Urban and Environmental Systems

Report No. UES 73-2
October 1973

THE MANAGEMENT OF URBAN FREEWAY TRAFFIC

by
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FOR PRESENTATION AT THE
87th ANNUAL CONGRESS OF THE
ENGINEERING INSTITUTE OF CANADA
MONTREAL, OCTOBER 1973

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McGill University
Montreal

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ABSTRACT

The advent of computer-controlled electronic freeway surveillance and control systems in the past decade represents a potentially significant new operational tool for traffic operations engineers in large urban areas. These systems are capable of responding to rapidly changing traffic conditions and in various demonstration projects they have proven useful in maintaining an acceptable level of service for freeway operations, reducing the extent and duration of traffic congestion, minimizing the adverse effects of accidents and other incidents on traffic operations, and reducing accident experience. Significant new surveillance and control systems are being developed in Los Angeles and Minneapolis (where a primary objective is the efficient operation of express bus service in mixed freeway traffic), and research is in progress in France, West Germany, Great Britain, Italy, and Japan, as well as in North America. Surveillance system goals and techniques for achieving these goals are reviewed in this paper with particular emphasis on the problem of managing unexpected capacity-reducing incident situations. Recent research has demonstrated the feasibility of detecting incidents from traffic flow data, and the usefulness of this technique is compared with alternatives such as closed circuit television surveillance and emergency roadside telephones.

INTRODUCTION

The urban highway planner's traditional solution to congested freeways has been to build more freeways, but there is growing recognition that congestion cannot be prevented by highway design alone. Furthermore, unless the necessary right-of-way has already been reserved, it is becoming economically and politically more impractical to either widen existing freeways or build new ones in developed urban areas. A need has thus developed for techniques to make better use of existing freeways by managing the traffic seeking to use the freeway. Freeway congestion is largely a phenomenon of morning and afternoon peak periods, and it is at these times that freeway capacity should be considered a scarce public resource whose allocation to users is regulated.

Congestion is the result of there being too many vechicles on the freeway. The capacity of the freeway, the maximum number of vehicles that normally can pass through in a given time period, is reached at traffic densities of about 60 vehicles per mile per traffic lane. At greater densities average speeds decrease, traffic flow decreases, and operations in general become unstable. The traffic engineering solution to congestion should be to prevent excess traffic by restricting access to the freeway when necessary. Research in the past 15 years has led to the evolution of the electronic freeway surveillance and control system where a digital computer monitors the traffic on the freeway and determines optimal control strategies to divert the excess traffic. Typically, the attractiveness of the freeway has led to under-utilization of adjacent city streets, so a control strategy works toward greater utilization of all components of the freeway corridor. Surveillance system goals and techniques for achieving these goals are reviewed in this paper with particular emphasis on the management of congestion caused by unexpected capacity-reducing incidents.

FREEWAY SURVEILLANCE AND CONTROL

All freeways are kept under surveillance by moving police partrols, and in recent years closed circuit television systems have been used to monitor the traffic on bridges, in tunnels, and troublesome sections of freeways. The advent of sophisticated computer-supervised freeway surveillance and control systems adds a potentially significant new dimension to the term surveillance. In 1964 Weinberg [1] defined computer-supervised surveillance as

> A closed loop system ... that provides for surveillance of traffic operations which can be processed by a computational logic in a real-time computer, testing observed conditions against a set of decision rules, selecting commands in light of the results of the tests, activating appropriate controls or communicating with drivers to improve traffic movement when necessary, and then reassessing the traffic behavior to determine if further corrections are to be made.

The principal goal of a freeway surveillance and control system is to maintain an acceptable level of traffic service on the freeway. Traffic is monitored by means of induction loop detectors imbedded in the pavement or ultrasonic devices on overpasses, generally at half-mile intervals in each lane. When freeway demand exceeds capacity at some point, the entry of additional vehicles to the freeway upstream is restricted by means of traffic signals installed at each entrance ramp. Excess demand is either "stored" or diverted to alternate routes (Figure 1). Vehicles queued at the entrance ramp signal represent stored demand which is allowed to enter the freeway after some delay. This can be an effective way to control freeway congestion if sufficient entrance ramps are metered and excessively long ramp queues can be avoided through diversion.

