THE DETECTION OF FREEWAY CAPACITY REDUCING INCIDENTS BY TRAFFIC STREAM MEASUREMENTS

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SUMMARY OF FINDINGS

In response to the increasingly significant effects of unpredictable, yet frequently occurring on-freeway capacity-reducing incidents such as accidents and breakdowns, this research was directed toward several aspects of automatic incident detection utilizing the Lodge Freeway surveillance and control system. Particular emphasis was placed on elements necessary for prompt and accurate detection and control system response. A system of activities and events and a model were structured to assist engineers in their analysis of various possible incident detection and response systems. Objectives and figures of merit for incident detection systems were enumerated. Existing systems used in incident detection were characterized and evaluated in terms of the event time model structure.

Data for this study were gathered using the extensively instrumented system on the John C. Lodge Freeway in Detroit with 13 detectors located at four stations spaced from 0.3 to 0.9 mile apart. Traffic volume and occupancy data were regularly compiled for successive one-minute intervals during weekday afternoon peak periods by an IBM 1800 computer system located at a control center. Information on incidents was obtained by television surveillance with nine cameras spaced along this two mile section of the Freeway.

The record of on-freeway incidents recorded by television observers during 1969 was studied and a representative sample of 50 peak period incidents (including 18 accidents) for which all required data were adequate was selected for further analysis. Prevailing lane volumes ranged from 1200 to 2000 vehicles per hour and occupancies from nine percent to 45%. Operations ranged from free flowing to congested. All of the incidents generated some congestion with flow reductions ranging from ten percent to 60% and averaging 21%. These incidents generally blocked only one lane, had a typical on-freeway duration of 6.1 minutes, and generated an average of ten minutes of congestion. The incidents were found to be uniformly distributed over the four peak hours.

The reliability of recorded television surveillance incident occurrence times as a basis for measuring the effectiveness of automatic incident detection approaches was studied. More than 50% of the incidents were detected first by the automatic system, a fraction that should be zero. Hence, all time values were related to the minute when congestion was first recorded at one of the stations near the incident site.

To compare incident-free and incident operations, flow data for eight days of dry weather and four rainy days were compiled.

Eight candidate detection models were evaluated. Five of the models had been studied by the Texas Transportation Institute (TTI) in its 1968 research on the Lodge Freeway. One model studied was developed by the California Division of Highways and two were first developed by The University of Michigan. The five models developed by TTI were calibrated with the 12 days of 1969 incident-free operational data and tested against the 50 incident sample. The critical values of the parameters were established for a false alarm risk level of one percent based on incident-free operations for rainy and clear days treated separately. The effectiveness of these models in detecting an incident during the resulting congestion ranged from 32% to 90%.

Studies showing the independence of the two best TTI models led to a decision to combine them in a Composite Model utilizing the distribution of kinetic energy among the lanes at a station and the simultaneously recorded difference in operations at two adjacent freeway stations in the speed-occupancy domain. This model detected 96% of the incidents in an average time of 0.8 minutes and signaled the end of 75% of the incidents correctly with a two percent false alarm rate.

The Modified California Model, after elaborate calibration, was found to be somewhat less effective in detecting incidents (80% level of detections for geometrically homogeneous portions of the Freeway) but generated false alarms only 0.1% of the time.

The use of exponential smoothing or weighted averaging of recent data as a model structure was explored and the results were encouraging. Further development of such a model is believed to be warranted.

One of the possibly serious problems in automatic incident detection is the "false alarm" in which an incident is signaled when one has not taken place. Since the costs to operating agencies in responding to these signals vary with their aid systems and operational policies, a major effort was directed toward the exploration of the false alarm rate for the most promising models. It was found that false alarms are a real problem for all of the models since there is a large overlapping area in which traffic stream variable measures are the same during both incident-free and incident operations. The magnitude of the trade-off between detection probabilities and false alarms was identified.

A test of the critical parameters developed by TTI for their 1968 research indicated a similar or improved level of detection of the 50 1969 incidents compared to the parameters developed from 1969 incident-free days but at a false alarm level that reached as high as 11%.

The effectiveness of the Station Discontinuity Model by itself and as a part of the Composite Model led to the conclusion that individual lane detection at a station is desirable to maximize model detection capabilities.

The four models that were most effective in detecting incidents were tested for their ability to signal the return of operations to their pre-incident state. The Modified California Model was 100% effective and the Composite Model (75% effective) could easily be developed to a higher level of effectiveness.

The 14 incidents occurring during free-flowing occupancies below 14% were detected as well as were those in denser traffic streams, implying that these models may be effective at quite low flow rates and be useful during non-peak hour conditions.

The theoretical and empirical evidence supporting automatic detection by the use of macroscopic traffic stream measurements generated for use in freeway information and control systems was explored. The effects of distance between stations and geometrical discontinuities were investigated. The best models generally located the incident to the nearest adjacent detector station. The spacing between the detectors, ranging from 1460 feet to 4815 feet did not appear to be a factor in the ability of these models to detect. However, those models which compare traffic characteristics between adjacent stations are less effective where there is a geometric discontinuity in the form of a lane drop between two stations.

The considerable variability in incident impact on traffic operations and the demand service mechanism past an incident make it a challenging task to model the problem mathematically. Over 80% of the incidents generated increased upstream and decreased downstream occupancy, the situation to be expected through application of the concepts of Lighthill and Whitham.

Among other characteristics of these incident detection models, weather conditions do not appear to be a factor in detection effectiveness. All eight of the incidents occurring in rainy or snowy weather were detected. However, the models tested required separately developed parameters to maintain the same false alarm level. Models based on data from freeway subsystems were more sensitive to weather than those using only data from a single station.

None of these models was able to distinguish between accidents and other less critical types of incidents, but since the magnitude of the capacity reduction is a model output, this information may serve to determine the relative priority in dispatching patrol units where detections conflict with each other. The prompt detection capability of these models should be beneficial in reducing the time lag for aid to arrive at the scene.

One month's incident data from the television surveillance operation were compared with data from a Citizens Band (CB) emergency radio system operated by the City of Detroit. It was observed that the CB system detected some incidents missed by the television system and that the police response to CB calls was more rapid than to calls from the TV control center. The CB response was only 20% as effective as would be expected from a uniform distribution of fully cooperative CB-equipped vehicles.

In conclusion it is believed that traffic stream measurements can be used to detect virtually all on-freeway incidents that generate congestion within the first two minutes after the onset of congestion. This approach can readily be incorporated into operational dynamic information and control systems. Since the magnitude of the capacity reduction is also known in a format directly interpretable by the process controller, prompt and effective control response in terms of ramp metering control and diversion of freeway demand is feasible.

PART ONE

CHAPTER ONE

RESEARCH APPROACH

INTRODUCTION

Urban freeways play a vital role in motor vehicle movement and circulation in our cities. Freeways are designed to provide safe and rapid service for the many motorists making longer than average trips. However, in many cities the level of service actually provided by the freeway network during the hours of peak flow unfortunately does not reach the expectations of either designers or the many regular users of the system. This can be partially attributed to the excess demand resulting from the popularity of freeways. With excess demand, severe congestion frequently develops with a deterioration in speed and safety.

This congestion often occurs daily and is quite predictable, both in effect and duration. In addition to new facility construction programs, various operational measures have been developed in recent years to minimize congestion using ramp metering and other information devices. It has been clearly established that if the demand can be kept well below a critical value, called the capacity, desirable operating conditions can be maintained. Engineers responsible for achieving the highest possible level of service on existing freeways are continuing their intensive efforts to effect increases in or maintain capacity, as well as to control the volume of traffic using the freeways (9, 10, 11, 16, 32, 33, 34, 36, 46, 47, 48, 49, 50)*.

There is another cause of congestion that has recently reached a level of impact on freeway operations that some consider even more severe than recurring, unsatisfactory daily operations (49). This is the flow-disruptive event that occurs unpredictably, often during peak periods when demand is high, and reduces the capacity and level of service provided by the freeway. The capacity of a freeway, the maximum hourly flow of vehicles it can serve, varies with the permanent design of the freeway and fluctuates with many changes in the environment such as weather, distractions to drivers, and temporary obstructions to flow. Many of these transient distractions and obstructions to flow are caused by elements of the traffic stream, such as vehicles involved in accidents.

Figure 1 shows one kind of incident, an accident, and the resulting queues observed on the Detroit freeway system.

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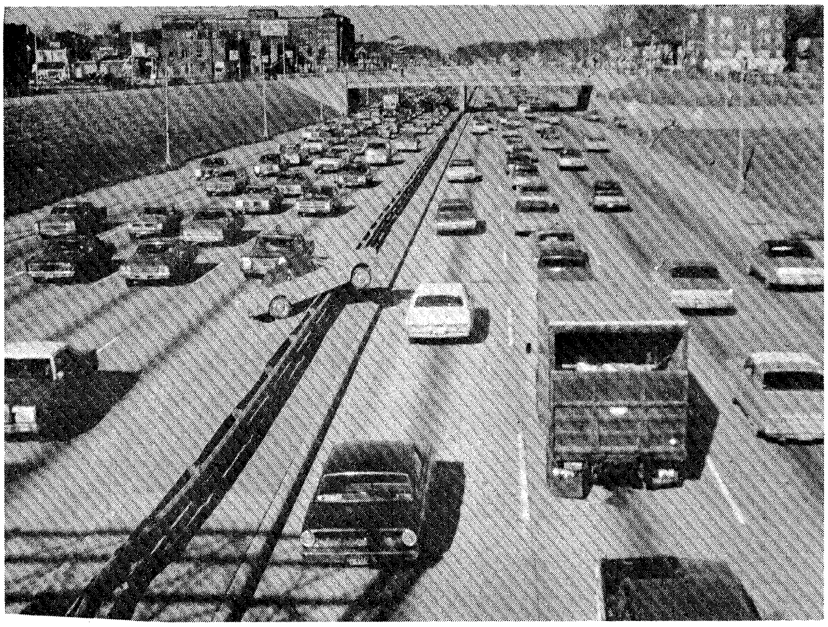
*Numbers refer to references at the end of Part One of this report.



AN INCIDENT ON THE LODGE FREEWAY

QUEUE BEHIND INCIDENT

FIGURE 1
INCIDENTS REQUIRING AID

There are other types of capacity-reducing incidents such as mechanical failures resulting in a stoppage or the dropping of debris from vehicles or overpasses. In this study the occurrence of any event on the freeway right-of-way that significantly influences traffic performance is considered to be a capacity-reducing incident. It should be noted that driver aid studies, particularly those specifically concerned with problems of the stranded motorist with an inoperative vehicle or participants in an accident involving personal injuries or blockage of the freeway creating a hazard for other vehicles, often use the same term to describe these types of events (8, 13, 14, 15, 20, 22, 24, 28, 31, 37, 41, 51). While there are similarities between the two problems, there are many incidents that do not require aid and many aid situations that do not seriously affect traffic flow.

Lunenfeld estimates that accidents account for only six percent of emergency stops (30). In 1968 there were almost 1,900,000 reported accidents on urban freeway facilities, slightly more than one eighth of the U.S. total of 14,600,000. He also estimates that there are more than 125,000,000 emergency stops per year on U.S. roads. Almost one quarter of these stops occur in urban areas, a total of 21,000,000 on freeway type facilities. Of these on-freeway emergency stops, almost 2,100,000 occur on the roadway and require prompt detection and removal if optimum freeway operations are to be maintained or restored.

Lunenfeld has estimated that the number of accidents resulting from vehicles stopped in the roadway exceeds 40,000 for urban freeways. His analysis indicates that 750,000,000 vehicle-hours of delay result from urban freeway incidents.

The above statistics scale the general costs to freeway users in lives and congestion and indirectly indicate the extent to which the freeway is operating unsatisfactorily as an important component of the highway network. Studies conducted by this agency in Detroit in October 1969 showed that the total travel service (in vehicle-miles during the four-hour afternoon peak period) decreased 13% on three days with accidents as compared with 19 days without accidents.

There have been several detailed studies of reported incidents. The list of references includes most of those believed to be significant. Since incidents tend to be partially independent of each other, they cluster both in time and at locations along the freeway. A further complication is the variation in nature and criticality of the emergencies. A minor accident involving property damage and no injury may require no allocation of emergency response resources, whereas a major multi-car collision may necessitate a full response from the community including police, ambulance service, tow-trucks, fire-fighting equipment, and hospitals. Despite the fact that the urban freeway user is a highly motivated individual who uses the freeway frequently, makes few information stops on the freeway and practically no leisure or rest stops, still many voluntary stops are made which should not be permitted. This irregularity in type and seriousness of incidents, the peaking of demand and the wide variety of aid required makes it difficult to effectuate countermeasure systems.

Information on the frequency of occurrence and characteristics of events or incidents are given in several studies (3, 5, 10, 14, 21, 22, 24, 26, 28, 31, 34, 41). A recent Texas Transportation Institute (frequently referred to as TTI in this report) Houston Freeway study showed an average of 2,500 stops per mile per year, ten percent occurring in traveled lanes. Almost 40% of the stopped vehicles remained at the site more than 30 minutes with an average site stay of 54 minutes (21). Crane estimated that there are 6,400 accident-related lane blockages each year on the 50 mile Detroit freeway network. These accidents account for 6.7% of the hours with one or more lanes blocked (11). He believes that 14% of the time there are one or more lanes blocked by an incident somewhere in the system. On a 3.2 mile section of Detroit freeway an incident occurred every 3.5 hours on workdays. There is one incident every

3.3 hours per mile on the San Francisco-Oakland Bay Bridge (24). In California, one incident per 20,000 vehicle miles was observed, while one incident for each 33,000 miles of travel was predicted for Illinois (22). One morning peak-period Houston accident resulted in a delay of 340 vehicle-hours (20). DeRose observed one accident for each three vehicle breakdown incidents (14).

Pogust found that 95% of all incidents occur on the shoulder, the location of the complete stop (37). He noted that only 47% require assistance and that from 20 to 40% are "unnecessary." From 40 to 60% of the San Francisco-Oakland Bay Bridge stops require no service (24).

The duration of time that a lane is occupied by an incident is not generally very long. Crane observed an average duration of 3.5 minutes for incidents (11). DeRose, in an early Detroit study, found a 6.1 minute average stay on the traveled lanes when there was an accident and 4.9 minutes for a disabled vehicle (14). Only 12% of the vehicles remained on the freeway longer than ten minutes. On the San Francisco-Oakland Bay Bridge, accidents block the facility for an average of 24.6 minutes after detection (24). These incidents result in an average blocking time of 13.1 minutes.

The effects of a lane-blocking incident on traffic flow are significant. Both TTI and Crane found that a one-lane blockage halves the capacity of a three-lane section and reduces the capacity of a four-lane section by one-third (11, 33). Activity at the side of the road reduces capacity by two-thirds of a lane. A 22% reduction in capacity was found by Goolsby in a study of the effect of a "shoulder" incident (20).

There is no question that weather has a significant effect on incident occurrence. Early studies on the Lodge Freeway showed that the incident rate was as much as six times as great in bad weather as in good conditions (14).

The time lag between the occurrence of an incident and its removal obviously depends upon the speed of detection and the response time of the appropriate aid. The latter factor varies widely depending upon the service called upon for removal. Goolsby reported an average response time to an incident of 11.2 minutes, a vehicle clearance time of 4.0 minutes and an on-shoulder investigation time of 24 minutes (20). Each of these response times was observed to range up to 60, 27 and 90 minutes, respectively.

Lunenfeld quotes a study showing that average detection times are approximately five to ten minutes in urban locations (30). He believes that the detection notification time on urban limited access facilities is on the order of five to ten minutes, the ambulance arrival time on the order of ten to 20 minutes and debris and hazard control by service vehicles and wreckers on the order of 30 minutes. Graf indicates that a 15 minute response by a service vehicle is rapid (22).

As is true in other congested traffic situations, the costs and inconveniences to the stalled vehicle in an incident are only a small fraction of the total costs to all freeway users resulting from an incident. Usually the stranded motorist is indifferent to the social costs his predicament exacts from other road users. In Lunenfeld's national study it was found that a savings of ten minutes of delay would save a grand total of 312,000 vehicle hours per year of delay to involved motorists. On the other hand, the reduction in delay to other users would be 400 times as much (30). The possibility of achieving these savings can be scaled by noting that it has been estimated that the benefits to the individual motorist of a rural call-box system would be five minutes for removal of the vehicle from the scene and six minutes savings in receiving medical attention (28). Savings of this order of magnitude would not be realized on urban freeways.

Desai's analysis and several TTI studies indicated that a reduction in accidents can be achieved by maintaining freer flow during peak periods (15, 33). Lunenfeld observed that as many as ten percent of accidents occur in queues and that faster incident detection would save one percent of all fatalities, injuries and property damage accidents. In an urban freeway environment this involves 12 occupant fatalities, 818 non-fatal occupant injuries and 3,800 property-damage-only accidents.

Lunenfeld has estimated that 65 of the 5,472 fatalities occurring on urban controlled access facilities in 1968 could be prevented if the time lag for notification of the police agency were reduced from eight to zero minutes. Crane believes that earlier detection can reduce by 100 the hours of lane obstruction per year on each mile of a freeway (11).

The importance of additional work in each of the many areas of incident detection, response and removal has been recognized by several researchers (2, 6, 10, 13, 15, 22, 36, 38, 42). Most past studies have been particularly concerned with that part of the post-incident period problem dealing with getting aid to the motorist requiring assistance. Less attention has been given to the disruptions in the traffic stream resulting from these events. West notes that the early location and rapid removal of freeway incidents remains one of the most promising areas for possible freeway operation improvement since the "unusual incident" is responsible for as much motorist delay in the urban area as is the "built-in" geometric "bottleneck" (47). The greater relative importance to society of maintaining the level of service on urban freeways versus the problem of the stranded motorist has been recently recognized. Moskowitz, in his review of research needs in traffic surveillance, stated that he believed the single most important problem in urban freeway traffic operations is the determination of how to detect stopped vehicles and the necessary steps after that which are required to remove the stoppage (36).

GENERAL APPROACH TO THE PROBLEM

A comprehensive program of coping with the freeway incident naturally involves concern with elements for which the freeway operations engineer has no responsibility. For example, it has been found that a large percentage of incidents on freeways in Michigan result from mechanical equipment failures, many of which could be eliminated through better design, maintenance and improved driver practices (41).

On a longer time scale the question can well be asked if advances in communication and control systems will obviate the need for concentration on the incident detection problem. It is believed that this question is answered by the studies of Fenton who envisages a dual-mode vehicle that will spend at least part of most trips on non-automated highways (18). Combining this information with the observed behavior of disabled or selfish drivers, it is believed that for the foreseeable future there will be stoppages reducing real-time capacity which can be most effectively detected by the techniques under consideration in this research. At the same time, the research should be directed toward the exploitation of the full capabilities and potentials of existing fragmented incident systems. Particular attention should be given to those elements which will form an integral part of systems developed in the coming five to 15 years.

The engineer responsible for operations on urban freeways increasingly views rapid incident detection and response as being closely related to other aspects of freeway traffic control (16). As early as 1964, Weinberg stated that a

> "closed loop system for an urban freeway ... provides for surveillance of traffic operations, acquires data on traffic operations, processing data in real-time, comparing outputs with decision rules, selecting tactics, and activating the information and control system for real-time changes" (47).

Modern systems are heavily based on real-time modification of freeway demand by ramp metering and by other efforts to divert motorists attracted to the freeway to alternate routes (10, 34, 42, 50).

In present systems, capacity has been treated as constant. Steps are being taken to modify capacity to account for such conditions as weather (27). A natural next step will be to modify capacity to account for the effects of the frequent yet unpredictable incidents of unknown location and duration that affect capacity. In such systems, automatic and dense surveillance coverage is necessary if capacity change inputs are to be detected, quantified and input to control programs. For example, Los Angeles has committed itself to a program which is deeply concerned with all aspects of the incident detection and response problem and is installing 700 sensors on a portion of the freeway network in that city to assist in control and incident detection (42).

It seems well established that there is no alternative to improved response as a means of optimizing flow during an incident. The magnitude of peak period freeway demand is so great that diversion of a large enough fraction of the on-freeway motorists to other routes to effectuate desired operations is infeasible because of the lack of capacity in the supporting road system.

None of the systems presently in use are very satisfactory from the viewpoint of the urban freeway operations engineer. For example, considering roadside telephone systems, a California study showed that only 40% of the motorists used the phones (22). Even on a rural Michigan freeway, while 77% of the motorists knew of the phones, only 52% used them (40). In bad weather, motorists will not leave their cars to place a call. A Texas study showed similar results, and further, that one-third of those seeking aid were gone by the time the requested aid arrived (21). Also, more than one of ten users of this system requested the wrong type of service.

Even systems not requiring active motorist cooperation are subject to failures in detecting incidents. While the television surveillance system in Detroit proved effective in improving detection time by 2.5 minutes, one study showed that up to 20% of the incidents were missed (4). A recent study has shown a detection rate of only 75% for individuals watching traffic on closed circuit television at ranges up to 1500 feet (45).

Further complications arise from the interaction of those public and private agencies concerned with incident detection and response activity. Their objectives differ and their operational policies to date do not provide a generally satisfactory or balanced approach to the problem.

The approach followed in the conduct of this study is based on the belief that the many possible systems which can be used to detect and respond to incidents have such different characteristics that it is necessary to carefully structure the variables of interest in order to make an effective systems comparison (or systems analysis) possible. The next section of this chapter develops such a structuring and a sub-model which should be useful in systems analysis.

Another area of interest to those responsible for the planning, design and operation of an incident response program is an estimate of the way in which various existing and possible systems would interact in actual operations. The existence in Detroit of a television surveillance installation, an experimental Citizens Band radio system designed for incident detection and an extensive network of flow and occupancy detectors on the John C. Lodge Freeway which are linked to a digital computer operating an information and control system provide an opportunity for some of the characteristics of the interaction between these systems to be explored.

Among the means available for detecting the occurrence of a capacity-reducing incident and communicating this to a central control, the traffic stream itself can be used as one of the links in a communication channel. This is possible as the disturbance to normal flow rates caused by a capacity-reducing incident is propagated both upstream and downstream of the incident location. While individual motorists using a freeway vary widely in their driving capabilities and practices, the measurement of their collective driving performance gives remarkably consistent time averages and dispersions for the flow characteristics of many drivers, the volume or flow, the speed of the stream and the density or concentration of vehicles. Under heavy flow conditions when such characteristics of the driving environment as capacity change, these measures also respond. This response can be looked at as consisting of three parts: (1) A transient phase of immediate and rapidly changing flow in the vicinity of the capacity-reducing incident; (2) A steady-state condition that follows the transient phase and continues until the incident is ended; and (3) A period during which flow returns to normal following the removal of the causative element. Traffic stream characteristic incident detection models have been developed which are based on discernible regularities in macroscopic group behavior under various traffic environmental conditions and flow phenomena during the transient and steady-state performance conditions described above.

The models considered in this study are based on the capabilities of the existing presence detectors on the Lodge Freeway. These detectors interrogate the Freeway many times per second for the presence of a vehicle. The stream of information received makes it possible to determine the number of vehicles passing the detector during an interval and vehicular density.

It would be expected that there would be differential time and incident detection accuracies for different longitudinal spacings between detector stations. Also, it would be expected that lane drops and other geometric discontinuities would influence the performance of this type of model. A third characteristic which may have a significant effect on incident detection and response is the weather (27).

In 1968 the Texas Transportation Institute commenced a study of incident detection using macroscopic traffic flow parameters on the Lodge Freeway in Detroit (10). Six separate approaches were considered. These approaches were based on the accumulation of vehicles in a section of freeway, traffic stream energy based models, speed-density characteristics and ramp-metering control variable setting. Only limited and general conclusions could be drawn from the data collected in the available study time. It was concluded that

> "All models demonstrated some ability to detect incidents and may therefore merit further consideration. They did, however, exhibit a high false alarm rate, and it is felt that considerable refinement would be required to produce an operational incident detection scheme."

The remaining sections of this introductory chapter provide a detailed background, necessary preliminary development and a description of the approach used in this research. The structuring of the incident detection communications-response system in terms of cost-effectiveness is first considered. The various physical and operational strategies used to meet these needs and their shortcomings are then treated. The nature and form of traffic stream characteristic incident detection models are described. This is followed by a description of the test facility used for the research, the John C. Lodge Freeway Surveillance System. Texas Transportation Institute findings, data acquisition, processing and analysis used in the research approach are then described. Chapter Two presents the findings of the analysis. Chapters Three and Four discuss implications of the research and present conclusions and suggestions for additional study.

SYSTEM STRUCTURING FOR URBAN FREEWAY INCIDENT DETECTION

The ultimate objective of the urban freeway operations team is to achieve a desired level of operational effectiveness for the least expenditure of resources. The complexities of urban freeway incident detection and response have been described in the introductory section of this chapter. Final decisions regarding incident detection and response systems, only one of the functions of an operational program, will frequently be based on factors external to the basic incident problem such as inadequate funds, legal constraints, or police attitudes toward this function. The approach to the incident problem adopted in this study is to attempt to identify some of those elements of incident detection and response that necessarily will be considered in the analysis of any system. This approach will be referred to in this report as "system structuring." Since much of the problem is one of communications, the multiple uses of a system and alternate ways of achieving the same flow of information must be carefully considered by the engineer studying the alternatives available. Much effort has recently been expended in developing this aspect of the problem (13, 30).

Since the operation of many candidate systems can be adequately described by cost factors this structuring attempts to describe elements of these systems in an orderly statement of requirements, capabilities and cost related parameters to facilitate alternative system comparisons. As an example, consider the problem of the "false alarm" in which the operating system indicates that an incident has occurred at a location when, in fact, no unusual event has taken place. If the response to the incident signal merely involves an operator switching his attention to the appropriate television monitor for visual confirmation of the incident, the cost of a false alarm can be relatively low. However, if the police are to be dispatched to the scene of the incident, the cost of false alarms may be significant as the police are delayed in reaching "real" incidents because of the necessity to go to the sites of one or more false alarms.

The development of a useful system structure requires the definition of the objectives of the system and the measures of effectiveness to be used in the evaluation of the candidate alternatives. The results of this effort are described in the next section of this chapter. The general nature of the incident detection part of the task is indicated in Figure 2 in which the time factor of delay is shown against the likelihood that an incident is signaled by the detection system. The problem of the false signal is indicated, as well as the time lag in signaling the occurrence of an actual incident.

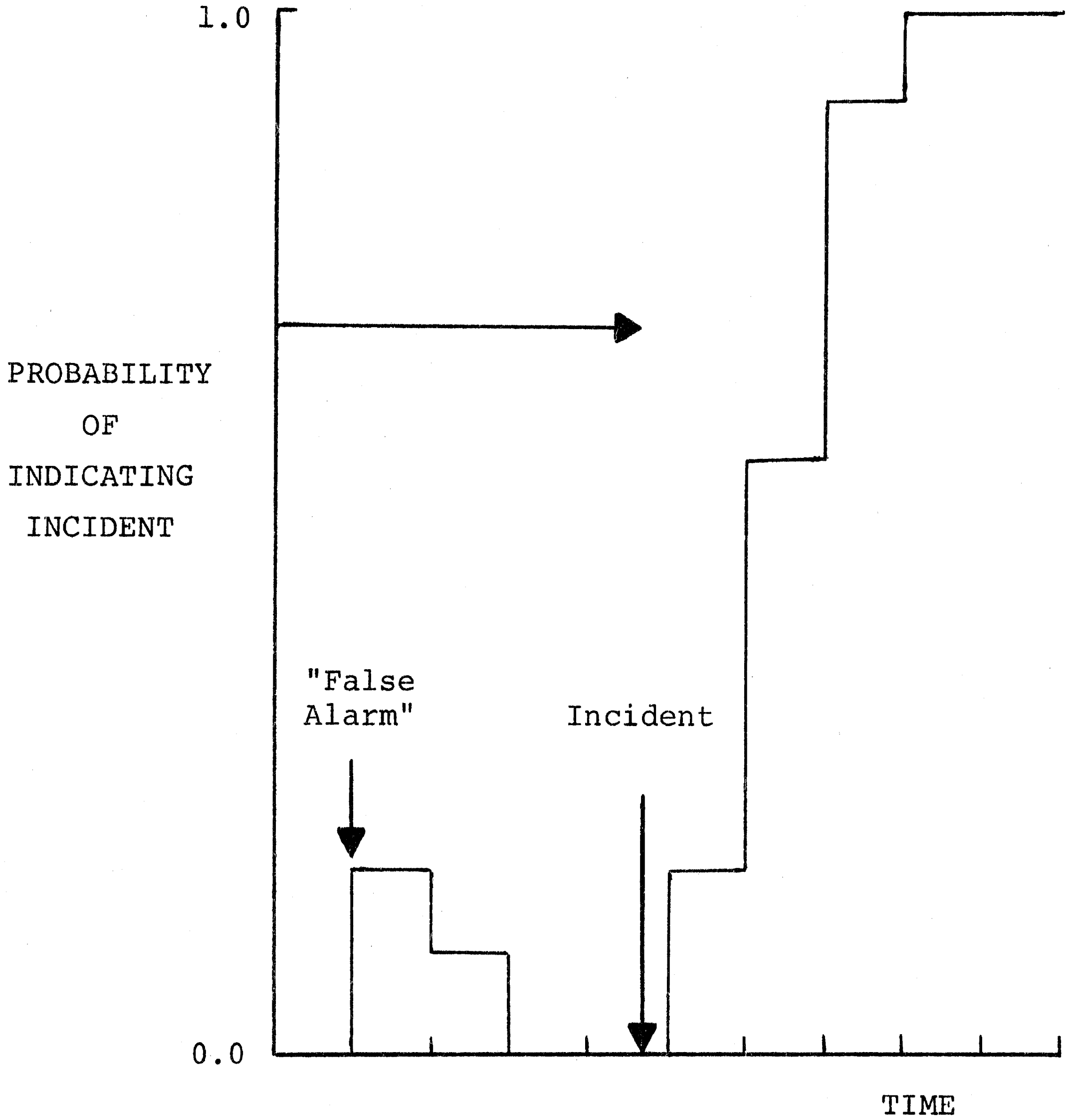


FIGURE 2
THE INCIDENT DETECTION MODEL PROBLEM

OBJECTIVES AND FIGURES OF MERIT

The primary goal of an urban freeway operational system should be to improve the convenience and safety of the freeway. The achievement of this goal can be approached by adopting incident-related objectives concerned with accident occurrence, travel and waiting time and smoothness of flow. Explicitly, the objectives of an urban freeway incident detection and response system should be to:

1. Reduce the total delay caused by incidents;
2. Restore operations to their pre-incident level as rapidly as possible;
3. Reduce the frequency of accidents "caused by" incidents; and
4. Reduce the severity of accidents due to incidents.

The specific measure of these objectives can be expressed in terms of the time responses to the various functions to be performed. To a large extent, these time responses are dependent on communication, queuing and transportation problems. The following paragraphs identify specific criteria which can be used to evaluate parts or entire operational systems which are to fulfill some role in achieving these objectives. These criteria are often expressed in terms of probabilities because of the stochastic nature of the processes and the ultimate tradeoffs among alternatives that may have to be made because of this statistical variation.

As indicated in the introduction, the estimated delay caused by urban freeway incidents is often very large. Figure 3 shows the effects of the most significant criterion affecting this delay, the time of restoration of capacity flow. In the figure an incident completely blocks the freeway for a short time. There is restricted flow until removal of the incident again makes possible capacity flow. Ending the incident sooner reduces the number of vehicles delayed, reduces the waiting time for many of those who are delayed and reduces the period during which peak capacity discharge at the bottleneck delays downstream ramp users in entering the freeway until the capacity flow is no longer necessary and the ramp control system can again provide entrance opportunities.

Current thinking regarding the operation of freeway control systems recognizes that the detection of a capacity-reducing incident should initiate a modified information and control strategy that will respond to the lowered capacity at the incident site. This should be accomplished by reducing input upstream from the site, directing traffic

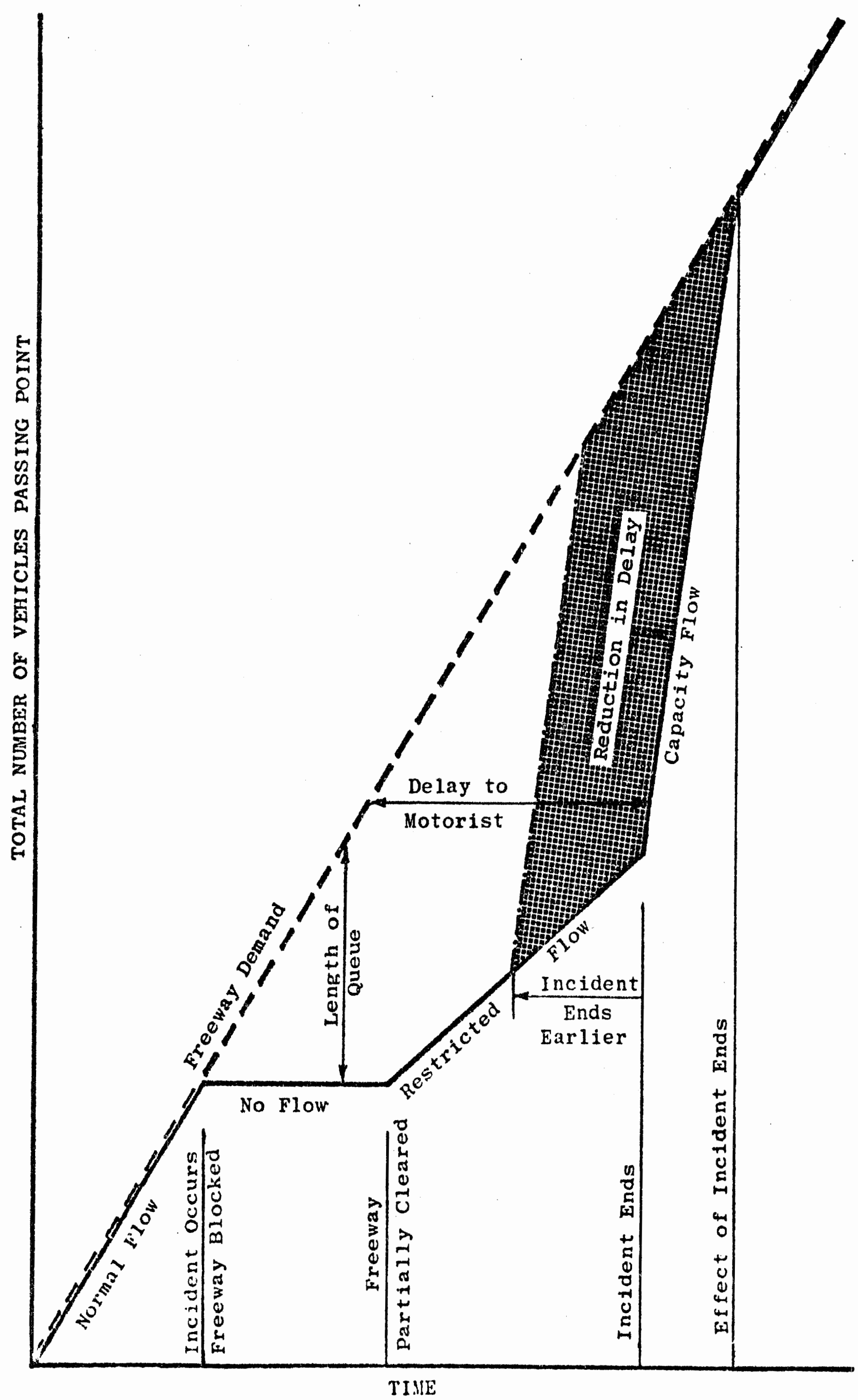


FIGURE 3

EFFECTS OF A CAPACITY-REDUCING INCIDENT

through the bottleneck at the highest flow consistent with good management at the incident site and allowing more vehicles access to the freeway downstream to fully utilize the unused capacity. Figure 4 shows an incident similar to that presented in Figure 3 in which the incident detection and the establishment of a restricted flow capacity are taken into account by the information and control system to encourage some upstream drivers to follow an alternate route and restore favorable operating conditions earlier than would otherwise be the case. The criteria that are relevant are the prompt notification of the occurrence and end of the incident and information on the maximum allowable flow possible during the blockage. This indicates a minimum need for one or more measures of traffic flow.

Another desirable feature of an incident detection system is the ability to detect those incidents which have a significant impact on freeway operations. This implies that the detection of many shoulder or other off-freeway incidents is not important because of their small impact on freeway operations. However, there are off-freeway accidents and "busy" shoulder incidents that can produce an effective capacity reduction and which must be detected by an effective detection strategy.

