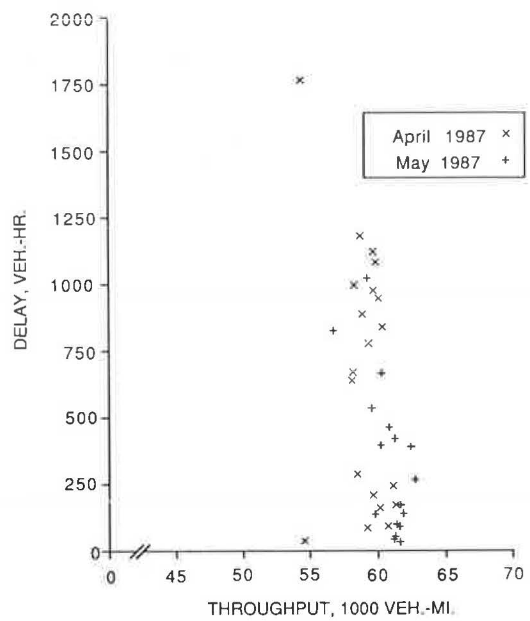

FIGURE 2 Scatter plot, morning peak period (6 a.m.–9 a.m.), delay versus throughput, Interstate 8, College Avenue–Spring Street, April–May 1987.

ACKNOWLEDGMENTS

This research was funded jointly by the California Department of Transportation and FHWA, U.S. Department of Transportation. Special thanks are due to members of the Caltrans staff in San Diego, especially Lawrence Wherry and Don Day, for their assistance; to Van Hurdle, who reviewed the project report and made many helpful suggestions; and to the author's research assistants, Yahya Faramarzi and Sherman Daley.

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Effect of Grade on the Relationship Between Flow and Occupancy on Freeways

BHAGWANT N. PERSAUD AND FRED L. HALL

In this paper, 30-sec data for the median lane of a freeway section with significant grades are used to explore how the uncongested flow-occupancy function is affected by grade, as well as to examine the implication of this effect for incident detection logic. The results accord with intuition: significant grades cause differences in speed at affected locations, resulting in differences in occupancy for a given flow. The size of the difference depends not only on the grades at each location but also on the vertical profile of the upstream sections and on the prevailing flow. Distinct flow-occupancy functions are required for each affected location, and because the effect of the grade might vary with environmental and traffic operating conditions, it appears desirable to continuously update these functions on line in traffic management systems. This task appears to be feasible and is expected to improve the efficiency of occupancy-based detection algorithms.

The relationship among speed, flow, and occupancy can be described as the kingpin of most freeway traffic management systems. For example, incident detection, which is one of the major components, is generally occupancy based, but there are implicit assumptions about the nature of that relationship. It therefore seems natural that a thorough understanding of traffic operations should be vital to efficient freeway traffic management. Accordingly, in recent years, some research effort has been focused on better understanding patterns in flow-occupancy-speed data (*1–7*). In one series of papers (*3–7*), catastrophe theory evolved as a reasonable three-dimensional representation of the flow-occupancy-speed pattern, and on this basis, an alternative incident detection logic has been suggested (*7, 8*). All of the earlier work, however, has used only data pertaining to "ideal" freeway conditions, that is, for locations with no grade or other geometric constraints, and from time periods without inclement weather. The reason for thus confining the earlier analyses is that there were hints in the data that weather and geometric conditions (in particular, grade) would confound the task of seeking a fundamental understanding of traffic operations.

Understanding the effect of grade on traffic operations is vital for the designers and operators of freeway traffic management systems. Most such systems, at least in North America, use some variety of the California-type algorithms for detecting incidents (*9*). In essence, the principle of these algorithms is that a significant change in the traffic operation pattern (usually represented by some function of occupancy) between successive detector stations is indicative of the presence of an incident between those stations. Threshold values are used to indicate how significant a change is required before an incident is declared. If, as appears intuitively obvious, relatively steep upgrades and downgrades can cause natural changes in traffic operations between successive detector stations, then it is easy to see that the presence of changes in grade presents difficulties in the detection of incidents on freeway segments.

These difficulties are partly alleviated in some systems by varying thresholds from location to location. This works if the location-specific thresholds can be accurately calibrated, but further difficulties might be presented if the effect of grade varies over time, depending on weather and traffic conditions. It should be noted that some systems in operation today do not allow for location-specific thresholds. In such situations, to reduce false alarms due to upgrades, the systemwide threshold can be set so high that most incidents are not detected. Conversely, natural reductions in occupancy due to downgrades might require a low threshold that could result in many false alarms at other locations.

The purpose of this paper is to provide some insights into how grade might affect the flow-occupancy-speed relationship and to explore whether a single three-dimensional model, such as the catastrophe theory model, might adequately represent these varying effects. It has already been suggested that such a model might usefully complement existing algorithms by providing a logic system for detecting incidents on the basis of data from a single detector station (*7*). If this model automatically captures the effect of grade, then it would be particularly useful for detecting incidents at locations where operations are affected by relatively steep upgrades and downgrades. A related paper (*10*) examines the effect of weather on the flow-occupancy relationship.

The text of this paper is structured into four substantive sections, followed by a summary. First, details of the data are provided. Next, a brief review of the catastrophe theory representation of data that is unaffected by grade follows. Then the dependence of the flow-occupancy pattern on grade is empirically explored and reconciled with the theory. The implications for incident detection are discussed before the summary.

DATA

The study site was a segment of the Queen Elizabeth Way near Hamilton, Ontario, Canada. It contains level, upgrade, and downgrade sections (Figures 1 and 2). The Burlington Skyway Freeway Traffic Management System records 30-sec averages of speeds, flows, and occupancies in each of at least two lanes

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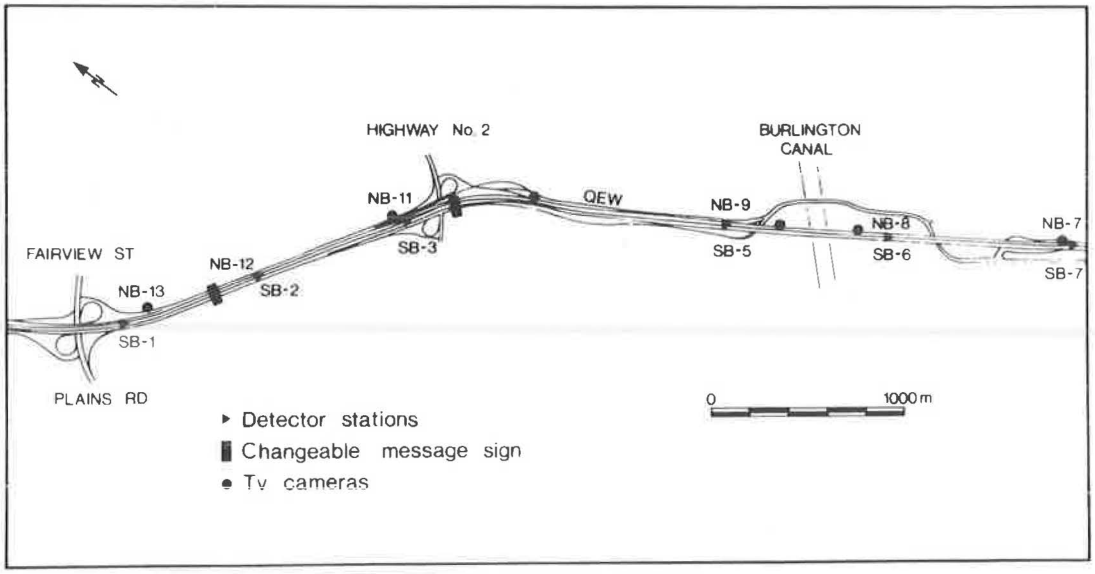

FIGURE 1 Schematic diagram of the Skyway Freeway Traffic Management System on the Queen Elizabeth Way, Ontario, Canada.