Ramp metering is thus the functional basis of the system. By limiting the rate at which vehicles enter the freeway, the ramp metering controls freeway corridor operations. For drivers already on the freeway there should be tangible benefits in terms of less congestion during the peak period and more orderly merging movements at the entrance ramps. Demonstration projects in Houston, Chicago, and Detroit have shown significant reductions in the extent and duration of peak period congestion and in the number of accidents that occur on the freeway [2,3]. The reduction of merging conflicts benefits the ramp user as well. A study of rear-end collisions on an entrance ramp in Atlanta where the acceleration lane was of insufficient length showed that ramp metering brought about a 90% reduction in these collisions [4]. Ramp metering installations thus can compensate for substandard geometric features and perhaps reduce the number of accidents on the entrance ramps.

DRIVER WILLINGNESS TO DIVERT

Savings in travel time by on-freeway users are at the expense of the ramp user unless improved freeway travel times compensate for his entrance ramp delay. Over a long period of time drivers may learn to avoid congested ramps and avoid the freeway for short trips. This will mean more travel on city streets and there must eventually be a trade-off in the amount of congestion that can be transferred from the freeway and the congestion that may be created on city streets.

Some researchers maintain that demand redistribution can be accomplished by providing drivers with current traffic conditions information on the freeway. Heathington, Worrall, and Hoff surveyed 732 Chicago-area drivers on the information desired by them in a freeway corridor [5]. They found that drivers on the freeway desired relevant traffic information no matter what the prevailing state of traffic operations. If they were confronted with congestion they desired specific information as to whether there was an accident or other capacity-reducing incident ahead. Dudek, Messer and Jones surveyed 505 Texas drivers and found the most preferred types of information to be the location and length of the congested area (71% of the respondents) and severity of congestion (69%) [6]. The majority of the respondents would use an alternate route to a freeway to bypass such congestion.

Although the above results apply to drivers already on the freeway, it can be inferred that drivers intending to enter a freeway would desire much the same sort of information prior to their entry. Dudek, Messer and Jones found that motorists would prefer to divert to an alternate route before reaching the freeway rather than when already on the freeway. [6] With specific information regarding the extent of the disruption drivers can determine their best alternate route to avoid the congestion and still conveniently reach their destination.

Several experiments with variable message signs to inform drivers have been conducted on the Lodge Freeway in Detroit. No effort was made to encourage freeway drivers to leave the freeway in the event of congestion, but lane control signals and variable speed limit signs were used to provide advance warning of congestion and encourage more orderly traffic movements. [7] Drivers generally ignored the advisory speed signs but did tend to obey lane closure signals if freeway demand was less than capacity. When demand exceeded the remaining capacity when a lane was closed the signals had little impact. Thus, during peak periods of high demand "the benefits of the lane control signals [were] very small" in terms of improving freeway travel times. Lane control signals are the primary means for surveillance and control on the Trans-Canada Highway to be opened in 1974 in downtown Montreal. If the Detroit experience is repeated in Montreal, then it is unlikely that the signals will be effective in alleviating peak period congestion, although they should be useful during uncongested periods in providing advance warning of lane blockages.

To encourage diversion before drivers enter the freeway, dynamic ramp condition information signs were installed in 1968 and 1969 along a convenient surface street alternate route to the Lodge Freeway.[8] Drivers approaching the vicinity of each metered entrance ramp were informed of the existence of uncongested downstream entrance ramps should the adjacent ramps be congested or advised to continue along an alternate route should all the ramps displayed on a sign be congested. A survey of Lodge Freeway users showed that 41% claimed to use the signs and 27% would avoid the freeway altogether if a sign indicated all entrance ramps congested.[8]