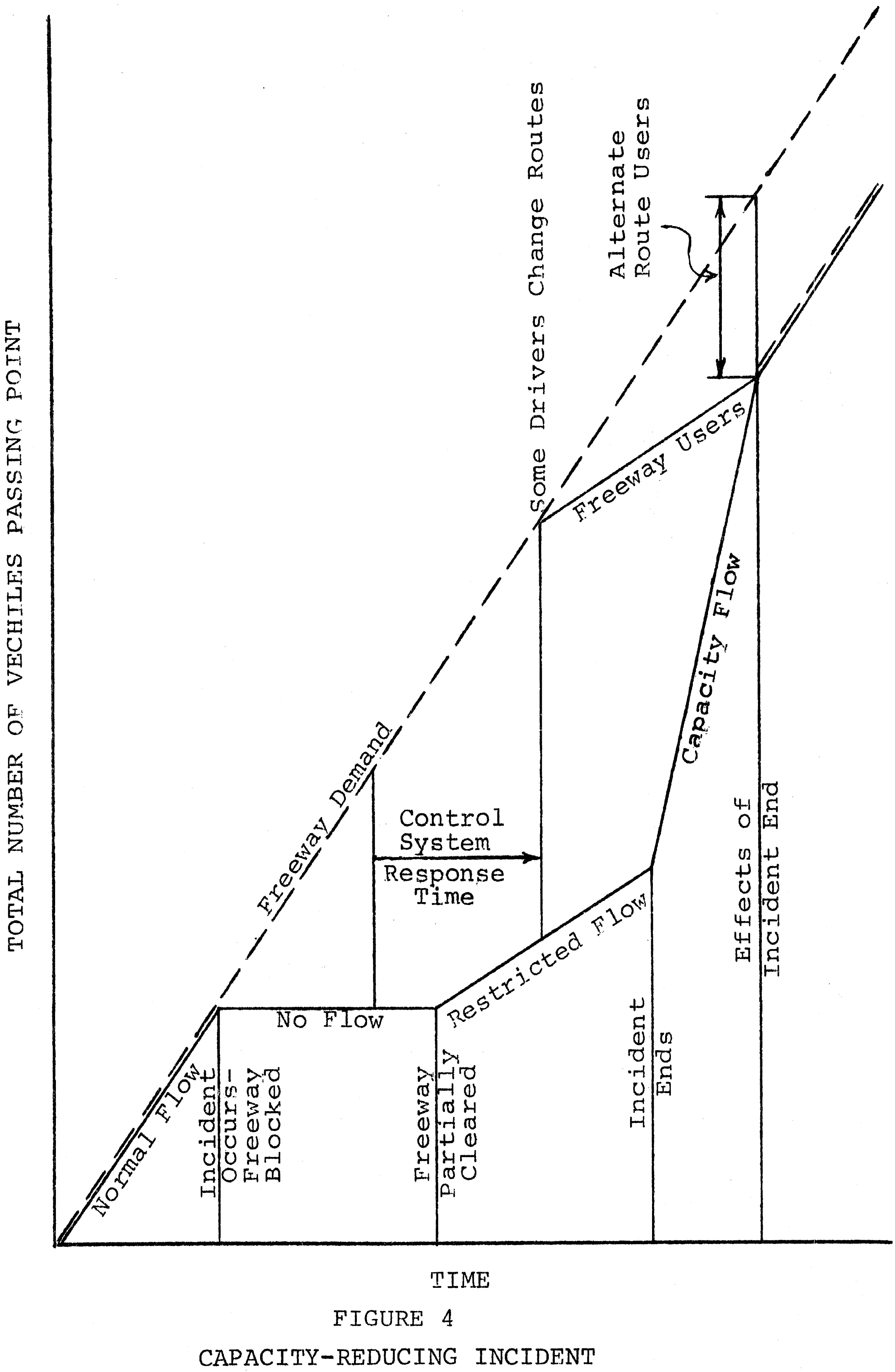


FIGURE 4

CAPACITY-REDUCING INCIDENT
TRAFFIC CONTROL RESPONSE

Some on-freeway incidents may not be detectable. These would most likely be momentary stalls and minor accidents where the involved vehicles promptly leave the scene or the drivers have little trouble reaching a shoulder.

An effective system should minimize false alarms. Incidents are rare enough that even a small number of false alarms may be a significant proportion of the incident signals. Since one of the operational objectives of the detection system is to provide the surveillance controller with the necessary flexibility to adjust control parameters as conditions warrant, a false alarm has the potential of causing less than full utilization of the capacity of the system.

Another desirable criterion is that the system should promptly transmit enough information to permit a sufficiently accurate diagnosis of the character of an incident in order to dispatch the correct type of assistance. An effective system also provides information that will enable the operator to determine the cost in lives or delay that will result from a failure to respond immediately to the incident. In this way the response strategy to a waiting line of incidents can appropriately assign priority to those for which the costs are the greatest.

There are several characteristics desirable in a communication channel used to transmit information that an incident has taken place. Incidents at different locations should not compete with each other in the use of the communication channel. It is particularly desirable if the communication channel exists and its usage for incident detection does not interfere with its other purposes. It is desirable that the system be integrable with other highway and vehicle systems, and that it be capable of being implemented as needed, not requiring a larger investment than initially adequate to meet the current problem.

Privacy, the protection of the disabled vehicle from those who would prey on it and its occupants, is becoming an increasingly desirable characteristic of the communication channel.

Spatially, the system should be able to detect the location of an incident to a degree which is satisfactory for the response dispatch and freeway control. At the same time, the system should be sensitive to incidents that occur at any location on the freeway or right-of-way where public action is appropriate.

Earlier in the chapter, numerous examples of the fallibility of the individual motorists were pointed out. It is therefore believed that a desirable criterion to be used in the evaluation of a candidate system would be its lack of dependence on voluntary motorist cooperation. Another important criterion is the reliability of operation in the sense of mechanical or operational abilities to respond when needed and not fail because of an external cause or weakness. The capability of easy and frequent serviceability checks is deemed to be a highly desirable characteristic.

A consistent response in which the time variables are or are nearly constant is much more desirable for the stated objectives than is a highly variable response.

Among the changing environmental conditions with which the ideal detection system must cope is the weather and its effect on visibility and the willingness of motorists to leave their vehicles to give aid or seek assistance. Darkness is also a condition which is frequently encountered during hours of peak flow and the effective operation of a system under this condition is an important criterion of a successful detection approach.

Figure 5 shows the time-related effective operations of a system which would satisfy many of the criteria listed above. A short time after the occurrence of the incident, the probability of a signal indicating the incident begins to

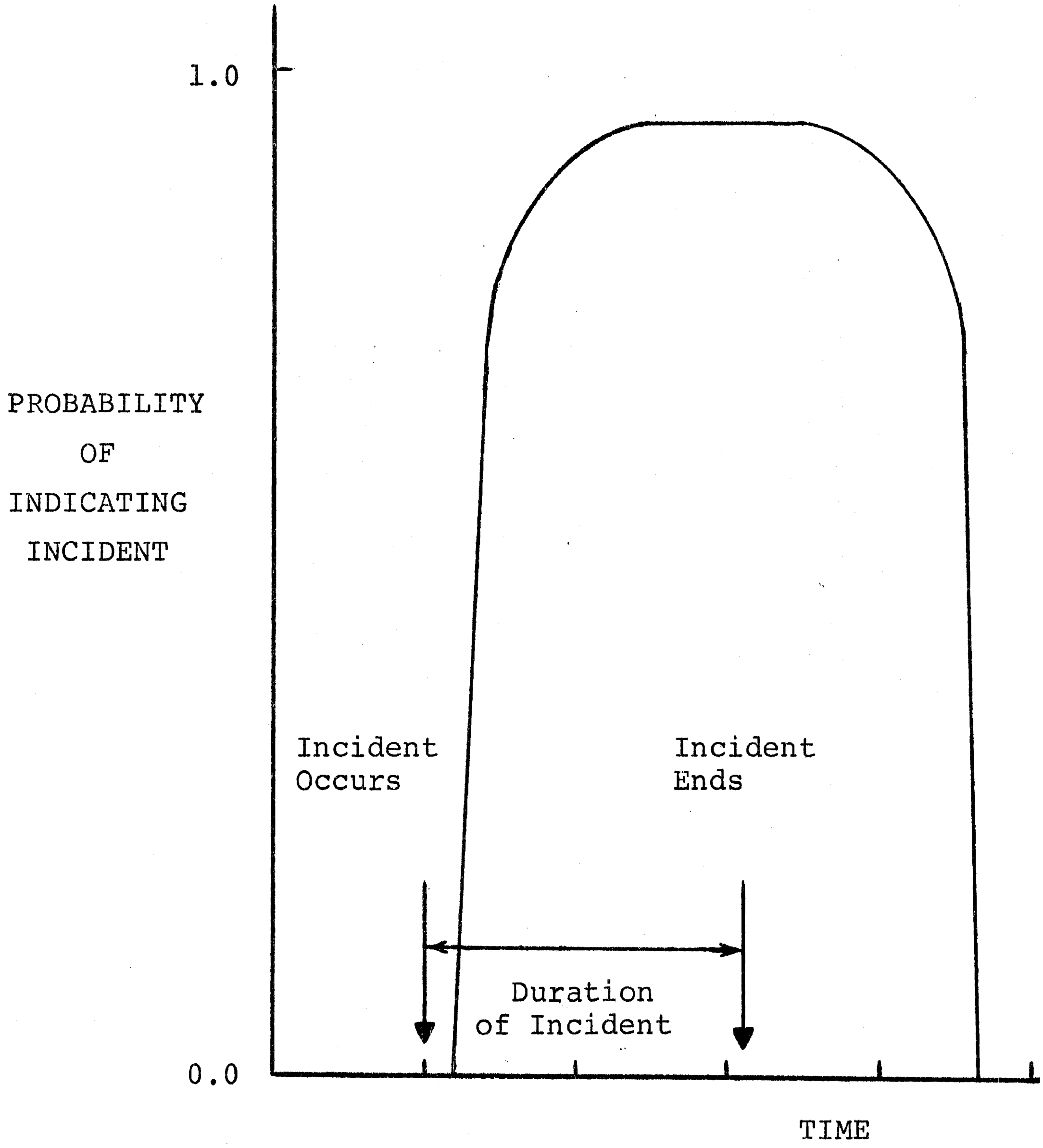


FIGURE 5

INCIDENT DETECTION MODEL
RESPONSE TO INCIDENT

increase rapidly with time. After a short interval, the probability of detection is near 100%. Following the end of the incident, the probability of a signal that the capacity-reducing incident is ended is very high.

THE MODEL

The general model envisaged for the systems analysis of alternative incident detection and response candidate systems is a cost-effectiveness model in which every candidate system is evaluated with respect to the criteria listed in the previous section. Costs for installing and operating each system are estimated and the decision on which system to adopt is based on conventional multidimensional cost-effectivness techniques.

In this research, efforts are particularly directed toward the times of occurrence of those events which are needed for the measures of effectiveness. The following paragraphs describe the event time sub-model developed for this research.

Figure 6 presents a structuring of the history of a single incident from the viewpoint of this research. Important events are shown in the boxes while continuing activities are shown between the boxes. The typical response of urban freeway traffic flow to a capacity-reducing incident is given on the right-hand side of the figure. When demand exceeds the incident location capacity as shown here, congestion continually increases until the incident is terminated.

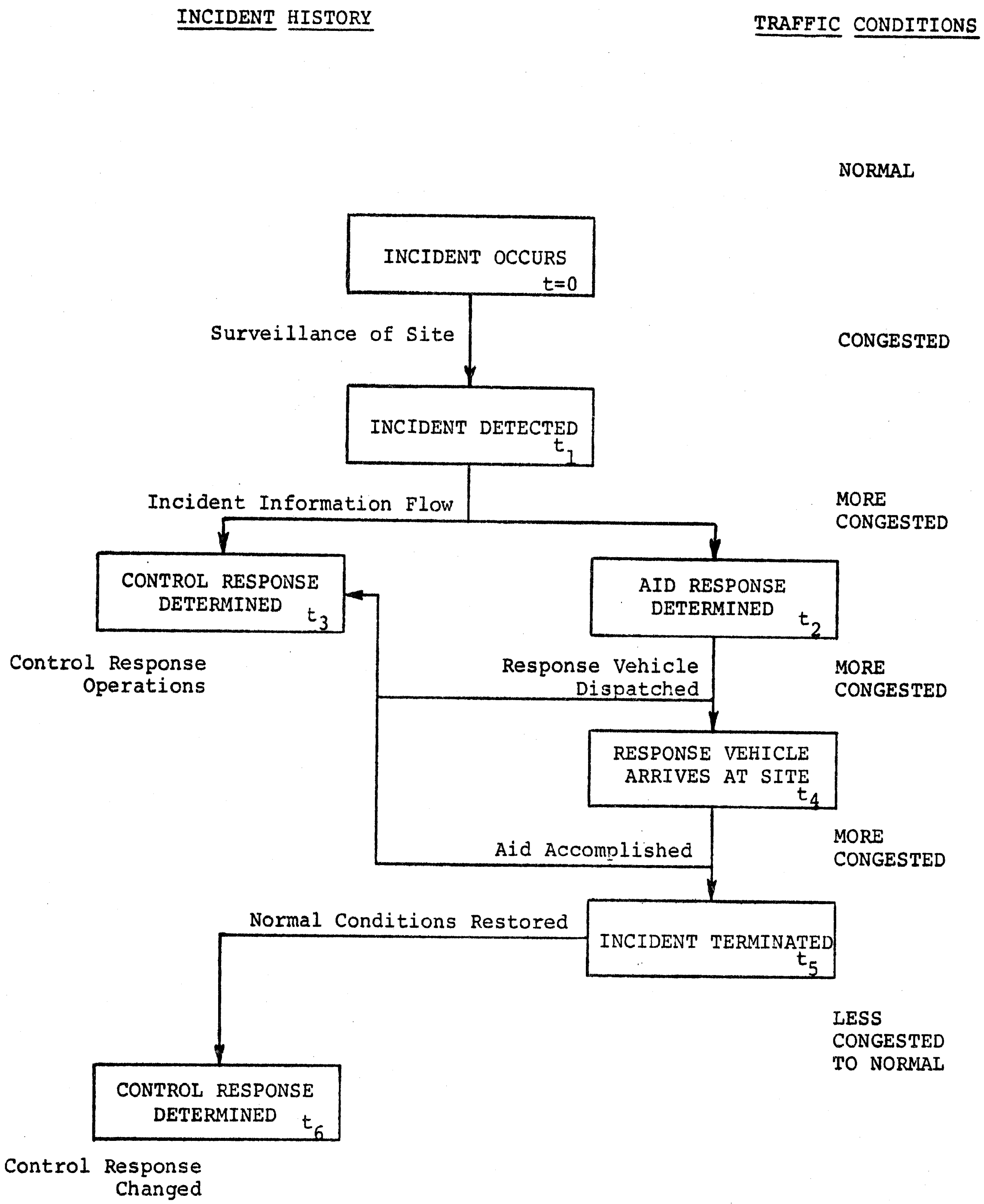


FIGURE 6

HISTORY OF AN INCIDENT

It is apparent that an improvement of operating conditions can be achieved by making the time of any post-incident event occur earlier. These events are t_1, the time that a signal indicating the presence of the incident is received at the operating agency's communication center; t_2, the determination of the type of aid, wrecker, police, mechanical, etc., required at the site; t_3, the times of the determination or updating of the appropriate control response to maintain optimal freeway flow; t_4, the arrival of the aid vehicle at the site; t_5, the completion of the incident through restoration of the site to the capacity that existed prior to the occurrence of the incident; and t_6, the transition point at which operational information and control responses change in reaction to the removal of the incident.

This sequence is not followed for every incident as defined in this study. Some incidents are resolved by the involved motorist himself. For example, a tire failure resulting in a vehicle stalled so near the traveled lanes that traffic flow is impeded is frequently handled by the motorist by changing the tire and then departing. Such an incident requires no aid. On the other hand, the chance arrival of a wrecker might result in the vehicle being moved to a location where there is little or no effect on traffic stream flow. In some cases the incident may be detected, the aid type determined and dispatched only to find that the incident has been terminated for any of several reasons.

Once an incident has been detected, two types of information are required to respond in a way that will satisfy the criteria listed earlier. One of these is to determine the nature of the incident so that proper aid can be dispatched to the motorist and the sequence of events required to clear the incident from the freeway begun. The other is to introduce the optimal freeway information and control parameters. If the form of response required is not adequately determined by the detection scheme, delay in removing the incident or changing control can be expected as a result of the necessity to communicate further, often following the arrival of a police officer.

The events shown in response to an incident result from several types of actions: the surveillance of the freeway seeking evidence of an incident; the determination of the nature of the response deemed appropriate for an incident that has been detected; the implementation of an appropriate control strategy; the arrival of the response vehicle at the site; and the provision of assistance and restoration of capacity at the site. In this structuring there is a continuing flow of information to the operational control system. In evaluating candidate operational systems for their effectiveness in meeting the incident-response problem it is necessary to place appropriate weight on the functions served, both within and outside of this problem. Police patrols on freeways are carried out, for example, for other purposes than incident detection. It is also apparent that a cruising police vehicle is capable of detecting an incident, determining the needed response, communicating a control strategy and frequently providing the needed aid. Other systems may fulfill only some of these functions.

In terms of reducing the total duration of an incident and the corresponding adverse effect on traffic operations, the time from incident occurrence until determination of the appropriate response may be as important a factor as the time to detection, and hence is also an important consideration for the incident detection scheme. The longer an incident that is adversely affecting traffic operations goes undetected, the more the number of delayed vehicles in the queue upstream increases as does the time it will take for this congestion to be dissipated. As the time lag for incident detection becomes a larger proportion of the total duration of the incident, the control response becomes less effective.

The ideal detection of a capacity-reducing incident, t_1, would happen as soon as the incident occurs. There are few systems which offer the possibility of accomplishing this objective. On the other hand, the actual detection of a capacity reduction resulting from an incident is a good indicator of the character of the congestion problem since the magnitude of the incident's effects on traffic is determined by the demand conditions that pertain at that time and the nature of the incident.

Some detection-response systems generate "false alarms." A false alarm will exact costs or reduce benefits when it results in the needless waste of resources associated with the dispatch and travel of a response vehicle to a non-existent incident or the actuation of a flow-reducing control response when not needed. An equally serious problem is the case of a false alarm signal delaying the determination of the required aid and the response vehicle's arrival at the site of an actual incident because of the time required to process the false alarm.

In summary, the recommended time related cost-effectiveness model elements are based on the time costs to freeway users shown in Figure 4. An extension of a British model of time savings requires the availability or development of the information listed below for the evaluation of a candidate system (34).

1. Traffic flow and input demand.

2. Flow reduction caused by an incident.

3. Incident event times:

   a. t_1, incident detection time;

   b. t_2, response aid determination time;

   c. t_3, information and control response time (or times);

   d. t_4, response vehicle arrival time;

   e. t_5, incident termination time; and

   f. t_6, final information and control response change time.

4. Flow improvement achieved after arrival of response vehicle.

5. Fraction of traffic diverted upstream and non-freeway travel time for that traffic.

6. Reductions in delay to downstream vehicles queued at ramps.

The application of this model should make evaluation of the time-related elements straightforward.

INCIDENT DETECTION AND RESPONSE SYSTEMS

There are many existing and proposed systems which play a role in the times of detection, identification of aid required and determination of control response, the main concerns of this study. While the capabilities of these systems to accomplish other freeway operational tasks is often of great significance, it is important to be able to evaluate these systems from the limited but important viewpoint of incident detection and response.

There are several possible systems that can be used to fulfill the surveillance function that culminates in the detection of a capacity-reducing incident. The only existing system that is continuous in both time and space is a television system with constant monitoring. Systems which scan each location at discrete intervals include television systems with intermittent monitoring, police and mechanical aid patrols and observation from moving aircraft. Citizens Band radio equipped vehicles which pass incidents also fall in this classification. Other systems which provide information for fixed locations on demand include roadside telephone systems and approaches that rely on cooperative passing motorists.

The traditional means of urban freeway incident detection is the police traffic patrol. A 1963 survey of 88 large American cities found that all of them have some regular provision for police freeway surveillance, although most did not assign special enforcement and accident investigation personnel to freeway duty only. Most frequently, a freeway was patrolled from a frontage road two or three times an hour as part of regular police patrols of the city. Incidents, of course, vary in their impact on freeway traffic, and in practice the detection of the more serious capacity-reducing incidents by police patrol is given more attention and effort. Since these may produce considerable congestion over some distance, this unexpected congestion often serves to alert police units upstream or passing near the freeway.

An early study of 46 freeway accidents on a section of the Lodge Freeway in Detroit indicated an average response time by the police of 7.9 minutes (26). The average response time for 39 vehicle breakdowns on traffic lanes was 5.2 minutes. At the time of the study, the Freeway was regularly patrolled by freeway traffic control and assistance units operating as a separate unit of the Detroit Police Department. Other police units used the Lodge Freeway and frontage roads as travel routes and thus constituted an additional irregular patrol. Private tow trucks in radio contact with the police also conducted an irregular freeway surveillance.

As an incident detection system, police surveillance has several advantages. Since officers are at the incident scene they know exactly the nature of the incident and are able to communicate this information by radio to the freeway surveillance control center and to appropriate sources of aid. There may be an initial time lag before this information is relayed to the control center, but the police will later be able to state the exact time the incident ceases to be a traffic hindrance. Police surveillance is indispensable for the handling of incidents and as a service to the freeway user. It must be considered an integral part of the freeway control system.

There are several systems that utilize fixed observers charged with the responsibility for surveillance, incident detection and communication. Television surveillance systems have been established that maximize the advantages of the human observer and interpreter and minimize the time lag for detection. Operational systems are increasingly being reserved for specific troublesome areas such as bridges or tunnels. A single observer can keep a large segment of freeway, 3.2 miles in the case of the Lodge Freeway, under continual visual surveillance with a fairly high degree of probability of detection of incidents except those of very short duration. A system of TV monitors on an urban expressway, however, did not yield adequate information to permit a remote viewer to deduce the reason for stoppages on the shoulder in the majority of instances (5).

The probability of detection is partly a function of observer training, ability, dedication and fatigue over time. A study of observers of the Lodge Freeway television system found that the best test subject detected only 78% of the estimated total number of incidents taking place during the study (4). This is still a high level of surveillance. As a supplement to police surveillance, television surveillance on the Lodge Freeway has significantly reduced police response time to accidents by an average of 2.5 minutes (from 7.9 to 5.4 minutes) according to a 1965 study (21). On-freeway incidents doubtless have a very small time lag for television detection since the ensuing congestion would quickly attract the attention of the observer even if the incident did not.

One difficulty with television surveillance as implemented on the Lodge Freeway where the cameras are mounted on overpasses is the multiplicity of cameras required to obtain thorough coverage. It has been suggested that cameras equipped with telephoto lenses be installed on nearby tall buildings, towers, or even suspended from balloons positioned over the freeway to achieve comparable coverage with fewer cameras (47, 48). The use of aircraft for surveillance greatly increases the viewing range. The ability to see more of the freeway than an observer on the ground or in a car partially offsets the fact that aerial surveillance occurs only at periodic intervals. Weinberg considers aerial surveillance to be inherently more efficient in the use of the observer's time than television surveillance. The television operator spends much of his time observing normal freeway operations while the aerial observer with his great mobility can cover a larger area and move promptly to oversee a traffic problem. There is little information in the technical literature concerning time lags in the detection of freeway incidents when aircraft are used. For the wide range of visual observation, the response time for a major incident with its resulting congestion could be fairly short, although probably not competitive with television surveillance.

Aerial surveillance is somewhat vulnerable to weather and visibility conditions. Helicopter operations can be grounded by high winds, fog, or severe icing conditions, although in Buffalo this stops a daily helicopter patrol only an average of six times a year (47). Fixed-wing aircraft are also affected by low cloud ceilings since they must stay at higher altitudes than helicopters. It should be pointed out that television surveillance is very satisfactory under these various climatic conditions.

Both fixed-wing aircraft and helicopters, the latter considerably more expensive in hourly operating cost, have been employed in various capacities by police departments, radio stations and researchers for traffic surveillance. They are quite capable of detecting any incident involving stopped vehicles. A study of incident detection by fixed-wing aircraft patrol on rural California highways resulted in 23% of the incidents observed being disabled vehicles and 16% parked or abandoned vehicles (22). Weinberg concluded that a light aircraft patrolling at 85 mph at about 2000 to 3000 feet, consistent with the operating capabilities of the aircraft, provides good area coverage and is satisfactory for the observation of specific details (47).

As an alternative to searching for capacity-reducing incidents, it has been suggested that such incidents seek out the freeway control center. Systems using this principle involve the installation of radios, roadside telephones or some other road or vehicular communication device. The benefits to motorists in rural areas where patrols may be sporadic and distances to private telephones great are apparent, but these installations are also actively considered and implemented in urban freeway systems. Should calls of distress be automatically relayed to the freeway surveillance center as well as the police, this would amount to a form of incident detection where both the location and type of incident are given. The time lag for detection depends on the method by which the motorist communicates to the authorities. In a 1966 Detroit pilot project more than 100 Citizen Band radios were installed in vehicles with a specific channel assigned for messages to the freeway control center (3). The Detroit experience indicated that drivers in the test vehicles, as well as many others with privately-owned units, were very willing to communicate incident information.

Some 2600 on-freeway telephone call boxes are in operation on 325 miles of Los Angeles County freeways, with calls relayed directly to state or county police (22). A study of 2483 calls demonstrated the advantages in saving of police time since only 20% of the calls required police assistance. A disadvantage of on-freeway call-boxes is that it encourages vehicles to stop along the shoulder and people to leave their vehicles. Among the problems in the operation of call-box systems are the technological problems of maintaining circuitry, vandalism, and protection against lightning. Operational problems include false alarms as well as slow police communication center response to incoming calls.

The good-will of passing motorists is further exploited in a system that consists of having them blow their horns or flash their lights at designated points to signal an incident (13, 38). Presently being implemented along a

50-mile section of Interstate 4 in Florida, an electronic sensor will register these signals, and after several had been received would signal an alarm to a central authority. A disadvantage of this scheme is that the nature of the incident is not known until a patrol vehicle reaches the scene, thereby introducing additional delay in getting proper aid to the scene if required.

The above detection schemes all provide a form of continuous freeway surveillance although the probability of detection has been found to be low for the minor types of incidents.

Table 1 presents an evaluation of the effectiveness of several systems in reducing the time lag between the occurrence of the events of particular interest shown in Figure 6. Three of these systems, closed circuit television, cooperative motorist, and traffic stream characteristics, were specifically studied in the research contained in this report.

The systems which are most effective in signaling the occurrence of an incident (time t_1 in Figure 6) include closed circuit television, a signal from a disabled vehicle and information on macroscopic traffic stream characteristics. Police patrols, cooperative motorists and roadside telephone systems are deemed only fair in this respect.

TABLE 1

EVALUATION OF CAPACITY-REDUCING INCIDENT DETECTION AND RESPONSE SYSTEMS

System	Incident Detection Time, t_1	Aid Response Time, t_2	Control Response Time, t_3	Incident Termination Time, t_5	End of Control Time, t_6
Closed Circuit Television	Good	Fair	Fair	Good	Poor
Disabled Car Signal	Good	Good	Poor	Fair	Poor
Roadside Telephone	Fair	Good	Poor	Poor	Poor
Cooperative Motorist	Fair	Poor	Poor	Poor	Poor
Police Patrol	Fair	Good	Fair	Good	Good
Traffic Stream Characteristics	Good	Poor	Good	Good	Good

After an incident signal is received, the time required to determine the aid response needed is usually shortest when this information comes directly from the disabled vehicle itself, the roadside telephone or police patrols. Closed circuit television systems also perform this function satisfactorily. Cooperative motorists and traffic stream characteristics systems provide little help in this function and are rated as poorly performing systems.

The system which provides the most useful information for real-time traffic information and control response is the traffic stream characteristics system. Police patrol and closed circuit television systems are capable of providing some information for this function, but are limited by their inability to provide accurate numerical scaling of the problem.

Shortening the time lag between aid type determination and the end of the incident and identifying the time when the incident is removed is accomplished effectively by closed circuit television, police patrol and traffic stream characteristics systems. The time when additional information and control is not needed is best determined by police patrols and traffic stream characteristics.

From this evaluation, it can be seen that the traffic stream characteristics system can be extremely useful in the minimization of time lags in incident detection and response, particularly when real-time traffic control systems are in use. This research is particularly concerned with the further exploration of some of the characteristics of this type of system.

COMPARISON OF TELEVISION SURVEILLANCE AND CITIZEN BAND RADIO INCIDENT DETECTION

During 1969 several of the incident detection systems considered for urban freeways were operational on the John C. Lodge Freeway. Police patrols, television surveillance and a CB (Citizens-Band) radio network were in use and a real-time computer surveillance and control system was in operation. This research program took advantage of these installations to explore the interaction between the Lodge Freeway television surveillance system and the Citizens Band radio system.

The "CB Radio Driver Aid Network" serves as a roadway surveillance system by providing two-way communication with motorists owning a CB unit. The system, developed by the General Motors Research Laboratories, has been operated by the Detroit Department of Streets and Traffic since July 1966 (3). As a detection scheme the CB network is a cooperative motorist system and depends on the willingness of observers to report incidents they encounter while driving. A major advantage of this system is its ability to provide two-way communication from the scene of the incident, thus determining the type of assistance needed at the incident site. Television surveillance also has the capability of determining the type of assistance needed at an incident seen on one of the monitors. The CB system, like television surveillance, provides detection by a passive observer not in direct communication with the persons involved in the incident, unless a CB operator himself is involved.

The CB system would be expected to experience some difficulty in determining assistance needs, but its close proximity to the incident should serve to reduce the percentage of unknowns in comparison to television surveillance. Bauer, Quinn, and Malo have pointed out that when notified of an incident detected by means other than police patrol, the police occasionally make their own verification of assistance need by dispatching a patrol unit to the incident site before requesting specialized aid (3). The Lodge television logs (see Appendix A) occasionally note instances of the police failing to stop after being notified of an incident. It is believed that in these cases a police unit passed the site and determined on closer inspection that no aid was required.

A comparison of incident detection experience by the two systems was made by examining the records of both the television and CB systems for the month of June, 1969. These results are reported in Chapter Two.

THE JOHN C. LODGE FREEWAY CORRIDOR CONTROL AND DATA SYSTEM

The research reported in this study was conducted at the National Proving Ground for Freeway Surveillance, Control and Electronic Traffic Aids in the John C. Lodge Freeway Corridor in Detroit, Michigan. The John C. Lodge Freeway is a six-lane facility built in the early 1950's which extends generally northwest from the central business district to the near northern suburbs of Detroit. Computer surveillance and control extends over an eight-mile section northbound from the interchange with Grand River Avenue to West McNichols Avenue. The southernmost point is approximately one mile north of downtown Detroit and the northern limit is about two miles south of the city limits. Peak period congestion is generally found throughout much of this section of the Freeway, particularly north of the Ford Freeway Interchange.

Every vehicle entering or leaving the Freeway is detected. To accomplish this, detectors are placed on all entrance ramps and exit ramps as well as at the limits of the surveillance area. At several locations there are individual lane detectors over each of the northbound lanes (9, 10, 11, 23, 46).

The detection of and response to accidents, stopped vehicles and other unusual incidents has always been an important part of the Lodge Freeway surveillance and control program. A 3.2 mile section of the Freeway from the Edsel Ford Interchange north to the Davison Interchange was placed under television surveillance in January 1961. One of the first observations made after surveillance began was the sensitivity of freeway operations to on-freeway incidents (17). An incident may have been quickly removed to the shoulder, but congestion back-ups as much as a mile or more in length and lasting an hour or more were observed.

Over the years, the emphasis of the incident detection effort on the Lodge Freeway has shifted from providing motorist aid to minimizing hazards and maximizing traffic flow. As previously indicated, the television surveillance system alone, although incapable of communicating directly with a motorist in need, reduced police response time to an incident and facilitated notification of the appropriate form of aid (police, ambulance, fire department, etc.). Variable speed signs and lane closure signs were added to the system to alert other freeway users of lane blockages and possible congestion downstream, thus promoting better traffic flow and reducing the possibility of vehicular conflicts.

Recent research efforts in the control of freeway inputs through ramp metering and establishment of alternate routes for freeway users provided the means for more effective surveillance and control of traffic operations during a capacity-reducing incident. To effectively implement diversionary measures, it is necessary to have available the means for detecting these incidents.

The research section of the Lodge Freeway contains a closed network of vehicle presence detectors linked to a central digital computer. The system is capable both of sensing fluctuations in traffic conditions as brought about by congestion and capacity reductions and of responding to them through restrictions of ramp inputs and route diversion.

The portion of the Lodge Freeway Corridor under computer surveillance currently consists of eight subsystems over a 6.1 mile section. A subsystem is a section of freeway bounded by a detector station and with only one entrance ramp. For purposes of this study, the three shortest adjacent subsystems included in the television surveillance system were used (Figure 7). These are the subsystems extending from Seward Avenue north to Chicago Boulevard (Subsystem One), a distance of 4815 feet; from Chicago north to Calvert Avenue (Subsystem Two), a 1460 foot section; and from Calvert north to Glendale Avenue (Subsystem Three), a length of 4335 feet.

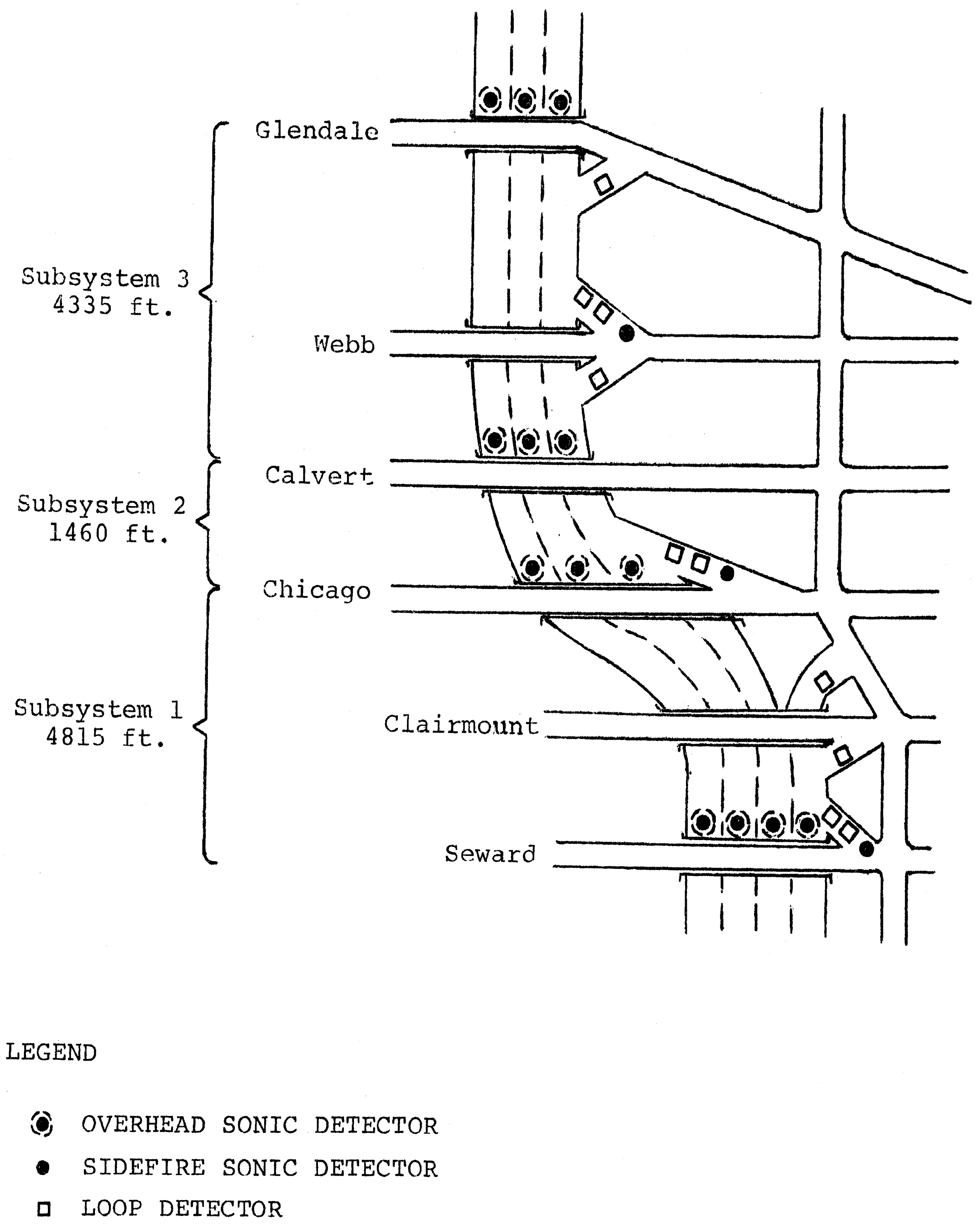


FIGURE 7

LODGE FREEWAY DETECTION SUBSYSTEMS
AND SENSING EQUIPMENT

There is at each station an overhead ultrasonic vehicle presence detector located over each lane and one or more detectors on each on- and off-ramp as shown in Figure 7. The Freeway section made up of these three subsystems contains one of the major northbound Lodge Freeway bottlenecks, the poor geometry in the vicinity of Chicago Boulevard.

Freeway surveillance projects now being planned in which incident detection is to be incorporated envision rather short detector spacings of a thousand feet or less (34). Subsystem Two, the shortest of the Lodge subsystems, 1460 feet in length, is comparable to these plans and also can serve as a basis for comparison with the other two much longer subsystems. The result of these comparisons should prove useful in cost-effective analyses made to determine if the detector spacings planned for future projects are optimal.

The number of lanes at each detector station was another geometric factor to be taken into consideration in selecting the study subsystems. At three of the selected freeway stations there are three traffic lanes, but the Seward station, the southern boundary of Subsystem One, has four lanes. The fourth lane, however, ends at the Clairmount exit ramp and is not a through traffic lane. Downstream from Seward the lane is marked as being for exiting purposes only. In order to avoid the effects of the low average occupancy in this lane, an average occupancy derived from the other three traffic lanes was used. Total volume at Seward was based on data from all four lanes.

The surveillance and control system is coordinated by an IBM 1800 digital computer with a 16,000 byte core capacity. All information is received by the computer using process interrupts and digital inputs (10). The primary control function of the computer in Lodge Freeway surveillance is the determination of metering rates for traffic on eight entrance ramps. Metering rates are based on Lodge Freeway flow conditions and are controlled by digital outputs from the computer. Approximately 25% of the available computer time is occupied in evaluating data and establishing metering rates.

To accomplish the ramp metering operation the computer interrogates each of the detectors once every 100 milliseconds. Flow and occupancy data are totaled and evaluated each minute, thereby producing the data necessary to update metering rates every minute. A system of information signs is also operated utilizing these data.

The detectors described above are the source of traffic characteristics data for the research. The IBM 1800 system was originally put into operation in 1968. Since that time one-minute volume and occupancy figures for the afternoon peak period from 1:00 to 7:00 p.m. have been accumulated on punch cards, providing an extensive set of data for later studies.

The television surveillance system augments computer-derived data with visually obtained data. From the Ford Freeway Interchange to the Davison Freeway Interchange (3.2 miles), 14 television cameras are mounted in an approximately northerly direction to cover both north and southbound lanes and shoulders. All but one of the cameras are mounted on overpasses 26 feet above the Freeway and approximately centered between the north and southbound lanes. One camera, because of freeway geometrics, is mounted on a 15 foot tower adjacent to the Freeway.

Distances between cameras range from 800 to 1800 feet. Each camera is equipped with two lenses, a wide-angle lens for normal surveillance and a telephoto lens. It is possible to distinguish general traffic patterns or a vehicle on the shoulder at a distance of up to 1500 feet with the regular lens. Normally, the telephoto lens is used for confirming observations beyond 500 feet. In regular surveillance operation, 79% of the Freeway is continually visible. By utilizing the panning and tilting capabilities of each camera, 96% of the Freeway can be seen (39).