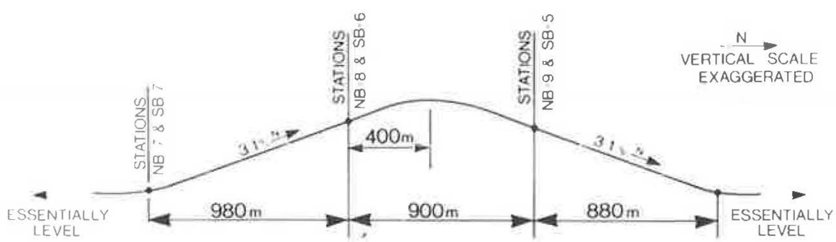

FIGURE 2 Vertical profile of the Burlington Bay Skyway on the Queen Elizabeth Way, Ontario, Canada (vertical scale is exaggerated).

at each of six southbound (SB) and six northbound (NB) stations on the segment of interest. Two related papers (*7, 10*) were based on operations at Station NB-7. The data set that is the basis of this paper consists of samples of 30-sec data for the median lane at Station NB-7, as well as those stations at which operations are thought to be affected by grade, that is, NB-8, NB-9, SB-5, SB-6, and SB-7. Details of the vertical profile at each of these stations are summarized in Table 1.

TABLE 1 DETAILS OF VERTICAL PROFILE

	Approximate Grade	
Station	At Station	Upstream
NB-7	Level	Level
NB-8	+3%	Level
NB-9	−3%	+3%
SB-5	+3%	Level
SB-6	−3%	+3%
SB-7	Level	−3%

The data that were originally extracted represented normal behavior, as well as behavior before, during, and after nine incidents that occurred during good weather near the stations of interest during the week ending August 15, 1986. For this paper, it was decided to confine the analysis to the uncongested data. This decision was partly based on information contained in scatter plots such as Figure 3, which is taken from one of the related papers (*7*). This plot demonstrates that it is only the uncongested flow-occupancy data (in the tightly defined Area A) that can sensibly be described by a functional relationship. Inclusion of the widely scattered congested data (Area B) would probably distort the relationship. In addition, given the premise of this paper, all that is of interest for the moment is to define the limits of uncongested operation (Area A) to see what effect changes in grade have on them.

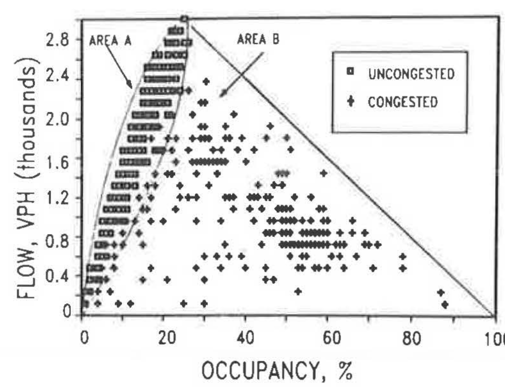

FIGURE 3 Scatter plot of 30-sec flow-occupancy data in the median lane, for Station NB-7 before, during, and after six downstream incidents.

To obtain data sets consisting of only uncongested data, congested data were deleted according to the following rules:

Rule 1. Data for stations affected by an incident were deleted for the duration of reported incidents. As discussed elsewhere (*7*), the beginning and end of an incident were marked by distinct changes in speed at the station immediately upstream.

Rule 2. Any occasional data point caused by slow-moving vehicles or shock waves, identified by a drop in speed of at least 10 km/hr from average speed for the occupancy at that point, was deleted.

Although Rule 2 appears to be somewhat arbitrary, it should be pointed out that 95 percent of the data deletions were in accordance with the more credible Rule 1. In the end, the number of uncongested data points ranged from 341 for Station NB-8 to 840 for Station SB-7. (The reason for this spread is that six of the nine incidents affected operations at Station NB-8, whereas operations at SB-7 were virtually unaffected by any of the incidents.)

The analysis was done with median lane data for reasons detailed elsewhere (*7*). In essence, because of the presence of trucks, patterns in the shoulder lane data are harder to distinguish. In particular, the distinction between congested and uncongested operation is not as clear-cut. Equally important, it appears feasible to base incident detection logic on the median lane data alone (*7*).

REVIEW OF RELATED WORK

The data in Figure 3 are from Station NB-7, where operations are unaffected by grade. As indicated earlier, uncongested data occur in a tightly defined area (designated Area A), whereas congested data caused by downstream incidents are scattered in a roughly triangular area (Area B). Changes from uncongested to congested operation and vice versa are marked by a smooth change in flow and occupancy, with sudden discrete speed changes of the order of 15–25 km/hr between consecutive 30-sec intervals (*7*).

In earlier work (*5–7*) this behavior was found to be reasonably explained by catastrophe theory, which takes its name from the sudden discrete changes in one variable during smooth changes in other related variables. The suggested representation, shown in Figure 4, accommodates discrete changes in speed during smooth change in flow and occupancy—the pattern observed in the data on which Figure 3 is based. Uncongested operations unaffected by grade occur along a tightly defined line on the upper surface of Figure 4, and on breakdown to congested conditions, operations fall directly to the lower surface where they become highly variable and remain until recovery.

In this paper, it is the uncongested operations on the upper surface that are of interest. The working hypothesis in this exploration is that if these operations are affected by grade, this factor merely affects the location of the tightly defined line on the surface; or, in effect, that a single upper surface can feasibly model the varying effects of grade on uncongested operation. In this paper, however, it is simply the flow-occupancy curve, not the flow-occupancy-speed surface, that is examined to investigate the grade effect.

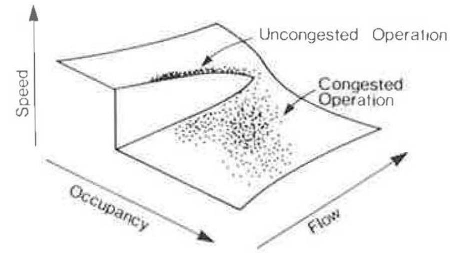

FIGURE 4 Conceptualization of traffic operations on a catastrophe theory surface.

This review has been intentionally brief because full details are given in the background papers (*5, 6*) and more detailed reviews are provided elsewhere (*7, 10*).

METHOD AND RESULTS

The first step in the analysis was to extract the uncongested data according to the rules specified earlier. Then, for each station, the mean flow for each occupancy value was plotted to obtain some initial insights on the functional form of the flow-occupancy relationship and on the possible effects of grade. Visual inspection of these plots, three of which are shown in Figure 5, indicates apparent differences among the stations and that a function of the form flow = $a[\text{occupancy}^{b_1}]$ might be appropriate. This form is also consistent with that used in examining the effect of weather (*10*).