THE IMPACT OF INCIDENTS ON TRAFFIC FLOW

Accidents and other incidents are statistically rare events, occurring once every 20,000 to 30,000 vehicle-miles of travel, but on high volume freeways they will occur with such frequency that they must be taken into account by surveillance and control systems. For example, 4 to 5 lane blockages occur each day on a 6.5 mile section of the Gulf Freeway in Houston.[9] The effects of a lane-blockage incident on traffic flow are significant. Blockage of a single lane halves the capacity of a three-lane freeway, a capacity reduction disproportionate to the reduction in width of the travelled way.[9] An accident that blocks two lanes out of three was found to reduce capacity by 79%, and even incidents on the shoulder occasionally affect freeway traffic when they attract the attention of passing motorists.

The presence of a lane blockage incident is likely to create considerable excess freeway capacity downstream which can be used to advantage in optimizing freeway corridor operations if the means are available for diverting freeway demand to these sections while the incident is in progress. Plots of downstream volumes during three Lodge Freeway incidents at varying times of the peak period are presented in Figure 2. The considerable amounts of available downstream freeway capacity are evident. The shaded areas represent the stored demand upstream of the incident. For the incident of long duration in the upper part of Figure 2, during which time freeway traffic was stopped by the police for several minutes, over 1000 vehicles were prevented from passing the downstream detector station between 3:14 and 3:35 p.m.

MANAGING INCIDENT SITUATIONS

The optimal strategy for a surveillance and control system during a capacity-reducing incident is to immediately restrict or prevent additional vehicles from entering the freeway upstream of the incident, with these drivers advised to enter downstream and take advantage of uncongested freeway conditions there (Figure 1). As indicated in Figure 3, the diversion of some freeway users will allow normal operating conditions to be restored sooner, and the total delay to on-freeway users will be reduced by the shaded area.

The desired demand redistribution can be achieved by informing potential ramp users of congestion specifically caused by an incident by ramp condition information signs or variable message signs (Figure 1). Metering rates upstream can be more acceptably reduced, or the ramps closed, if the reason is an incident and drivers are made aware of this through the signing system. Concurrently, drivers can be advised to proceed along alternate routes with the knowledge that, whatever the downstream operations are at present (on-freeway traffic that had passed before the incident began) downstream capacity will be available by the time the diverted drivers reach the downstream entrance ramps. This, of course, can be accomplished only if immediate response is made by the surveillance controller to the incident. Once an incident has begun, demand at downstream stations will slacken within minutes. To fully utilize this excess capacity there must be immediate diversion of upstream vehicles to the surface streets. Conventional means of communication with drivers are presently inadequate for the task. A Houston evaluation of commercial radio announcements of freeway accidents showed time lags averaging 20 to 30 minutes in reporting them [10]. The stations received their information from the police.

The ability of the Lodge Freeway surveillance system to divert traffic is indicated in Table I when a four-car accident occurred at 3:14 p.m. (see also, Figure 2) between the Seward Avenue and Chicago Boulevard entrance ramps. Over 100 vehicles, some 20% of the demand at the nearest two ramps upstream, West Grand Boulevard and Seward, were diverted to the downstream Chicago and Webb ramps. This diversion was doubtlessly beneficial to freeway operations although insufficient to prevent some freeway congestion. Surti and Gervais [11] found that the addition of approximately 200 more vehicles during a half hour period on the service drive of the Lodge Freeway caused tension levels and travel time to significantly decline. However, the service index of the service drive remained better than that of the freeway when badly congested. Their study demonstrated the ability of city streets to handle some diverted traffic, the limit being perhaps when the service indices become equal for both the freeway and the alternate routes.

COMPUTER-SUPERVISED INCIDENT DETECTION

The Lodge Freeway surveillance and control system was about 10 minutes late in imposing minimum metering rates upstream of the incident of Table I. Since the forte of computer surveillance and control is its adaptility to rapidly changing traffic conditions, a need is thus indicated for an incident detection logic, as indicated in Figure 1, which could override surveillance control parameters to respond more effectively to incident situations.