In addition to distance limitations, the field of view is restricted by overpasses and horizontal curves. In the latter case, it is difficult to distinguish the nature of a traffic obstruction or the lane in which a vehicle is stopped as the range limit of the camera is approached. It has been found that precipitation in the form of rain or fog does not impair visibility because of the focal properties of the cameras which provide better visibility than the human eye in these conditions (39).

At night, only incidents taking place within a few hundred feet of the cameras can be directly seen. Except for those incidents occurring within this limited night range, only vehicle headlights are visible. Under these conditions, an on-freeway incident is detectable only by noting eccentricities in headlight patterns. Vehicles on the shoulder are detectable only if their headlights or flashers are on, and at distances over about 800 feet even these stopped vehicles are difficult to distinguish.

On the 3.2 mile section of the Lodge Freeway under television surveillance there are an average of 3.64 on-freeway incidents every day (5). One-fourth of these are accidents, the remainder are vehicle disabilities. This represents a rate of 9.8 incidents per million vehicle miles.

As previously indicated, the detection probability of television surveillance, estimated to be 95% of all incidents according to Pogust, is strongly a function of observer training, ability and motivation (37). A study of five test subjects by Bergsman showed that differences in detection performance among individuals were the largest single source of variability (4). All the test subjects improved with experience over the four-week evaluation period, the best subject improving his detection efficiency from 56% of the estimated total number of incidents the first week to 84% the fourth week. Under test conditions, no fatigue factor was evident for the four-hour shifts. As illustrated in Appendix A, Figure A-1, the layout of the control room on the Lodge Project placed the television observer at the focal point of project activity. The observer would better be able to perform his duties in a more isolated location away from the center of activity.

The other important motorist benefit measures of effectiveness of television surveillance are the ability to determine the nature of an incident and the proper form of aid, if any, and the time it takes to detect and respond to an incident. With the use of the telephoto lens, it is often possible to discern the nature of an incident either by the condition and position of the involved vehicles or the actions of the involved motorists. However, it has been found that the cause of 31% of all shoulder incidents could not be determined by the television observer using only the standard lens (5). Under these conditions, he cannot respond by sending the appropriate aid.

During 1969, television surveillance was maintained with a single observer responsible for recording incident characteristics and informing the City of Detroit Police Department of those incidents requiring their attention. Incident characteristics, including time and duration, type, location and prevailing weather conditions were recorded on log sheets (see Appendix A and Figure A-2). These operations, as well as continuing telephone contact with local police agencies, were carried out from 6:00 a.m. to 8:00 p.m. each working weekday and provided data on most of the incidents occurring in the section during the entire year.

INCIDENT DATA COLLECTION

Data from the detector-computer system were aggregated and recorded for each minute of the afternoon for north-bound flow as described by the Texas Transportation Institute (10).

Information regarding freeway incidents was compiled from television surveillance records. Early analysis of traffic data during incidents led to the conclusion that the detection of shoulder incidents and the like was difficult if not nearly impossible. Their impact on freeway operations generally is very slight except for those that distract freeway drivers. Thus, for purposes of this research, the detection of capacity-reducing incidents was restricted to those incidents that physically reduce the capacity of a freeway by blocking one or more lanes for some length of time.

Television surveillance records from December 1968 to the end of television operations in December of 1969 were searched for on-freeway incidents taking place in each of the three study subsystems between 2:30 and 6:30 p.m. Eliminating those for which traffic flow data were unavailable, a total of 50 on-freeway incidents were found suitable for analysis. Among these incidents were 18 accidents, 28 stalls or breakdowns, two instances of debris and two short maintenance operations involved with picking up debris. Regular maintenance operations such as median guardrail repairs were not included because this type of lane closure is generally planned in advance and is scheduled during times when interference with freeway traffic is minimal.

Some of the detection models described later employ threshold values of traffic variables based on incident-free traffic operations. In order to compile these, the television surveillance records for more than 200 days in late 1968 and 1969 were searched for days which experienced no incidents during or shortly before the afternoon peak period and also had no off-freeway incidents that could distract freeway drivers. It was hoped that at least four days could be found with each of the following afternoon peak period weather conditions prevailing: clear sky, rain, and snow.

Eliminating those days where the records indicated detector failures during the peak period, traffic flow characteristics for a total of 23 days were compiled. On certain rain and snow days where precipitation took place during only a portion of the peak period, characteristics were compiled only for that portion of from one to three hours out of the total four-hour peak period.

The control system record for each of these days was then inspected for detector failures not noted in the historical records. The passage of no vehicles at all under a detector for a minute, either because the lane had no traffic or because traffic was halted for that minute, was used as a criterion to identify this type of failure. Since such failures have an extremely low probability of occurrence on days without capacity-reducing incidents, several days were eliminated for recording no flow at least one-third of the time at one station. It was also decided to discard the six days which recorded several no flow minutes. The final sample days contained no zero lane flow conditions.

The remaining group of 17 sample days did not include sufficient numbers of full days of each type of weather condition to accomplish the desired stratification. Communication problems made incident-free, snowy days with all detectors operational particularly difficult to find.

It was decided to discard the partial days of rain or snow in order not to bias the final distributions in any way. Inspection of some of these days, including a two-hour raging blizzard (perhaps the worst peak period weather encountered in 1968 and 1969), did not disclose any unusual or distinctive variable performances except for the inevitable greater prevalence of congested conditions (27). The section of the Lodge Freeway under study contains no significant grades and Detroit seldom receives more than several inches of snow at a time. Therefore, it appeared that no matter what the condition of the pavement, peak hour traffic could always move as long as there were no incidents blocking the Freeway.

After completing this filtering and consolidating weather factors, a total of eight incident-free dry weather days and four days with rainy peak periods were selected for further analysis. Environmental characteristics for these

12 days are presented in Tables B-1 and B-2 in Appendix B. The set of sample days includes a variety of temperatures and days of the week. However, it is believed that neither are a factor in the analysis. One of the rainy days is listed as having both rain and snow, and for another day the rain was not quite continuous, but prevailed for most of the peak period. Since each day had a four-hour analysis period, a total of 1920 minutes of performance was available for clear weather conditions and 960 minutes for rainy weather. The comparable 1968 TTI data set contained four clear weather peak periods totaling 960 minutes of observations (10).

TRAFFIC STREAM CHARACTERISTICS INCIDENT DETECTION APPROACHES

Just as some cooperative and helpful motorists in the traffic stream consciously report the occurrence of incidents, it has been suggested that the group behavior of all motorists in the traffic stream be used as both a signal and a communications channel in incident detection. This suggestion is based on the observation that capacity-reducing incidents, particularly those blocking one or more freeway lanes, significantly affect traffic flow by causing moving vehicles to respond jointly in a way that will affect the time average of one or more of the macroscopic variables used to describe traffic flow. This belief is held despite other observations that there are wide variations in desired individual vehicle performance. In busy traffic, however, the presence and behavior of other vehicles nearby causes reasonably predictable and consistent responses.

It is fortunate that these traffic flow variables are the same as those needed for effective freeway control systems, thereby making it possible to utilize jointly the instrumentation and communication links installed for advanced traffic information and control systems.

As an example of traffic flow data recorded before, during and after an incident a typical record of one-minute volumes and occupancies for an observed stall in Subsystem One is depicted in Figure 8. According to television records the stalled vehicle blocked the median lane 1800 feet downstream of the Seward detector station for 14 minutes. The shaded area represents the estimated duration of the congestion generated by this incident as recorded at the two detector stations. In this particular case the congestion is of less duration than the blockage time, perhaps because the lane was only partially blocked. As described in the previous section, similar records were developed for all 50 incidents and constituted the basis for evaluation of various incident detection models and related questions.

In this section of the report the theoretical basis for traffic stream incident detection modeling is described, ways in which field installations are used to provide data for the models are set forth, model approaches identified and special problems associated with this approach to incident detection presented.

The theoretical basis for using the traffic stream as a communications channel is built upon the operational interactions in time and space among the individual vehicles in the traffic stream. It is believed that such interactions can be identified at volumes as low as 700 vehicles per

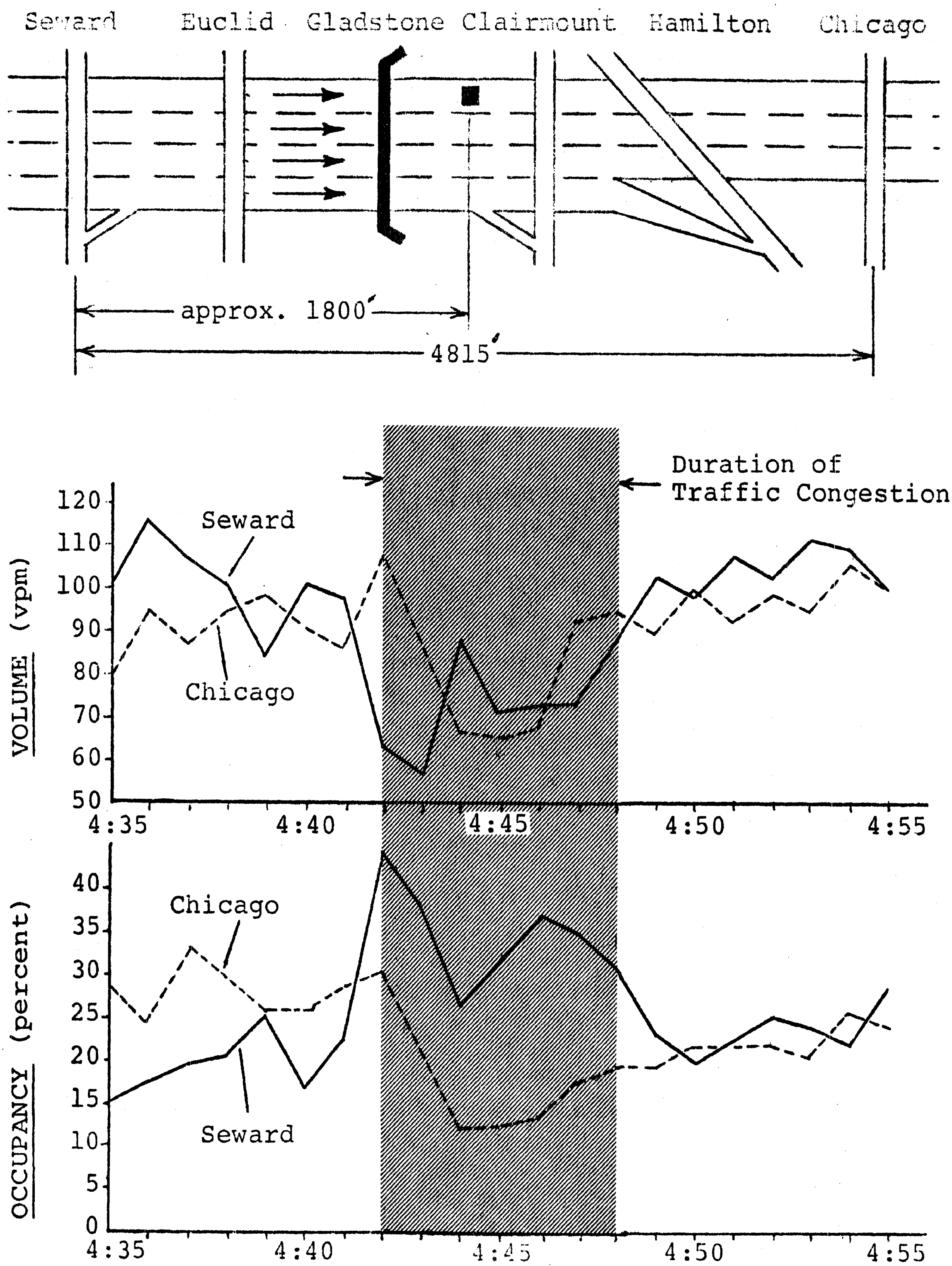


FIGURE 8

VOLUME AND OCCUPANCY CHANGES DURING
A CAPACITY-REDUCING INCIDENT

hour per lane, although earlier investigators state that at levels of 1,000 vehicles per hour per lane or less the interaction among vehicles is inadequate to propagate a response to the occurrence of a traffic incident for any substantial interval (37). This phenomenon can be viewed as a stimulus-response situation in which a freeway incident causes a slowing or stopping of vehicles reaching the point of the incident. If it is a capacity-reducing incident, by definition a bottleneck will be established. This bottleneck will affect traffic flow both up and downstream of the site. If the incident blocks a lane, there will be lane changing upstream from the incident and the distribution of vehicles among the lanes downstream of the incident will be unusual for some distance.

There are several macroscopic traffic variables which can be used to describe traffic flow at a point or on a section of highway. Those variables appropriate at a point include the traffic flow or volume, the speed of vehicles at that location and the occupancy or time that part of a vehicle is at the point. The variable most relevant for a section of highway is the density or concentration of vehicles. Among the three macroscopic variables used to describe traffic flow, there is less information error in inferring the state of the system when density or speed is used than when volume is used since identical volumes can be measured under both congested and uncongested conditions.

The theoretical foundation for incident detection is based on the work of Lighthill and Whitham on the propagation of density discontinuities, or shock waves, on crowded highways (29). They assume that two of the three fundamental macroscopic variables of traffic flow, volume, average concentration and average speed, are independent. The third can then be derived using continuum relationships. Their work provides a basis for predicting the speed and nature of the propagation of the shock wave both upstream and downstream from a temporary or permanent bottleneck.

Figure 9 illustrates the effects of a capacity-reducing incident on traffic operations based on Lighthill and Whitham's theory. This approach represents the limiting behavior of a stochastic process with a large number of vehicles over a long road and long periods of time. Referring to the diagram in the figure, the density, k_1, represents prevailing traffic concentration before the incident occurs. After the incident, traffic upstream operates in the congested density regime, k_2, if demand exceeds capacity. Immediately downstream of the incident, density is reduced to k_3, a function of the bottleneck capacity and fundamental characteristics of flow. A shock wave with velocity c_1 proceeds downstream, and a shock wave of congestion growth proceeds upstream at velocity c_2. In the figure, this shock wave has reached a detector station upstream of the incident.

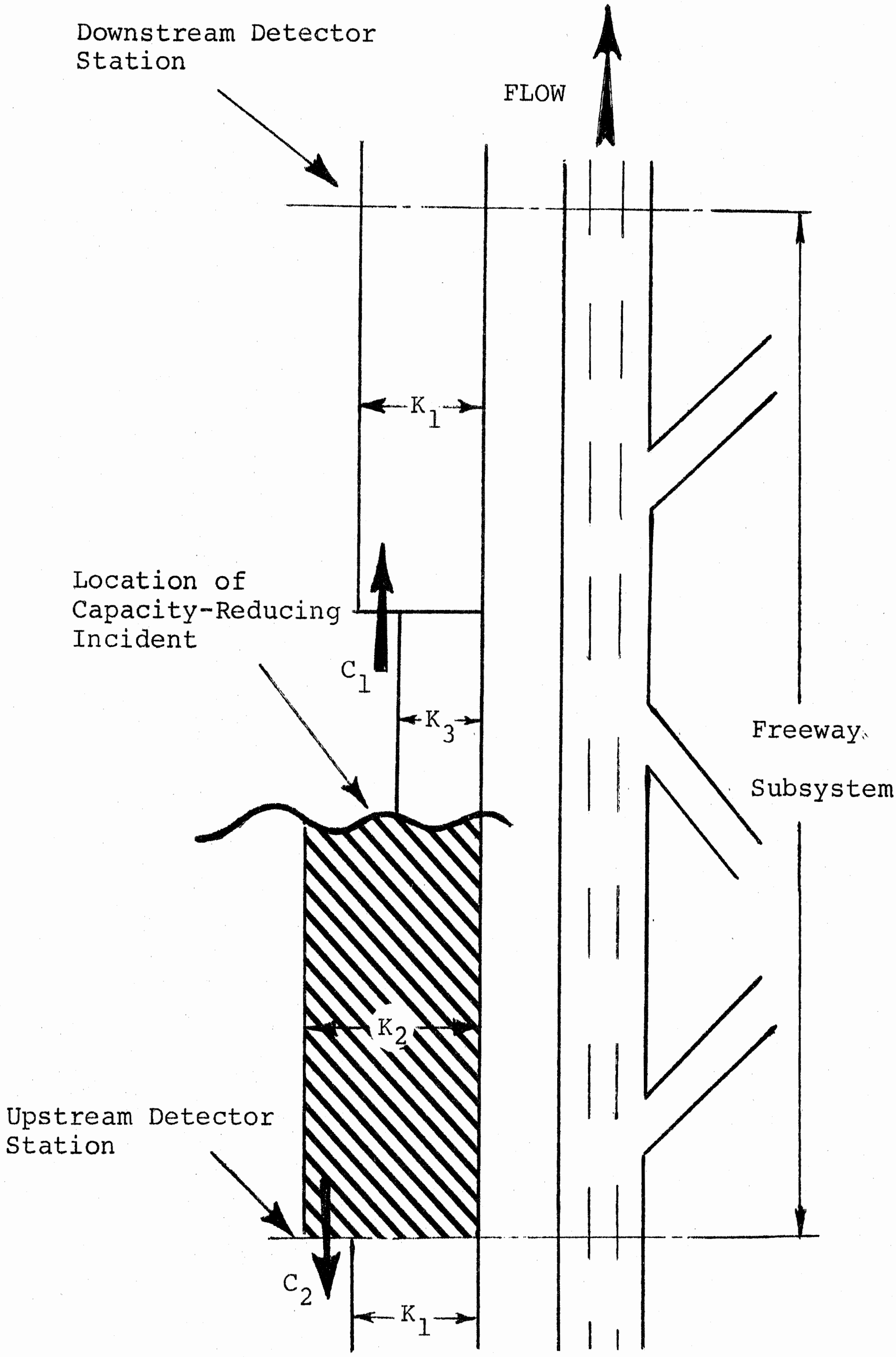


FIGURE 9

TRAFFIC FLOW THEORY APPROACH TO INCIDENT DETECTION

Traffic stream characteristic incident detection models can be designed to signal as soon as possible after these waves pass upstream or downstream detector stations. The models should detect the actual passage of either or both of the waves or recognize the joint occurrence of the k_2 and k_3 states of traffic operations as being abnormal. Although not all incidents produce the sequence of events depicted in Figure 9, many do. This research explores this facet of incident effects.

Inspection of the one-minute volume and occupancy records shown in Figure 8 reveals a distinct upstream occupancy shock wave at the Seward Station at 4:42 p.m. despite the natural variability of traffic operations and the masking effect of averaging occupancy over a one-minute period. It would be expected that the most effective detection models would be those which most sharply delineate the passage of shock waves or otherwise accentuate the sudden change in traffic flow patterns or are sensitive to the different regimes existing behind the shock waves.

Detection of incidents should be prompt, occurring as soon as possible after the shock waves delineating different flow states reach the upstream and downstream detector stations adjacent to the incident. This is necessary if the surveillance controller is to be aware of the capacity reduction in time to make effective adjustments in traffic information and control strategies.

Figure 10 illustrates several of the sources of variability during a capacity-reducing incident for traffic volume for three incidents occurring on the John C. Lodge Freeway in Detroit in 1969. The incident durations ranged from three minutes to over 20 minutes and were representative of the incidents evaluated in this study. Although volumes before and after the incident were similar for all three incidents (from 80 to 100 vehicles per minute), the general magnitude of the reductions varies widely. From minute to minute the behavioral pattern also shows different variability.

Considering data needs for this approach to incident detection, the first requisite is the measurement of traffic operations over time and space. The most satisfactory data would be obtained by tracking each vehicle within the freeway system by measuring its trajectory in time and space continuously. Hardware limitations and economic inefficiencies eliminate this microscopic approach. Hence, existing surveillance and control systems use point detectors located at key positions to sample traffic operations discretely in space and almost continuously in time. The number and location of detectors has a bearing on the errors in the information available and the applicability of this information to incident detection.

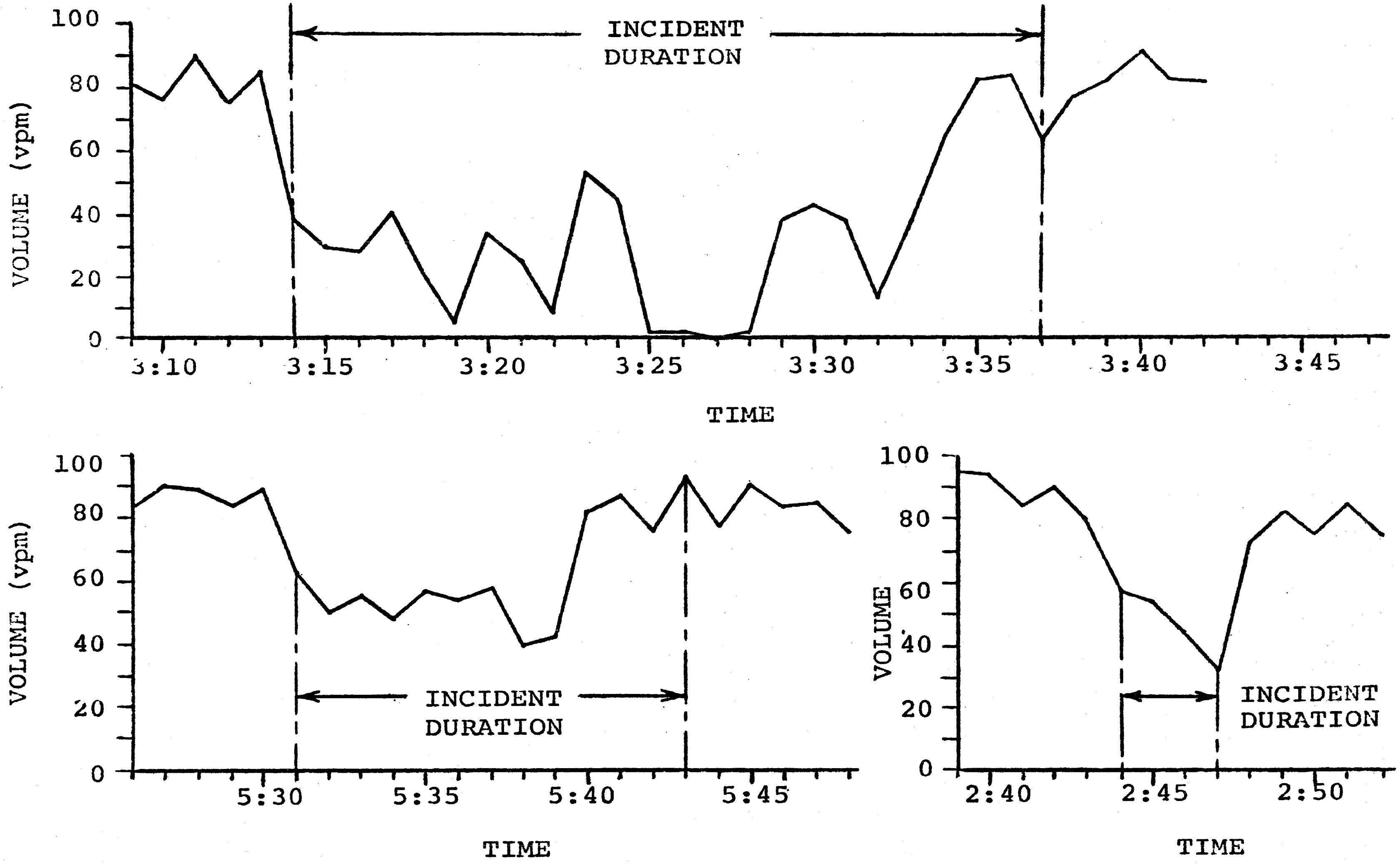


FIGURE 10
VOLUME VARIATION DURING THREE INCIDENTS

The conceptual approach to this problem is to locate a sensor over each lane at several transverse locations on the freeway, including also points of egress and access at ramps. Traffic flow information is averaged over a time period for each of these points and information on shock wave and lane usage used to signal the likelihood of occurrence of an incident based on the unusual characteristics of the basic traffic flow variables.

The set of traffic variables that can be measured without information error is constrained by the discrete sampling in space. A typical lane detector currently in use registers the passing of each vehicle, and from this information the flow rate in vehicles per time interval and time headway between vehicles can be developed. The fraction of time that a vehicle spends at the sensing point provides the basis for the time occupancy measure. The speed of a vehicle can be measured from the time it takes to pass the detector, but since vehicle length is unknown and must be estimated the result contains some information error. Knowledge of the number of vehicles present at some time between two detectors separated in space makes it possible to estimate the accumulation of vehicles between them, this measure of density being called the storage. However, the initial storage value is only estimated by these detectors through calculation of total travel and average speed between detector stations.

While the detectors provide signals for each passing vehicle there is so much variability in individual vehicle performance that it is desirable to accumulate data for a detector over a short time interval and use these data as inputs for surveillance and detection. Data for detectors for each of the several lanes serving freeway traffic moving in the same direction and located adjacent to each other at the same freeway location can also be aggregated to provide freeway station data. Detection system logic can operate on each variable separately as well as on functions of both variables for each detector or group of detectors.

Figure 11 shows a sketch of detectors located both upstream and downstream of an incident and the notation used in describing the various models used in this study. Lower case values are for individual lanes and upper case letters designate data aggregated from all the detectors at a station.

Since the behavior of traffic at the many different types of capacity-reducing incidents has been shown to be highly variable there is the problem of devising a model that responds as effectively as possible to these variations. A prime concern is the ability of the model to detect an incident that does occur. Another one of the problems that may be particularly critical in traffic flow characteristics incident detection modeling is the "false alarm" in which

Δ Lumped data time interval

$q_{ij}^{(\ell)}$ Flow in ℓ^{th} lane measured at station i during the j^{th} time interval

Q_{ij} Total flow at Station i during the j^{th} time interval $\left(Q_{ij} = \sum_{\ell} q_{ij}^{(\ell)} \right)$

$\theta_{ij}^{(\ell)}$ Fraction of time vehicles are present (Occupancy) at detector for ℓ^{th} lane at station i during j^{th} time interval

θ_{ij} Mean fraction of time vehicles are present, Occupancy, at Station i during j^{th} time interval $\left(\theta_{ij} = \frac{\sum_{\ell} \theta_{ij}^{(\ell)}}{L} \right)$

Q_{ij}^{E} Total flow entering freeway between station i and i+1 during j^{th} time interval

Q_{ij}^{L} Total flow leaving freeway between station i and i+1 during j^{th} time interval

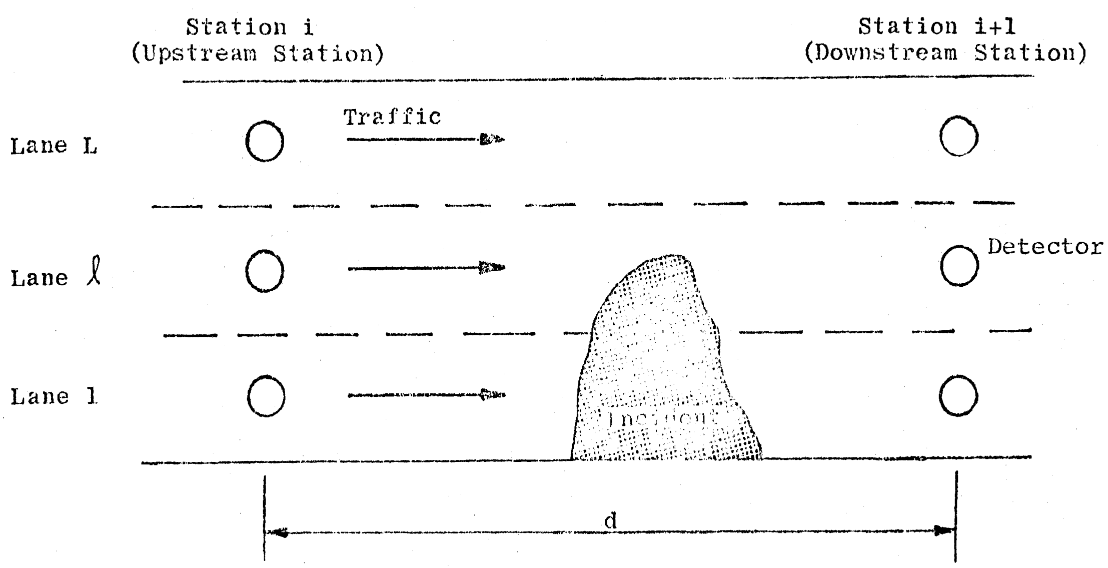


FIGURE 11

TRAFFIC STREAM FLOW VARIABLES

the occurrence of an incident is falsely signaled. This is conceptually identical to the statistical error of the first type or alpha risk used in statistical decision theory. Since these models are based on statistically sampled data, there is a possibility that the critical value of the traffic flow variable will be exceeded by chance and that there will be a false signal. This false signal may be corrected as more time elapses and confirming or contradicting data are received. Whether or not this is bad depends upon the costs associated with dispatching a vehicle needlessly to determine the type of response required and the delay resulting from waiting for confirmation and of the incident signal. It is convenient to structure this problem using a queueing approach in which the incident signals indicating the presence of an incident are accurate and the response type determination and response are service elements. The queue is formed by incidents waiting to be investigated or served (with possibilities of priorities for "stronger" signals). A typical queueing cost-effectiveness sensitivity analysis is then possible in which variations in the fraction of false alarms are tested for candidate response systems. An external system consideration is the effect on the control system if it responds to false alarms by changing traffic capacity parameters and unnecessarily causes additional costs to users of the freeway network.

The simplest models consider only the most recent minute of traffic data at one station and signal the occurrence of an incident near the station by comparing the variable with a pre-established threshold value. More complex models could signal incidents by measuring changes in traffic characteristics over time by considering data for earlier minutes. In the spatial dimension the more complex models could be designed to detect discontinuities in subsystem performance as inferred from data taken from the two adjacent stations that bound the subsystem. On a grander spatial scale models could be developed which would operate on time histories at several contiguous stations to detect incidents detrimental to optimal system performance. These models could be most useful for extensive freeway systems with many stations spaced close together.

The performance of eight incident detection models was investigated in the course of this research. Their categorizations are indicated in Table 2. Six of the models consider only the most recent minute's volume and/or occupancy data. Two models require data from only one station and three models use inputs from adjacent stations. One station model uses individual lane data. One of the models that was studied, a modification of the California incident

TABLE 2

DATA INPUTS FOR INCIDENT DETECTION MODELS

TIME / LOCATION	PREVIOUS ONE MINUTE	PREVIOUS TWO MINUTES	PREVIOUS SEVERAL MINUTES
One Freeway Station	Station Energy (Q, θ) Composite (Q, θ)		Exponential Smoothing (Q):(θ)
Individual Lanes	Composite ($q^{(\ell)}$, $\theta^{(\ell)}$) Station Discontinuity ($q^{(\ell)}$, $\theta^{(\ell)}$)		
Subsystem (Two Adjacent Stations)	Subsystem Energy (Q, θ) Subsystem Shock Wave (Q) Subsystem Discontinuity (Q, θ)	Modified California (θ)	
Several Adjacent Stations			

Depending on the type of traffic data available, a great many methods for detecting capacity-reducing incidents can be envisioned. The variety of ways to temporally and spatially classify model inputs is summarized here in Table 2.

detection scheme, considers occupancy changes at adjacent detector stations for the most recent two minutes. The eighth model studied considered the history of traffic flow for several minutes at one location. No attempt was made to devise and test a several station model because of the nature of the field study data available.

While the John C. Lodge Freeway installation uses detectors over each lane, the Chicago surveillance system operates on information from occupancy and flow sensing detectors placed only in the middle lane (32). If middle lane detectors only can provide an adequate level of detection capability, then their use may become standard practice in detection surveillance as well as in freeway control.

The spacing between detector stations can be expected to have an effect on both the time to detection, t_1, and, depending upon the damping of the shock wave with distance from the sensing stations, the characteristics of the signal. The speed of propagation of the discontinuities can be expected to range from 15 miles per hour and often as much as 45 miles per hour. This would result in delays ranging up to one minute before new congestion could be detected for 0.5 mile detector spacings. One of the purposes of this research was to explore the effects of spacing, utilizing three of the freeway detector stations (two approximately 0.9 miles and one 0.3 miles) on the Lodge Freeway for which data were available.

Another important factor is the interaction of geometry with incident effects. Subsystem One, with its lane drop, provides an opportunity to explore this factor.

It is also desirable to explore the possibility that traffic flow variable data can also be used to determine the characteristics and severity of the incident and the time when the incident effects have ended.

While the interval during which data are accumulated prior to averaging obviously affects the time at which an incident detection signal is generated, as well as the other values of interest, it was not possible to accumulate data for the John C. Lodge Freeway Corridor for times other than one minute because of limited resources. Therefore, this research does not provide insight into this possibly important detection system design parameter (1).

In summary, this incident detection research program makes use of the operational freeway surveillance and control installation and television surveillance system in the Detroit John C. Lodge Freeway Corridor to explore several aspects of capacity-reducing incident detection by macroscopic traffic flow parameters. The program includes the review, development and testing of eight suggested models. These models were evaluated in terms of their time lag characteristics and their propensity to correctly signal the occurrence of incidents as well as the likelihood of false alarm signals being generated. There is an investigation of the implications of this data flow for real-time traffic freeway corridor control and an attempt to determine whether or not macroscopic traffic flow information provides information regarding the type of incident which has occurred, particularly in terms of the possible duration of the incident as well as the type of assistance which may be needed. Insofar as it is possible, the effects of detector spacing were explored as well as the observed discontinuity in the number of freeway lanes found on the facility.

REVIEW OF TEXAS TRANSPORTATION INSTITUTE RESEARCH

The Texas Transportation Institute (TTI) commenced work in incident detection research as a part of their John C. Lodge Freeway Corridor study program and one phase of this research effort was a review and extension of their studies (10). They developed six models to detect incidents and evaluated them in terms of promptness and effectiveness in detection and the minimization of false alarms. The basic data inputs for these six models are individual lane volumes and average lane occupancies.

These incident detection models attempt to characterize traffic operations during a capacity-reducing incident so that they can be distinguished from normal traffic variations. The six models calculate values that register the impact of congestion upstream of an incident and/or simultaneously record the reduced flow downstream. One of these approaches uses the freeway control system ramp metering rates for the entrance ramps in each subsystem as the traffic parameter for detection. This approach was not investigated in this research because the ramp metering strategy used at that time in Detroit was only indirectly related to freeway incident effects.

The other five models all use various combinations of one-minute lane volumes and occupancies acquired at either individual or at adjacent detector stations. TTI and earlier researchers found occupancy (θ, the percentage of time that a detector is actuated by a vehicle passing underneath it) to be nearly linearly related to density, so in these studies occupancy was used as an equivalent for vehicular density for which theoretical bases have been developed (10). The five approaches are described below and formulas presented in Appendix C.

Freeway Station Models

These models operate on data acquired at an individual detector station. The inputs are the last minute's volume and occupancy for each lane at that location.

Station Energy: The kinetic energy of a traffic stream (the square of the volume divided by the occupancy) is a TTI concept derived from an energy-momentum analogy between traffic flow and the flow of a compressible fluid. The Station Energy Model uses the total flow recorded in all three lanes as the volume and the average of the individual lane occupancy as inputs. The actual kinetic energy variable used in the model is normalized and hence dimensionless as formulated in Appendix C.

This variable should be very sensitive to decreases in volume accompanied by increases in occupancy, the state frequently found upstream of an incident site. Unusually low values of kinetic energy, those below an empirically established critical level, actuate an incident signal from this model.

Station Discontinuity: The Station Discontinuity Model is based on a comparison of the kinetic energies of individual lanes. This is the only TTI model that specifically uses individual lane flow characteristics. The incident detection variable relates the lowest lane energy to the average of the other two lane energies for a three lane section. This variable can range from 0.0 to 1.0. A value of 0.0 would indicate no energy in one lane, a result of either no traffic at all in the lane because it is blocked upstream or traffic stopped altogether in the lane because of a blockage downstream, while at the same time some traffic in the other lanes is moving. A value of 1.0 would indicate an equal distribution of energy across the three lanes. Very low values of the variable actuate an incident detection signal. The incident is most probably downstream from the station generating the signal. Also, if the incident were immediately upstream of the station, passing vehicles would have little or no opportunity to re-enter the blocked lane and this could also actuate a signal. It was believed by TTI that this model would be effective only for incidents taking place near the detector station.

Freeway Subsystem Models

These three TTI models operate on the most recent minute's data from two adjacent detector stations. The freeway section between these stations is called a subsystem.

Subsystem Energy: It might be expected that a lower value of kinetic energy upstream and higher kinetic energy downstream will occur during an incident than had existed prior to that incident. The difference between the downstream and upstream energy values should produce a traffic stream characteristic variable, the "energy differential," that strongly reflects this situation.

Subsystem Shock Wave: At the end of each minute there are a certain number of vehicles contained within a subsystem. Instrumentation limitations make it impossible to calculate the actual number, but the minute-by-minute change in the number of vehicles "stored" within the subsystem can be approximated by subtracting the recorded downstream and off-ramp volume (output) from the upstream and on-ramp volume (input). If an incident were to take place near the upstream detector, the reduced flow down through the length of the subsystem would result in fewer vehicles within the subsystem after a minute. Conversely, an incident far downstream would create congestion and thus more vehicles stored upstream. TTI believed that this model would be less effective for incidents near the center of the subsystem because increased upstream storage would approximately balance decreased downstream storage.