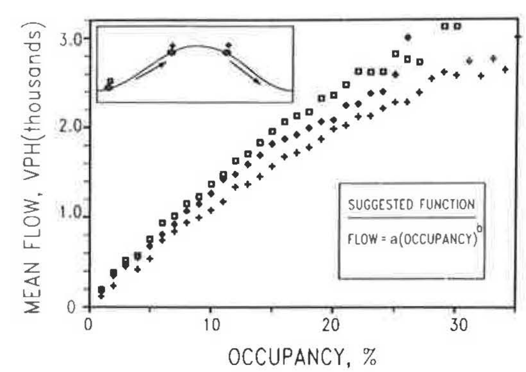

FIGURE 5 Mean value of flow versus occupancy for three stations (uncongested data only).

The next steps were to calibrate the function for each station and to statistically test whether different functions are required for each station. The calibration was carried out by first doing the usual linear transformation on this type of model. In effect, a and b_1 were estimated by doing linear regressions of ln[flow] on ln[occupancy]. Estimated values for the intercept, ln[a], and the slope, b_1, of the log-linear models are presented in Table 2, along with the statistics of the fits. These statistics, along with plots such as Figure 6 (which shows how the fitted functions relate to the flow-occupancy data), indicate that the model form and the fits are quite reasonable for the entire occupancy range.

TABLE 2 REGRESSION ANALYSIS ON UNCONGESTED DATA SETS

	ln[a]		b_1			Number of Data
Station	Coefficient	t Ratio	Coefficient	t Ratio	R^2	Points
NB-7	5.32	272.3	0.824	109.4	0.949	649
NB-8	5.10	245.9	0.822	111.7	0.948	341
NB-9	5.24	321.8	0.820	118.5	0.959	603
SB-5	5.28	244.6	0.800	96.1	0.948	503
SB-6	5.10	264.8	0.846	113.0	0.955	605
SB-7	5.41	367.3	0.819	130.1	0.953	840

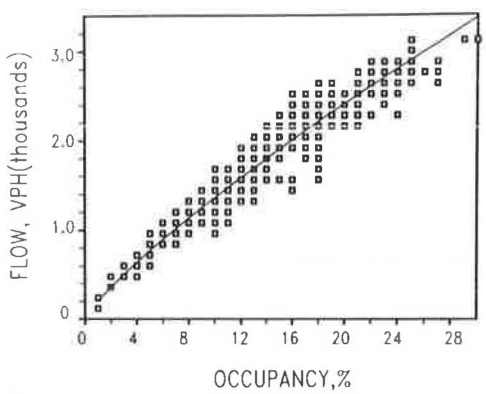

FIGURE 6 Uncongested flow-occupancy data and fitted function for Station NB-7.

The question that remains is whether there are significant differences among the fits, that is, whether a single set of coefficients can be used for groups or all of the stations. To answer this, Station NB-7 was used as a base for comparison because, it will be recalled, operations there are thought to be unaffected by grade. The Station NB-7 data were combined with that for each of the other days, and for each combination, regressions were performed to estimate coefficients for the following function:

$$\ln[\text{flow}] = \ln[a]' + b_1' (\ln[\text{occ}]) + b_2'(D) + b_3'(D)(\ln[\text{occ}]) \quad (1)$$

where D is a dummy variable assigned a value of 1 for data points for station NB-7 and 0 otherwise. If there are significant differences between the functions for Station NB-7 and the station of interest, one or both of b_2' and b_3' would be significant. The coefficients for the other station would be $\ln[a]'$ and b_1'—the same as those in Table 2. If a separate function is required, the coefficients for NB-7 in Table 2 can be reproduced by simply summing the relevant coefficients in Equation 1 (i.e., $\ln[a]' + b_2'$, and $b_1' + b_3'$, to get $\ln[a]$ and b_1, respectively).

The results of this set of regressions, presented in Table 3, indicate that each of the other stations requires a different function from NB-7, the station at which operations are unaffected by grade. It is not surprising that the two stations on upgrades, NB-8 and SB-5, both require different functions from NB-7. What is mildly surprising at first glance is that functions for the two stations on downgrades, NB-9 and SB-6, and the function for SB-7, which is on a level section, are all significantly different from that for NB-7. However, close inspection of Figure 2 reveals that NB-9 and SB-6 are both just beyond relatively long upgrades, so it appears likely that operations there might still be adversely affected by the preceding upgrade. Also, SB-7 is at the foot of a long downgrade, so it might be expected that speeds there would be faster than speeds at a station preceded by level freeway (such as NB-7). This expectation is indirectly confirmed by the negative dummy variable coefficients for the NB-7/SB-7 comparison, which suggest that for a given flow, SB-7 has a higher occupancy, and therefore a faster speed, than NB-7.

A similar set of regressions was performed to determine whether there are significant differences between stations that appear similar in location with respect to grades. NB-8 and SB-5 are both about two-thirds of the way up the 3 percent grade. For this pair of stations, the results of the dummy variable regression, also presented in Table 3, indicate that there is a significant difference between the functions for these stations. Similarly, there is a significant difference between the functions for NB-9 and SB-6, even though both appear to be on identical downgrades. This would indicate that it is difficult to specify how operations at a station might be affected by grade by merely specifying the grade and its length. What came before the grade of interest also appears to be important. This creates a problem if the aim is to be able to identify the flow-occupancy function for a station by specifying its geometrics, because to specify the various combinations of grade, length of grade, and grade "history" would require a large number of combinations. This issue will be explored further in the next section.

DISCUSSION OF RESULTS

In Figure 7, the final regression lines for the three northbound stations are plotted. In many ways, this plot is a confirmation of intuition: if an upgrade is large enough and long enough to affect traffic operations at a station, then it will result in a higher occupancy for a given flow. What is not intuitively obvious is that the difference in occupancy between two functions increases with flow. For example, the expected difference in occupancy between NB-7 and NB-6 increases from about 2 percent at a flow of 1,000 vph to about 5 percent at a flow of 2,000 vph. Examination of the actual data on which the functions are based indicates approximate upper 95th percentile values for these numbers of 10 percent and 25 percent, respectively. This finding has important implications

TABLE 3 REGRESSION ANALYSIS ON DATA FOR PAIRS OF STATIONS

	ln[a]		b_1'		b_2'		b_3'	
Section Pair[a]	Estimated Coefficient	*t* Ratio	Estimated Coefficient	*t* Ratio	Estimated Coefficient	*t* Ratio	Estimated Coefficient	*t* Ratio
NB-7, NB-8	5.10	171.2	0.822	77.8	0.239[b]	6.73	−0.0070	−0.54
NB-7, NB-9	5.24	355.5	0.820	131.7	0.115[b]	4.36	−0.0091	−0.86
NB-7, SB-5	5.28	246.4	0.800	96.8	0.0665[b]	2.26	0.0149	1.33
NB-7, SB-6	5.10	264.1	0.846	112.7	0.239[b]	8.71	−0.0308[b]	−2.91
NB-7, SB-7	5.41	369.9	0.819	131.0	−0.0713[b]	−2.91	−0.0039	−0.39
NB-8, SB-5	5.28	248.0	0.800	97.4	−0.173[b]	−4.71	0.0219	1.63
NB-9, SB-6	5.10	233.3	0.846	99.5	0.124[b]	4.68	−0.0217[b]	−2.06

[a]In each case, data for the first station listed are used as the basis for comparison; $D = 1$ for that station.
[b]Dummy variable coefficient is significant at the 5-percent level of significance.