A typical lane blockage incident has a duration of 5 to 25 minutes and is not detected until 5 to 10 minutes have elapsed. [9,12] Incidents are detected by police patrols on most freeways and some cities, notably Chicago, Washington, and Los Angeles, have installed emergency roadside telephones for use by stranded motorists. The combination of telephones and police patrols was found by Keller [13] to be the most cost-effective detection network from the point-of-view of motorist service, but not from the point-of-view of freeway operations engineers. Computer incident detection would provide a numerical scaling of the magnitude of the capacity reduction, information that could only be guessed at by a human observer. Furthermore, control measures could be undertaken immediately without the inevitable time lag where human interpretation is involved. A detection logic would also serve as a decision-maker by detecting and responding only to those incidents that significantly affect traffic operations.

The author has investigated a number of detection algorithms and found the most effective one to be the forecasting technique of exponential smoothing, using a basic traffic variable such as volume (vehicles per minute) or occupancy (a surrogate for traffic density). [14,15] Incidents are detected by the shock waves of congestion they generate in the traffic stream when the traffic variable in question deviates significantly from the forecast. The algorithm detected 46 of 50 typical lane blockage incidents within two minutes of the onset of congestion at the detector station. This is a better detection performance than by conventional methods and is even better than television surveillance. Experience with television surveillance on the Lodge Freeway has shown that even the best of observers will detect only 78% of the incidents visible on television because of error or fatigue.[16] Another study has shown a detection rate of 75% for individuals watching traffic on closed circuit television at distances of up to 1500 ft.[17]

Detection algoritms may thus be useful in supplementing a television system by directing the attention of observers to incident situations. By freeing observers of the necessity to continuously monitor freeway operations, the range of televison surveillance could be expanded with little or no increase in manpower and the less intensive system could serve as a means for confirming the validity of detection signals before costly aid resources are dispatched.

Detection algorithms remain in the developmental stage because they generate many false alarms and this would be a severe operational problem if the police were dispatched every time. The U.S. Federal Highway Administration is sponsoring research on the refinement of these algorithms to reduce **the** false alarm problem with a goal of having operational algorithms by 1975 or 1976. They also are investigating the potential for using these algorithms to determine the type of incident that has taken place, so that the proper aid can promptly be dispatched.

POTENTIAL ADVANCES IN DETECTION TECHNOLOGY

Receiving a detection signal would be straight-forward if it were possible to track each vehicle on the freeway continuously in time and space. Weinberg explored the present feasibility of continuous tracking and concluded that hardware limitations and prohibitive costs eliminate this approach[18]. For example, he felt that the external tracking of a vehicle's characteristic "signature" (such as voltage variation or phase shift) would be too costly for operational use and that the installation of individual vehicle transmitters was impractical for the near future. Furthermore, the individual recording and interpretation of all the vehicles on a freeway would be "fabulously expensive". Moskowitz concurred with the above in 1970 when he wrote that "any automatic method of detecting disabled parked cars and of doing anything about them is expensive and therefore highly unlikely to be implemented on a large scale in the forseeable future". [3]

Hence, the major computer-supervised freeway surveillance and control systems now in existence or in the planning stage, notably those in Chicago, Detroit, Houston, and Los Angeles, use point detectors located at key positions to sample traffic operations discretely in space and almost continuously in time. Neither Moskowitz nor Weinberg foresee the development of truly low-cost but accurate presence detectors which could be so closely spaced as to approximate area detection in the near future. Fortunately, the detection algorithms investigated by the author remain effective at detector stations up to a mile distant from a lane-blockage incident.

SOME NEW SURVEILLANCE AND CONTROL SYSTEMS

A number of demonstration surveillance and control projects have been established in the past 15 years in the United States. The growth of automobile traffic outside of North America has prompted considerable research interest in France, West Germany, Great Britain, Italy, and Japan. [19] Some indication of the present state of the art may be gained by consideration of three operational systems soon to be or now under development in the United States.