Subsystem Discontinuity: Since there is a reasonably good linear relationship between average speed and occupancy for occupancies within the range of interest, the average speed can be estimated by dividing the one-minute volume by occupancy. In the Subsystem Discontinuity Model, speed values at adjacent stations are normalized by dividing by the observed "free speed" for each station. Similarly, occupancy values are normalized by dividing by observed "jam occupancies." The distance between the speed-occupancy points of two adjacent stations (see Figure 12) represents the difference in traffic operations in the speed-density plane at the two stations. Large differences would be expected to indicate the existence of a bottleneck between the two stations. In Figure 12, the upstream station (Point B) recorded a higher occupancy and lower speed than the downstream station (Point A) during the last minute. This situation could indicate a capacity-reducing incident in that subsystem. Subtracting the scalar value of the vector $\overline{AC}$ from the scalar value

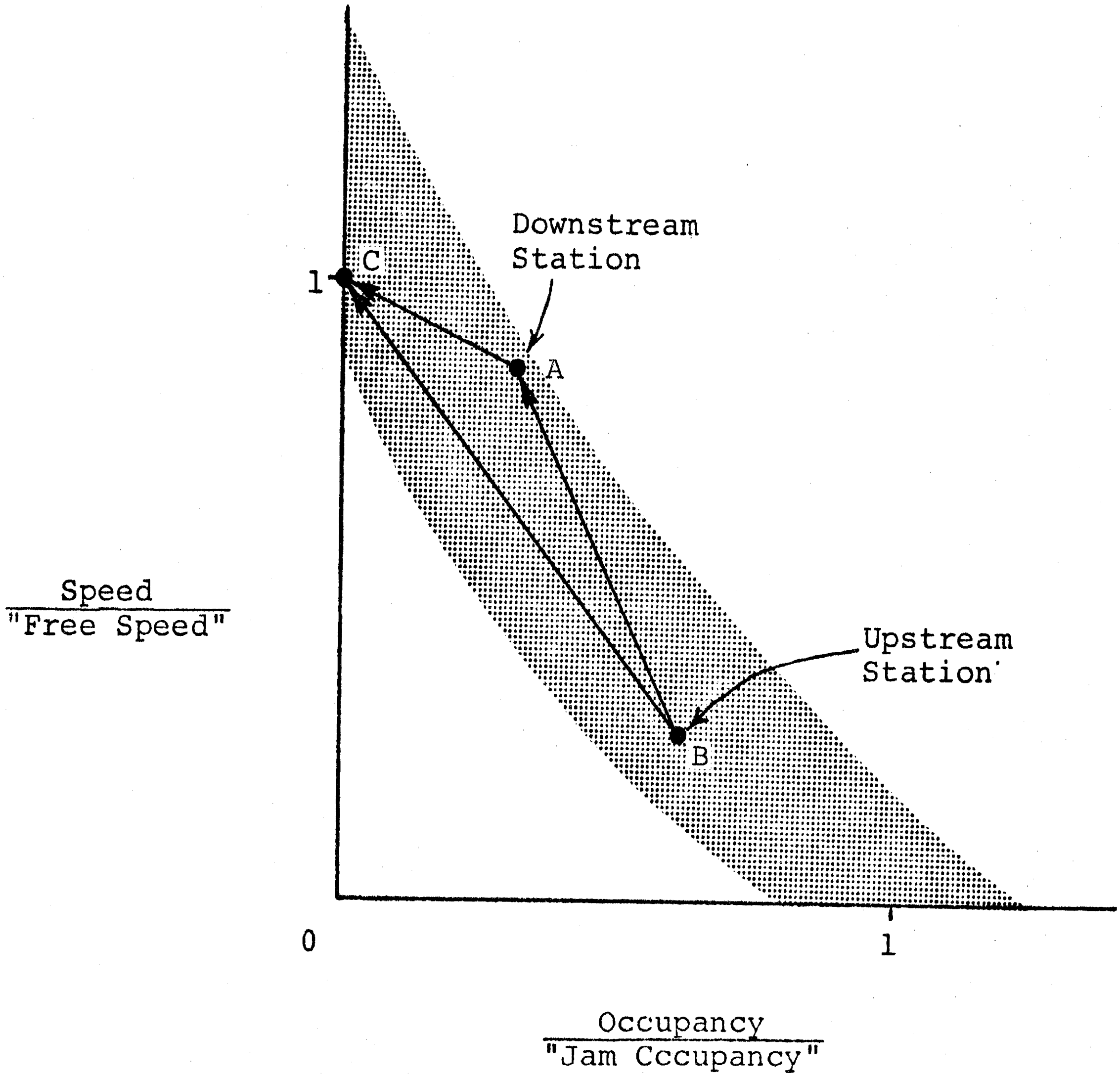


FIGURE 12

SUBSYSTEM DISCONTINUITY VARIABLE

of vector $\overline{BC}$ defines a positive or negative value which is an estimate of the vector $\overline{BA}$. The occurrence of unusually large positive values of the variable exceeding a predetermined critical value actuates a detection signal by this model.

Example of TTI Incident Detection Models

As mentioned previously, information on the five TTI model variables was printed minute-by-minute spanning the duration of the 50 on-freeway incidents selected for analysis. Sample plots for each of the models for one incident (the same shown in Figure 7) are depicted in Figure 13. The incident duration is indicated by the shaded area. Each TTI model is observed to respond as expected for this incident.

TTI Research Findings and The University of Michigan Research Approach

TTI determined "normal traffic" values for each model variable by studying 240 minutes of data from each of four afternoon peak periods. The probability of a false alarm signal ("alpha" error) was arbitrarily set at one percent (10). Hence, the critical value of "one-sided" variables was obtained by using the 99 percentile value. The 0.5 and 99.5 percentile values from the cumulative distribution function were used as the critical values for those variables

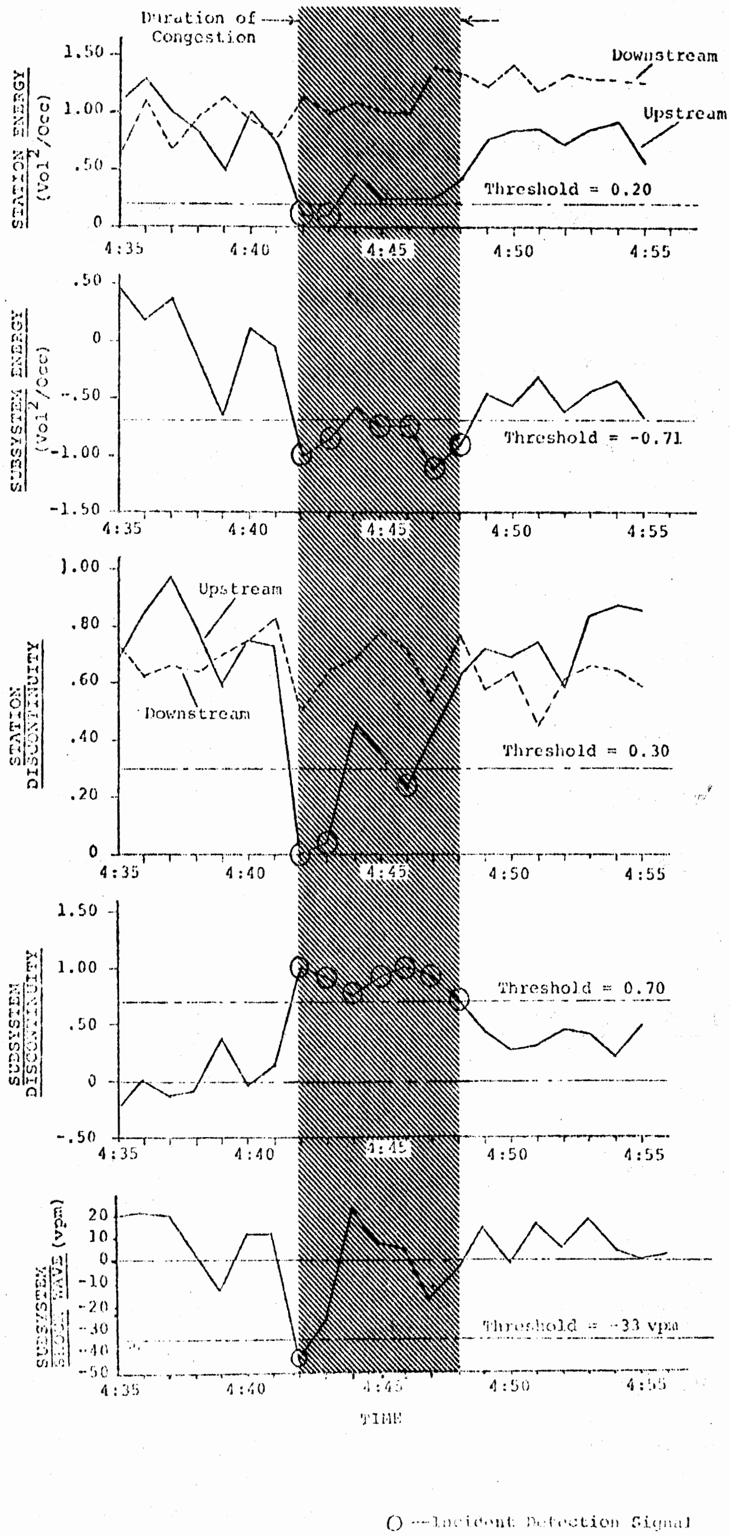


FIGURE 13

PERFORMANCE OF THE TTI DETECTION MODEL VARIABLES DURING AN INCIDENT in which "two-sided" variation is used to signal the occurrence of an incident.

During the 1968 research, data from 25 "incident" days for five detector stations were analyzed. On these days there were 29 on-freeway incidents and 315 off-freeway incidents as determined from television surveillance records. Off-freeway incidents were defined as incidents on the shoulder of the road or any other occurrences that could pose a visual distraction to freeway drivers. TTI recommended that a larger sample be obtained as a basis for more specific conclusions.

Their findings were encouraging, with 90% of the on-freeway incidents being detected within one minute after the onset of congestion, and all of the on-freeway incidents being detected within six minutes. As might be expected, the detection of off-freeway incidents was a more challenging problem. Only 50% were detected after one minute, and 25% remained undetected after nine minutes.

The 1968 TTI final report gives little indication of the individual detection and time lags in the performance of each model and their relative performance during an incident (10). The University of Michigan research program was structured to give definitive answers to these questions.

Since TTI incident analysis data were not available, a separate and larger sample of 50 on-freeway incidents was studied.

Also, TTI concluded that a usable incident detection system would be difficult to formulate directly and that additional investigations would be required before such a system could be developed. As a part of this research an effort was made to advance the development of such a system.

All of the TTI models generated considerable numbers of false alarms, substantially more than the anticipated one percent. The number of false alarms exceeded the count of correct signals. In an exploration of ways of responding to the false alarm problem, TTI researchers suggested the simultaneous application of the five models. They assumed the variables of the different models to be independent of each other. For their selected data base of detections they calculated the probability of a false alarm signal from any one of the models in a given minute to be almost five percent. This would amount to a false alarm signal approximately once every 20 minutes at each detector station. Since actual freeway incidents, especially on-freeway incidents, occur far less frequently than every 20 minutes, false alarm indications would still greatly exceed true incident signals.

Noting the 50 to 85% reduction in false alarms as later data were received for those incidents of several minutes duration, TTI concluded that their models were more effective for the detection of incidents lasting more than one minute. They then reduced the probability of false alarms by redefining an incident indication to be a variable value exceeding the critical threshold value for more than one consecutive minute. Assuming independence of these variables over time, TTI calculated that the probability of a false alarm lasting two consecutive minutes was 0.25%.

There are problems with this approach. Since many of the models use identical inputs, it would be expected that the "incident occurrence" signals would not be independent and the relative frequency of false alarms not reduced as expected. Also, at least one model, the Subsystem Shock Wave Model, cannot be expected to confirm itself in the second minute on theoretical grounds. Since a confirmation sequence would have degraded the performance of the TTI model, this approach was not adopted in the present research program.

An improved understanding of the relationship between signals generated by actual incidents and false alarms was a prime objective of this research. Values for an ideal variable recorded during an incident would never occur in the course of normal traffic operations. The frequency distribution of these values would extend over a different range than the distribution achieved during normal traffic operations. A major objective of this research was to explore the trade-off between the two types of errors, false alarms and failure to signal the occurrence of an incident, for TTI models.

Recognizing that macroscopic traffic flow variables respond to such dynamic environmental characteristics as time of day and weather conditions, TTI recommended utilization of a larger sample of incidents as a basis for studies of the benefits of stratifying the data and developing incident signal thresholds for a variety of conditions as a means of improving the performance of their models. This suggestion was explored as a part of this research. Moreover, there is a question of how representative of traffic conditions a cumulative distribution can be. The distribution must include all levels of traffic operations in proportion to their likelihood of occurrence. In addition to days of inclement weather, there are days when traffic simply is not "running well," often when a major incident has taken place previously. Congestion in the form of clusters of stopped vehicles may have cleared away, but effects may linger for hours afterward.

The automatic operation of a real-time control system or readjusting priorities in investigating incidents would benefit substantially from the proper signaling of the end of the capacity-reducing effects of the incident. The TTI models were evaluated in terms of their capability of signaling the end of an incident that had previously been detected.

Since the research program was based on the television surveillance system, it was also believed necessary that some exploration of the reliability of the data derived from the television records be made, particularly as the data was consistent with recorded congestion at nearby detector locations.

Another problem to which attention was directed in the research was that of the nature of the incident. If the traffic flow characteristics recorded in the early phases of the detection process contained information as to whether or not an incident was an accident or data that would help predict the duration of the incident, this would be valuable. Any information on likely flow rates through the bottleneck in the next few minutes would facilitate a more accurate ramp and information control response to an incident. As a part of this research an effort was made to identify characteristics of these types from the sample of 50 incidents.

University of Michigan Research Approach: The first step in the further analysis of the TTI models was the development of cumulative distribution curves for each traffic variable for "normal" operations at each of the four contiguous stations and the three subsystems encompassed by them. Appropriate critical parameters were selected and each model evaluated on the basis of time to detection, t_1, and the other time- and false-signal-related characteristics of interest for the 50 incidents described previously.

As did TTI, the 99th percentile was used to determine the threshold value for detection of an incident for each model. In the case of the Subsystem Shock Wave Model the presence of an incident could be indicated either by an increase or decrease in subsystem storage, so the 0.5 and 99.5 percentile were used to achieve an overall one percent likelihood of false alarms. Two representative cumulative distributions with the 99th percentile indicated are presented in Figures C-1 and C-2 in Appendix C.

THE CALIFORNIA INCIDENT DETECTION MODEL

Contact with researchers in freeway surveillance in Los Angeles, California, led to consideration of what is here termed the "California Model" (42). In the universe of detection models shown in Table 2 the California Model stands distinct from all the TTI models by considering the previous two minutes of traffic data rather than just the one most recent minute. It also uses only one variable, average station occupancy. The significance of this additional factor can be seen by again considering the hypothetical capacity-reducing incident of Figure 9. Where the TTI models are intended to detect the passage of the incident shock wave or the ensuing theoretically static state of traffic operations, the California Model is designed to detect the dynamic sequence of events that result in operations going from those prevailing before the incident flow to the congested state depicted in Figure 9.

The California Model consists of three sequential tests all based on occupancy changes at the upstream and downstream detector stations of a subsystem. An incident is signaled only when the threshold values for all three variables are exceeded, indicating that the sequence of events associated with a typical capacity-reducing incident has occurred. In California the model is applied to moving average data for the most recent two minutes and updated every twenty seconds.

The first test is the "shock wave" test. It measures the current difference in occupancy between two adjacent stations, called the k_1 variable. If the traffic is significantly more dense upstream than can be explained by regular fluctuations in traffic operations, then this is the first indication that a bottleneck or capacity-reducing incident has taken place within the subsystem. The second test is a normalization of the first, the fractional difference in downstream occupancy from the upstream occupancy, the k_2 variable. If the critical value for this variable is exceeded, it indicates a considerable difference in the state of traffic operations at the two stations. The model logic then proceeds to the final test, that of measuring the fractional change in occupancy over time at the downstream station in the past two intervals. This is the k_3 variable. A decrease in occupancy is more characteristic of an incident than a mere bottleneck because it marks the reduced flow past the incident. A significant decrease will result in the signaling of an incident by the model. The formulas for each test are presented in Appendix D along with a flow chart of the model logic. Figure 14 shows the performance of this model for the same incident to which the TTI models responded in Figure 13.

Research Program for the California Model

The research into the performance of the California Model was conditioned initially by the differences in the data streams. It was not deemed desirable to use a moving average of three one-minute values for the Lodge Freeway as a substitute for the three 20-second values used in the California Model. However, it was believed that the

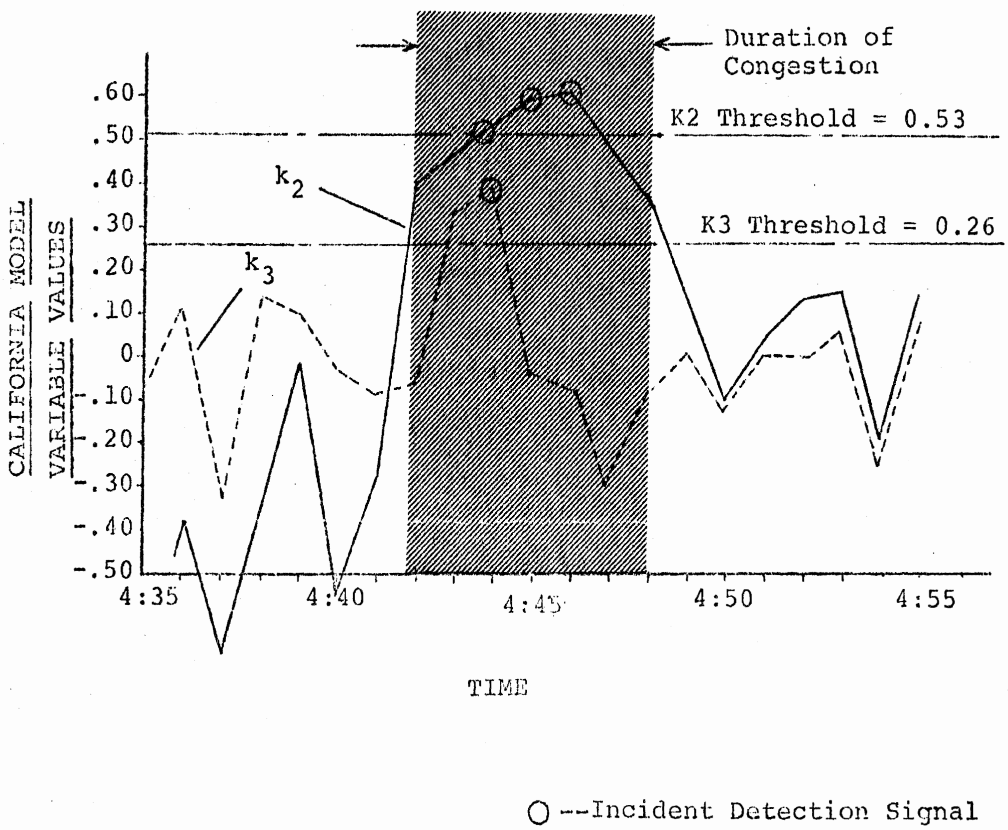


FIGURE 14

PERFORMANCE OF THE CALIFORNIA MODEL
DURING AN INCIDENT

model could be fairly tested using Lodge one-minute data. The research plan as finally adopted involved a study of the effectiveness of this model for the same 50 incidents used to test the TTI Models. Much of this study parallels the analysis of the TTI Models. The results for both model groups are presented in Chapter Two.

Optimal Parameters: Critical thresholds called K1, K2, and K3, respectively, are associated with each of the above tests. These control parameters could be developed in the same way as the TTI model parameters, with data from days without incidents compiled in order to produce statistically infrequent threshold values for detection. However, since it is the sequence of these three parameters signaling that accomplishes the detection, another method for selecting threshold values was used which ensured a high probability of detection without an undue number of false alarms.

To achieve this, the California Model was initially programmed and applied to six peak periods of traffic data which contained 11 on-freeway incidents. This preliminary study was intended to both test the validity of the model for the Lodge Freeway and to determine approximately optimal values for the three detection parameters. A program was written to cycle through various combinations of values of these test parameters for each day of data. The iterations included the following values:

K1: 6, 8, and 10% occupancy

K2: 0.45, 0.50, 0.55

K3: 0.20, 0.22, 0.24, 0.26, 0.28, 0.30

The optimal test parameters for largest numbers of incidents detected and fewest false alarms were K1 = 10% and K2 = 0.55 for all three subsystems. There was insufficient data to determine an optimal value for K3 except that the above range appeared to include the optimal values.

The number of successful detections and false alarms associated with the range in values of the K2 and K3 parameters is given in Table 3 for the three subsystems together. The same results were obtained for all three values of K1. It is apparent that within the above ranges a criterion for optimality could be the reduction in false alarms. The maximum number of false alarms observed was 22 for all subsystems with the lowest K2 and K3 values, and the minimum number was one for the highest values. The range in incident detection is from six to eight, indicating the nature of the trade-off between detection success and false alarms for this model. The K3 parameter was the most sensitive in reducing the number of false alarms. This was to be expected since it is this parameter that distinguishes between a fixed bottleneck and temporary capacity reduction.

TABLE 3

NUMBER OF SUCCESSFUL DETECTIONS AND FALSE ALARMS ASSOCIATED WITH CALIFORNIA MODEL DETECTION PARAMETERS*

K3 PARAMETER	K2 PARAMETER		
	.45	.50	.55
.20	8 (22)	8 (13)	8 (6)
.22	7 (15)	7 (9)	7 (4)
.24	7 (13)	7 (8)	7 (4)
.26	7 (13)	7 (7)	7 (3)
.28	7 (11)	7 (5)	7 (1)
.30	7 (9)	7 (5)	6 (1)

*In the preliminary study there were 11 incidents. The number of successful detections is given above for each set of parameters. False alarms associated with each set are in parentheses.

Model Modifications: Despite the difference in data accumulation time intervals and their treatment, the parameter values found above were similar to those suggested by researchers from California (42). Their method of compiling data each 20 seconds would be expected to be more sensitive to downstream changes in occupancy and provide faster response than possible with Lodge Freeway data. The use of more historic data would slow the Lodge response on the average, although it would perhaps make it less vulnerable to the stochastic properties of the data stream over time. It was concluded that the California Model could be used satisfactorily with one minute data.

With the use of optimal K2 and K3 parameters for each subsystem, of the total of 11 incidents there were eight detections with the California Model. There were two false alarms, a very low rate considering that the model was applied over 2,000 times in each of the subsystems during the six peak periods. This preliminary performance demonstrated the capability of the model to detect incidents reasonably well at a false alarm rate much lower than demonstrated by the TTI models.

The preliminary work and listings of all the threshold parameters in the later work led to the conclusion that the K1 parameter served no useful function. It appeared to signal more often than the K2 parameter. Setting the K1 threshold higher was useless because the parameter frequently was not much greater than ten percent when the incident was detected. The K1 parameter was compiled for purposes of research but not used in the detection logic.

The California Model, both as described and as finally developed in this research, contains termination logic for the end of an incident. Once an incident has been detected, the incident stays declared until either the k_2 variable is below K2 or the downstream occupancy for the first time exceeds the occupancy at the start of the incident. For the most part, these two termination signals occur at the same time but in some cases the k_2 test ends the incident because the occupancy downstream lingers below the threshold occupancy. In general, the termination signal always coincides with the end of the detectable congestion in the 50-incident study data set.

After the preliminary studies of the California Model were finished, it was decided to incorporate a confirmation sequence in the model logic in order to eliminate some false alarms. In the next minute after the K2 and K3 parameters were exceeded, the K2 threshold had to be exceeded again before an incident signal was given. The k_3 variable cannot be expected to signal more than once since it indicates the passage of the downstream shock wave of reduced capacity, but the k_2 variable stays above the threshold for the duration of the incident. This confirmation sequence did not affect model performance in Subsystems Two and Three, but did result in more missed incidents in Subsystem One. The confirmation sequence, however, is judged desirable. The results in Chapter Two present what is believed to be a fair assessment of the capability of the model. As indicated previously, confirmation logic in the second minute of detection was not considered for the TTI models because so many detections were only for a minute. The reduction in false alarms would not have compensated for this severe a degradation of performance. A flow chart of the California Model program logic as used for the remainder of the studies is given as Figure D-1 in Appendix D.

There were two more phases in the studies of the California Model. Before the model could be applied to the 50-incident data base the K2 and K3 threshold values had to be more precisely determined. To accomplish this, the Modified California Model was applied to 18 peak periods which contained a total of 27 incidents, at least eight in each subsystem. The 18 days included four days of rain and one of snow so that the resulting threshold values could be stratified by weather if significant changes in performance were found. Preliminary values of K2 equaling 0.54 and

K3 equaling 0.18 were used in the program to sort out most of the incidents and false alarms. The 18 days encompassed 4860 minutes of analysis. It was anticipated that this sample size would yield a satisfactory indication of the incidence of false alarms. The k_2 and k_3 values for all subsystems were printed for each minute. The data were manually edited to refine the threshold values to produce the best performance with fewest false alarms. Table 4 shows the optimal values of both variables for each subsystem and for different weather conditions.

TABLE 4
OPTIMAL PARAMETERS

SUBSYSTEM	THIRTEEN DRY DAYS		FIVE RAINY OR SNOWY DAYS	
	K2	K3	K2	K3
1	.53	.26	.53	.26
2	.53	.21	.56	.30
3	.61	.11	.61	.24

In most cases, the rain thresholds are not significantly different from the dry thresholds. In the case of the K3 parameter in Subsystems Two and Three the rain thresholds diverge from the dry thresholds principally in order to reduce false alarms on two rainy days. The few rain and snow incidents included in the 18 days either signaled or fell far short of the thresholds. The two minute confirmation logic was quite necessary in Subsystem Two and Three to eliminate false alarms that occurred on rainy days. This experience demonstrated that the model is vulnerable to prevailing bottleneck conditions such as occurred on these isolated days.

THE DOUBLE EXPONENTIAL SMOOTHING MODEL

In the universe of detection models in Table 2, a next logical step in the use of volume and occupancy data beyond the California Model would be to consider more than two minutes of past data. A time series of any combination of these two sets of traffic data will exhibit some degree of variability or "noise" that masks to some extent the underlying trends as theoretically depicted in Figure 9.

All of the subsystem models already presented detect temporal or spatial shifts in variable performance. Thus, the three TTI subsystem models (Subsystem Energy, Subsystem Shock Wave, and Subsystem Discontinuity) and the Modified California Model compensate for the stochastic tendencies of their variables by setting threshold levels extreme enough to overcome the fluctuations of normal traffic and reduce the possibility of false alarms. As previously indicated, the potential disadvantage of this approach is the lack of sensitivity to the occurrence of actual incidents. The TTI station models, Station Energy and Station Discontinuity, must also contend with traffic fluctuations but their thresholds are set to detect variable extremes and not extreme values of variable differences.

The advantage of considering more than just one or two minutes of past data would be the determination of real-time historical trends and a real-time estimate of the variability of the traffic variables being observed. A double exponential smoothing model, as described by Brown, was selected to meet these objectives (7). Exponential smoothing is a scheme of the autoregressive type where the predicted value of the variable in the coming minute is a simple function of several recent observations. The most recent observed value is given a weight, and the other older variable values are geometrically given less and less weight back in time.

Computation formulas for the Double Exponential Model are presented in Appendix E. The model automatically corrects for trends in the data stream. With simple exponential smoothing the prediction would fail to converge on actual conditions during a systematic trend. Trend would, of course, be present in peak period data as traffic builds to a peak and slackens off toward the end of the period.

The standard deviation of the traffic variable over time is estimated by applying exponential smoothing to the series of estimate errors to produce a current estimated standard deviation that can be applied to the task of incident detection. The objective of smoothing models in general is the detection of abnormal shifts in parameter values. Whitson, et al., applied moving average smoothing to a series of traffic volumes (50). They reported that a five minute moving average with detection thresholds of two standard deviations was successful in the detection of shock waves as evidenced by sudden shifts in volume at a station.

To demonstrate this type of model it was decided to apply it separately to station volumes and occupancies. These variables would not be expected to perform well without smoothing because of their variability over time. In both cases a smoothing constant of 0.3 was chosen, which meant that exponential smoothing was approximately equal to a weighted moving average of the six most recent observations.

Incident detection was accomplished through use of a "tracking signal." The tracking signal is the algebraic sum to the present minute of all the previous estimate errors, divided by the current estimate of the standard deviation. The signal should dwell around zero since the predictions match either the actual outcome or compensate during the following time period. Consequently, if the signal strays too far from zero, this constitutes an incident detection.

Volume was used as a variable in an analysis of five peak periods containing six incidents, and occupany was applied to three days containing six incidents. The sample was small, but was expected to provide information on the general feasibility of the model and an indication of the threshold values required for the tracking signal. Several values of the smoothing constant other than 0.3 were tried. Higher values resulted in no detections at all and lower values greatly increased the false alarms as the predictions were more strongly influenced by the immediately preceding variable value. Thus the two exponential models used a smoothing constant of 0.3 for the eight days of trials.

A MULTIPLE STATION MODEL

An incident detection model that takes into consideration the relative traffic patterns of a series of stations along a freeway is included in the universe of detection models presented in Table 2. The output of such a model would provide a more accurate picture of the state of freeway operations and the disturbances propagated by an incident both upstream and downstream. This would certainly be desirable for freeway surveillance control operations although perhaps difficult to achieve owing to the complexity of traffic interactions in both time and space.

The traffic response to a stalled vehicle just upstream of Calvert at the four stations represented in this study is depicted in Figure 15. Average station occupancies are plotted for this incident, selected for portrayal because of the short but pronounced effect it had on freeway operations. The time of onset of congestion caused by the incident was 4:38 p.m. at which time several of the models evaluated in this study signaled an incident in Subsystem Two. The reduced flow downstream as inferred from reduced occupancy is evident at the Calvert station at 4:38 p.m. and about two minutes later some 4500 feet further downstream at the Glendale station. Comparison of the two downstream stations indicates a propagation speed of occupancy changes ranging from 30 to 55 miles per hour.

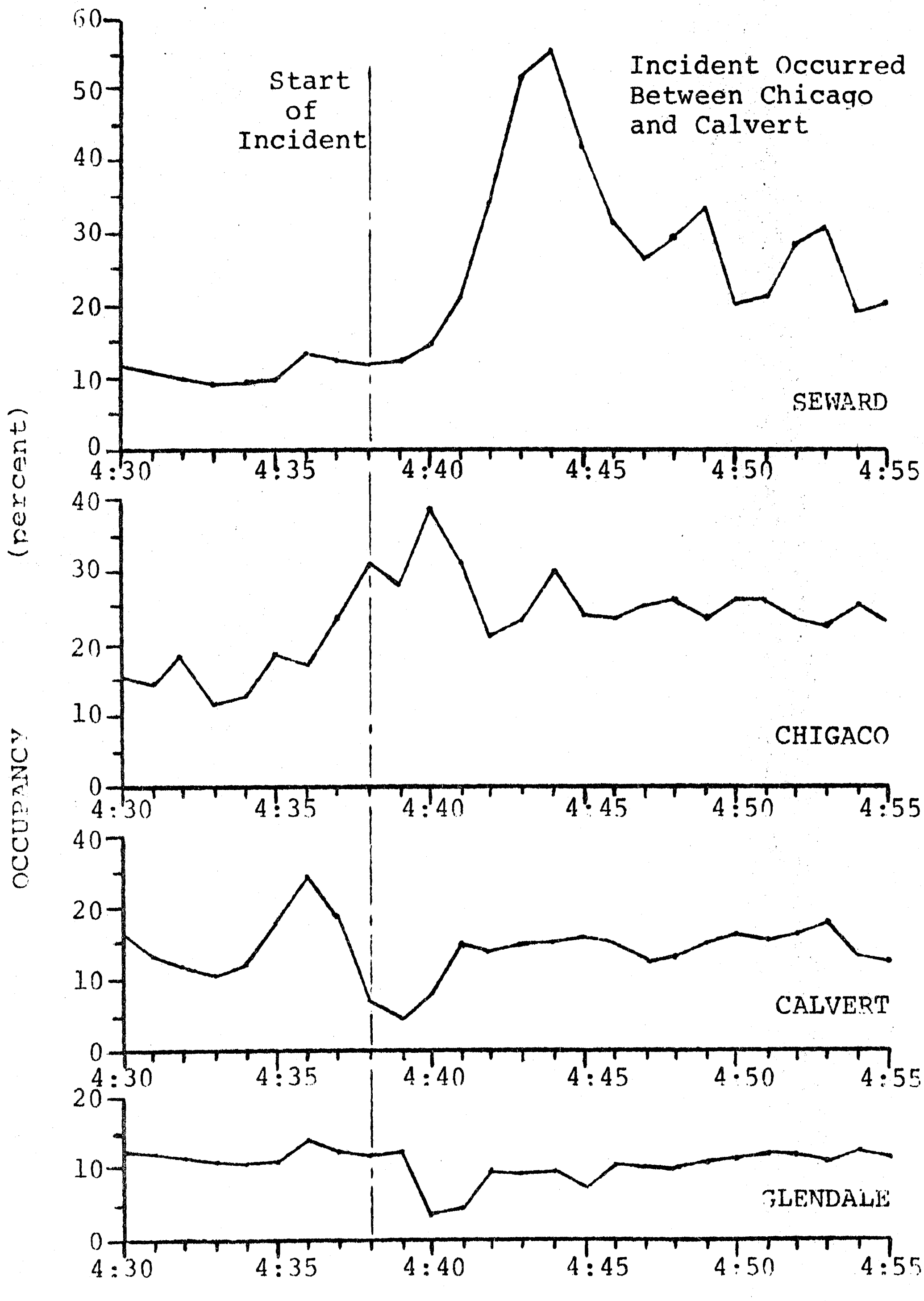


FIGURE 15

EFFECTS OF A SHORT DURATION INCIDENT
ON FREEWAY OPERATIONS

Upstream the transition to congested flow at the Chicago station is amplified to a severe shock wave passing the Seward station 6000 feet upstream about five minutes later. This corresponds to a propagation velocity of about 14 miles per hour upstream. The net result is traffic brought virtually to a standstill at Seward and congested oscillatory flow ensuing for the ten minutes following the incident while downstream flows have promptly recovered.

The incident detection models previously discussed evaluate traffic operations at individual stations or subsystems and do not pick up these system-wide effects. Whether or not considering the simultaneous operation of a series of stations improves detection effectiveness or increases model sensitivity can only be answered by exhaustive study of many incidents. This effort was not made in this study, partly because the small number of stations and variety in subsystem length did not appear to lend itself to the development of other than a highly empirical set of conclusions. Conceptually, multi-station models seem attractive where large numbers of more closely spaced detector stations are considered for surveillance.

CHAPTER TWO

FINDINGS

CHARACTERISTICS OF FIFTY ON-FREEWAY INCIDENTS

As described in Chapter One, data for 50 on-freeway congestion generating incidents based on television surveillance records were compiled. For each incident the volumes and occupancies at the upstream and downstream freeway detector stations and the values of the variables used in each detection model were calculated and printed for each minute. These records began approximately ten minutes before the incident was noted as starting from the television records until about ten minutes after the last traces of incident-caused congestion had disappeared.

It is believed that this sample of on-freeway incidents is representative of those which would be observed on many U.S. freeways and that the results can be extrapolated for use in other urban areas.

The average volumes observed before the incident occurred ranged from 3600 to 6000 vehicles per hour (1200 to 2000 vehicle lane per hour). Prevailing occupancies ranged from nine to 45% with the great majority extending from ten to 30%. This range is approximately equivalent to vehicular densities of 80 to 250 vehicles per mile. Conditions ranged from free flowing to congested.

Since Desai has shown that the effect of a freeway incident on other traffic varies widely with the time of day, the time of occurrence of the 50 incidents investigated in this report was studied (15). As the only criteria for selection of the incidents were that they occur sometime in the afternoon peak period and that all the on-freeway detectors in the particular subsystem be working, it would be expected that incidents would be found to occur at random times throughout the peak period. A frequency distribution of the starting times for the 47 incidents taking place between 2:00 and 6:00 p.m. is presented in the following tabulation:

TIME INTERVAL	NUMBER OF INCIDENTS
2:00 - 3:00 p.m.	6
3:00 - 4:00 p.m.	17
4:00 - 5:00 p.m.	14
5:00 - 6:00 p.m.	10
	47

With a sample of this size the hypothesis that incidents occur uniformly over the peak period cannot be rejected with a five percent error of the first type. Hence, it is tentatively concluded that incidents are randomly distributed during the evening peak period.

TIME OF INCIDENT OCCURRENCE

The need for a consistent basis for the comparison of the effectiveness of the various models, the demanding requirements of television surveillance upon the observers, and the project administrators' experience in supervising this activity led to an auxiliary study. In this study, the relationship between the time the incident occurred as recorded in the television surveillance log (see Appendix A), and the onset of incident-related congestion, as determined from the sensing system and recorded by the digital computer, was explored.

Figure 16 shows the distribution of times recorded by the television observers relative to the minute the onset of incident-caused congestion was recorded by the computer. It is noted that for the 50 incidents studied, television surveillance had a detection range of from five minutes prior to congestion onset to six minutes following incident detection by the automatic control system. It generally would be expected that the television system would detect incidents from one to three minutes sooner than would the traffic flow incident detection system. However, 25 of the 50 incidents, 50%, were recorded at least as soon by the automatic system as by the television response system. Television observers were instructed (Appendix A) to estimate the starting time of incidents discovered in progress, and as a consequence some log times must be regarded as approximate.