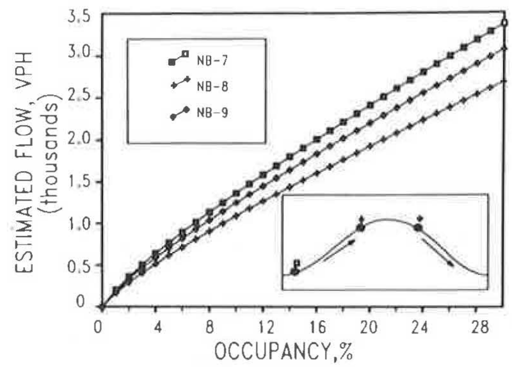

FIGURE 7 Regression lines for three northbound stations.

for incident detection logic, so it will be dealt with in the next section.

The question of whether the varying effects of grade can be explained by catastrophe theory remains to be explored. This explanation would be particularly desirable because one of the premises for developing the theory is that it might be able to capture the entire range of freeway operations within a single model. One way that catastrophe theory might model the effect that grade has on operations is suggested by the definition of occupancy. That definition implies that an upgrade causes uncongested occupancy to increase if it causes vehicles to reduce speed and occupy a detector for a longer time. Because of the curvature of the surface on which the catastrophe theory model is built, lower but uncongested speeds would occur closer to the drop-off. In other words, the grade that produces the slowest operating speeds will produce an uncongested flow-occupancy function that is close to the edge of the upper surface (higher occupancy and lower speed for a given flow), whereas faster speeds on more gentle grades will produce points higher up and to the left of this edge. This has not been modeled mathematically at present, but it appears feasible that the catastrophe theory model can accommodate this feature of traffic operations.

IMPLICATIONS FOR INCIDENT DETECTION AND FURTHER WORK

It is quite common for incident detection logic to be based on a comparison of occupancy (or on some related measure, or both) between successive detector stations. If the difference exceeds some preset threshold, then an incident is tentatively declared. It appears obvious from the present results that because grade might cause natural changes in occupancy, such comparative algorithms would require specific thresholds for each pair of stations to be compared. Although this has undoubtedly already been recognized in some systems, such recognition has been in an ad hoc fashion in those systems with which the authors are familiar and not on the basis of functions such as those in Figure 7.

An important implication of the finding that the magnitude of the downward shift in occupancy due to grade increases as flow increases is that the threshold for the spatial difference in occupancy between affected stations should depend on the flow. The preliminary indication is that this dependency might be reasonably accounted for by "normalizing" the spatial difference in occupancy by dividing it by the occupancy at the upstream station. Most versions of the California-type algorithms do compare this relative spatial occupancy difference against a threshold, but it is also necessary to compare the actual spatial occupancy difference against another threshold. Because this latter threshold should clearly depend on flow, it appears desirable for such algorithms to directly or indirectly incorporate the flow-occupancy function for each detector station for the prevailing operating conditions.

Most of the time, on most freeways, station-specific calibration of comparative algorithms is not a problem because, conceivably, detector data can be used to give a ready-made set of functions calibrated for each station, for day or night, during normal weather conditions. The problem is that it is difficult, if not impossible, to specify the entire range of freeway operating conditions and have a separate function for each possible condition. For example, there are many degrees of weather conditions, and it would be necessary to specify what a condition is in terms of its effect at a given station. A possible solution that is being explored in ongoing work is to update the uncongested flow-occupancy functions on line. Experience with 30-sec data suggests that this approach is likely to bear fruit.

It should also be pointed out that thresholds are required even for incident detection logic systems that are not based on comparing stations, such as that of point detection (smoothing) and that of the flow-occupancy-speed–based model suggested previously (7). In such cases, the importance of being able to explain the effect of grade on operations is that it would be necessary to identify the uncongested flow-occupancy function for each detector station at all times. In principle, it is desirable to know, for each flow value, the prevailing occupancy limit for uncongested operation.

SUMMARY

The results presented in this paper are in accord with intuition and reality: operations on a freeway can be affected by its vertical profile, and in effect, upgrades can cause an increase in occupancy for a given flow. Because this effect might vary over time with environmental and other traffic operating conditions, it has been suggested that incident detection logic should be capable of continuously updating the flow-occupancy function at each detector station.

Three useful directions for further work are indicated. First, it appears feasible and fruitful to explore how uncongested flow-occupancy functions can be continuously updated for each detector station. This process should automatically capture the confounding effects of weather, but it might still be desirable to explore how a combination of inclement weather and grade affects operations. The second direction is a more detailed exploration of how occupancy-based thresholds in comparative incident detection logic might be allowed to depend on flow at stations where operations differ because of grade. Finally, the results of trying to capture the variety of uncongested flow-occupancy functions with a single catastrophe theory model should be interesting. Conceptually, this appears feasible, but the issue will remain unresolved until the flow-occupancy-speed relationship can be mathematically transformed into a catastrophe theory surface. Also, it is necessary to examine whether grade affects the widely scattered congested operation and, if so, whether such an effect can be modeled. For the present purposes, however, this issue is not of primary interest, because the main purpose of this paper was to seek improvements to incident detection logic by being better able identify the limits of uncongested operation.

ACKNOWLEDGMENTS

This research was supported under a grant from the National Sciences and Engineering Research Council of Canada. Data were supplied by the Freeway Traffic Management Section of the Ontario Ministry of Transportation.

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Impacts of TSM Improvements on Eastbound SR 520

NANCY L. NIHAN

In 1986, the Washington State Department of Transportation sponsored a project that analyzed and evaluated the impacts of ramp metering and a new ramp HOV lane on eastbound highway SR 520, which connects Seattle to the suburbs east of Lake Washington. The data analyzed included postcard origin-destination surveys, postcard surveys of perceived travel times and vehicle occupancies, manual vehicle occupancy counts, floating car travel times, queue length counts, electronic volume and lane occupancy counts, and bus travel times. The results indicated that the number of carpools and vanpools increased significantly on the ramp with the new HOV lane and that the overall level of service was improved for main-line SR 520. A significant number of trips were diverted from the local neighborhood to I-5. This result was expected and had the desired effect of diverting trips from the neighborhood and increasing HOV ridership.

In this paper, the assessment of transportation system management (TSM) improvements to two on-ramps on the highway SR 520 eastbound link connecting the city of Seattle, Washington, to suburbs east of Lake Washington is summarized. The on-ramps in question (at Montlake and Lake Washington Boulevard) are the last eastbound on-ramps before the SR 520 bridge across Lake Washington. Figure 1 shows the study location, including the SR 520 link. Figure 2 shows the locations of the two on-ramps. The two communities adjacent to these two ramps are the University of Washington (UW) to the north and the Montlake residential neighborhood to the south.

The TSM improvements at the study location consisted of the installment of ramp metering at both ramps and the construction of a high-occupancy vehicle (HOV) bypass lane at the Montlake on-ramp. The primary objective of the TSM improvements for the Montlake community was to divert through traffic from the neighborhood, whereas for the Washington State Department of Transportation (WSDOT) the objectives were to increase the percentage of HOV travel and to improve the main-line level of service.