Los Angeles: In the Los Angeles metropolitan area about 2.5 million motorists use the urban freeway system every day, and it is estimated that the cost of freeway delay because of congestion and accidents or other incidents is about $65 million a year. In an attempt to eliminate much of this delay the California Division of Highways will spend $115 million during the 1970's to develop an electronic freeway surveillance and control system for 600 miles of area freeways.[20]

In 1971 the first stage of the project was completed, the "Los Angeles Area Freeway Surveillance and Control Project" covering 42 miles of the Santa Monica, San Diego, and Harbor Freeways in central Los Angeles. The project has central computer control, ramp metering at 56 interchanges, and more than 700 traffic detectors located at half mile intervals along the freeway. Detection of an accident by the computer will be signaled to control center personnel who can order a helicopter equipped with a TV camera to the scene to relay pictures back to the center. In this manner the required type of aid can be dispatched. Other freeway motorists may be alerted by radio broadcasts and variable message signs.

Minneapolis: The ability of freeway surveillance and control to manage traffic is being used in Minneapolis to encourage express bus service patronage in the I-35W freeway corridor extending 16.5 miles south of the Minneapolis central business district.[21] Automobile access to the freeway will be controlled by entrance ramp metering and buses will get preferential access. Surveillance and control will ensure a satisfactory level of service on the freeway so that buses will avoid freeway congestion and enjoy reliable travel times, a vital factor in attracting commuters.

The project goal is to attract 15% of the freeway users to bus transit. The completed system is expected to cost $9.4 million and be completed in 1973. To compare capital costs, the 14.5-mile Lindenwold rapid transit line in the Philadelphia area cost $94 million and the 11 miles of exclusive bus lanes on the Shirley Highway near Washington cost perhaps $15 to $20 million.[22] All three systems have a similar goal of providing public transportation between low population density suburbs and the central business district.

Long Island: In July 1973, the New York State Department of Transportation announced plans to establish a surveillance and control system on 30 miles of the Long Island Expressway. [23] Traffic will be monitored by a central computer by means of detectors imbedded in the pavement at half-mile intervals. Variable message signs will be used to advise drivers in advance to leave the expressway and use an alternate route in the event of severe congestion. The system is expected to save $4 million a year in travel time saved and accidents prevented because of more orderly traffic operations.

SUMMARY AND CONCLUSIONS

Computer-controlled electronic freeway surveillance and control systems in the 1970's have become a significant new operational tool for traffic operations engineers. They have proven useful in maintaining an acceptable level of service for freeway operations, reducing the extent and duration of traffic congestion, minimizing the adverse effects of accidents and other incidents on traffic operations, and reducing accident experience. Among the more important research needs now are investigations of driver willingness to travel at less congested periods or take alternate routes instead of the freeway, and improved methods for detecting and managing incident situations. Computer incident detection algorithms will probably become operational within a few years and increase the reliability and speed of detection.

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TABLE I

ENTRANCE RAMP DIVERSION IN RESPONSE TO
AN ACCIDENT BETWEEN THE SEWARD
AND CHICAGO RAMPS ON THE
LODGE FREEWAY

ENTRANCE RAMP	TOTAL ENTRANCE RAMP VOLUME BETWEEN 3:15 and 3:35 P.M.		
	AVERAGE OF THREE INCIDENT-FREE DAYS (December 2, 3, 5, 1969)	DAY OF THE ACCIDENT (Thursday, December 4, 1969)	CUMULATIVE DIFFERENCE
WEST GRAND BOULEVARD	362	318	- 44
SEWARD AVENUE	161	75	-130
CHICAGO BOULEVARD	134	224	- 40
WEBB AVENUE	110	174	+ 24
TOTAL	767	791	