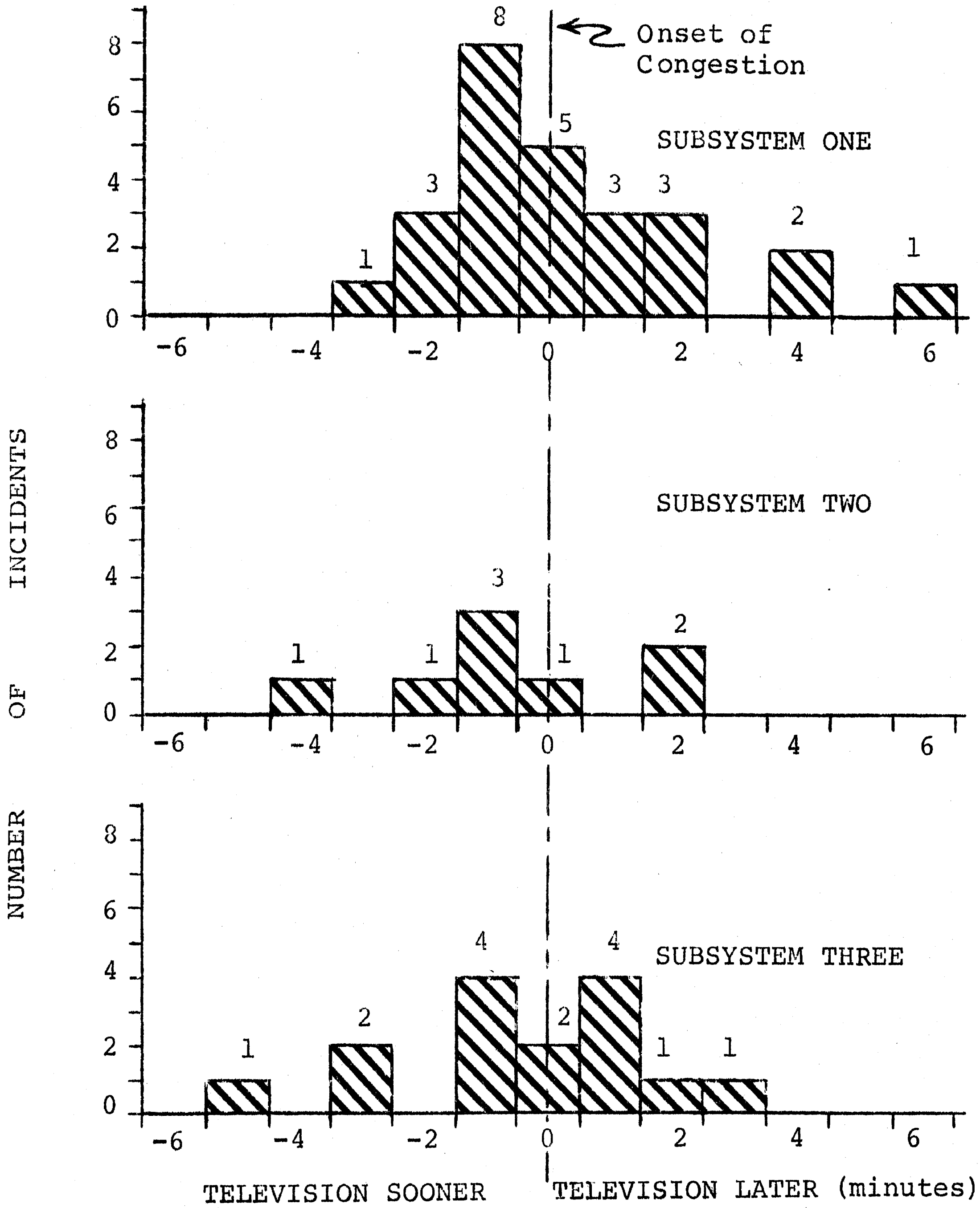


FIGURE 16

TELEVISION DETECTION TIME RELATIVE TO ONSET OF CONGESTION

As a result of this analysis it was decided that it would be impossible to use the time as recorded by the television observers as a basis for the consistent comparison of the rapidity of detection of an incident by the various models. It was decided that each model would be tested against the onset of congestion as determined by traffic flow characteristics. An incident detection was defined as the generation of a signal at anytime during the period of incident-generated congestion. It is noted that this time base is not the same as that used by TTI, and hence that the time values recorded by TTI and referred to in Chapter One cannot be compared directly with those recorded in this study (10). The unavailability of TTI data made it impossible to conduct independent analyses of their findings.

INCIDENT AND CONGESTION DURATION

Figure 17 shows the cumulative distribution of freeway blockage times for the 50 incidents based on television records. The average duration of on-freeway blockage for these incidents was 6.1 minutes, with times ranging from one to 19 minutes. Half of the incidents blocked lanes for less than five minutes and 80% for less than ten minutes. In only one case was more than one lane blocked and the freeway was never completely blocked. In two-thirds of the cases the lane adjacent to the median was the blocked lane, apparently a reflection of the lack of a shoulder refuge at the median (see Figure 1) which necessitates crossing two freeway lanes to reach the outer shoulder.

Figure 18 presents the distribution of durations of congestion attributable to the incident. In 60% of the cases the effects of the incident disappeared within ten minutes of its beginning. However, ten percent of the incidents affected traffic flow for a period longer than 25 minutes.

As can be seen, freeway operations tend to recover quite rapidly to their pre-incident operational state. However, for two cases not plotted, the congestion lingered for at least 15 minutes and beyond the range of printed data. In a third case, a five-vehicle accident occurring at 3:14 p.m.

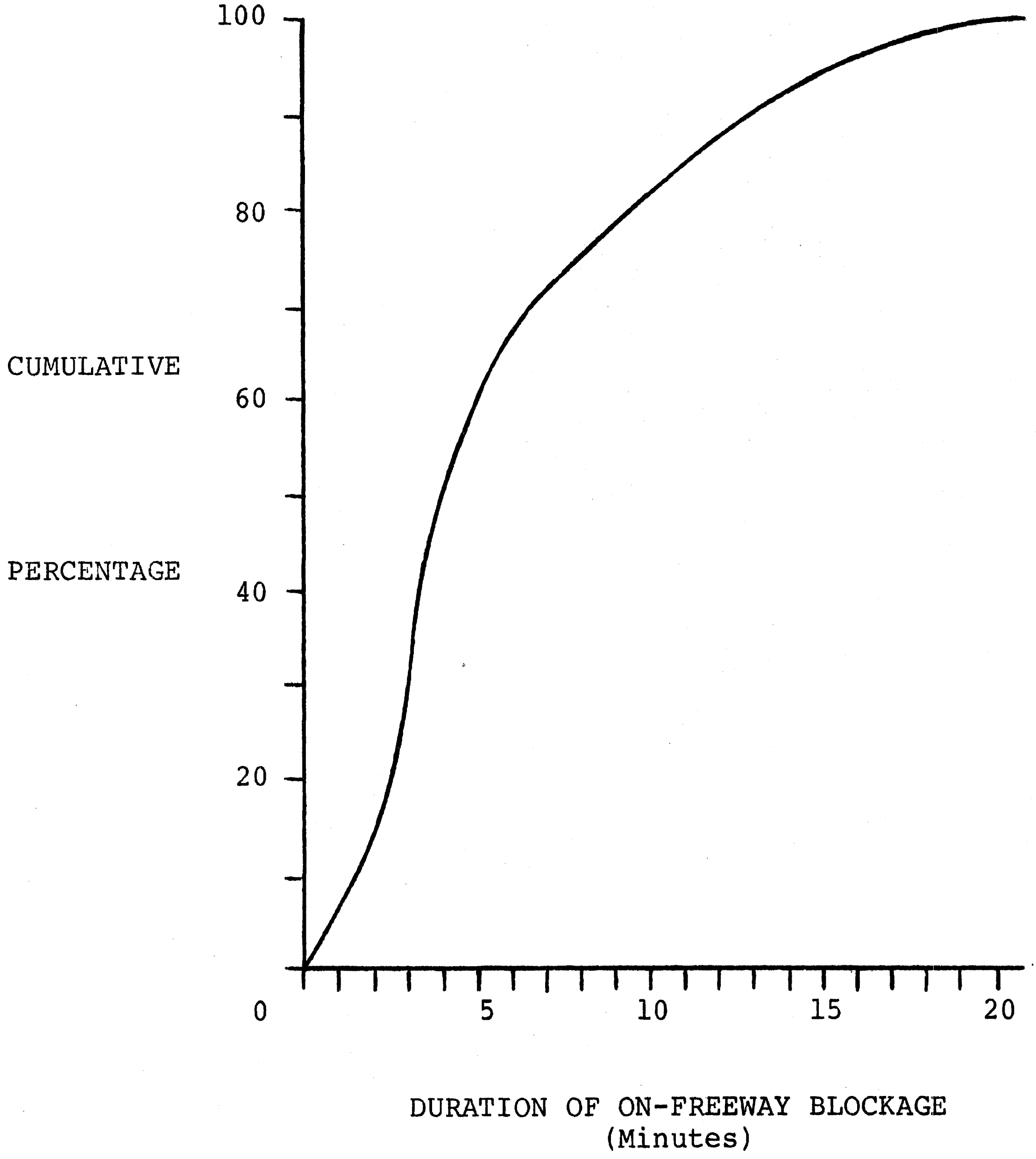


FIGURE 17

CUMULATIVE DISTRIBUTION OF ON-FREEWAY BLOCKAGE TIME

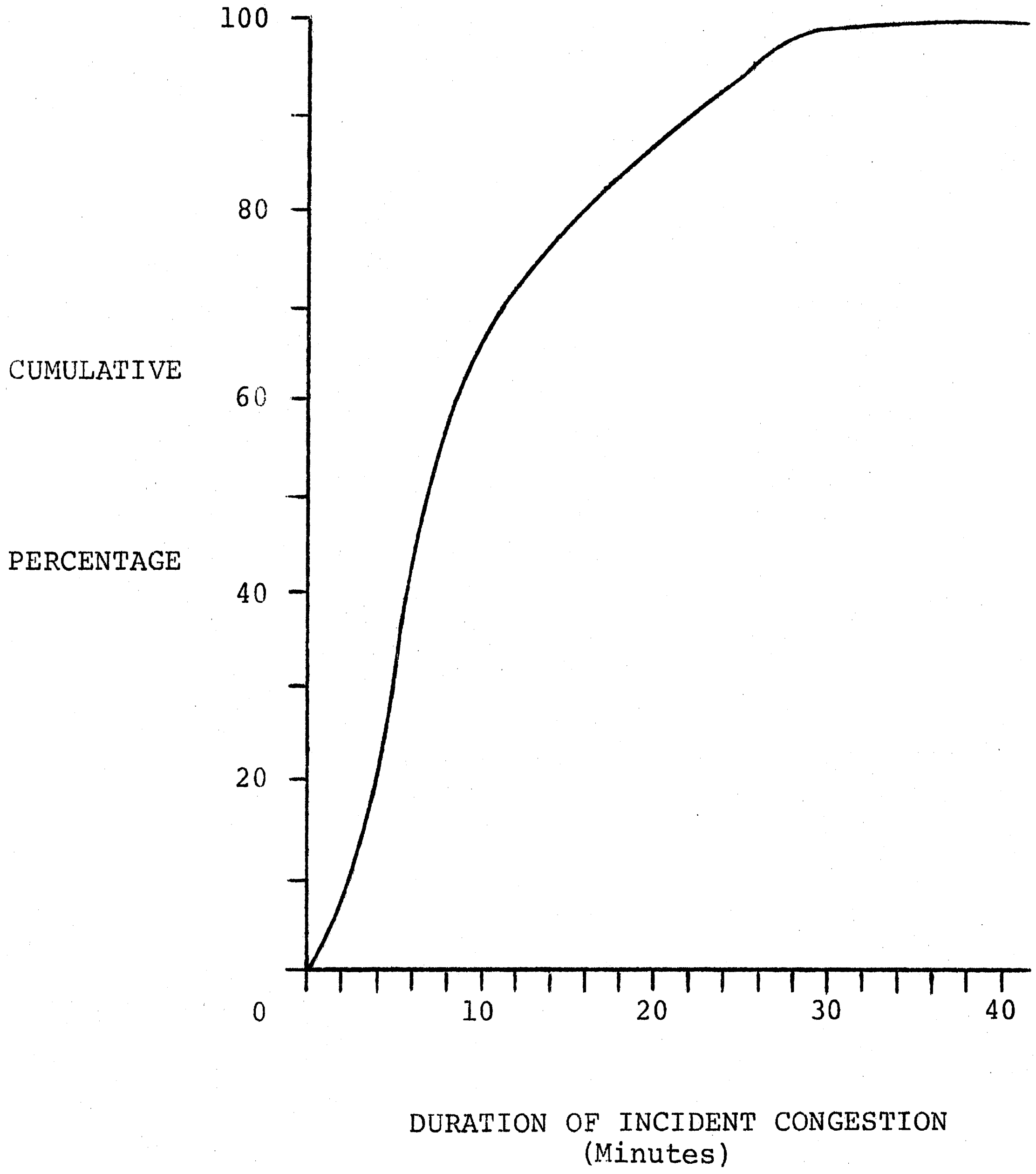


FIGURE 18

CUMULATIVE DISTRIBUTION OF
DURATION OF INCIDENT CONGESTION

generated congestion which lasted for an hour or more during which time another accident took place upstream in the same subsystem. This latter accident, despite the prevailing poor state of traffic operations, generated a further detectable disruption in traffic.

CAPACITY REDUCTION

Figure 19 compares the average volume downstream of an incident during its duration with the volume for the ten minutes preceding the incident. Although downstream volume generally decreased over that prevailing before the incident, in seven cases volume actually increased slightly. Six of the seven incidents with increased downstream flow were located at the upstream end of Subsystem One. They were generally characterized by considerable congestion, particularly at the downstream station. In every case, the average upstream demand before the incident occurred exceeded the flow output downstream during the incident. The capacity reduction appeared to have a beneficial effect on operations downstream. Also contributing to additional downstream flow could be the relatively high entrance rate at the Seward ramp. Entering traffic would be unaffected by the above six incidents and the less congested flow state existing in most of the subsystem downstream of the incident would tend to increase the metering rate at Seward. The seventh incident with increased flow downstream from the incident was one in Subsystem Two with very atypical traffic flow response characteristics.

The average prevailing downstream volume before the incident occurred was 81.4 vehicles per minute which was reduced 21% to an average of 64.8 vehicles per minute during

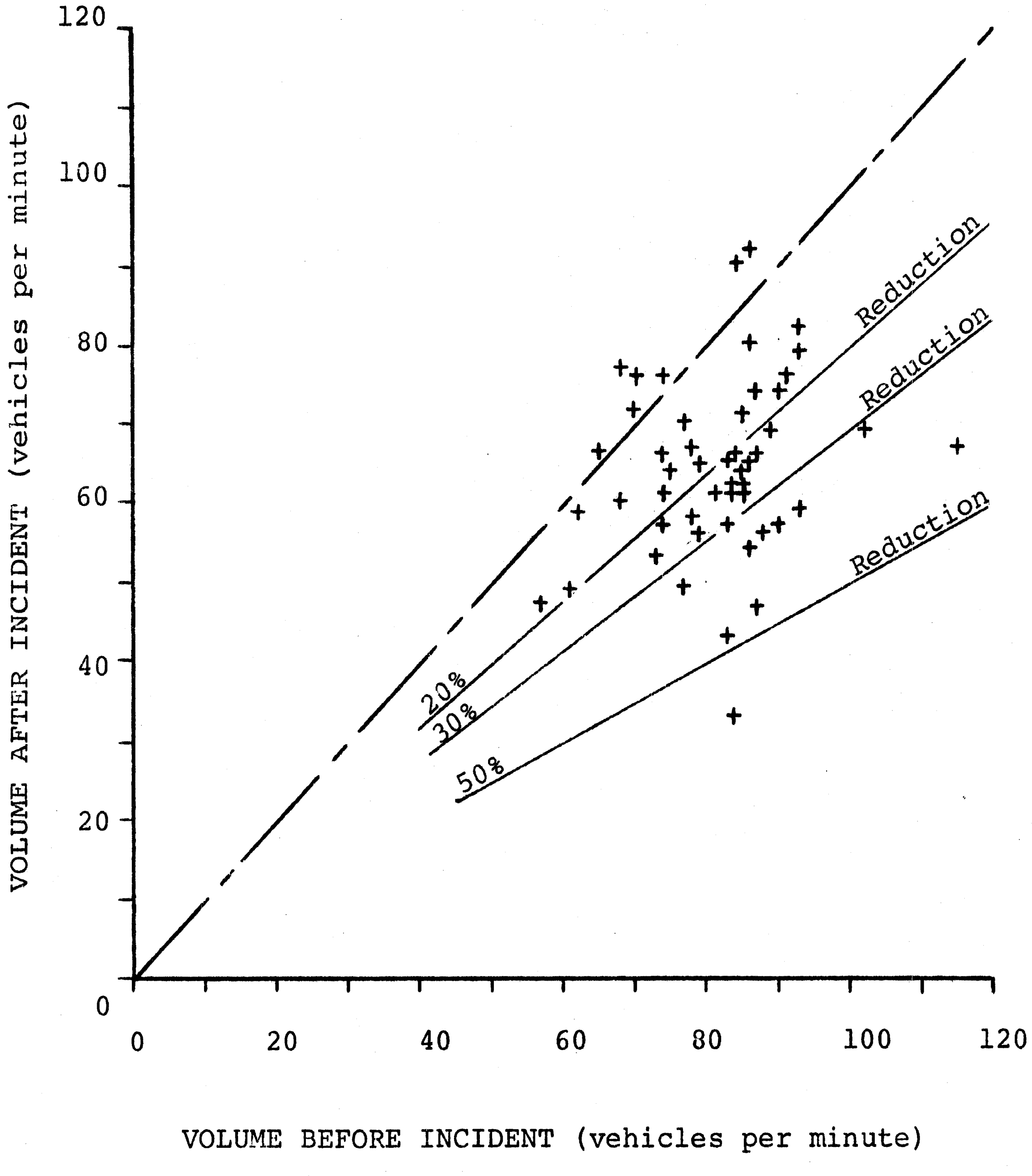


FIGURE 19

EFFECT OF INCIDENTS ON DOWNSTREAM TRAFFIC VOLUME an incident. This average decrease is less than the 40% or more reduction in capacity observed by others when one of three lanes is closed to through traffic at some position along a freeway (11, 25).

There was considerable variability in the effects of the incidents on flow as plotted in Figure 19, ranging up to 60%. For the majority of incidents the decrease in flow during an incident ranged from 10% to 40%. The pattern was similar in all three subsystems although there was a tendency toward greater flow reductions in Subsystem Three. The incidents of shortest duration, those with four minutes or less of congestion, showed a comparable scatter, so congestion duration would not appear to be related to the severity of the flow reduction.

These results indicate that despite the 50 incidents being similar in that all but one represented the blockage of one lane, the downstream flow reduction is unpredictable, both for different incidents and during an individual incident (see Figure 8). This has ramifications for the real-time adjustment of freeway surveillance control which will be expanded upon in Chapter Three and for the applicability of mathematical queueing models.

DETECTION MODEL PERFORMANCE

The five TTI and the Modified California incident detection models were tested using the 50-incident data set. Every incident but one was detected by at least one model, including all of the incidents in the two longest subsystems. According to television records, the incident that was not detected was an accident in the shoulder lane of Subsystem Two with an on-freeway duration of only two minutes. Considerable congestion was generated at the upstream station (lasting 15 minutes) but downstream operations shifted to a slightly higher occupancy level (from nine percent to 13%) with no effect on volume, possibly a result of ramp metering rate changes.

INCIDENT DETECTION AND TIME LAG

Taking the time of onset of the first noticeable congestion as the start of the incident, the average time lag for the first detection of an incident by the best model for each incident was 0.55 minute. This indicates that generally at least one of the six models detected the incident either at the onset of congestion or one minute later. Because the actual time an incident begins is not known, no conclusions are possible on the actual time lag until detection or the time it would take the shock waves to reach the upstream and downstream detector stations. Hence, the above figure of 0.55 minute is taken to represent a standard for the evaluation of the effectiveness of individual models in detecting an incident after at least one shock wave has passed a detector station.

The detection performance of the five TTI models and the Modified California Model is illustrated in Figure 20. No model detected all 50 incidents. Performance varied from 45 detected by the Station Discontinuity Model to only 16 for the Subsystem Shock Wave Model. These differences in model performance were found to be highly significant by the Chi-square test ($\alpha = .05$). Large differences in detection capability, separating the two best models from the others, are very apparent. The Station Discontinuity Model is significantly better than all other models and the Subsystem Discontinuity Model is significantly better than the three models with incident detections ranging from 52 to 58%. The Subsystem Shock Wave Model is significantly poorer than those three models.

Average times to the first detection signal are also depicted in Figure 20. The Modified California Model performed the best with an average time lag of 0.96 minute as compared to the optimal figure of 0.55 minutes. The time lag is for the first detection and does not include the recommended second minute confirmation. The most successful

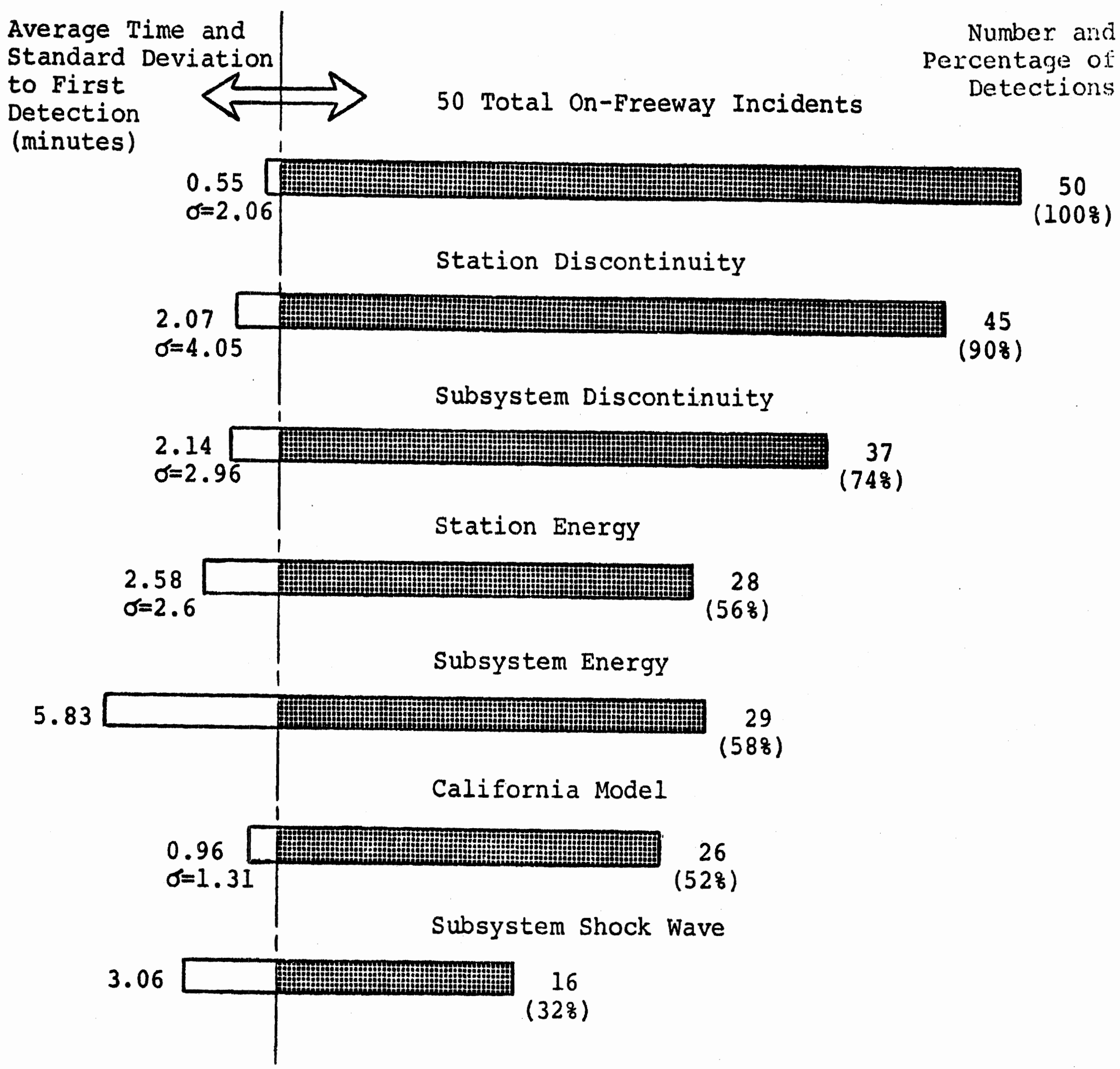


FIGURE 20

INDIVIDUAL MODEL INCIDENT
DETECTION PERFORMANCE

average detection time lag for a TTI model was recorded by the Station Discontinuity Model, a value of 2.07 minutes. The least successful performance was 5.83 minutes by the Subsystem Energy Model. The 1.11 minute difference between the average time lags for the Modified California and Station Discontinuity Model was not statistically significant at the five percent level with this sample size.

As seen in Figure 20, the California Model sample standard deviation of 1.31 minutes was less than that of any of the TTI models or the record of earliest detections by any model ($\sigma = 2.06$). This has implications for the response to incidents by a surveillance system. Among the better models those with the lowest variance can more effectively be integrated into a response strategy that includes, for example, ramp metering changes.

Histograms showing individual incident detection times are presented in Figure 21. The majority of detections took place the minute of onset or the next minute. The 2.07 minute mean for the Station Discontinuity Model is accounted for mostly by two detection times exceeding ten minutes.

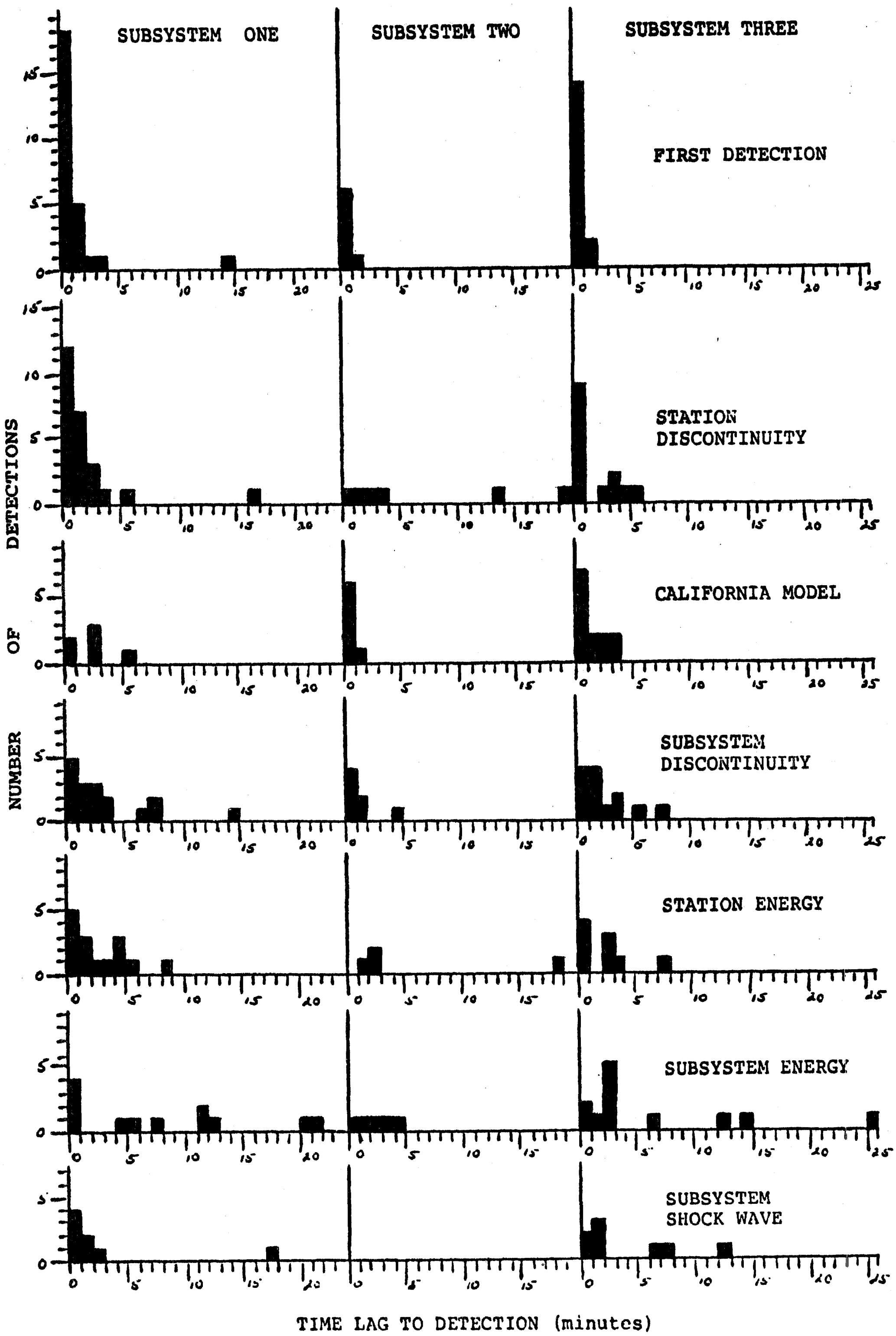


FIGURE 21

INDIVIDUAL INCIDENT DETECTION TIMES

Detections that take place some ten minutes after the first noticeable congestion and frequently after the incident has been cleared away according to television records are not very useful. It will be recalled that detection was said to have taken place if it occurred any time during the period of incident-generated congestion. This increased the time lag for the Subsystem Shock Wave Model which, if it failed to detect the initial shock wave, occasionally detected the recovery wave instead. The Subsystem Energy Model, however, was evidently often just slow to generate a signal.

Another perspective on the relative effectiveness of the models is given by the cumulative distributions of the times to detection presented in Figure 22. The distributions commence at the end of the second minute for clarity of presentation. Since detection within the first two minutes of the onset of congestion is the most desirable performance, the relative position of the models at that point in time is another useful comparison. The effectiveness of the Modified California Model in these early minutes is contrasted with its mediocre overall effectiveness. The other models continue to signal detections as late as 24 minutes after the onset of congestion. The Station Energy Model is seen to be superior to the Subsystem Energy Model despite the fewer total detections because of its markedly better performance in the early minutes of congestion.

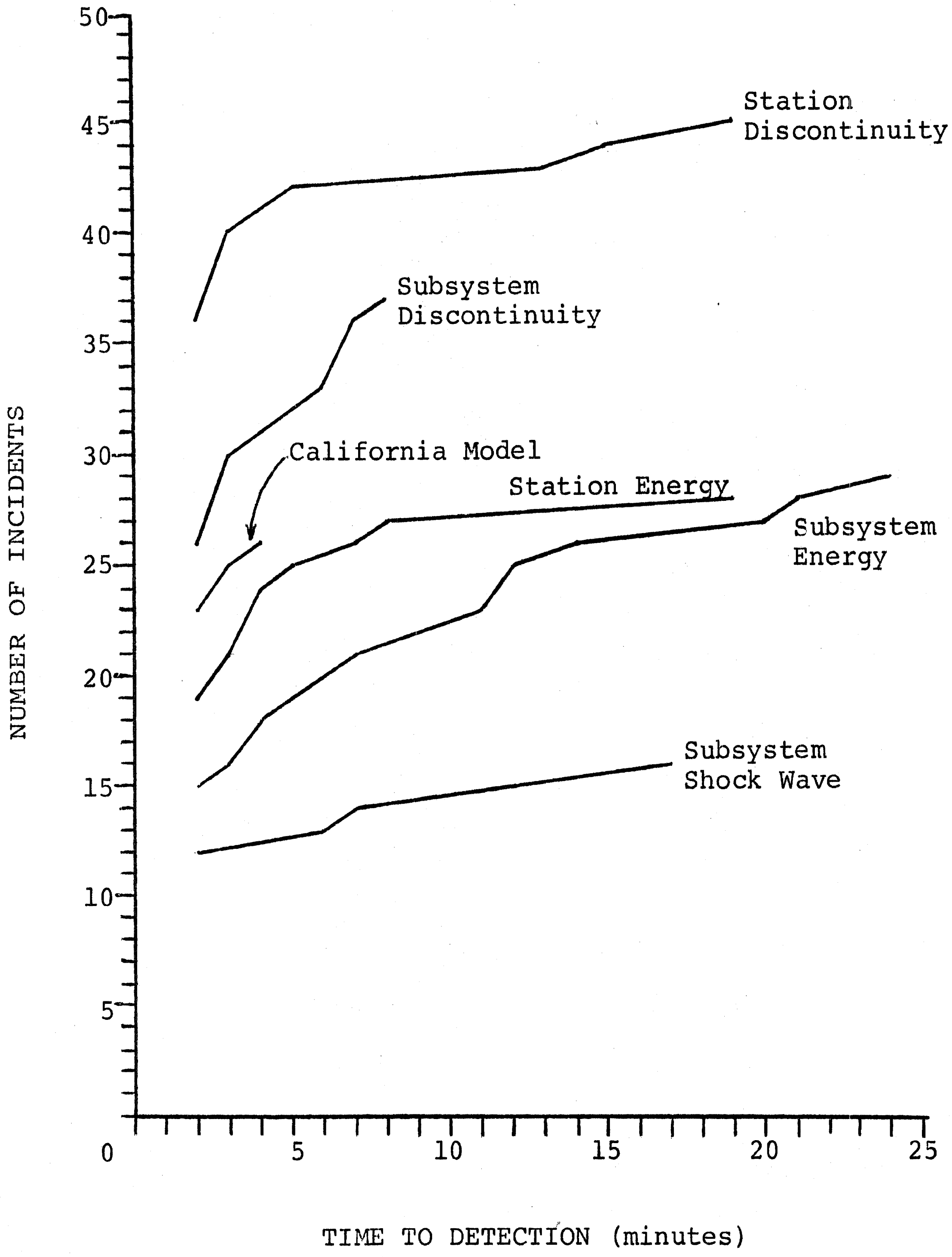


FIGURE 22

CUMULATIVE DISTRIBUTIONS OF MODEL DETECTION TIMES

With this pattern there was a tendency for the six detection models to be more effective in finding those incidents with longer durations of on-freeway congestion. The trend for detection of incidents with longer durations is evident from the data presented in Table 5.

TABLE 5

CONGESTION DURATION EFFECT ON INCIDENT DETECTION RATES

INCIDENT DURATION	PERCENTAGE OF INCIDENTS DETECTED (ALL MODELS)
Congestion Duration Five Minutes or Less:	46
Congestion Duration Six Minutes Through Ten Minutes:	67
Congestion Duration Greater Than Ten Minutes:	70

The one undetected incident had a duration of congestion of 14 minutes.

The effectiveness of these models in detecting those incidents with least demand in the form of prevailing occupancies before the incidents of 12% or less was also investigated. There were 14 incidents in this category. All were detected the minute of onset of congestion or the minute after by one or more models. It was concluded that the range of model effectiveness extends to occupancies of nine percent.

COMPARISON BY SUBSYSTEM

Additional differences in model performance among the three subsystems were explored. The results of detection capability are shown in Table 6.

TABLE 6

DETECTION MODEL PERFORMANCE

SUBSYSTEM	TOTAL INCI-DENTS	NUMBER OF SUCCESSFUL DETECTIONS (PERCENT OF TOTAL INCIDENTS)						
		CALI-FORNIA	TTI. MODELS					Any Model
			1*	2	3	4	5	
1	26	6 (23.1)	25 (96.3)	17 (65.4)	12 (46.2)	15 (57.8)	4 (30.8)	26 (100)
2	8	7 (87.5)	6 (75)	7 (87.5)	5 (62.5)	4 (50)	0 (0)	7 (87.5)
3	16	13 (81.3)	14 (87.5)	13 (81.3)	12 (75)	9 (56.3)	8 (50)	16 (100)
TOTALS	50	26 (52)	45 (90)	37 (74)	29 (58)	28 (56)	16 (32)	49 (98)

*Numbers refer to Models as follows:

1. Station Discontinuity
2. Subsystem Discontinuity
3. Subsystem Energy
4. Station Energy
5. Subsystem Shock Wave

Treating the entire set of models as a joint model did not reveal any subsystem differences since only one of the 50 incidents was not detected by any model. Combining the individual effects of all six models, the following tabulation was made:

SUBSYSTEM	INCIDENTS	PERCENT DETECTED
1	26	53%
2	8	60%
3	16	73%

This difference in detection was tested by the Chi-square goodness-of-fit test and was found to be highly significant with the greatest overall detection capability recorded in the long, northernmost subsystem (Subsystem Three) and the least effective performance in the equally long subsystem at the southernmost end of the system (Subsystem One).

The four subsystem models, including the Modified California Model, were next compared as a group with the performance of the two station data models. No significant difference was found in subsystem model performance versus station model performance in either Subsystems Two or Three. However, there was a highly significant difference in Subsystem One, where station model performance was markedly better than subsystem model performance. Inspection of the data presented in Table 6 revealed that both station models performed the same or slightly better in Subsystem One than in Subsystem Three, while the subsystem models all performed distinctly poorer in Subsystem One as compared to Subsystem Three, particularly the California Model.

The net effect of this analysis is to isolate individual station characteristics as a potential determining factor. Referring to Figure 7, the geometric differences found in the stations consist of freeway alignment, the number of lanes, and the location of ramps relative to the stations. Flow characteristics are different at each station, and this was taken into consideration in the formulation of the models. These differences may adversely effect subsystem model performance where the linking of two stochastic station data on streams (upstream and downstream) introduces further variability which would tend to obscure the effects of an incident. Since the only adverse effect was noted in Subsystem One, the additional lane at the Seward station appears to be the significant geometric discontinuity. The region downstream of the fourth lane drop (Figure 7) near the Chicago station was observed by TTI to be a traffic bottleneck (10). It is possible that the presence of a geometric discontinuity such as this renders the subsystem models less sensitive to incidents.

Referring to the columns of Table 6, an analysis of the relative effectiveness of each model in each of the three subsystems was then made. When appropriate, Chi-square tests (not shown) were made.

The Modified California Model responded very differently to incidents in each of the three subsystems. While the average overall detection capability was 52%, more than 80% were detected in Subsystems Two and Three and only 23% in Subsystem One, a statistically significant difference.

The Station Discontinuity Model, the most effective single detection model, did well on all subsystems although there is a slight but not statistically significant probability that it does not perform as well on the short Subsystem Two as on the longer subsystems. On the other hand, there is a small indication that the second best model, the Subsystem Discontinuity Model, may perform better on short subsystems and less effectively on longer subsystems such as Subsystem One with its lane discontinuity.