The literature on TSM experiences in other cities (*16*) supports the findings of the SR 520 study. TSM strategies such as ramp metering and exclusive HOV lanes have been proved to increase main-line speeds and vehicle occupancies in Minneapolis, Sacramento, Portland, Miami, Houston, Boston, Los Angeles, Washington, D.C., Chicago, and other cities. These effects were the two prime WSDOT objectives for the SR 520 project, and both were satisfactorily realized. The Montlake Community objective, diversion of trips through the neighborhood, was also realized.

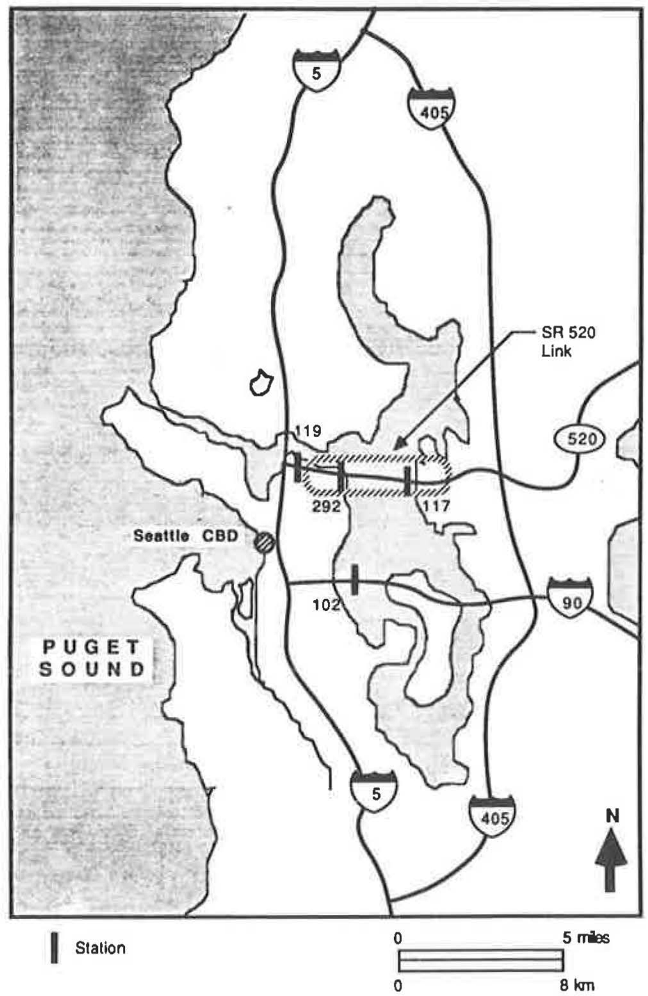

FIGURE 1 Study location.

STUDIES AND ANALYSIS

On March 10, 1986, ramp metering of both the Lake Washington Boulevard and Montlake on-ramps began, along with operation of the HOV lane at the Montlake ramp. To evaluate the impact of this TSM intervention, the following data collection procedures were employed:

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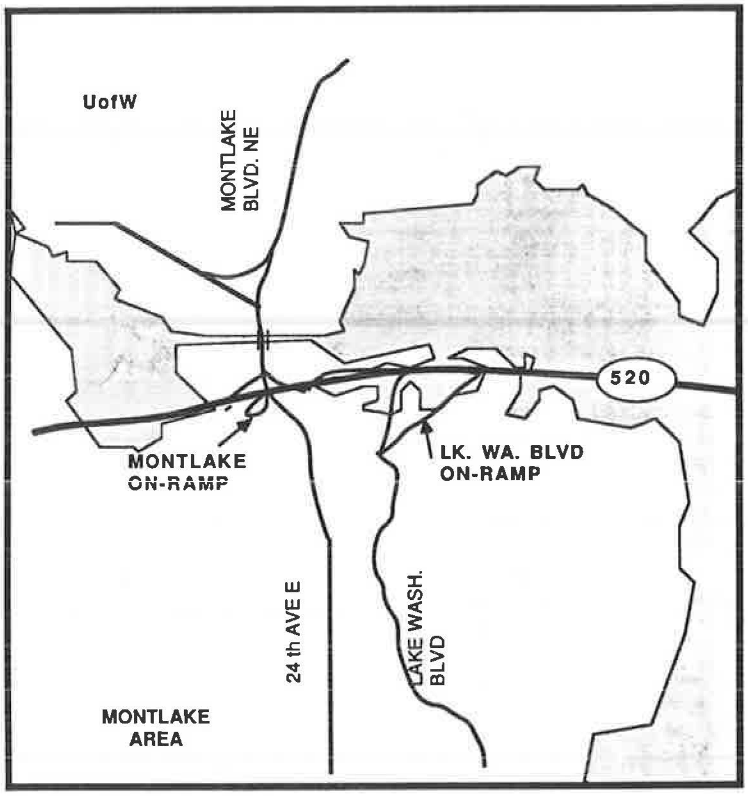

FIGURE 2 Eastbound on-ramps for SR 520 bridge link.

- Postcard surveys of origin and destination, travel time, and vehicle occupancy (February 25 and April 29, 1986);
- Manual vehicle occupancy counts (February 24 and 25, April 28 and 29, 1986);
- Bus arrival time counts (February 24 and 25, April 28 and 29, 1986);
- Manual counts of queue lengths on the ramps (February and April 1986);
- Floating car studies of travel time February through April 1986);
- Electronic volume and lane occupancy counts for main-line and ramps (February through April 1986); and
- Electronic bus passenger counts and travel time counts (February through April 1986).

A detailed description of the data collections and statistical analyses is given by Nihan (*7*). A summary of these findings follows.

Postcard Surveys

Origin-Destination (OD) Data

On February 25 and April 29, 1986, a postcard origin-destination (OD) survey was conducted at both the Montlake and Lake Washington Boulevard on-ramps during the 2-hr afternoon peak period. Some 1,000 postcards were handed out at each ramp at this time period during both the before and after data collections. The number of returned cards for the February and April counts were 627 and 531 for the Montlake ramp and 571 and 486 for the Lake Washington Boulevard ramp, respectively. The postcard questionnaires were duplicates of questionnaires that had been handed out in April 1982 as part of a previous WSDOT study. This earlier survey yielded 407 responses for the Montlake ramp and 556 responses for the Lake Washington Boulevard ramp. With the results of this additional survey, there were two sets of before data (April 1982 and February 1986) and one set of after data (April 1986).

As mentioned previously, one concern of Montlake community residents was the percentage of travelers from downtown and other zones of origin. Most of these commuters should reasonably have selected the I-5 route to SR 520 but were instead using local streets and arterials to enter SR 520 at the Montlake or Lake Washington Boulevard ramps.

The before and after OD surveys indicated that before ramp metering, 40.3 percent of the trips using the two eastbound on-ramps had originated in these other zones. This was reduced to 33.3 percent after metering. Thus ramp metering had a diversionary effect on vehicles entering the two on-ramps, and a statistically significant percentage of those trips that had previously come from downtown and southern zones and passed through the Montlake neighborhood were diverted to other routes (most likely I-5). There were two reasons for these desired route diversions: (*a*) increased queues and travel times for drivers of single-occupant vehicles (SOVs) at both SR 520 on-ramps after metering and (*b*) improved level of service (LOS) for all vehicles on I-5 because of the improved LOS on main-line SR 520 after ramp metering.