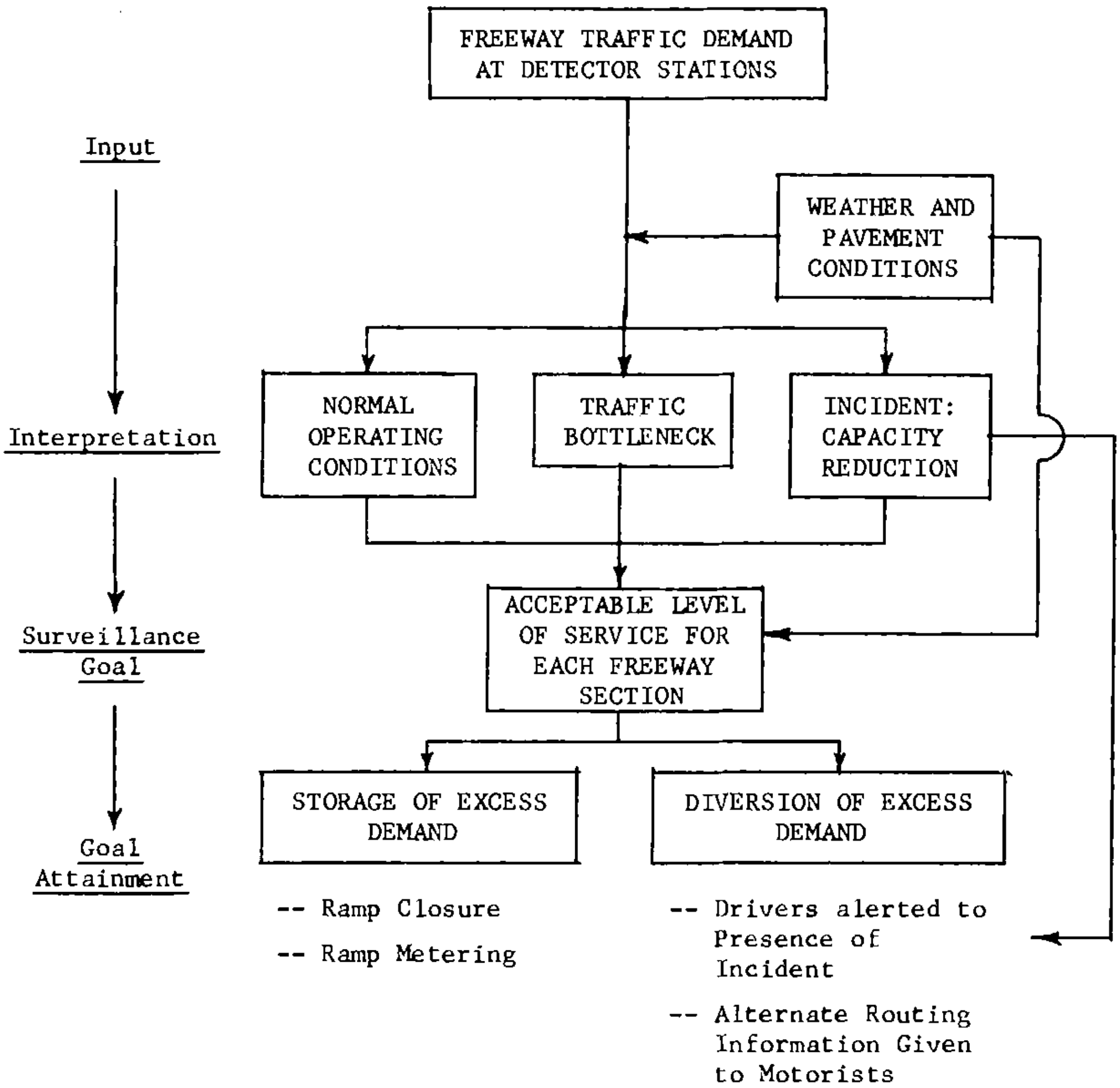


FIGURE 1

FREEWAY SURVEILLANCE
AND
CONTROL SYSTEM GOALS AND STRATEGIES

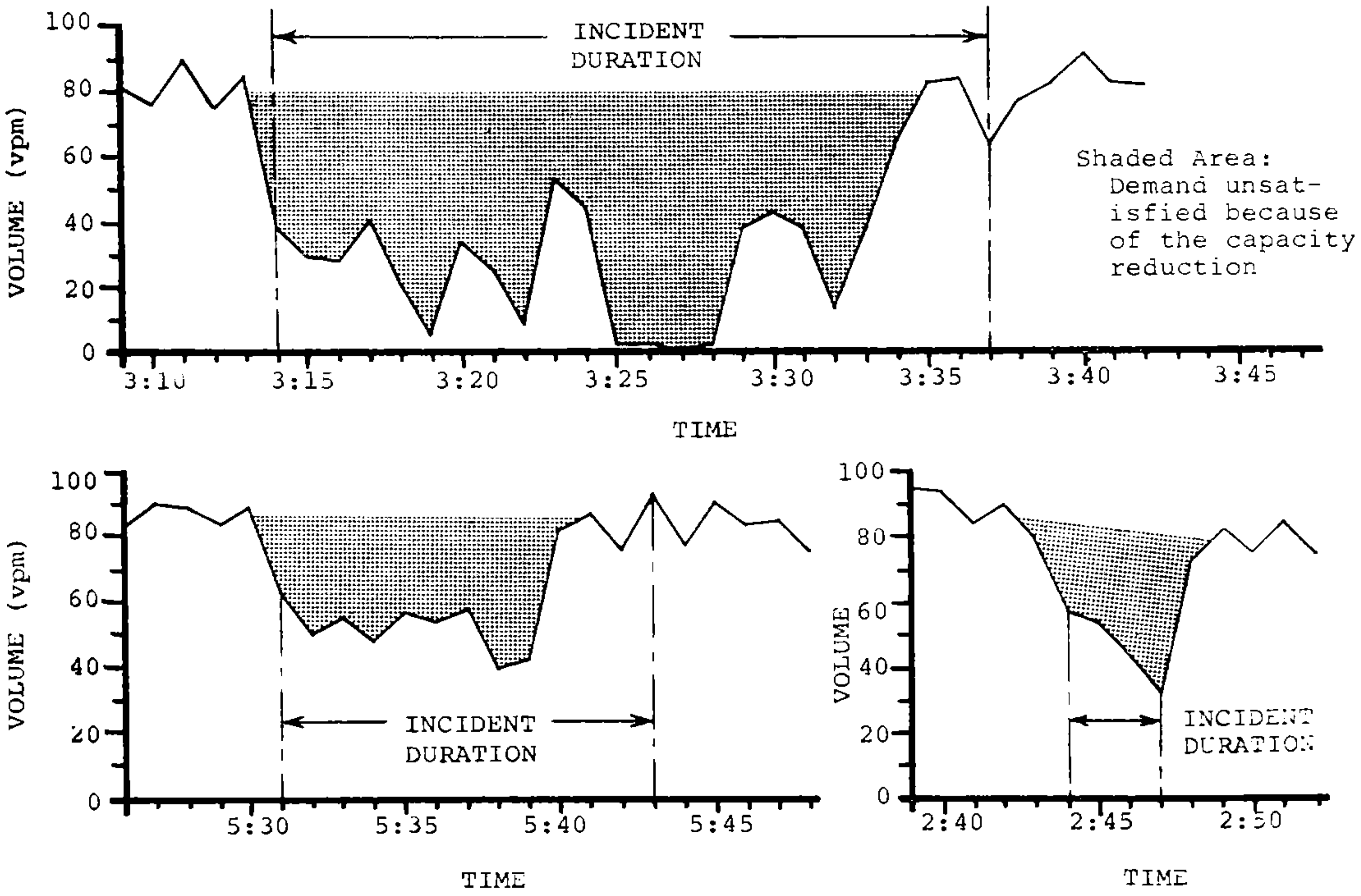