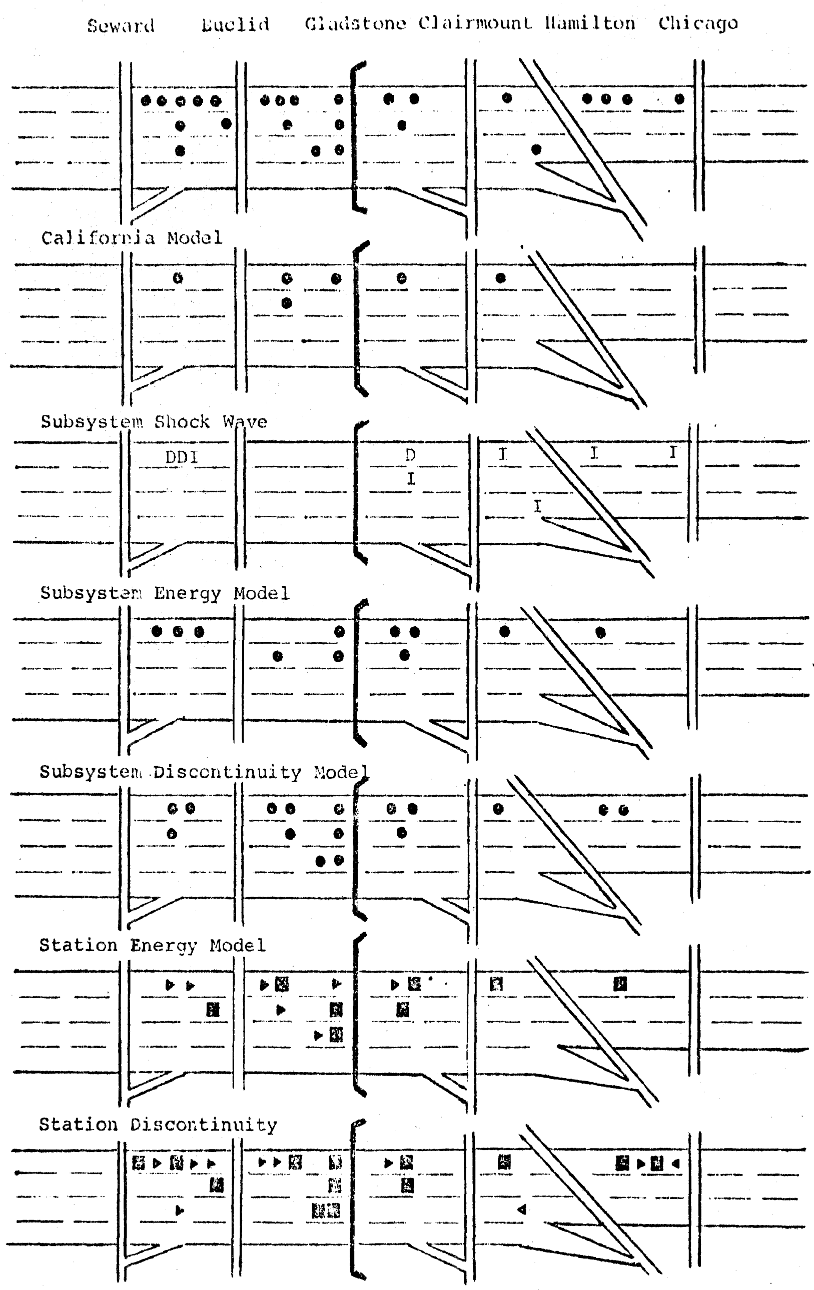
The Subsystem Energy Model performed weakly in Subsystem One (significant at $\alpha = .10$). The Station Energy Model displayed no differences among the three subsystems. The Subsystem Shock Wave Model did very poorly on the short subsystem (significant at $\alpha = .05$). None of the eight incidents in Subsystem Two were detected by this model. Because this is the shortest subsystem, perhaps the length might be a factor. Chapter One explained that changes in vehicle storage during an incident come about through increased numbers of vehicles in the dense congestion upstream, or decreased numbers downstream. In Subsystem Two there evidently was not enough distance for the presence or lack of congestion downstream to cause a significant change in storage. Storage change thresholds were too high because they took into account traffic variability in the form of platooning, which would be more significant for short subsystems than for long ones.

In general, except for the Subsystem Shock Wave Model, it was not possible to note any consistent performance differences attributable to subsystem length. The lane discontinuity at Seward appeared to account for the poorer subsystem model performances in Subsystem One.

In another attempt to determine if subsystem length was a factor in the detection of incidents, the location of incidents within the subsystem was investigated. Data for the study was gathered through the television surveillance system. Five television cameras were required to survey Subsystem One, and three were required in Subsystem Three. Television records also note whether incidents occurred within the normal range of each camera or far down range requiring the use of a telephoto lens by the television observer. Hence, incidents could be located by the television cameras at ten approximate positions in Subsystem One and six in Subsystem Three. These positions and the blocked lane for each incident are depicted in Figures 23 and 24 for Subsystems One and Three respectively. Since subsystem Two was covered by only one camera, data for an analysis of this type were not available.

Based on this spatial distribution of successful detections for each model, it does not appear as if proximity to a detector station is a factor in the ability of the models to detect incidents. Two possible exceptions might be the use of the Subsystem Discontinuity and Station Energy Models in Subsystem One, where the greater proportion of detections were in the center of the subsystem. Though most of the incidents took place in the median lane, the lane of occurrence seems to be an insignificant factor in detection for these models.

Figures 23 and 24 also demonstrate an important aspect of incident detection for the two station models, Station Energy and Station Discontinuity. Spatial proximity within the bounds of these subsystems may not be a factor in detection, but the problem still arises whether the detection signal at a station indicates an incident upstream or downstream of the station. The figures indicate that in the case



LEGEND:

● --Incident Location

I --Storage Increase

D --Storage Decrease

■ --Detected both upstream and downstream

▶ --Detected upstream only

◀ --Detected downstream only

FIGURE 23

SPATIAL DISTRIBUTION OF
INCIDENT DETECTIONS (SUBSYSTEM ONE)

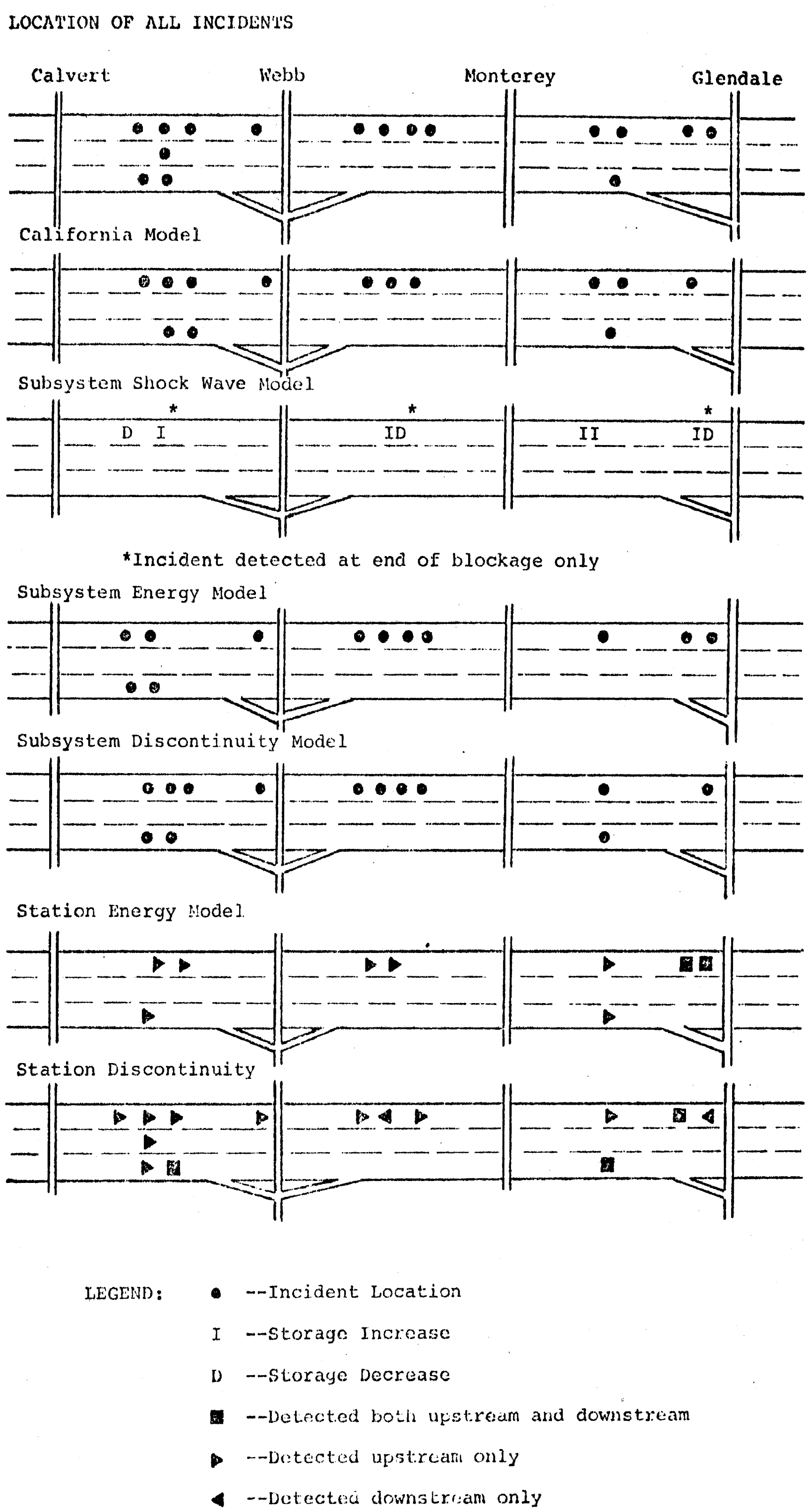


FIGURE 24

SPATIAL DISTRIBUTION OF
INCIDENT DETECTIONS (SUBSYSTEM THREE)

of the Station Energy Model, the incidents are downstream of the station for both subsystems. This is expected since this model detects the congestion that occurs upstream of the incident. The Station Discontinuity Model, however, does not pinpoint the location of the incident as well. In most cases the incident will be downstream, but in a few cases, in both subsystems, the incident is fairly close upstream. It is noted that many Station Discontinuity detections were at both stations encompassing the subsystem. Upstream detections resulted because the blocked lane contained stopped vehicles or slower moving vehicles than in the other lanes. Downstream it was presumed that the blocked lanes contained disproportionately few vehicles and all lanes were moving freely. In Subsystem Two one of the six incidents detected by this model was upstream of the station, the others were downstream.

Table 7 presents the average time to initial detection of an incident for the three subsystems. It can be seen that the average duration of the incidents in the three subsystems as recorded by television and automatic sensing systems are similar.

TABLE 7

AVERAGE TIME TO FIRST DETECTION

SUB-SYSTEM	INCIDENT DURATION		AVERAGE TIME TO FIRST DETECTION (MIN.)						
				TTI Models					
	Reduced Capacity	TV Log	Cali-fornia	1*	2	3	4	5	Best
1	8.96	6.62	2.00	1.48	2.88	7.75	2.20	2.63	0.92
2	10.75	6.13	0.14	6.34	0.86	1.80	5.75	**	0.14
3	11.12	5.22	0.92	1.22	1.85	5.58	1.78	3.50	0.13
AVERAGE	9.95	6.13	0.96	2.07	2.14	5.83	2.58	3.06	0.55

*Numbers refer to Models as follows:

1. Station Discontinuity
2. Subsystem Discontinuity
3. Subsystem Energy
4. Station Energy
5. Subsystem Shock Wave

**No successful detections

Referring to Figure 21, where individual detection times in separate subsystems are shown, it can be seen that the average time to first detection by the best joint model is similar for all three subsections when the substantial effect of the one Subsystem One incident that took 15 minutes to detect is considered. This one incident explains most of the differences among the averages shown in Table 7.

A detailed study was made of the detection time distribution in the three subsystems for the three fastest responding models, the Modified California, Station Discontinuity, and Subsystem Discontinuity Models. It was found that there were no statistically significant differences in average detection times (analysis of variance) or in the distribution of detection times (Smirnov test). The average detection times differed less than one minute and differences of this order generally would not be important.

There was also no identifiable differential detection time response among these three models in the three subsystems after it was noted that the Station Discontinuity Model had two large, unexplainable detection times in Subsystem Two.

FALSE ALARMS

It was desirable that the feasibility of reducing the false alarm rate be further explored. One percent thresholds for detection were employed by TTI (10) and continued in this research on a tentative basis.

Example incident-free cumulative distributions of the variables for the Station Discontinuity and Station Energy Models were compiled and are presented in Appendix C, Figures C-1 and C-2. In addition, cumulative distributions for the signal values for each successful detection by model at the Seward and Calvert stations and the lowest values when an incident was not detected are presented in these figures.

For both models the incident curves are distinctly different from the incident-free operations curves. In neither case, however, do the incident curves extend over a separate and distinct range of parameter values. This is particularly true of the Station Energy Model, where nearly every signal value can be found within the range of normal operations. The curves indicate that to detect every incident with the Station Energy Model the threshold levels would have to be raised to the five percent false alarm level at Seward and ten percent at Calvert. The one percent threshold level could not be reduced without drastically lowering the effectiveness of the model. These observations confirm the intuitive notion that kinetic energy fluctuations are not specific to capacity-reducing incidents. There are, however, low Station Discontinuity Model variable values which signal an incident that are seldom observed in normal traffic operations. This, plus the significantly better performance of the Station Discontinuity Model, indicate that the former model is more specific to incidents than is the Station Energy Model. It is evident, however, from Figure C.2 that the one percent threshold also cannot be lowered for the Station Discontinuity Model without swiftly lowering performance.

The effectiveness of the Station and Subsystem Discontinuity Models, the two best TTI models, in distinguishing capacity-reducing incident situations from regular traffic operations can be inferred from the cumulative distributions of the respective variables during congested operations known to be caused by incidents. In Figure 25 data for 242 minutes of congested operation at Seward generated by the 26 downstream incidents in Subsystem One are presented in cumulative form. Cumulative percentiles for these variables under "non-incident" conditions on eight days are also included in the graphs.

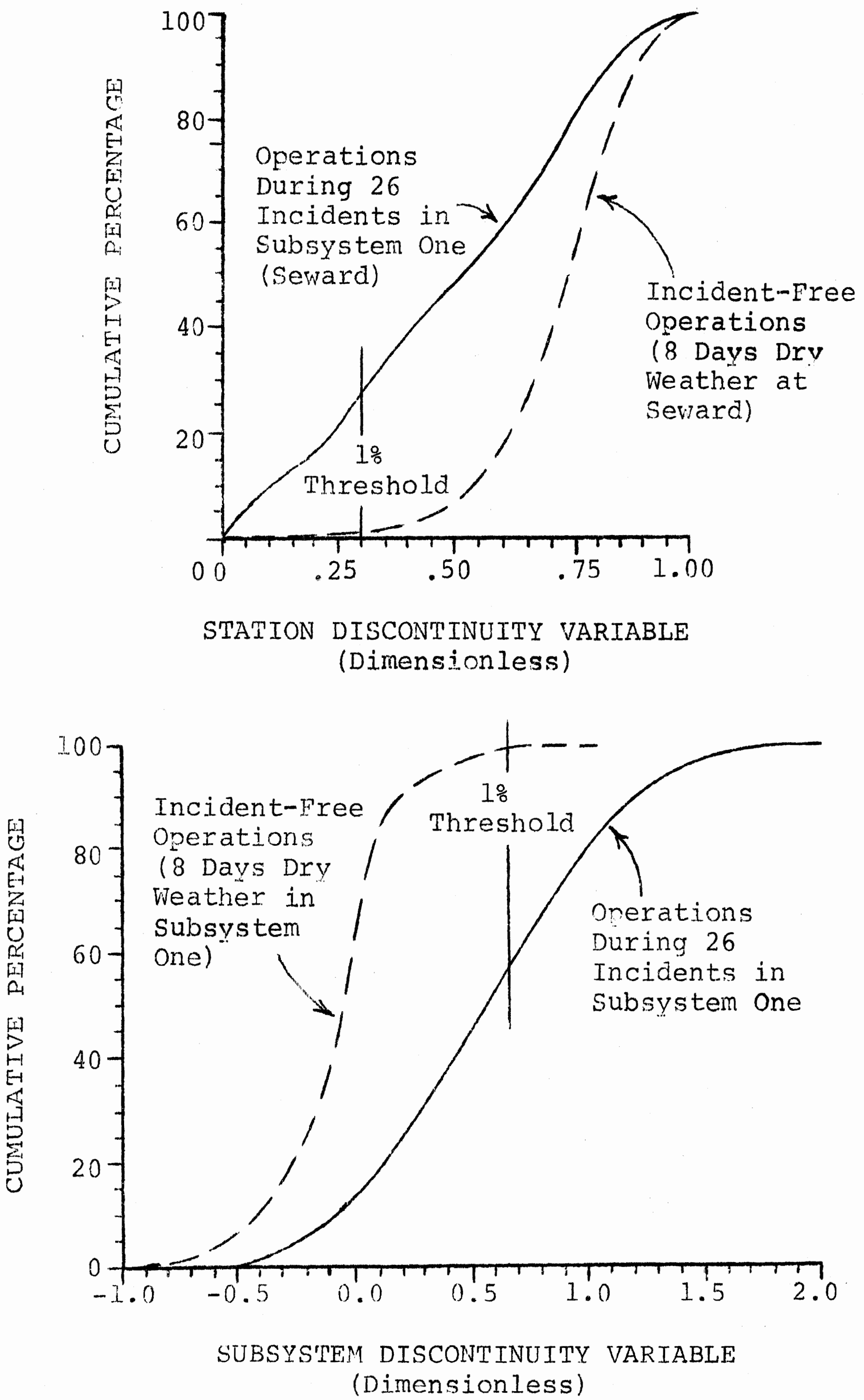


FIGURE 25

DISTRIBUTIONS OF TWO DISCONTINUITY MODEL VARIABLES DURING INCIDENT AND INCIDENT-FREE OPERATION

A high level of detection performance with few false alarms is facilitated if the distribution of the detection variable in response to an incident extends over a range of values distinct from incident-free variable distributions. For the Station Discontinuity Model, comparison of the incident-free distribution with the incident congestion distribution demonstrates that while low values of the variable occur much more frequently during an incident than in regular operations, they are not observed exclusively. Rather than ranging over a different set of variable values the distribution curve during incidents is merely shifted toward the lower values of the variable with some increase in variance. The only exceptions to this are extremely low variable values as indicated in Appendix Table C-6. Depending on the station and weather conditions, the lowest value observed during incident-free operations ranged from 0.00+ to 0.19. During incidents, however, variable values of zero were occasionally recorded, and it was noted in Chapter One that zero was never observed in the set of normal observations.

In contrast, the incident congestion distribution for the Subsystem Discontinuity Model extends over a different, although still considerably overlapped, range as the incident-free distribution in Subsystem One. In particular, there were a number of variable values greater than the maximum of 1.18 observed for incident-free operations in Subsystem One. Values as high as 1.89 were observed, indicating the apparent severity of some flow discontinuities during incidents. This was also noted, but to a lesser extent, in the other two subsystems (Appendix Table C-9).

In Figure 25 it is seen that the Subsystem Discontinuity detection threshold is exceeded over 40% of the time during an incident as compared to 25% for the Station Discontinuity threshold. The reason for this is that for incidents of durations greater than about four minutes, large variable shifts were frequently observed in successive minutes for much of the congestion interval. A good example of this is shown in the time plots of TTI model performance already presented in Figure 13 in Chapter One. The Station Discontinuity Model exhibited this tendency to a lesser extent. Thus serial correlation is evidenced in the Subsystem Discontinuity Model for incidents of longer duration and greater impact on traffic operations. It would not appear, however, that this characteristic can be used advantageously in incident detection as the objective is the detection of as many incidents as possible. This necessarily includes those incidents that the model detects only once or not at all.

In conclusion it appears that the one percent threshold level and hence the false alarm rate can only be lowered by decreasing the detection capability of the individual models. Since one model did achieve a 90% level of successful detections, there may be little merit in raising the threshold further. A more productive means for reducing false alarms, if this is considered necessary for an operational scheme, would seem to lie with further model refinements. Some serial correlation is present in the variables of some models, including the Subsystem Discontinuity Model, which indicates that false alarms are also somewhat time dependent. During the compilation of the frequency distribution curves for the incident-free data it was noted that the overall one percent thresholds would seldom, if ever, be reached on certain days, and on other days be exceeded much more than one percent of the time. Since these predetermined threshold values stray from the one percent false alarm level on a daily basis and most probably during the day, one possible refinement to these models may be to use flexible threshold values determined in real-time by a technique such as exponential smoothing.

The means for accomplishing this have already been developed in this research effort, namely, the mean absolute deviation estimate of standard deviation used in the exponential smoothing models. If the threshold values can statistically be related to the standard deviations of the parameter frequency distributions, then the mean absolute deviation estimate compiled every minute could be used to compile flexible threshold limits. Such factors as changing traffic conditions, time of day or day of week, and environmental conditions would automatically be taken care of with this arrangement. The strategy would at least keep the threshold level for detection theoretically at the one percent level for prevailing conditions. It might, however, allow the use of more stringent thresholds without impairment of model performance. Inspection of the frequency distribution statistics for the various Texas Transportation Institute models in Tables C-2 through C-9 reveals that in most instances the mean parameter value plus or minus (as appropriate) one standard deviation is a reasonable estimate of the one percent threshold values. The estimates are no worse than the differences observed among dry and rain values, or between the 1968 and 1969 values for dry weather. On-line analysis would confirm the validity of this modification of the Texas Transportation Institute detection strategy.

DETECTION OF INCIDENT TERMINATION

For surveillance control purposes the termination time of a capacity-reducing incident is a desirable input to a strategy which seeks to fully utilize the excess downstream freeway capacity during, but not after, an incident. The capabilities of each model were explored by comparing the estimated end of congestion with the cessation of detection signals for each model. If the cessation point was within several minutes of the end of congestion, a model was considered successful in detecting the termination point. Real-time incident detection requires that the detection signal be relatively continuous throughout the duration of each incident for it to be said that a distinct detection termination had been achieved. The only exception to this was the Subsystem Shock Wave Model where a successful termination signal was the detection of the recovery wave after an initial detection of the incident shock wave.

The results for each of the models by subsystem is presented in Table 8. Incidents with durations of one or two minutes were not included since termination time is not pertinent for such short incidents. For the remaining incidents, the ability of the individual detection models to signal a reasonably distinct termination signal ranged from

TABLE 8

SUCCESSFUL TERMINATION SIGNALS FOR THE DETECTION MODELS BY SUBSYSTEM

SUBSYSTEM	PERCENT OF SUCCESSFUL TERMINATION SIGNALS*					
	CALIFORNIA MODEL	TTI MODELS**				
		1	2	3	4	5
1	100% (5)	42% (21)	73% (15)	64% (14)	30% (11)	42% (7)
2	100% (7)	0% (6)	73% (7)	0% (4)	40% (5)	***
3	100% (13)	31% (13)	61% (13)	55% (9)	17% (12)	25% (8)
TOTAL	100% (25)	33% (40)	61% (35)	52% (27)	25% (28)	33% (15)

*Number of successful detections in parentheses.

**Numbers refer to Models as follows:

1. Station Discontinuity Model
2. Subsystem Discontinuity Model
3. Station Energy Model
4. Subsystem Energy Model
5. Subsystem Shock Wave Model

***No successful detections

25% to 100%. The California Model in every case signaled the end of the period of detectable congestion. The end of congestion does not correspond to the time of removal of an incident from the freeway, but it is the best that can be expected with traffic stream measurements. Furthermore, this is the point at which the incident ceases to be of interest for surveillance contol purposes.

The TTI models were distinctly inferior in performance to the California Model, and the signal, of course, was actually the lack of incident confirmation signals since no formal provisions had been made for termination in the model logic. The Subsystem Discontinuity and Station Energy Models, with 61% and 52% successful terminations, respectively, were better in this respect than the others, and it was noted that these two models were the most likely among the TTI models to signal continuously during incident congestion. There was no consistent interaction among the subsystems although the failure of the two station models to terminate any incidents in the short subsystem (Subsystem Two) is noted.

In general, it is concluded that the TTI models require more in the way of termination logic than simply the cessation of critical variable values. The California method of signaling the termination when downstream occupancy again rises to the level preceding the incident was found to be effective and intuitively satisfying. For real-time detection operations this more precise termination signal would be less ambiguous and thus more effective. Should any of the TTI models be incorporated into an on-line detection system, a similar method of detecting the end of the flow discontinuity should be incorporated.

EFFECT OF WEATHER

For each analysis day the mean value, standard deviation, maximum value, and minimum value of each model variable were determined. For the set of dry and rainy days, means and standard deviations were computed. All of this information as well as the overall maximum and minimum values observed and the respective threshold values are presented in Tables C-5 through C-9 in Appendix C. In most cases there was a significant difference in the dry and rainy weather means as determined through application of the Central Limit Theorem. For the Station Energy variable which most directly reflects the greater congestion in adverse weather, the rainy day means were all consistently and distinctly lower than the dry weather means. The Station Discontinuity distribution means were not significantly different. This may indicate that relative lane operations are general characteristics of traffic operations and driver behavior rather than functions of external influences such as weather. That is, one lane of traffic will move more or less freely (different lane energy) than the other lanes for only a certain length of time before some drivers will move into that lane or abandon it and thus restore the even distribution of energies.

In nearly every case, the average standard deviations needed to be the same or somewhat smaller for rainy conditions than for dry. Inspection of the maximum and minimum values observed showed a consistently narrower spread of values for rainy than for dry weather.

The threshold values for each model are also presented in Tables C-2, C-3, and C-4 in Appendix C along with the values computed by TTI for their 1968 dry weather sample. In general, the rainy day incident signal thresholds are consistently different from the dry day thresholds for the different stations or subsystems within each model, but there is no consistency among the models. The thresholds are thus more extreme (farther from the distribution means) in rainy weather for the Station Energy and Station Discontinuity Models, but less extreme for the Subsystem Shock Wave Model. They are the same for the Subsystem Energy Model. Unfortunately, these differences, although consistent within each model, are of the same order of magnitude as the differences between the 1968 and 1969 dry weather thresholds. This may be due to the scatter of variable values at the fringes of these distributions.

Some consistent patterns are evident in the set of cumulative distributions and thresholds established for the five TTI models. There are striking differences in model performance at the different stations or subsystems. There is also justification for treating dry and rainy weather situations separate from each other. None of the above observations, of course, have any direct bearing on the ability of the TTI models to detect capacity-reducing incidents, but it was anticipated that they would prove beneficial in analyzing the validity of the threshold concept.

1968 PARAMETER EFFECTIVENESS

The detection thresholds developed by TTI in 1968 were applied to the Station Discontinuity and Subsystem Shock Wave Models, the best and worst performers, respectively, in order to compare their effectiveness with those derived from a separate set of incident-free days in 1969. Use of the TTI thresholds for the Station Discontinuity Model also resulted in detection of 90% of the 50 incidents, although two incidents were detected only with the TTI values and two other incidents detected in this research were undetected using the 1968 thresholds. Interestingly, the one 1969 incident undetected by all models was detected with the considerably less stringent TTI threshold at the Calvert detector station. Detection performance of the TTI thresholds for the Subsystem Shock Wave Model was improved from 32% to 44 % of the 50 incidents.

In general, these variances merely reflect the differences in threshold values. The TTI values do not take weather conditions into account, and more importantly, false alarm rates are affected by changing the thresholds. Based on the UM compilation of incident-free statistics, the TTI station discontinuity threshold of 0.51 used at Calvert to detect the 50th incident yields a false alarm rate of 11% (see Figure C-2).

NATURE OF INCIDENTS

The feasibility of distinguishing accidents from stalls and breakdowns solely by means of traffic stream measurements was investigated based on the premise that accidents might generate a greater impact on traffic operations because of the greater number of vehicles involved and greater potential for distraction. Based on the television records none of the investigated accidents appeared to be serious or involve serious injuries as inferred from the lack of ambulances dispatched to the accident scene. All such aid vehicles were to be noted in the television logs as explained in Appendix A.

The 18 accidents did not generate a greater disruption in traffic flow than the remaining 32 incidents as evidenced by their being scattered randomly among all 50 incidents in impact on downstream flow in Figure 19. This may be a consequence of the lack of flow data at the incident location where the effects of distraction on flow past the incident could be significant. Further downstream these effects would be masked as traffic operations recover.

There was also no apparent interaction in the ability of the detection models to distinguish between accidents and other incidents or detect one type better than the other. Hence, it is concluded that it does not appear likely that it will be possible to determine the nature of a capacity-reducing incident by means of traffic stream measurements alone.

MODEL INDEPENDENCE

The assumption made by the Texas Transportation Institute that their models were independent of each other was investigated as this has a direct bearing on the suitability of using several models jointly to further increase detection capability (10). This was done by comparing the relative detection performance and detection times of pairs of models.

The three subsystem models all detected the situation of upstream congestion and lack of congestion downstream of the incident. The Subsystem Shock Wave Model detected the sudden transition to these conditions, but the other two, Subsystem Discontinuity and Subsystem Energy, were detecting the same steady-state situation present during an incident by different methods. The independence of the detection performance of these two models is investigated in Table 9.

TABLE 9

SUBSYSTEM MODEL DETECTION INDEPENDENCE

		SUBSYSTEM ENERGY MODEL		ROW SUM
		Detection	No Detection	
SUBSYSTEM DISCONTINUITY MODEL	Detection	28	9	37
	No Detection	1	12	13
	COLUMN SUM	29	21	50

$$\chi^2 = 18.3$$
$$\chi^2_{.01,1} = 6.6$$

A highly significant interaction is evidenced in this tabulation and it is concluded that these two models are far from independent. If the models were independent, fewer than six of the 50 incidents, rather than 12, would have been missed by the joint application of both models.

Station Energy and Subsystem Energy were similarly compared in Table 10.

TABLE 10

ENERGY MODEL DETECTION INDEPENDENCE

		STATION ENERGY		ROW SUM
		Detection	No Detection	
SUBSYSTEM ENERGY	Detection	21	8	29
	No Detection	7	14	21
	COLUMN SUM	28	22	50

$$\chi^2 = 7.6$$

$$\chi^2_{.01,1} = 6.6$$

The overall detection performance of these two models was nearly identical, but again the interaction in detection performance is highly significant. If the models were independent, only nine instead of 14 incidents would have been missed by both models. In this case, there was more reason for expecting the models to be independent since one considered kinetic energy at a station and the other the difference in energy between stations.

Finally, the two TTI models that gave the best performance, Station Discontinuity and Subsystem Discontinuity, were compared by an exact multinominal test (Table 11).

TABLE 11

STATION AND SUBSYSTEM DISCONTINUITY
MODEL INDEPENDENCE

		SUBSYSTEM DISCONTINUITY		ROW SUM
		Detection	No Detection	
STATION DISCONTINUITY	Detection	34	11	45
	No Detection	3	2	5
	COLUMN SUM	37	13	50

In contrast to the comparisons of the other model pairs, these two models appear to be independent of each other in detection performance. This result justified the further investigation of the joint use of these two models for incident detection presented in the next section of this chapter.

SUMMARY

To summarize the performance of the TTI and California models, there were significant differences in model detection. The Station Discontinuity and Subsystem Discontinuity Models were particularly effective with detection rates of 90% and 74%, respectively, at a one percent false alarm rate. These two models, unlike the others, were independent of each other in detection performance. Subsystem length was not a significant factor in the ability to detect incidents except for the Subsystem Shock Wave Model. The subsystem models were somewhat less effective in Subsystem One where a geometric discontinuity (four lanes merging to three) is present. There was no apparent difference in detection by the two station models in the three subsystems. Eight of the 50 incidents took place in rain or snow, but since they were all detected by one or more models, weather conditions were evidently not a factor in detection. However, separate threshold parameters are needed for rain or snow. All of the TTI models, except the Station Discontinuity Model, identified the incident subsystem location accurately. For the latter model incidents may have taken place either upstream or downstream of the detector station. The models were unable to distinguish accidents from stalled vehicles and the like, and also did not consistently provide a distinct signal for the end of incidents. The one percent threshold level could not be made more stringent in order to reduce false alarms without impairing model performance.

A COMPOSITE INCIDENT DETECTION MODEL

Since two of the TTI detection models, Station Discontinuity and Subsystem Discontinuity, were found to be independent of each other and were distinctly superior to the others in performance, the feasibility of using the two models jointly was explored. Together the two models detected 48 of the 50 incidents (see Table 6), a performance level of 96%. One of the two undetected incidents went undetected by all models.

On comparing these two models with all other models it was found that of the 49 incidents detected by any model, four were detected by the Station Discontinuity Model only, one by the Subsystem Discontinuity Model only, and two by both of these models but by none of the others. Thus, the best combination of any set of the remaining models would yield a maximum of 42 detections. It is evident that the use of these two models together represents the most effective combination of TTI models.

The average time lag for detection of the 48 incidents by a composite model is 0.81 minute, an improvement from the 2.1 minute average of the models alone. This represents a better performance than the Modified California Model and indicates that the great majority of detections take place within the first or second minute of the onset of congestion.

The sample standard deviation of 2.10 minutes is nearly the same as that for the earliest detection times by any model, 2.06 minutes. However, this is still more than the 1.31 value for the Modified California Model, although not statistically significantly greater ($\alpha = .05$). The composite model signaled a reasonable termination to 75% of the detected incidents, better than any individual TTI model but not as good as the California Model.

A cumulative plot of detection times for this joint model is shown in Figure 26 which compares it with the performance of other models. Detection performance in the first few minutes is markedly improved as 14 of the incidents that went undetected by one of the models are detected at the first or second opportunity.

The independence of the two models follows from the different traffic characteristics or "discontinuities" measured by each model. For the Subsystem Discontinuity Model it is the joint detection of congestion at the upstream station and freer flow downstream. The Station Discontinuity approach, on the other hand, detects an energy imbalance caused by one lane being blocked. There is no particular evidence that this imbalance is a function of the flow rate such that a significant difference in flow characteristics between stations would also be accompanied by a greater likelihood of lane energy imbalance or vice versa for

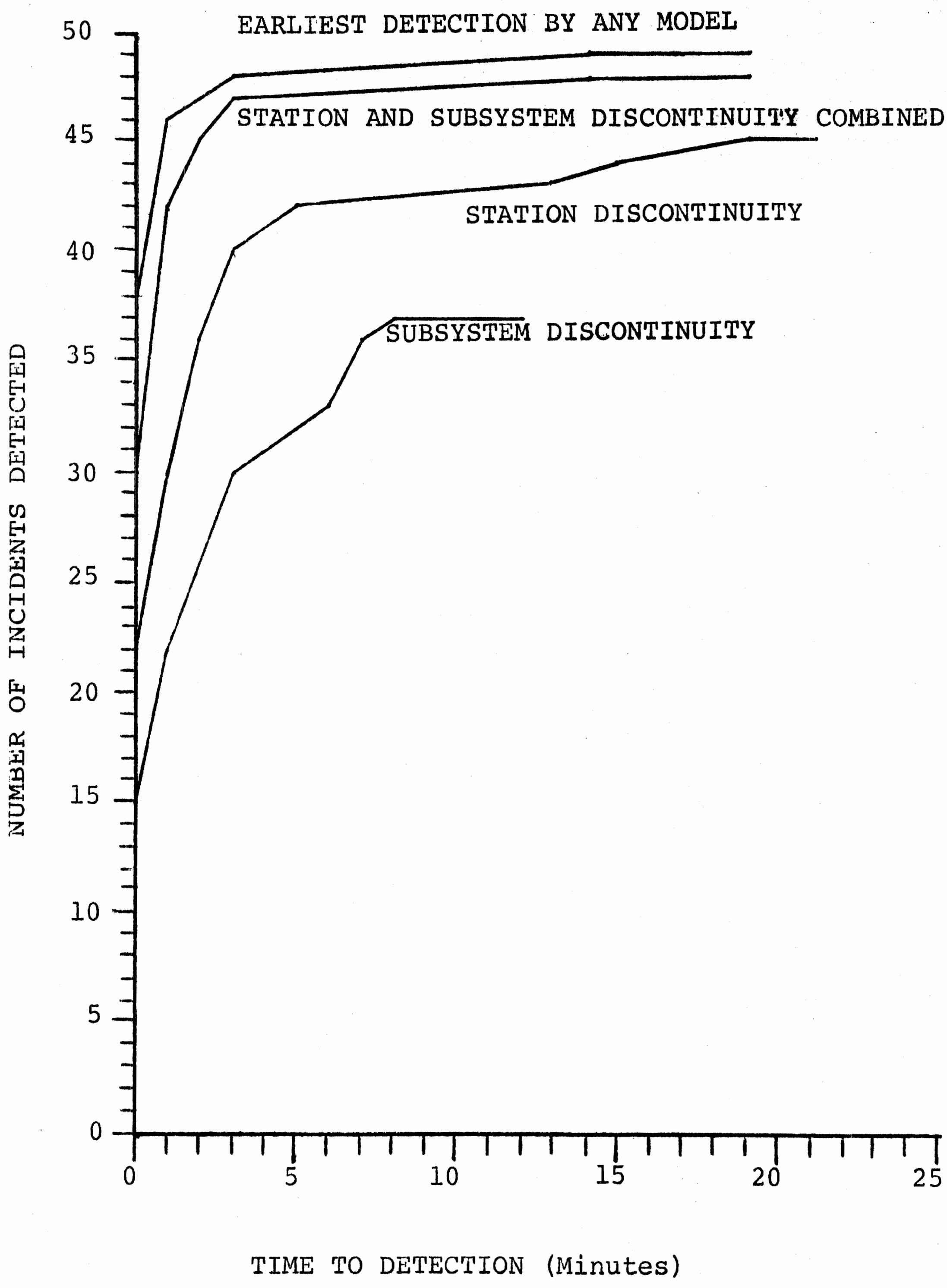


FIGURE 26

PERFORMANCE OF COMPOSITE
DETECTION MODEL

regular traffic operations. Naturally occurring imbalances would be corrected by drivers changing to those lanes which appear to be moving better as the opportunity presents itself. The flow operations in parallel lanes thus would fluctuate around the steady-state of lane energy balance. Worrall, et al., assumed that lane changes were independent and isolated events in the traffic stream except in merging areas (52). In their Markovian model of lane-changing, flow was a constant factor to be applied at the end of the calculations although in theory the steady-state transition probabilities could be functions of flow rate. If it were possible to keep track of individual vehicle trajectories through space and time, then shifts in these probabilities (i.e., increased lane changing) could serve as means for detection. The Station Discontinuity Model detects the end product of these shifts, the blockage or near blockage of one or more lanes of travel.

In conclusion, it appears that the joint use of models based on the comparison of lane energy and speed and occupancy differences at adjacent stations produces the best level of performance among the models included in this study. Ninety-six percent of the incidents are detected by the two, in most cases either in the minute of onset of congestion or the following minute. The two models appear to be independent, so the joint false alarm rate will be nearly two percent. Although serial correlation is frequently evidenced for at least one of the models, the use of second minute detection confirmations or the use of one model to confirm the other in order to reduce the rate of false alarms would defeat the objective of using both to detect as many incidents as possible. However, if greater value were placed on the detection of major incidents requiring police or other aid, such confirmation could very well be effective in reducing the false alarms at the expense of fewer overall detections.

MODIFIED CALIFORNIA INCIDENT DETECTION MODEL PERFORMANCE

The performance of the Modified California Model has already been discussed with regard to detection of 50 on-freeway incidents. Several important observations should be emphasized. A summary of the studies done with the California Model is presented in Table 12.

The 18 days of analysis contained 4860 minutes. A similar number of model tests were performed in each subsystem. There were ten false alarms out of 14,580 test situations. This is an exceedingly low rate of less than .001. Subsystem Two, the short section, recorded the most false alarms, eight. There were no false alarms in Subsystem One, but it appears that the reason for this was the general insensitivity of the model in that subsystem. Considering Subsystems Two and Three alone, there were 17 incidents and ten false alarms. The false alarm rate approximates or is less than the rate of actual occurrence of on-freeway incidents.