Perceived Travel Times and Vehicle Occupancy

The postcard survey questionnaire also included questions about travel time and vehicle occupancy. For the 1986 before and after surveys, a statistically significant increase in perceived travel time occurred on both ramps after the introduction of ramp metering. Average total travel time increased from 35.9 min to 38.4 min for the Montlake ramp ($p < .05$) and average total travel time increased from 35.7 min to 38.9 min for the Lake Washington Boulevard ramp ($p < .01$). It therefore appears that total perceived trip travel times increased slightly for both ramps due to the ramp metering. These results are further supported by actual travel time data collected by the floating car method and by the volume/lane occupancy data collected electronically. These increased travel times for SOV users of both ramps contributed to the desired route diversions mentioned previously.

The average vehicle occupancies for vehicles sampled in the 1986 postcard surveys were also statistically analyzed. These included single-occupant automobiles, carpools, and vanpools but did not include buses. The before and after postcard surveys of 1986 indicated that the TSM strategies caused no change in vehicle occupancy for the Lake Washington Boulevard ramp, but there was a significant increase in vehicle occupancy for the Montlake ramp. Average vehicle occupancy for the Montlake ramp increased from 1.30 people/vehicle to 1.49 people/vehicle ($p < .01$) after the introduction of the HOV lane and ramp metering. This result implied that a significant increase in the number of carpools and vanpools had been caused by the introduction of the HOV lane on the Montlake on-ramp and by the increased queue lengths that resulted from the metering on both ramps. This conclusion was further supported by data from manual counts.

Manual Vehicle Occupancy Counts

Vehicle occupancy counts were taken during the peak hours of February 24, 25 and April 28, 29, 1986, for the Montlake and Lake Washington Boulevard on-ramps and the two eastbound main-line SR 520 lanes. The vehicle occupancy data available for buses were not sufficient for analysis and will not be discussed here. The results indicated a significant decrease in the percentage of single-person automobiles and significant increases in percentages of carpools and vanpools on the Montlake ramp after introduction of the HOV lane. There was an increase in the percentage of single-person automobile trips and a corresponding decrease in carpool and vanpool trips observed on the Lake Washington Boulevard ramp, indicating a possible shift of carpool and vanpool trips to the Montlake HOV lane. Although the percentages of HOV changes at each ramp were similar (4 percent decrease in SOVs at Montlake and 4 percent increase in SOVs at Lake Washington), volumes on the two ramps (5,074 at Montlake versus 3,460 at Lake Washington Boulevard) indicated a larger absolute increase in HOVs at Montlake than would be explained totally by the shift from the Lake Washington Boulevard ramp. The main-line SR 520 lanes did not exhibit significant changes in vehicle occupancy.

With the exception of the possible shift in HOVs between ramps, the manual count results supported the postcard survey data and can be summarized as follows:

- HOV usage increased at the Montlake ramp. The postcard survey indicated an increase from 1.30 to 1.49 people/vehicle on the Montlake on-ramp. The manual counts indicated a change from 1.23 to 1.32.
- Some carpools and vanpools may have shifted from the Lake Washington Boulevard on-ramp to the Montlake on-ramp. The manual counts indicated a change from 1.26 to 1.20 people/vehicles. This was contradicted by the OD survey data, which indicated no significant change in vehicle occupancy at the Lake Washington Boulevard on-ramp.
- Vehicle occupancy on main-line SR 520 remained stable.

Although both the postcard surveys and the manual counts indicated a significant increase in vehicle occupancies at the Montlake on-ramp, the observed occupancy levels were lower for the manual counts than for the surveys. This difference may have been caused by a sample bias in the postcard returns that favored non-SOV drivers or a simple difference in the manual counts, which included counts for two extra days (Monday, in each case). Because Tuesday is a more representative day, the postcard survey data may be favored here. In any case, both data sets indicated an increase in HOV travel at the Montlake on-ramp.

Bus Arrival Times

Bus arrival times for February 24, 25 and April 28, 29, 1986, were collected at the Evergreen Point Freeway station on the east side of Lake Washington (east end of the SR 520 link) between 3:30 p.m. and 6:00 p.m. These data did not display significant differences in late and early times when they were compared with the actual schedules for these days. A parallel electronic data collection was conducted by Metro, the local transit authority, using specially equipped buses. However, this sample, which provided only 11 travel time values for all before-and-after periods and all bus routes, was inadequate for serious study.

A better indication of the effect of the ramp metering on bus service was Metro's determination over several months that buses were arriving at the Montlake and Evergreen Point Freeway flyer stations earlier after installation of the ramp controls and HOV lane. Metro therefore revised its fall 1986 schedules to reflect these time savings. Schedules for buses coming from downtown on I-5 to SR 520 were revised to reflect a savings of 3 minutes; schedules for buses using the Montlake ramp to SR 520 were revised to reflect a savings of 4 minutes. These facts, coupled with the time savings realized by the HOV lane on the Montlake ramp and the faster speeds on main-line SR 520 due to the metering, suggested that all bus service benefited from the TSM improvement. (It should be noted that there was no bus service using the Lake Washington Boulevard ramp either before or after the improvements.) Subsequent Metro ridership increases supported these conclusions (*9*).

Manual Ramp Queue Counts

Data on queue lengths were also collected manually. Queue lengths were measured every 15 min from 2:30 p.m. to 5:45 p.m. at both on-ramps. The 10 weekdays between February 17 and 28, 1986, provided the before data, and the 10 weekdays between April 14 and 28, 1986, provided the after data. Queue lengths were expressed in vehicles and were displayed graphically for day and time of day in three-dimensional plots. The total of before data for each station was also aggregated, as was the total after data. These totals were compared by using before-and-after histograms and the Mann-Whitney U statistic. It was found that the queue lengths were significantly longer at both ramps after the ramp controls were in effect. The average queue length for the Montlake ramp increased from 60 to 113 vehicles ($p < .01$), whereas the average for the Lake Washington Boulevard ramp increased from 14 to 80 vehicles ($p < .01$). This had the desired deterrent effect on SOVs and non-neighborhood traffic.

Figure 3 shows the queue length data for the Lake Washington Boulevard on-ramp for 8 days before the ramp metering and 10 days after the ramp metering. The before days included January 18–February 21, 1986, and February 24–28, 1986, and the after days included April 21–25, 28–30, and May 12, 1986. The plots show queue length in vehicles by date and time of day between 2:30 p.m. and 5:45 p.m. A similar plot was obtained for the Montlake on-ramp. Both plots indicated an increase in queue length for the on-ramps after the ramp metering intervention. This increase in queue length was most pronounced for the Lake Washington Boulevard on-ramp.

Floating Car Studies

Floating car studies of travel times were performed for February and April. From the collected data, 10 before runs and 10 after runs from the Montlake parking lot at UW to Evergreen Point (the end of the bridge), all made between 4:30 p.m. and 5:30 p.m. and using the Montlake on-ramp, were available. For each of these runs the time to reach the Montlake ramp from the parking lot (t_a), the time on the Montlake on-ramp (t_b), main-line time across the bridge (t_c), time to reach main line ($t_a + t_b$), and total travel time ($t_a + t_b + t_c$) were computed.