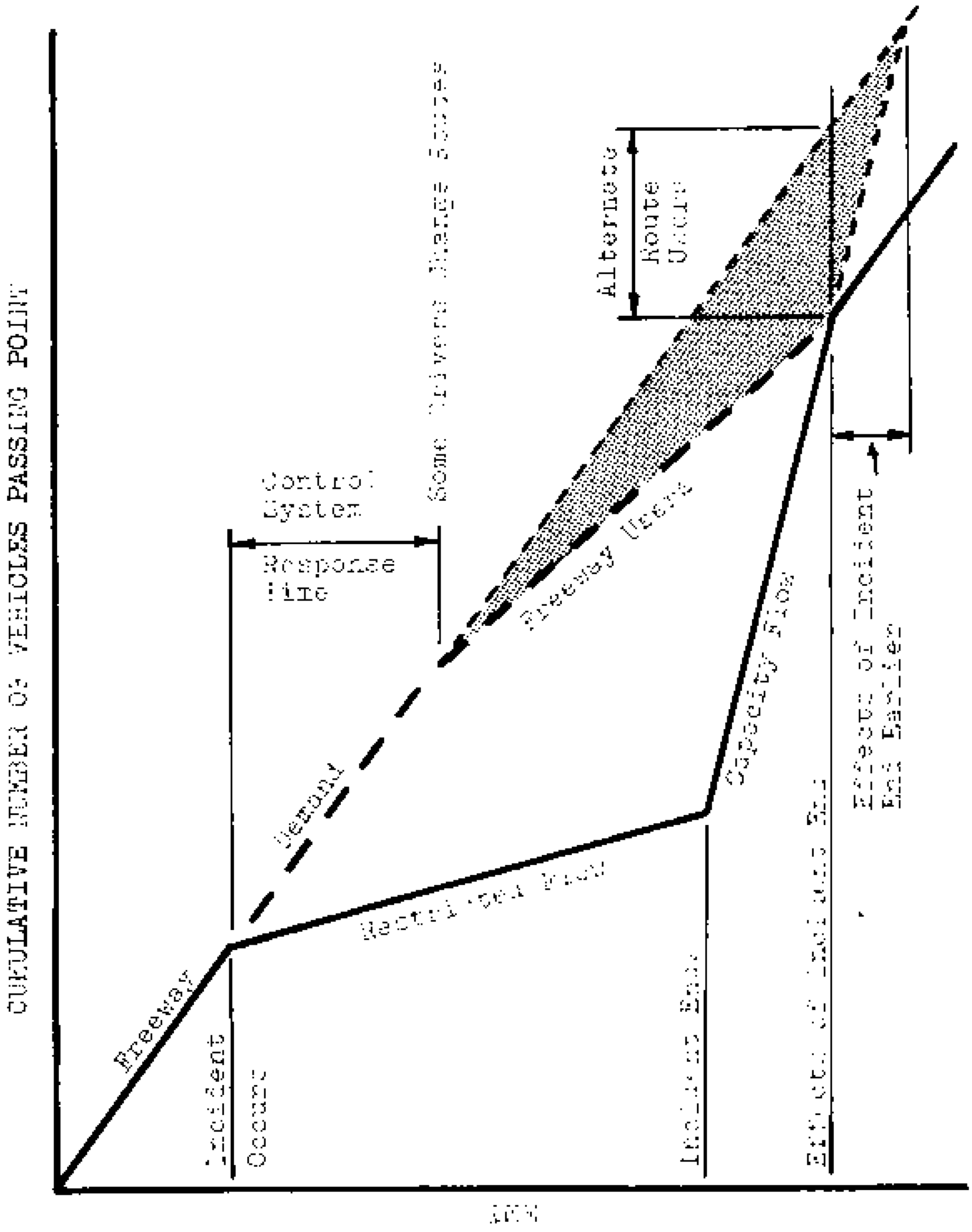


FIGURE 2

EFFECT OF INCIDENTS ON TOTAL TRAFFIC FLOW



Shaded Area: Reduction in delay to on-freeway users because others have diverted to alternate routes.

FIGURE 3

SURVEILLANCE CONTROL RESPONSE TO A CAPACITY-REDUCING INCIDENT

(Source: Reference 14)