When the Modified California Model was applied to the full set of data for 50 incidents, a total of 26 were detected. Similar performances were recorded in Subsystems Two and Three where an average of 83% of the incidents were successfully detected, indicating that subsystem length is not necessarily a factor for the California Model. However,

TABLE 12

CALIFORNIA INCIDENT DETECTION MODEL PERFORMANCE

SUB-SYSTEM	OPTIMAL PARAMETER				18 DAYS* ANALYSIS			TOTAL INVESTIGATION		
	Dry		Rain/Snow		Inci-dents	Percent Detected	False Alarms	Inci-dents	Total Detected	Percent Detected
	K2	K3	K2	K3						
1	.53	.26	.53	.26	10	40%	None	26	6	23%
2	.53	.21	.56	.30	8	88%	8	8	7	88%
3	.61	.11	.61	.24	9	89%	2	16	13	81%
TOTALS:					27	70%	10	50	26	52%
TOTALS NOT INCLUDING SUBSYSTEM 1:					17	88%	10	24	20	83%

*18 days totaled 4860 minutes of analysis. These days included 13 dry, 4 rainy, and 1 snowy day.

performance was extremely poor in Subsystem One with a detection rate of only 23%. A Chi-square test indicated that this difference in detection performances could not be attributed to chance at the five percent level.

The problem in Subsystem One was basically one of sensitivity, evidently caused by the geometric discontinuities discussed previously. In this particular subsystem, several incidents occurred that did not behave according to the assumptions of the model. However, of the 20 misses, 14 displayed a response similar to the California assumptions, but the response was not large enough to generate an incident signal. Including the 14 incidents with the six detections, the Modified California Model could be applicable to 77% of the incidents in Subsystem One, a percentage comparable to its success rate in the other two subsystems. It seems reasonable to assert that in the case of the California Model, optimal model performance may depend on the subsystems demonstrating geometric homogeneity.

EXPONENTIAL SMOOTHING MODEL PERFORMANCE

As discussed in Chapter One, separate double exponential smoothing of station volumes and occupancies was applied to peak periods containing six incidents. With occupancy as the variable, three of the six incidents were detected. With volume as the variable, four of six were detected. The number of false alarms, 12 for the occupancy model and three for the volume model, is comparable to the one percent rate anticipated for the TTI models.

There is insufficient data to develop conclusions on subsystem performance or actually compare performance by subsystem with the other models. Even without this comparison, there was dissatisfaction with the performance of the exponential model for a number of reasons.

A typical successful detection for both models is presented in Figure 27. The plot of predicted volume and occupancy illustrates the ability of double exponential smoothing to respond to these parameter changes and rapidly correct for trend. As mentioned in Chapter One, the predictions take into account the past six parameter observations. The "Mean Absolute Deviation" (MAD) is a running estimate of the current standard deviation (see Appendix E) which takes into account approximately the last 20 observations.

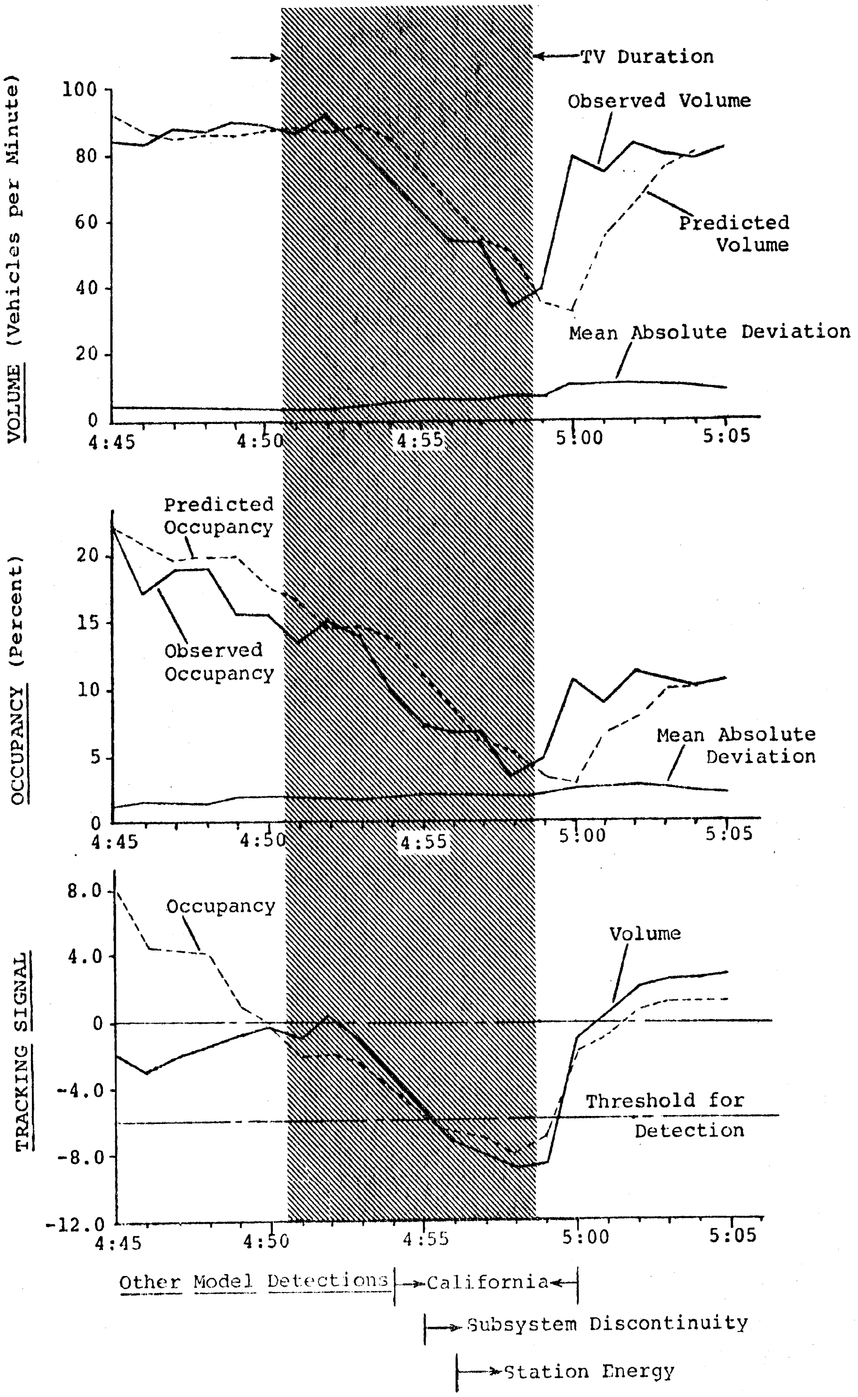


FIGURE 27

EXPONENTIAL SMOOTHING MODEL PERFORMANCE

Since the tracking signal is the cumulated past errors of prediction divided by the MAD, making the MAD less sensitive to very recent fluctuations results in better response by the tracking signal to sudden changes in the traffic parameter. The greater MAD is, the larger must be the shift in traffic performance or prediction error to get a significantly large tracking signal. The exponential model was designed to avoid false signals when the data stream had more than the usual variability over time.

When applied to incident detection, it becomes evident that the model requires traffic parameters that respond sharply and promptly to the passage of a shock wave generated by an incident. If there is little or no evidence of a shock wave there will be no detection because the model is designed to swiftly compensate for changes in parameter performance.

The incident depicted in Figure 27 was detected by all the detection models including both applications of the exponential smoothing models. The exponential models were a bit slow, signaling two minutes after the Revised California Model. From the graphs it appears that detection was obtained as anticipated. Both the downstream volumes and occupancies showed distinct gradual downward trends before the incident rather than sharp breaks. The exponential model compensates for trend but lags behind in prediction as long as the trend continues. This continual error of estimation builds the tracking signal until the threshold for detection is reached. The sharpest responses made by volume and occupancy are in the recovery wave after the incident. (It was at this time that the TTI Subsystem Shock Wave Model signaled a detection.) These shifts back to normal operations result in the tracking signal rapidly returning to the zero level. Rather than asymptotically approaching zero, the models overshoot and oscillate about the zero level. However, these secondary motions of the tracking signal are of little consequence for incident detection.

Figure 28 also shows further unanticipated behavior in traffic operations during an incident. Of all the incidents investigated, this incident behaved the least like the theoretical incident of Figure 9. Downstream of the incident the occupancy went up rather than down, perhaps because the incident took place near Seward where geometric discontinuities exist. The downstream detector being nearly a mile away, it perhaps was operating nearly independent of Seward conditions. Both volume and occupancy at Seward decreased considerably immediately preceding the incident. These changes were not sufficient to cause the respective tracking signals to activate, but they did cause the MADs to increase. The tracking signals thus became less sensitive

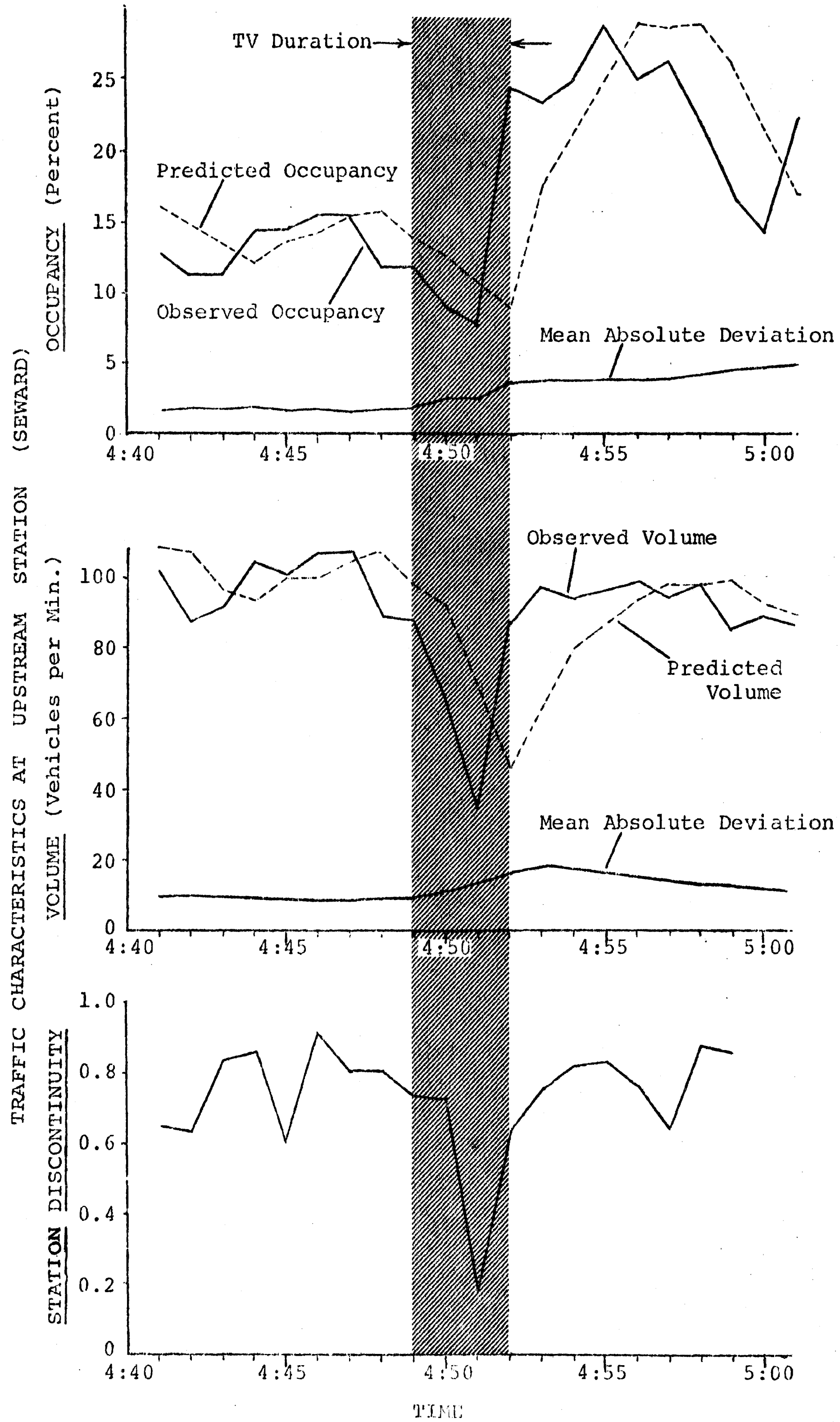


FIGURE 28

INCIDENT NOT DETECTED BY EXPONENTIAL SMOOTHING MODEL to the sudden jump in occupancy and volume generated by the incident at 4:51 p.m. One assumption made when the Exponential Smoothing Model was first considered was that immediately preceding an incident, traffic operations were remaining reasonably consistent over time.

Various logical techniques for overcoming these deficiencies in the model were considered. A minor modification would be the use of the previous MAD value, rather than the current value, to prevent the shock wave from increasing the MAD value applied to the tracking signal. Or, rather than use the cumulative sum of the errors in prediction for the tracking signal, the magnitude of the current error divided by the MAD (old or new value) could be used as the signal.

One conclusion was reached from this data that has a bearing on incident detection in general. Detection capability is facilitated, if the traffic variable selected registers the presence of an incident with a strong response of some kind. The accident in Figure 28 was detected by the two best TTI models, and the Station Discontinuity variable is plotted for the Seward station. Detection occurred for only a minute but parameter response was sharp, distinct, and significant. This model detected when the parameter dropped below the threshold level, but it would appear that detection could also have been achieved by registering the sudden shift in parameter values at 4:51 p.m. Successful application of a smoothing model, whether it be exponential or some other technique, will depend on the ability to identify similar traffic parameters.

CITIZENS BAND RADIO AND TELEVISION SURVEILLANCE SYSTEM COMPARISON

As described in Chapter One, comparable data on Television Surveillance (TV) and Citizens Band (CB) incident detection were developed for June 1969. During this period a total of 526 incidents were recorded by the television surveillance system on weekdays from 6:00 a.m. to 8:00 p.m. Of these, 55 were recorded as on-freeway blockages other than maintenance operations. The average on-freeway duration recorded was 7.5 minutes. Of these 55 incidents, eight (15%) were accidents involving one or more vehicles, 36 (69%) were the result of vehicle mechanical failure and eight (15%) were voluntary stops for such purposes as discharging passengers or litter or stopping to pick up fallen articles. The cause of the incident could not be determined in three (one percent) cases.

The CB Network reported 15 incidents on that portion of the Lodge under television surveillance during the same time periods. Of these, two were shoulder incidents and 13 were on-freeway incidents. Eleven of the on-freeway incidents were also detected by TV surveillance while two incidents, both resulting from vehicles blocking a lane of traffic, were not detected by TV. The 11 incidents, one accident and ten lane blockages, represent 20% of the 55 on-freeway incidents logged by TV. Those incidents detected by CB had an average on-freeway duration of 15.3 minutes compared to 7.5 minutes for the TV detected incidents. Based on the TV log notation for the time the incident began, CB detection reported incidents an average of 3.4 minutes after TV detection. This is despite three instances of the CB detection occurring first, including one incident detected eight minutes before the television detection. The TV observer did not notice this accident until the arrival of the police, alerted seven minutes previously by the CB Network.

In order to evaluate the effectiveness of the CB Network, consideration must be given to the thoroughness of coverage possible with the system. In June, 1969, the CB Network consisted almost entirely of motorists with their own CB units who voluntarily reported incidents (3). A total of 293 calls were logged in June for the 17-mile section of the Lodge Freeway from downtown Detroit to the interchange at Telegraph Road. Ten of these were made by personnel of the Detroit Department of Streets and Traffic which had 20 CB units in private employee cars and department cars. The remaining 283 calls were made by members of the general public.

In 1969 an estimated 17,500 CB licenses were owned by motorists in the Detroit metropolitan area. Each license permits at least one transmitter and one or more mobile units. Therefore, an estimate of 17,500 CB-equipped vehicles is probably conservative. In 1968 there were 1,944,000 registered motor vehicles in the Detroit area consisting of Wayne, Oakland, and Macomb Counties. Thus, it can be estimated that one out of every 111 vehicles has a CB unit. Although the usage of CB unit equipped vehicles is probably greater than that of other vehicles, it seems reasonable to assume for the analysis that at any given time, vehicles equipped with CB radios are proportioned throughout the community at locations similar to any other vehicles (freeways, surface streets, parking lots, garages, etc.). Hence, with the high volume levels on Detroit urban freeways, the likelihood of one or more vehicles equipped with CB radios passing a freeway incident site within a span of several minutes is quite high. The above frequency of CB units, coupled with the high likelihood of freeway travel, indicates that CB radios are capable of providing a potentially high level of detection capability. For example, from the volume levels passing an incident as shown in Figure 10, it can be seen that approximately 55 vehicles per minute pass the site during the blockage. CB-equipped vehicles can be assumed to be randomly distributed among the passing vehicles. With one in 111 vehicles equipped with a CB unit, it can be expected that a CB-equipped vehicle would pass the scene approximately every two minutes, an average arrival rate of 0.5 CB-equipped vehicles per minute. Under these circumstances, there would be a 40% probability that such a unit would pass within a minute, a 63% probability within two minutes, and a 92% chance that the incident would be seen within five minutes. Since these figures do not take into account vehicles passing in the opposite direction on the Freeway or observing the Freeway from the frontage road, it is evident that a CB detection system offers considerable potential, even without any additional CB installations.

The above predictions assume that every CB-equipped vehicle driver will report any on-freeway incident he sees to the surveillance center. The actual June 1969 experience on the Lodge Freeway fell short of that level of reporting. Only 11 of 55 on-freeway incidents were reported despite an average on-freeway duration of 7.5 minutes. As mentioned earlier, the incidents detected by CB had a duration of 15.3 minutes while those missed had a duration of 6.5 minutes.

The net effectiveness of the CB system would appear to be approximately 20% of that of the TV system. Various reasons can be given for drivers not participating in the detection program. These include ignorance of the program's existence, reluctance to participate, difficulty in making contact with the surveillance center, lack of interest or use of the CB unit for another purpose.

In summary, the television surveillance proved to be a more thorough detection system. Considering the high cost and the possibility of observer mistake because of the tedium involved in such a system as was operating in Detroit, a several times larger CB surveillance system offers a potentially comparable level of surveillance.

POLICE RESPONSE

Taking the sample of 293 CB calls logged for the entire Lodge Freeway during June 1969, the reasons given for calling were:

Accidents	47 calls	17%
Other on-freeway incidents	53 calls	18%
Other incidents	29 calls	10%
Information requested or volunteered	164 calls	55%

Discounting multiple calls for some incidents, a total of 111 reports were made, 110 to the appropriate police agency and one to the Detroit Fire Department. Based on television logs for those CB incidents taking place during television surveillance, police response time was 3.7 minutes, as compared to 7.6 minutes when the television observer made the notification.

Of the 526 incidents observed by the TV system, the police were notified 20 times. Three calls were later cancelled and in five cases a police vehicle did not stop at the scene. In these cases, a police unit probably passed the scene of the incident and judged that no aid was required.

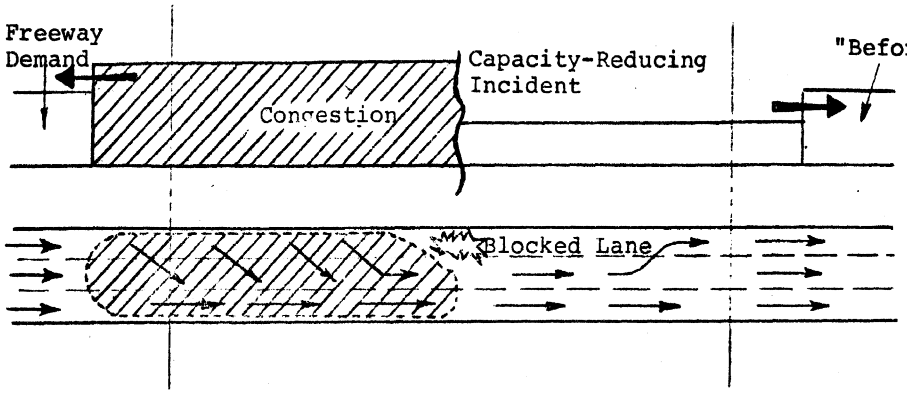
CHAPTER THREE

<u>INTERPRETATION, APPRAISAL, APPLICATION</u>

DETECTION OF CAPACITY-REDUCING INCIDENTS BY TRAFFIC STREAM MEASUREMENTS

This research effort has been limited to the use of macroscopic freeway traffic characteristics for the detection of on-freeway capacity-reducing incidents. These characteristics consist of one minute individual lane volumes at each freeway detector station and one minute average lane percent occupancies. One of the detection models, the Station Discontinuity Model, considered individual lane characteristics in the form of kinetic energies, while the other six models employed total station volumes and average station occupancies. The models all used either the basic volume or occupancy time streams or simple functions of these variables to form speed or kinetic energy as traffic variables which would change in a significant and predictable manner to indicate the presence of an incident.

Apart from the determination of the effectiveness of these various models in detecting incidents, this study has indirectly resulted in more knowledge about the manner of traffic response to a capacity-reducing incident. These findings are summarized in Figure 29.



Model	Means of Detection	Type	Specific to Incidents	Performance	False Alarm Rate
Composite	Lane Blockage and/ or Flow Discontinuity	Sub-System	Yes	96% Successful	Two Percent of Observations
Station Discontinuity	Stopped Vehicles or No Traffic In Blocked Lanes	Station	Yes	90% Successful	One Percent of Observations
California	Congestion Upstream, Reduced Flow Downstream	Sub-System	Yes	80% (Optimal)	Very Low, ≅0.1%
Subsystem Discontinuity	Shift In Traffic Flow Characteristics Between Stations	Sub-System	No (Bottlenecks, also)	74%	One Percent of Observations
Station Energy	Congestion Upstream of Incident	Station	No	56%	Same
Subsystem Energy	Congestion Upstream, Reduced Flow Downstream	Sub-System	No (Bottlenecks, also)	58%	Same
Subsystem Shock Wave	Upstream Congestion Shock Wave or Wave of Reduced Operations Downstream	Sub-System	No	32%	Same

FIGURE 29

REVIEW OF INDIVIDUAL DETECTION MODEL PERFORMANCE

The concepts of Lighthill and Whitham have been used to create the hypothetical situation (depicted at the top of Figure 29) of congestion upstream of an incident and reduced flow downstream (29). Relative to conditions before the incident, occupancy is higher upstream than before the incident and lower downstream. The changes generated by an incident are not recorded by on-freeway detectors until state change shock waves pass the upstream and downstream detector stations. Thus, the minimum possible time lag for automatic incident detection is a function of the spacing of the detectors. However, spacing of detectors does not appear to be a factor in the ability of automatic detection models to detect incidents.

The Modified California Model depends on the above sequence of occupancy changes over space and time for incident detection. Consequently, the performance of this model is one indication of the validity of the general model. In each subsystem, incidents either were successfully detected by the Modified California Model or the model responded properly but with insufficient sensitivity approximately 80% of the time. Thus, in at least four out of five cases this congestion forms a recognizable pattern that is distinctive of capacity-reducing incidents and thus amenable to detection.

The relative performance of the seven candidate detection models evaluated in this study is reviewed in Figure 29 and the models ranked in order of effectiveness. The Exponential Smoothing Model is excluded from the chart because it was not evaluated as fully as the others. The results demonstrate the feasibility of incident detection by means of traffic stream measurements, for the better models detect a majority of the on-freeway incidents up to a 96% level of effectiveness.

The Composite Model, representing the combination of the Station and Subsystem Discontinuity Models, achieved the 96% level of detection. This, however, was accompanied by a two percent false alarm rate, the highest of any model. The Station Discontinuity Model detected 90% of the incidents with a one percent false alarm rate. The Modified California Model is ranked third despite its inconsistent subsystem performance as it appears that the model is capable of detecting some 80% of the incidents with a minimal false alarm rate.

The subsystem models in general, and particularly the Modified California Model, were less effective in the subsystem containing a geometric discontinuity in the form of a lane drop. The truly effective models include the Subsystem Discontinuity Model with a 74% level of effectiveness.

Although significantly less effective than the Station Discontinuity Model, this model is independent of it in performance and may be amenable to further modifications to improve performance. The remaining models performed reasonably well, but since they are distinctly inferior to the above models, they are dropped from further consideration. A set of four candidate detection models with performance levels ranging from 74% to 96% and false alarm rates of up to two percent remain for further analysis.

The inconsistent detection performance of the Modified California Model recorded in this research makes it impossible to compare it with the Composite Model in terms of the trade-off between proportion of incidents detected and the false alarm rate. It seems that the false alarm rate can be considerably reduced with the California Model at some cost in performance and perhaps a considerable cost if optimal performance cannot always be achieved, as was the case in this study. The relative cost of false alarms and incident detection failures and time lags could then serve as a means of selecting the preferred model.

Further inspection of Figure 29 reveals that a distinguishing characteristic of the better models is the ability to differentiate between congestion caused by capacity-reducing incidents and normal, recurring daily congestion.

It has already been demonstrated by the very low rate of false alarms and high level of detection that the California Model detects congestion that is specific to incident situations. To a somewhat lesser extent this is also true of the Station Discontinuity Model. Lane blockage is certainly characteristic of capacity-reducing incidents as depicted in Figure 29. The Station Discontinuity Model detects either the presence of stopped or slow-moving vehicles upstream of the blocked lane or disproportionately few vehicles in the blocked lane downstream. Thus, both the Composite Model and the Modified California Model are capable of distinguishing the characteristics of capacity-reducing incidents from other flow perturbations, the California Model more so, as inferred from the smaller false alarm rate.

The two models, although somewhat different in detection levels, are also comparable in the time to initial detection. The average time lag for the California Model is 0.96 minute with a standard deviation of 1.31 minutes, while the Composite Model has a time lag of 0.81 minute and a standard deviation of 2.10 minutes. Thus, detection is consistently prompt for both models, with virtually all detections taking place either the minute of first noticeable congestion (zero time lag) or one or two minutes after. This is a highly desirable attribute for models intended for incorporation in real-time surveillance control.

The Modified California Model has a termination logic based on downstream occupancy levels returning to the levels preceding the incident for the first time. This accurately signals the end of incident congestion for every successful detection. The Composite Model, with no formal provisions for termination logic, yielded a successful termination for 75% of the detected incidents based only on critical threshold values for detection being recrossed. However, a logic similar to that employed by the Modified California Model appears to be a useful addition to the Composite Model. Again, knowledge of the termination time is a desirable attribute for incorporation in real-time surveillance control.

Once a detection signal has been received, the magnitude of the capacity reduction must be estimated from the volume and occupancy inputs received by the central computer. This is not as straightforward as it might seem owing to the variability of these traffic characteristics over time, particularly in the period immediately following the incident. A better estimate of the impact, however, may be provided by the application of smoothing techniques such as moving averages once a detection has been signaled.

The averaging of traffic variables may also be of benefit in the detection logic as a substitute for depending strictly on data for one or two previous minutes. Thus, a moving average of prevailing occupancy before an incident may serve to be a more satisfactory input to the termination logic than an occupancy value for a single minute. The use of smoothing techniques to yield an estimate of the real-time variance of a traffic variable may serve as the basis for the development of more flexible detection threshold parameters, particularly for the Composite Model. As discussed in Chapter Two, this may provide a means for reducing the false alarm rate for this model. Other modifications can doubtless be applied to either model, and online evaluation should serve to delineate the more desirable changes.

Both the Composite and Modified California Models are considered suitable for real-time incident detection on freeways where surveillance projects similar to that on the John C. Lodge Freeway are in operation. The essential equipment which must be present for the use of these models consists of traffic detectors capable of recording both volume and occupancy for each lane of traffic at a station and a digital computer capable of processing and interpreting the information obtained by the detectors.

The Modified California Model locates an incident within a specific subsystem. The Composite Model, in most cases, locates the incident to the nearest station upstream. However, in a few cases, this latter model locates the incident very close to the nearest downstream station.

The performance levels of these models are applicable to the evening peak period, the only portion of the day studied. In general, the models can be expected to perform well only in those situations where freeway capacity at the incident location is reduced to less than the prevailing traffic demand. In this study, volumes preceding the incidents ranged from 3600 to 6000 vehicles per hour, and densities ranged from 80 to 250 vehicles per mile. Pogust considered that detection by means of traffic stream measurements would be ineffective for densities of less than 60 vehicles per mile (37). Such a low density was not observed in this study, but it is noted that model performance was unimpaired as densities approached this level. It, therefore, cannot be concluded that these models will be constrained by the limit set by Pogust. The Station Discontinuity Model in most cases requires that congestion in the blocked lane extend at least to the nearest upstream detector station. This does not necessarily imply that demand exceeds capacity, but only that sufficient numbers of vehicles experience enough difficulty in leaving the blocked lane that a single lane of congestion is created.

INCORPORATION OF INCIDENT DETECTION LOGIC INTO FREEWAY SURVEILLANCE AND CONTROL

The objective of freeway surveillance and control is the maintenance of a desired level of service at all points along a freeway. Measures for the detection of capacity-reducing incidents can either serve as a useful adjunct to surveillance control or be the central objective of the surveillance effort as is the case with the Los Angeles Freeway Surveillance System (42). In either case, the relatively frequent occurrence of incidents, and the often severe impact they have on freeway operations, indicate that provisions for detection are necessary to maintain surveillance flexibility.

The role of incident detection in freeway surveillance control is indicated in Figure 30. Surveillance commences with the gathering of real-time traffic demand data at points or stations along the freeway. For the John C. Lodge Freeway in Detroit, these data are in the form of one minute station volumes and average occupancies by station. Another important input is weather conditions, particularly the presence of precipitation. Capacity reductions of up to eight percent have been observed during rainy conditions on the Lodge Freeway (27). The presence of rain also requires the modification of the detection parameters used by the detection models evaluated in this report.

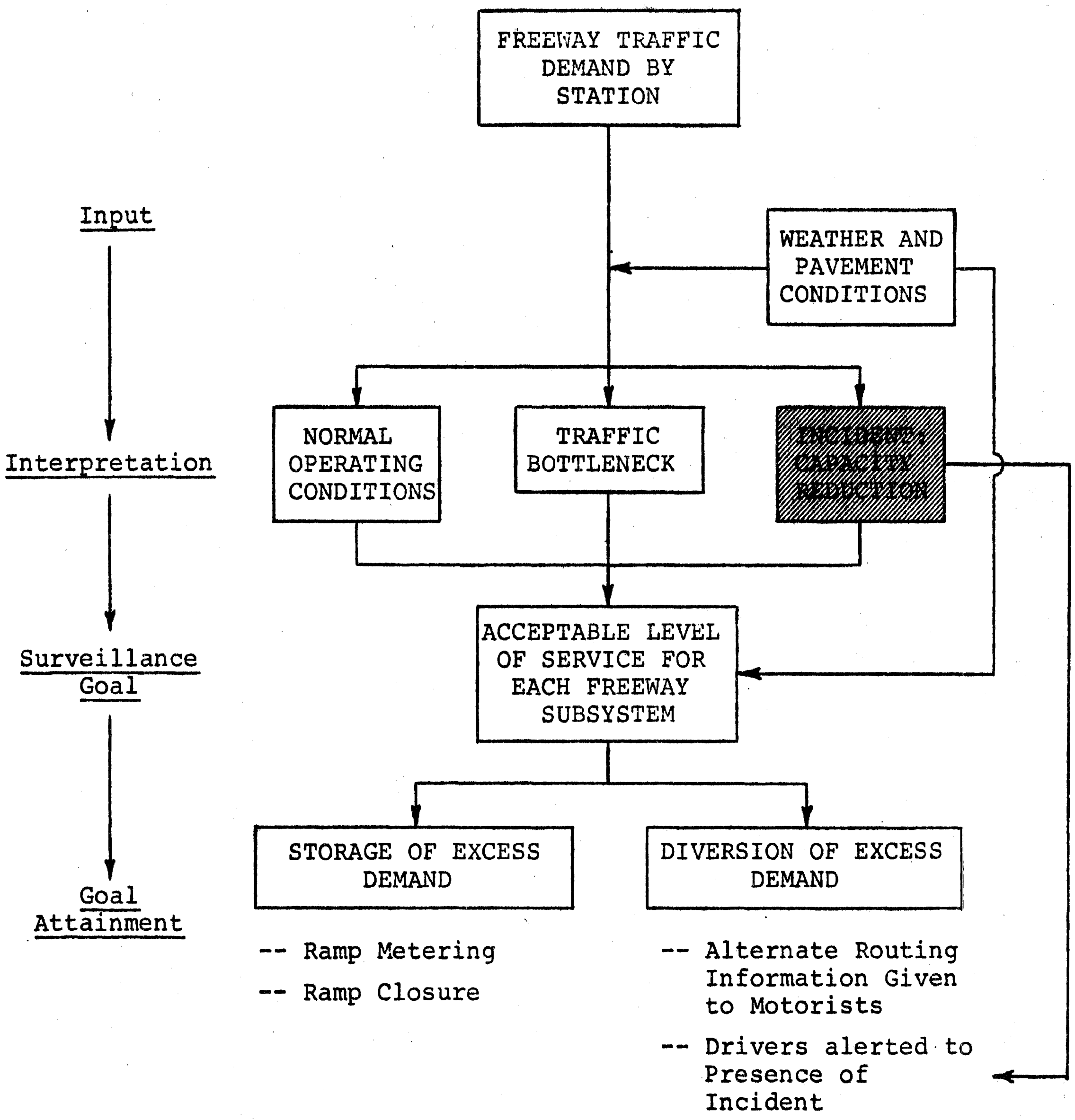


FIGURE 30

ROLE OF INCIDENT DETECTION IN FREEWAY SURVEILLANCE AND CONTROL

The next stage in surveillance is the interpretation of the demand data. The purpose of the surveillance effort is to prevent the development of bottleneck situations, but in the event they do take place, an effective control strategy will lessen their effects by reducing demand upstream of the bottleneck. Similarly, the detection of capacity-reducing incidents necessitates the reduction of upstream demand to retard the growth of congestion and delay to freeway users.

It is here that the advantages of incident detection by means of traffic stream measurements becomes apparent. Stream flow data provide the inputs required for application of the appropriate control measures, in particular, the severity of the capacity reduction, in a format that is directly useful to the surveillance computer. Furthermore, control measures can be undertaken immediately and automatically without the inevitable time lag implicit in any detection scheme involving human intervention. Also, since detection is based on traffic stream measurements, the detection logic serves as a decision-maker for the surveillance controller by detecting only those incidents that significantly affect traffic operations.

When freeway demand exceeds capacity at some point the surveillance system responds either by storing the excess demand or diverting excess demand away from the freeway. Demand storage is accomplished by means of entrance ramp metering of vehicles seeking to enter the freeway in the affected sections. Both the spacing out of entering vehicles over time and the provision of acceptable gaps in the shoulder lane traffic stream for merging have beneficial effects on freeway operations. Those vehicles queued at the ramps because the ramp demand exceeds the metering rate represent stored demand which is allowed onto the freeway after some delay. This can be an effective way to reduce demand upstream of freeway congestion if sufficient entrance ramps are metered and metering rates can be set low enough. On the Lodge Freeway, a considerable proportion of the on-freeway demand entered upstream of the surveillance section and could not be affected by such efforts.

The other means for reducing freeway demand is by diversion of freeway traffic around or away from the congested section. Ramp metering accomplishes this to a certain extent by diverting potential freeway users, particularly those with short freeway trips who choose to avoid the delays at metered ramps. To further encourage diversion and promote the increased use of uncongested freeway sections, both the Texas Transportation Institute in 1968 and The University of Michigan in 1969 installed dynamic ramp condition information signs along a convenient surface street alternate route to the Lodge Freeway (10, 40). Drivers approaching the vicinity of each metered entrance ramp were informed of the existence of uncongested downstream entrance ramps should the adjacent ramp be congested or advised to continue along the alternate route should all the ramps displayed on a particular sign be congested. The sign messages were keyed to ramp congestion, but congestion was directly related to congestion on the freeway. Thus the sign network served as a means for distributing some demand past the congestion via the surface streets. A survey of public attitudes toward the signs installed by The University of Michigan showed that 41% claimed to use the signs and 27% would avoid the freeway altogether if a sign indicated all entrance ramps congested (40).

It is felt that this sort of alternate route network can be integrated effectively into the control response to a capacity-reducing incident. The presence of an 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 incidents at varying times of the peak period are presented in Figure 31. 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 31, 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.

The high level of service available for freeway users beyond the incident can be utilized by generating demand for the available capacity downstream. In the control system this is accomplished by assuming that demand is large and by adjusting the metering rates at entrance ramps. Without provisions for incident detection, some demand redistribution will take place if the metering rate is responsive to freeway conditions. Fewer vehicles upstream of the incident will be allowed to enter because of congestion and more vehicles downstream because of the reduced flows.