Before versus after values were compared by using the Mann-Whitney U statistic. These results indicated an increased time to reach the main line, an increased total travel time, and a slight decrease in main-line travel time. When the results were analyzed separately, they indicated no statistically significant changes in the times to get to the on-ramp and the times on the on-ramp. However, the times were increased marginally in both cases. When the results were combined ($t_a + t_b$), there was a statistically significant increase in the total time to reach the ramp-merging point. This median increase was 243.5 s. The results also indicated an insignificant decrease in main-line travel time but a significant increase in the total travel time from point of origin to point of destination. The median increase in total travel time was 238.5 s.

The mean differences in total travel time ($t_a + t_b + t_c$) and time to the ramp merge ($t_a + t_b$) were 281 s and 301 s, respectively. The travel time results therefore indicated that a net total increase in travel time was experienced by travelers from UW to the east side. This increase was entirely due to a larger increase in the time it took to go from the point of trip origin to the ramp merge with SR 520 and was offset slightly by improved travel time on the main-line link. These results and the volume/lane occupancy results indicated that travelers already on the main line experienced a slightly improved travel time. The average increase in time spent on the Montlake on-ramp was 5 min. Thus, because the HOV bypass did not experience this increase, there was roughly a 5-min difference in trip time between SOVs and HOVs using the Montlake on-ramp.

Volume/Lane-Occupancy Counts

A special technique known as time series intervention analysis was used to analyze the electronic volume/lane occupancy data for the intervention effects of the ramp control program. This technique, described by Davis and Nihan (*8*) and Nihan and Davis (*9*), is related to other work (*10, 11*). At its simplest (linear models with residuals that are not serially correlated), this technique is just linear regression analysis performed on time series data with an intervention variable included as one of the independent variables. The intervention variable has values of 0 for time periods occurring before the intervention of interest and values of 1 for time periods following the intervention. Simple regressions are run for the performance variable of interest (e.g., volume on eastbound SR 520), using both a covariable to control for trends (e.g., volume on east I-90) and the intervention variable representing the time that the ramp controls were put into effect as independent variables. The resulting coefficient of the intervention variable for the above example gives the amount of increase or decrease in SR 520 volume due to the ramp controls. When correlated residuals are

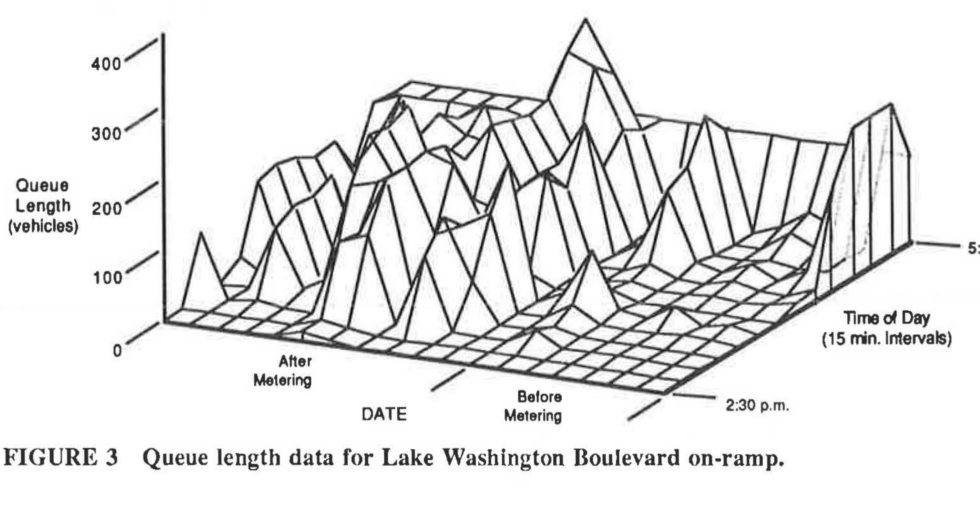

FIGURE 3 Queue length data for Lake Washington Boulevard on-ramp.

present, the time series data cannot be modeled with simple linear regression techniques, and more complicated time series models known as ARIMA intervention models may be required. Such model forms were not required for the SR 520 analysis but are discussed elsewhere (*8*).

During the study, electronic data for main-line and ramp volumes and for lane occupancy was continually being transferred to a UW data base through a telecommunication link between the WSDOT Traffic Systems Management Center (TSMC) in Seattle and UW. These data were in the form of 5-min volume/lane occupancy values for each lane from numerous presence detector stations throughout the Seattle area. The 5-min lane and ramp data could be summarized by time interval and by station.

The telecom data were used to analyze the change in LOS along the SR 520 section affected by the ramp controls. Three stations were chosen for these regression analyses (see Figure 1). These included station 292 (between Montlake and Lake Washington Boulevard on-ramps), station 117 (Evergreen Point Bridge toll plaza), and station 102 (I-9 bridge toll plaza). Stations 292 and 117 were chosen to assess the impact of the ramp controls on SR 520 main-line LOS, whereas station 102 provided covariable information used to control for trend effects. For each half-hour period between 3:00 p.m. and 6:00 p.m., for each station, and for each week day between February 10 and April 30, 1986, the total volume and average lane occupancy were computed from presence detector data.

Separate time series analyses on the lane occupancy data and on the volume data were performed to assess the true increases or decreases due to ramp metering at stations 292 and 117. The lane occupancy regressions indicated significant decreases in average occupancy for station 292 due to the controls and small but significant increases in average volumes. Thus the regression results indicated an improved LOS at station 292 that was probably caused by reduction of merging conflicts due to the ramp metering at the Montlake on-ramp. The results for station 292 were taken as the best LOS measures for the main line. It should be noted, however, that later investigation indicated that the loop detectors at station 117 were consistently overestimating volumes. Therefore the results for this station were largely ignored, although relative results supported the results obtained for station 292.

As analysis of the volume/lane occupancy data continued, the effective vehicle length suggested by TSMC (22 ft) was assumed, and it was also assumed that this effective length remained stable during the entire study period. A longer effective length would give similar relative results but would cause slightly lower before and after speeds. Main-line speeds were then calculated from the before and after volume/lane occupancy data. Table 1 presents these calculations for station 292. Speeds at station 292 were significantly increased for all time periods, representing significant improvements in main-line LOS at that point.

TABLE 1 INTERVENTION CHANGES AT STATION 292

Period	Before Speed (mph)	Change (mph)	Significance
3:00–3:30	25.1	+10.4	$p < .05$
3:30–4:00	24.4	+9.7	$p < .05$
4:00–4:30	23.9	+10.5	$p < .01$
4:30–5:00	26.7	+7.9	$p < .05$
5:00–5:30	27.1	+5.6	$p < .10$
5:30–6:00	25.2	+4.8	$p < .05$

In addition to the regression analyses, several days' worth of volume/lane occupancy data were plotted to produce graphical displays of the impacts of ramp metering on the SR 520 main line. Three sets of volume/lane occupancy plots were made for stations 292, 117, and 119. The plots displayed 5-min volume/lane occupancy values for the period 6:00 a.m.–6:00 p.m. for 3 days before the ramp control intervention (February 26–28, 1986) and 3 days after ramp controls were in effect (March 11–13, 1986). Although the ramp controls were in effect only during the afternoon peak period, full-day data sets were used to observe the complete volume and occupancy curves and therefore to assess the general capacity limitations and LOS ranges. As before, station 292 represented the location between the Montlake ramp merge and the Lake Washington Boulevard merge, and station 117 represented the former location of the Evergreen Point toll plaza. Station 119, located at the beginning of the eastbound SR 520 lanes just after the junction of I-5 and SR 520, represented flow upstream from the ramp merges.

Figure 4 presents the volume/lane occupancy plots for station 292. The solid circles represent points of volume/lane occupancy for days before the ramp controls were in effect, and the open circles represent the points on the volume/lane occupancy curve for days after the ramp control improvement.

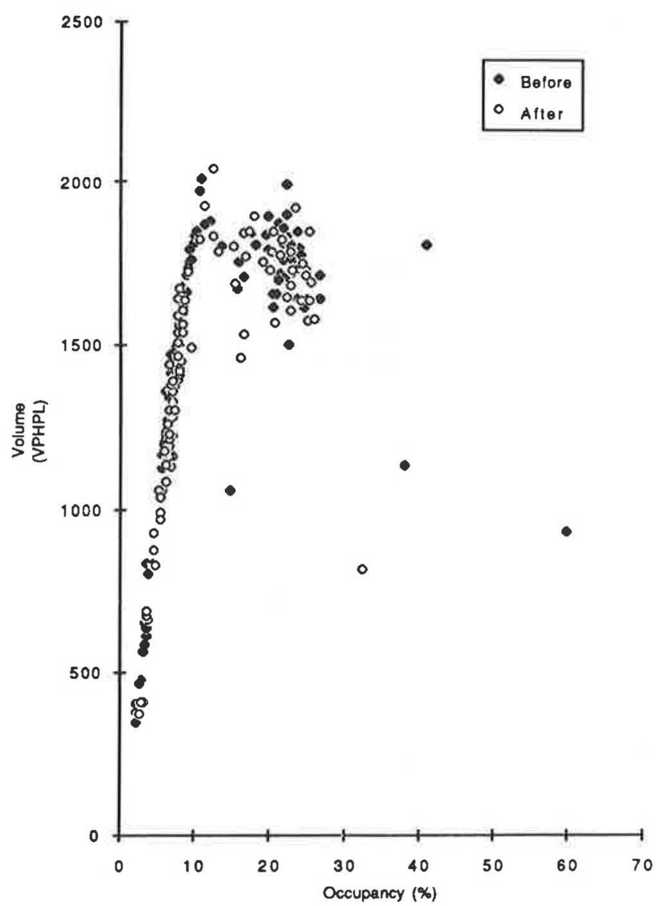

FIGURE 4 Volume versus lane occupancy (Station 292).

The graph illustrates a shift in points away from the LOS F range after the ramp control intervention. Note the scatter of solid circles to the right of each plot indicating level of service F. The open circles corresponding to the same time periods are less scattered and move to the left and vertically, indicating an improvement in LOS for these periods. Similar plots were obtained for stations 117 and 119. Both plots reflected improvements in main-line SR 520 LOS due to the ramp controls.

CONCLUSIONS

Postcard Surveys

Ramp metering appears to have had a diversionary effect on vehicles entering the Lake Washington Boulevard on-ramp so that a significant percentage of those who had previously come from the downtown and southern zones and then passed through the Montlake neighborhood were diverted to other routes (most likely I-5). This was one of the desired outcomes of the TSM strategy.

Total perceived trip travel times increased slightly on both ramps due to the ramp metering. This result was further supported by actual travel times obtained from floating car studies. The before-and-after postcard surveys indicated a significant increase in vehicle occupancies for the Montlake ramp but no change for the Lake Washington Boulevard ramp. Thus the postcard surveys, which were limited to automobiles and vans, implied a significant increase in the numbers of carpools and vanpools caused by the introduction of the HOV lane on the Montlake on-ramp. This conclusion was supported by manual vehicle occupancy counts.

Manual Vehicle Occupancy Counts

The data obtained for buses in these counts were not sufficient for analysis. The remaining data indicated a significant decrease in the number of SOVs and significant increases in the number of carpools and vanpools on the Montlake ramp due to the introduction of the HOV lane. The manual counts indicated a slight increase in single-person automobile trips and a corresponding decrease in carpool and vanpool trips on the Lake Washington Boulevard on-ramp, indicating a possible shift in carpool and vanpool trips to the Montlake HOV lane. The main-line SR 520 lanes did not exhibit significant changes in vehicle occupancy.

Volume/Lane Occupancy Results

The time series intervention analyses of volume/lane occupancy data indicated statistically significant improvements in level of service on main-line SR 520 after the ramp controls were introduced. Plots of volume and occupancy for several days' data supported these time series regression results. If a stable effective vehicle length for the before-and-after traffic streams is assumed, the electronic data showed significant improvements in main-line SR 520 speeds.

Travel Time: Floating Car Method

The statistical analysis of several days' travel time data indicated that a net total increase in travel time was experienced by travelers from UW to the east side (an average of 4.7 min). The average increase in travel time from the point of origin to the ramp merge with the main-line link was 5.0 min. These results and the volume/lane occupancy results indicated that travelers already on the main line experienced a slightly improved travel time, whereas travelers using the ramps were dissuaded from SOV travel and through travel on neighborhood arterials. Travelers using the new HOV lane on the Montlake ramp had a 5-min travel time advantage over SOV travelers.

Ramp Queue Lengths

Plots and statistical tests indicated an increase in queue lengths for the on-ramps after the ramp metering intervention. The increase in queue length was most pronounced for the Lake Washington on-ramp. These queue length increases for SOVs resulted in the desired shifts in route and mode choice. The 5 min saved by HOVs on the Montlake Ramp resulted in a change in the automobile occupancy from 1.3 people/vehicle to 1.5 people/vehicle. This change applied to vans and automobiles only and did not reflect the suspected additional increase in bus occupancy, which was not measurable.

Bus Arrival Times and Electronic Travel Times

The manually collected bus arrival time data did not give conclusive results. Also, the travel time data sample collected electronically by Metro was too small for adequate analysis. However, the observed main-line speed improvements, the 5-min HOV lane time advantage, and the changes that Metro made in the fall 1986 bus schedules to reflect improved travel times (an average of 3 min saved for buses coming from downtown on I-5 and 4 min for buses using the Montlake on-ramp) led to the conclusion that bus travel times were significantly improved due to the ramp metering and the introduction of the HOV lane.

RECOMMENDATIONS

The conclusions just discussed led to the overall final determination that the ramp metering and HOV lane have had the desired results. That is, these TSM techniques have

- improved main-line travel,
- increased the attractiveness of carpools, vanpools, and buses, and
- diverted unwanted traffic coming from other parts of the city into and through the neighborhood.

It is recommended that this type of TSM strategy be used in situations such as the SR 520 case, where main-line volumes are already at or near capacity during the peak hours and where even small volume diversions and volume controls can have a significant impact on main-line LOS.

ACKNOWLEDGMENTS

The research described in this paper was sponsored by the Washington State Department of Transportation. Special thanks are due to Mark Hallenbeck and Gary Davis, who assisted with the data collections. Davis also assisted with the computer runs.

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