The desired demand redistribution can be achieved by informing potential ramp users of congestion specifically caused by an incident by ramp condition information signs

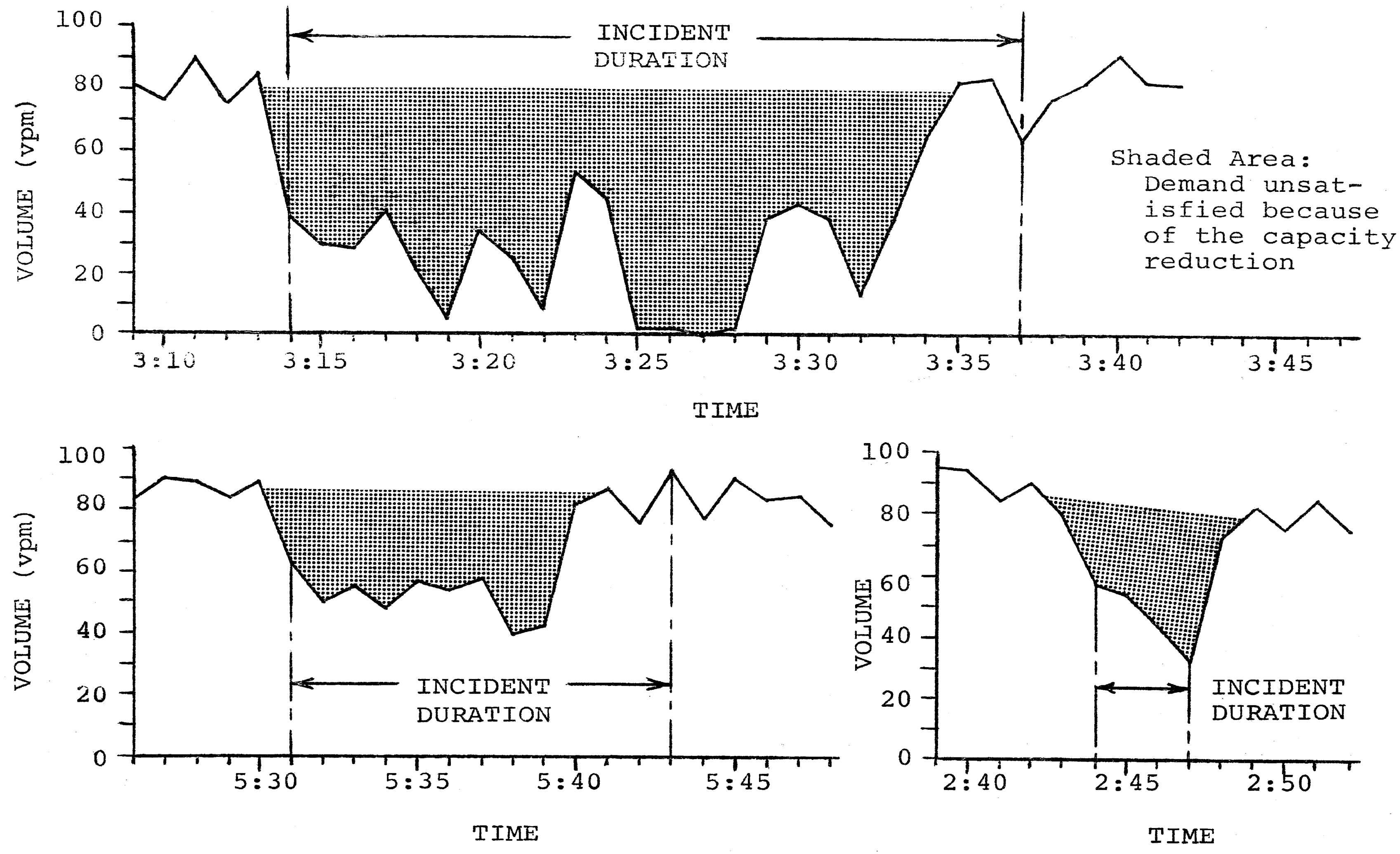


FIGURE 31

EFFECT OF INCIDENTS ON TOTAL TRAFFIC FLOW or variable message signs. 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. Again, an advantage of detection schemes based on traffic stream inputs over the other methods shown in Table 1 is evident. As can be seen from the variable flow downstream of incidents depicted in Figure 31, the reduced flow level can still only be approximated. Even this, however, is more information than can be supplied by other detection methods. In an operational control scheme, initial estimates of the reduction would be updated with moving averages should the incident prove of long duration. Surveillance response would thus consist of drastic adjustment in the metering rates upon receipt of a detection signal, the routing of ramp demand past the incident by means of dynamic routing signs on the surface streets, and perhaps, after a confirmatory time lag, direct notification to drivers of the presence of an incident. The latter may be necessary to avoid loss of faith in the system should it "cry wolf" too often.

That this diversion of demand moves toward the optimization of freeway corridor operations is seen when it is considered that during much of the peak period the freeway is operating at near capacity levels. After an incident is removed from the freeway, the congestion generated by the incident is slow to dissipate if the demand level remains nearly the same as the capacity. The general net result is an extension of the period of peak congestion until demand levels fall below capacity at the downstream end of the congested section. It was for this reason that Desai found incidents occurring earlier in the peak period to be far more disruptive of flow because of the longer period of disruption terminated only when peak period demand slackened (15).

Surveillance control in response to an incident, then, can reduce the demand contributed by entrance ramp traffic upstream of the incident. These vehicles, which would have experienced considerable entrance ramp and on-freeway delay, are diverted instead along surface streets to an entry point on the freeway with a high level of service. If this diversion is significant in numbers, the net effect for the freeway is to reduce the severity of impact of the incident and the duration of the peak period of congestion.

Since on-line experimentation with the detection methods evaluated in this report were not conducted, plans for measuring actual surveillance response to incidents were never implemented. However, all of the necessary equipment except for dynamic signs specifically informing drivers of incident situations existed in 1969 in the Lodge Freeway Corridor. This included a network of eight metered entrance ramps responsive to freeway traffic conditions, corresponding ramp condition information signs to direct ramp users to uncongested ramps, and dynamic trailblazer signs along adjacent arterials which were directly linked with the information signs (40). Lane control signals were in place at frequent intervals along the freeway, although in 1969 their use was restricted to occasional lane closure situations for maintenance work.

This surveillance system did respond to incident situations although there was no specific incident detection capability incorporated into the control logic (40). The incident of longest duration in Figure 31, an accident in

Subsystem One, had a considerable impact on freeway operations which was reflected in the ramp volume changes indicated in Table 13. As a basis for comparison, the average volumes for the same 20-minute period, 3:15 to 3:35 p.m., on three other days of the same week were recorded. Although the total entering demand was slightly greater at the four ramps the day of the accident, considerable diversion from upstream ramps (West Grand Boulevard and Seward) is still noted.

Three factors are assumed to account for this diversion. The first of these factors is the ramp metering strategy used on the Lodge Freeway which was based on keeping the amount of vehicular storage in each subsystem within allowable limits for the desired level of service. The net effect of the accident in Subsystem One was to decrease the metering rates at West Grand Boulevard and Seward Avenue, and increase those downstream at Chicago Boulevard and Webb Avenue. During this time of day the Seward ramp generally had maximum metering rates. On the day of the accident, however, the minimum metering rate of three vehicles per minute was established within 15 minutes after the incident began. This in itself produced a considerable decrease in the volume entering at Seward Avenue. West Grand Boulevard entering volumes were also decreased but to a lesser extent because of the bulk metering strategy employed at this ramp.

TABLE 13

ENTRANCE RAMP DIVERSION IN RESPONSE TO
AN INCIDENT IN SUBSYSTEM ONE

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 SEWARD STATION (SUBSYSTEM ONE)	362	318	- 44
SEWARD AVENUE CHICAGO STATION (SUBSYSTEM TWO)	161	75	-130
CHICAGO BOULEVARD CALVERT STATION (SUBSYSTEM THREE)	134	224	- 40
WEBB AVENUE GLENDALE STATION	110	174	+ 24
TOTAL	767	791	

A second factor contributing to the diversion is the ramp condition information signs which, once ramp congestion was detected at the upstream ramps, directed drivers to the downstream ramps of Chicago and Webb. Reinforcing the signs for those motorists driving along the frontage road between West Grand Boulevard and Seward was the third contributing factor, visual confirmation of congested freeway conditions.

The net result of those three factors, indicated in Table 13, was the diversion of over 100 vehicles, some 20% of the demand at the West Grand Boulevard and Seward ramps, around the incident to the Chicago and Webb ramps. Doubtless this diversion was beneficial to on-freeway operations, although insufficient to handle a traffic disruption of the magnitude created by the accident. Even if an incident response logic had been operational, it is clear that there could not be an adequate reduction in the on-freeway demand entering Subsystem One because of a lack of enough metered ramps further upstream.

Several observations, however, still can be made on the feasibility of dynamic response to an incident situation. First, it is evident that considerably more vehicles could have been diverted away from Subsystem One with more stringent ramp metering. The researchers were constrained from using metering rates less than three vehicles per minute when, in this instance, complete ramp closure would have been more appropriate. This latter action should be justifiable in incident situations, especially if there is a clearly marked alternate route existing as in the Lodge Corridor. Driver cooperation could be achieved through variable message signs stating the reason for the ramp closures.

Second, the control system was found to be slow in responding to the incident. This reaction was anticipatable as the system responds indirectly to an incident as the result of excess vehicular storage on the freeway (upstream of an incident only) and ramp congestion. For the above accident, a virtual detection was signaled by the Modified California Model at 3:15 p.m. and by the Composite Model at 3:16 p.m. However, minimum metering rates at Seward were not introduced for another ten minutes. One advantage of incident detection control logic would be to override surveillance control parameters to more effectively contribute to the alleviation of the situation. Many of the incidents in this study would have been over before the existing surveillance system effectively responded, and it already has been demonstrated that prompt upstream diversion is necessary in order to utilize the excess capacity downstream and allow vehicles to avoid passing through the congestion.

One missing element in the Lodge surveillance system which is necessary for efficient handling of diverted vehicles along alternate routes is a provision for handling the surges in traffic demand brought about by vehicles diverted past entrance ramps. For the example incident discussed above, it is doubtful that the alternate street network would have sufficient capacity to handle the number of diverted vehicles required to provide a satisfactory level of service on the Freeway. For those incidents of shorter duration, where fewer vehicles are involved for a shorter period of time, their dispersal through the network should be feasible if key traffic signals are responsive in real-time to demand fluctuations.

To summarize the incorporation of provisions for surveillance control and response to capacity-reducing incidents, it appears that tangible benefits in reduced delay and alleviation of congestion are feasible with surveillance equipment presently in existence or envisioned by urban freeway operation planners. This study has demonstrated that detection programs based on traffic stream measurements can be devised which will supply the necessary inputs to surveillance control. This includes a high probability of detection of those incidents having a significant impact on freeway operations within the first minutes following the indication of congestion. The severity of incidents in terms of capacity reduction is obtained directly with these techniques, and the termination of the incident as a capacity reduction can be consistently determined. It is therefore possible to provide a flexible and productive surveillance response to virtually all the capacity-reducing incidents that occur during the critical peak periods on urban freeways and thus render these vital elements of the urban transportation network less vulnerable to those unpredictable events.

CHAPTER FOUR

CONCLUSIONS AND SUGGESTED RESEARCH

CONCLUSIONS

Incident detection by means of traffic stream characteristics has been found to be a potentially useful addition to freeway surveillance and control. The models investigated in this research were capable of detecting up to 96% of a set of typical on-freeway incidents within a few minutes of the onset of congestion. The technique also provides the inputs required for application of appropriate control measures during periods of capacity reductions which generate unpredictable congestion. An incident detection model thus assists the surveillance controller by highlighting those incidents that significantly affect traffic operations.

Automatic incident detection is not a replacement for regular freeway patrolling. The great majority of freeway incidents requiring mechanical or police assistance do not generate traffic congestion and will not be detected.

A desirable automatic incident detection model should promptly detect the beginning and termination of the incident in terms of capacity reduction and the magnitude of the reduction, thereby providing useful information to a surveillance control system and to patrol vehicles designated to investigate the incident. The model should not fail to detect incidents with significant impact on traffic operations, for such failure would result in inadequate response to the incident-generated congestion by the control system. Similarly, false alarms should be minimized to avoid relative improper control responses and needless dispatches of investigative vehicles.

The effectiveness of eight different models in incident detection was evaluated. The conclusions reached apply to the detection of peak period on-freeway incidents, in most cases accidents or breakdowns, which block one or more through lanes for a length of time.

The 50 incidents used for the study had an average on-freeway duration of 5.9 minutes based on television surveillance records. Each generated an estimated average of ten minutes of congestion. The average volumes observed before the incidents ranged from medium flows of 3600 vehicles per hour to heavy movements of 6000 vehicles per hour in the three lanes. Occupancies ranged from 9% to 30%, equivalent to vehicular densities of 80 to 250 vehicles per mile in the three lanes. Traffic conditions ranged from free flowing to congested. The 50 incidents were randomly distributed during the evening peak period. Downstream volume during the incidents was reduced an average of 21%, from 81.4 vehicles per minute prevailing before the incidents to an average of 64.8 vehicles per minute during the freeway blockage. There was considerable variability in the effects of incidents on flow despite all but one of them being single lane blockages.

Much can be inferred about traffic operations during an incident from the behavior of the models under study for the 50-incident sample. All of the incidents, including the one incident not detected by any model, generated some congestion or noticeable disturbance in traffic operations. Two distinguishing characteristics, the capacity reduction reflected in an abnormal difference between occupancy upstream and downstream of an incident, and the presence of a blocked lane, have been applied successfully by the better detection models. Eighty percent of the incidents generated occupancy changes in a manner and sequence consistent with the theoretical work of Lighthill and Whitham. This sequence of increased upstream and decreased downstream occupancy is the basis for the Modified California Model, although this model was not sensitive enough to detect some incidents that possessed this characteristic. The success of the Station Discontinuity Model indicates that the detection of a blocked lane of traffic is feasible in spite of the relatively long distances between detector stations.

The detection models appear to work in adverse weather conditions as those incidents taking place in rain or snow were all detected. Likewise, while detection station spacing varied from 0.3 mile to 0.9 mile, subsystem length in general was not a factor in the ability to detect incidents. Most of the incidents took place in the median lane, but the particular lane of the incident also does not appear to be a factor in the ability to detect incidents.

Five of the detection models studied were developed by the Texas Transportation Institute in 1968. It was the purpose of this study to subject them to a more extensive evaluation. Each model consisted of the minute-by-minute computation of a traffic stream variable, the value of which would signal a capacity-reducing incident when it exceeded a pre-determined threshold. Threshold values were determined from frequency distributions of the respective variables compiled both for eight incident-free clear weather days and four incident-free rainy days.

The best model of the Texas Transportation Institute (TTI) was the Station Discontinuity Model. Abnormally low values of kinetic energy in one lane relative to the other lanes consitute the means for detection. This situation would indicate the presence of stopped or slow-moving vehicles in the blocked lane, or conversely, very few vehicles downstream of an incident. The Station Discontinuity Model detected 90% of the incidents, a statistically significant performance far better than the next best TTI model. The average time to detection was 2.1 minutes from the onset of the first noticeable congestion. The model detects capacity-reducing incidents downstream of a freeway detector station, or those that occur at an upstream location very near the station.

Since the threshold values for the Texas Transportation Institute models are set at the one percent level, the level of false alarms will also be one percent. The threshold levels could not be made more stringent without reducing model effectiveness. It was found that in most cases the threshold values could be estimated as one standard deviation away from the mean variable value. Thus, a more effective method for determining the threshold may be the use of real-time estimates of the standard deviation of the parameter values. The false alarm rate possibly could be reduced and the thresholds would be responsive to such factors as time of day, day of week and environmental conditions.

This approach might also do away with the need for separate frequency distribution curves for each freeway station and for different periods of the day or weather conditions. The distributions and the attendant thresholds were different for different stations, indicating that geometric factors do affect these traffic characteristics. Separate distribution curves were compiled for dry conditions and for rainy weather. The consistent differences found in these curves indicate the necessity to take weather into consideration.

In comparison to using real-time adaptive techniques such as smoothing of the data inputs, the use of historical traffic characteristics is computationally easier for the digital computer once the considerable initial compilation is accomplished. The disadvantage of historical records is that they may go out of date over long periods of time or be insufficiently flexible to changing traffic or environmental conditions.

A Composite Model was developed by combining the two best Texas Transportation Institute Models, Station and Subsystem Discontinuity. This model proved to be the most effective in detecting incidents. Of the 50 sample incidents, 96% were detected with an average time lag from the onset of congestion of 0.8 minute, indicating that the great majority of detections take place within the first or second minute after the onset of congestion. The discontinuities detected by this model are flow discontinuities in the form of abnormal differences in position along the speed-occupancy relation between detector stations, and discontinuity in the form of a blocked freeway lane. The two models were found to be independent of each other in performance. Consequently, the number of false alarms is nearly two percent of the incidents recorded by these models.

The seventh incident detection model studied, the Modified California Model, detects an abnormally large difference between the upstream and downstream occupancies at adjacent detection stations accompanied by a decrease in the downstream occupancy in the preceding minute. Overall, this model detected 52% of the incidents with an average time lag of 0.9 minute from the onset of first congestion. In two of the subsystems studied in the research, the model was successful in detecting over 80% of the incidents. It was, however, very insensitive in the third and longest subsystem where a geometric discontinuity in the form of a lane drop is present. It would appear that the Modified California Model is capable of an 80% detection rate, but the inconsistency of the model is disturbing.

The Modified California and Composite Models proved to be the superior models in terms of percent of incidents detected and time lag to detection. The Modified California Model is distinctly better in rate of false alarms, estimated to be 0.1% of observations. Depending on the cost of false alarms this can be one criterion for the selection of either model. The Composite Model has a two percent false alarm rate, which perhaps can be improved upon by the methods described above, but which still results in the high 96% level of detection. An evident trade-off in performance versus false indication is present with these two models.

Another model attribute that is desirable for incorporation into surveillance response and control is a signal terminating the end of an incident. The Modified California Model incorporates termination logic which signals the time at which occupancy downstream of the incident again rises to the levels prevailing before the incident began. This logic was successful for all detected incidents. Since this or similar logic could also be incorporated into the Composite Model, it is concluded that both models are comparable in this regard.

The eighth detection model investigated consisted of the exponential smoothing of the time series of station volumes or occupancies in order to detect shock waves emanating from an incident. Half of a small sample of incidents were detected by this technique, but it was concluded that simple volume and occupancy time series do not respond sharply enough to incident shock waves. However, inspection of the various traffic variables used by the other models yielded a promising candidate variable for future application of the Exponential Smoothing Model.

The lane energy variable used by the Station Discontinuity Model was found to respond sharply to incidents, a necessary attribute for detection of deviations from a smoothed time series. This variable has the further desirable feature of not being vulnerable to trends, since the distribution of lane energies at a station, regardless of flow state, should always be relatively uniform unless a lane blockage is present. The appeal of exponential smoothing is that with a traffic variable known to respond to a capacity-reducing incident, a high level of detection performance may be achievable. Such a model would obviate the need for historic traffic characteristics as with the TTI Models and perhaps yield a low level of false alarms because of increased model sensitivity and flexibility to changing traffic conditions.

In conclusion, incident detection by means of traffic stream characteristics has been found to yield a high level of detection performance with time lags of less than two minutes from time of onset of congestion. As a service to motorists in need of aid, the primary benefit of these models will be a reduced time lag in the arrival of police units to the scene of peak period on-freeway blockages. The models were found incapable of distinguishing between accidents and other on-freeway incidents, but since the magnitude of the disturbance is known, this factor can serve as the means for determining the priorities in the dispatch of aid units should surveillance extend over considerable freeway sections and separate detections compete for attention.

Regarding the other detection systems evaluated in this research, conclusions were reached regarding the effectiveness of the television system. There has been considerable past evaluation of television surveillance, and the contribution of this study has been of the accuracy of television observers in promptly observing on-freeway incidents. It would generally be expected that these incidents would be detected one to three minutes sooner via television than based on the onset of congestion detected by means of traffic stream measurements. However, 50% of the incidents in this study were detected at least as soon by the traffic stream models. In any event, automatic incident detection, if not the sole means of detection, appears to have the capability of supplementing the television system by directing the attention of observers to critical freeway situations. A modest success on the part of a Citizen Band radio system was also observed.

SUGGESTED RESEARCH

It was the intention of this research effort to give definitive answers regarding the feasibility of detecting on-freeway incidents by means of traffic stream variables for at least the models covered in this study. All of the necessary information for this research was already on file at the John C. Lodge Freeway Control Center. Otherwise, the obtaining of on-freeway incident data and traffic volumes and occupancies for each incident would have been an enormous undertaking. The 50 incidents studied in this research represented the culling of 12 months of comprehensive television surveillance logs and the corresponding historical records of traffic data compiled by the digital computer from 13 on-freeway sonic detectors. That such information was readily available for this research is to the credit of the many individuals who have been associated with the John C. Lodge Freeway Surveillance Project.

It is anticipated that future research will be on-line detection studies and more basic investigations of traffic behavior during an incident rather than simple extensions of the research presented in this report. Although much has been inferred in this study about the behavior of traffic during a capacity-reducing incident, the study was limited by the use of one-minute compilations of traffic data. This research effort has not exhausted the possibilities for handling one-minute data streams in the search for parameters that most distinctly register an incident. Whether or not this constitutes the most effective means for handling data for incident detection can only be answered by analysis of alternative schemes. There remain other data streams, including the microscopic level of single vehicle time-space trajectories first suggested by Barker (2). In any event, increased knowledge of traffic behavior during an incident should inevitably lead to more effective detection capabilities.

There is a need for more knowledge about the behavior of traffic in and around the site of a capacity reduction. This should include investigations of driver behavior and response while passing the incident site and investigations of the mechanisms of congestion build-up. The variability in traffic flow past the incident site observed in this study indicates a complex service mechanism that will be difficult to model mathematically and still be realistic.

Since most capacity-reducing incidents result in the closure of some, but not all freeway through lanes, the merging of traffic streams into a smaller number of lanes should be studied. Greater understanding of these mechanisms would facilitate the design of detection networks in terms of traffic variables used for detection and spacing of field detectors. A concomitant benefit would be better methods of handling traffic around freeway maintenance or construction sites involving lane closures.

Once a feasible detection program is incorporated into automatic freeway surveillance, it will be necessary to investigate the savings in travel time for freeway users. Comparisons should be made with the effects of control measures that treat the incident as ordinary freeway congestion. This requires knowledge of the effectiveness of surveillance control in handling congestion through adjustment of freeway inputs and routing traffic through alternate routes. The latter, of course, is a primary goal of the Lodge Project. From this information it will be possible to estimate the cost of false alarms (unnecessary restriction of inputs upstream by surveillance control) and missed incidents (failure by surveillance control to take into consideration a capacity reduction as the cause of congestion). This research would entail on-line computer evaluation of freeway system operations during incidents when a detection program and appropriate response programs are functioning.

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PART TWO

APPENDIX A

PROCEDURAL MANUAL FOR TELEVISION INCIDENT DETECTION AND RESPONSE

APPENDIX A

PROCEDURAL MANUAL FOR TELEVISION INCIDENT DETECTION AND RESPONSE

PURPOSE OF INCIDENT DETECTION RECORDS

The purpose of the television monitor system (see Figure A-1) is to aid in the detection of incidents that disrupt the flow of traffic on the John C. Lodge Freeway. Observations of the television monitor will reveal unusual incidents in the normal flow of traffic. One function of the trained observer is to record all such incidents. Since many of the incidents can be classified into several frequently-occurring categories, a scheme and a description of techniques for logging incidents are included in this manual.

The TV Surveillance Daily Log (Figure A-2) has been developed to provide a day-to-day record of vehicular breakdowns and unusual occurrences on the Freeway. However, the reduction of past logs has shown that many incidents which were once considered unusual, actually are not. For example, one can normally expect to have at least three shoulder usages per hour on the 3.2 mile section of the Lodge which is under observation. Because of their predictability and frequency, such incidents may be properly considered expected variations from normal freeway flow.

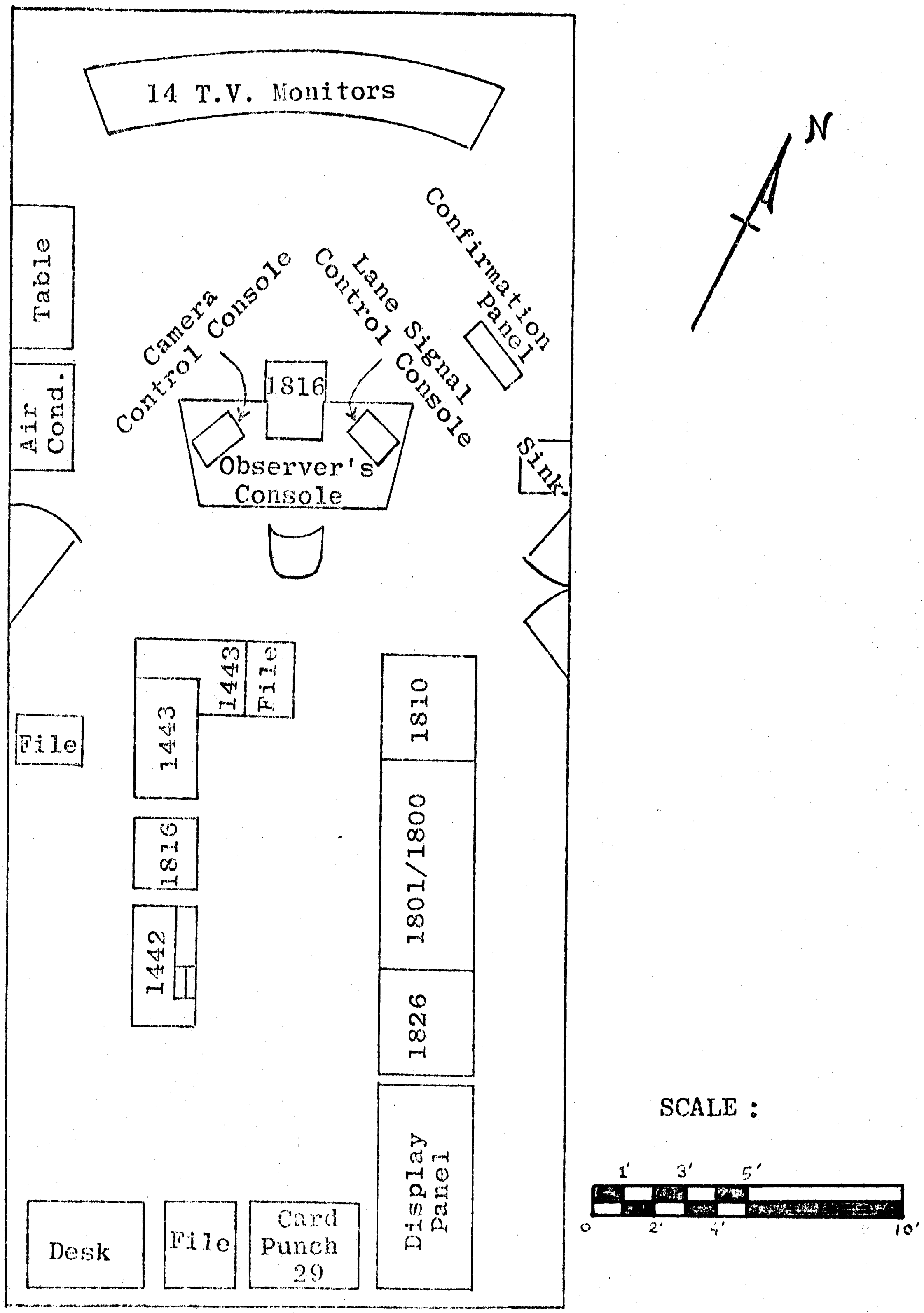

FIGURE A-1

CONTROL ROOM LAYOUT

STATE OF MICHIGAN
DEPARTMENT OF STATE HIGHWAYS
TRAFFIC AND SAFETY DIVISION

T. V. SURVEILLANCE DAILY LOG

PAGE 1 OF ____

Form 1578 B
(Rev. 11 67)

Tuesday

DATE October 7 19 69 OPERATOR ________ OBSERVER Pope / Shapiro

Incident Number	TIME			Cause	LOCATION		Vehicle Type	ASSISTANCE				Pav't Surf.	Weather	SIGNALS			REMARKS
	Start	End	To Shoulder		Camera	Lane		Time Notified	Time Arrived	Type	Action Taken			ON	OFF	D	
*	0600	—	—	B	1	—	—					WET	RN 55°				CAM #1 NOT WORKING
1	0650	1040	0654	A	4' FL	3	STD	—	0651	P	O						
1	0650	1030	0700	A	4' FL	3	STD				O						
1	0650	1600	0652	A	4' FL	3	STD				S						
1	0650	0920	0654	A	4' FL	3	STD				O						
1	0651	0710	0659	AID	4'	3	P										
1	0655	0711	0659	AID	4'	3	P										
1	0712	0731	—	AID	4'	S	PCT										
2	0720	1542	0722	A	2' T	3	STD	0721	0726	P.	S						
2	0720	1600	0722	A	2' T	3	STD				S						
2	0726	0735	—	AID	2' T	S	P										
2	0824	0857	—	AID	2' T	S	P										
3	0842	0920	—	B	9'	S	STD										
4	0848	1114	0848	A	3' T	3	STD				S						
4	0848	1157	0848	A	3' T	3	STD				S						
2	0851	0920	—	AID	2' T	S	W										
4	0924	1026	—	AID	3' T	S	STD										
4	1046	1100	—	AID	3' T	S	STD					WET	Cl./64				
4	1152	1157	—	AID	3' T	S	W					DRY	Cl./54				

FIGURE A-2
T.V. SURVEILLANCE DAILY LOG

This manual represents an attempt to standardize terms and procedures used in the log. It is mainly designed to give a new observer an idea of what to expect and to provide some tips, based on past experience, on the types of occurrences for which he should look. This manual, however, is not solely aimed at the novice and should be used as a guidebook by the veteran observer.

PROCEDURES AND TERMS FOR RECORDING INCIDENTS

Incident Number: This column is used to record and identify every incident observed during the day. Each incident, whether an accident or a common shoulder usage, is given a number. Any vehicles subsequently connected with a given incident should be logged under the original number. For example, if Incident No. 1 involves a car on the shoulder with motor trouble and a wrecker comes to aid the stranded motorist, the wrecker should be recorded under Incident No. 1 regardless of how many incidents have been logged since the original recording.

Incidents occurring in a lane rather than on the shoulder are to be logged in RED numerals. This aids immediate reference when the logs are being analyzed or consulted.

Finally, any incident which involves the same vehicle more than once, such as a car moving from one location to another, should be relogged under the original number. For example, a truck, logged as Incident No. 2, stops on the shoulder at Camera 9, then resumes its travel to Camera 7, where it again goes to the shoulder. The information at the new location should be logged separately from the previous notation for the truck, but the original incident number should still be used.

__Time:__ This is a triple column showing the time the incident started, the time it ended, and the time elapsed before the vehicle reached the shoulder. Military time is used instead of standard A.M. to P.M. time (Table A-1).

TABLE A-1

MILITARY TIME CONVERSION

A.M.			P.M.		
6 o'clock	=	0600	12 o'clock	=	1200
7 o'clock	=	0700	1 o'clock	=	1300
8 o'clock	=	0800	2 o'clock	=	1400
9 o'clock	=	0900	3 o'clock	=	1500
10 o'clock	=	1000	4 o'clock	=	1600
11 o'clock	=	1100	8 o'clock	=	2000

Minutes are denoted as 1105 (five past eleven); 1412 (twelve past two); 1806 (six past six), etc.

Start: This column denotes the time at which the incident is first spotted. If there is evidence that it began slightly earlier, the incident should be back-logged a minute or two. Such evidence could be a raised hood and the driver, tools in hand, trying to repair the malfunction or a car sitting on the shoulder with a message already written on the windshield.

End: This column shows the time at which the vehicle moves, or is removed, from the shoulder or lane (not to the shoulder) so that it no longer has any relevance to the log. (In some instances, back-logging may also be useful here.) This column should never be left blank unless the observer is the last one at night and the vehicle is still sitting on the shoulder when he leaves. The first observer each morning should make it a habit to check over the log to ascertain whether any of the incidents which he has found could have originated the night before. If there is evidence of such a relation, an extra notation should be put in the Remarks column (2nd DAY). The incident number from the night before is not used; a new incident number is given every day.

The observer should record the actual time of arrival and departure of any vehicles which become included after the incident began. (With the exception of multiple vehicle aids, in which only the most important is noted.) THEY ARE

NOT TO BE GIVEN THE ORIGINAL TIME THE INCIDENT STARTED, although they are given the incident number which corresponds to the original vehicle.

When a vehicle changes its location, the actual time of arrival and departure at the new location should be logged under the original incident number.

Time To Shoulder: This column refers to lane incidents in which some time usually elapses between the time the incident is logged (START) and the time at which the vehicle reaches the shoulder. For instance, if the incident involves a car stalled in Lane 3 of Camera 4, some time may pass before the stalled car is pushed or towed to the shoulder. This time elapse should be indicated by noting the time at which the car is safely on the shoulder. Any aiding vehicle should also be logged with START and TIME TO SHOULDER (if appropriate) under the corresponding incident number. If there is no appreciable time difference (the stalled vehicle moves or is moved immediately to the shoulder), TIME TO SHOULDER should be the same as START. DO NOT USE ABBREVIATIONS such as IMM for immediately.

Cause: In this column the reason for the incident is stated. For expediency and to save space, the cause is abbreviated. The list of abbreviations may be found on the upper left-hand slide leaf of the observer's console. The abbreviations are as follows:

A	-	Accident
ST	-	Stall
B	-	Mechanical Breakdown
M	-	Maintenance (Give details in REMARKS)
FL	-	Flat tire or blowout
AID	-	Aid
V	-	Violation
SO	-	Spin Out
V	-	Out of Gas
O	-	Other than above (Explain)
UNK	-	Unknown

Most of these abbreviations for cause are self-evident, but O and UNK may bear some explanation. O stands for other. If none of the listed codes are appropriate, O should be inserted in the Cause column and the cause given in the Remarks column. Such O incidents may involve a driver stopping to read a map or a truck driver adjusting his load. THERE MUST BE A NOTATION IN REMARKS AFTER AN O.

UNK stands for unknown. This code is used when the reason for the incident cannot be determined. This may be the result of darkness, or a car stopped in a blind area of the T.V. cameras. In such incidents, however, the police radio in the control room may supply the missing information. In that case, the cause should be noted, using the appropriate abbreviations, rather than leaving UNK in the Cause column.

Location: Two columns are needed to pinpoint the location of the incident. These are CAMERA and LANE.

Camera: The surveillance area covers 3.2 miles of the Lodge Freeway. This surveillance is made possible by fourteen cameras mounted on the overpasses; all cameras are aimed north. Camera 1, located at Glendale, is the northernmost camera and overlooks the Davison Interchange. Camera 14, the southernmost camera, is at the Ford Interchange. The direction of traffic flow in an incident should be denoted by a superscript, O for outbound (northbound), I for inbound (southbound). (A complete list of locations is given in Table A-2.) For example, if an incident is spotted in Camera 14 northbound, the location will be shown as 14^{O}. If an incident occurs in 7 inbound, the location is 7^{I}. The same form should be followed for all fourteen cameras.

Lane: This column denotes the lane in which the incident occurred. The lanes are counted from the median to the shoulder. The median lane is counted as Lane 1, and the shoulder lane as Lane 3 or 4, depending on how many lanes there are in the section.

TABLE A-2

CAMERA NUMBERS AND LOCATIONS

NUMBER	LOCATION*
1	Glendale
2	Monterey
3	Webb
4	Calvert
5	Chicago
6	Hamilton
7	Clairmount
8	Gladstone
9	Euclid
10	Seward
11	Pallister
12	West Grand Boulevard
13	Grand Trunk Western Railroad
14	Ford Interchange

*All cameras point north.

Other areas may be shown in the LANE column as follows:

Median	-	M
Shoulder	-	S
Ramp Shoulder	-	RS
Ramp	-	R

In some situations, the CAMERA column must be given special attention. For example, if a Wayne County maintenance crew comes into view at Camera 14^{O} to sweep the shoulder and leaves at Camera 7^{O}, this series of events should be recorded in the CAMERA column as $14^{O}/7^{O}$. The top number shows the first camera in which the crew was spotted and the bottom number shows the last. Another less common example is a vehicle which stalls in the top ranges of Camera 11^{O} in Lane 4 but, upon being pushed to the shoulder, is now in the bottom range of Camera 10^{O}. This situation would be shown as $11^{O}/10^{O}$. The change in lane status would be shown as 4/S.

<u>Type of Vehicle</u>: This column refers to the type of vehicle(s) involved in the incident. These vehicle types are to be abbreviated as follows:

STD - Standard. This refers to a standard production car, including compacts and foreign cars.

C - Combination. This refers to a tractor and trailer rig (semi).

SU - Single Unit. This refers to trucks which may be classed as stake trucks, dump trucks, etc. The main characteristic is in single-body construction.

VAN - This denotes commercial vans, moving vans, milk trucks, etc.

W - Wrecker. Wayne County wrecker is abbreviated W.C. in Remarks.

MC - Motorcycle.

P - Police Car. If other than Traffic Central, write PCT. (Precinct) in Remarks. Other possible police vehicles may be motorcycles (abbreviate PMC), Tactical Mobile Units (TMU), State Police (SP), etc.

A - Ambulance. This refers to commercial ambulances. A police ambulance (station wagon) is abbreviated PA.

F - Fire Truck

FL - Flasher Truck. Truck which usually follows any maintenance crews is equipped with flashing lights to warn approaching traffic of a maintenance operation. The type of maintenance operation and the truck's owners should be inserted in Remarks. The affiliation will usually be one of three types: W.C. (Wayne County); PLC (Public Lighting Commission); or BELL (Michigan Bell).

SW - Sweeper. This refers to a W.C. truck equipped with sweeping brushes and performing maintenance duties.

BUS - Bus.

PAN - Panel Truck.

PU - Pick-up Truck.

Assistance: This column has four sub-columns: time notified, time arrived, type and action taken.

1. Time Notified: If the control operator calls the police for assistance at an incident, the time of notification should be shown in this column. This time will usually be the same as that appearing in START. In some instances, however, there may be a discrepancy. For instance, if a car should stall in 8^{O}, Lane 4 at 1432, the operator might wait for a minute or two before deciding to notify the police.

2. Time Arrived: If the police are notified, the time of their arrival should be placed in this column. An elaborate study of police response time has already been made from this section of the log, so it is imperative that it be kept accurately. If the police are not notified but some other aid arrives, the time of its arrival is noted. In the case of several aiding vehicles, the most important one should be recorded.

3. Type: This column concerns the type of aiding vehicle that arrives. The six types of aid are listed below with their abbreviations:

S - Self

M - Passing Motorist

P - Police

W - Wrecker

A - Ambulance

F - Fire Department

4. Action Taken: This is the type of assistance given by the aiding vehicle. The types of action taken and their abbreviations are given below with explanations. If no entry is made, the action is interpreted as S.

S - Self to shoulder. The driver is able to move his vehicle to the shoulder and receives no other aid.

SF - Self to Freeway. The driver is able to resume his own way on the Freeway without aid.

O - Pushed or pulled to shoulder. The disabled vehicle is pushed or pulled to the shoulder by an assisting vehicle.

OF - Pushed or pulled to Freeway. The vehicle is pushed to a start, or even hooked up to a wrecker on the lanes of the Freeway.

OS - Self to shoulder with aid to stop traffic. The car is assisted to the shoulder by the police, who stop traffic to facilitate the movement.

In case of a complex incident, such as a four- or five-car incident, the action taken for each car should be inserted in the column, unless the action taken for each car is the same. In that case, one notation for the first car will suffice.

Pavement Surface: This column should give a running account of pavement conditions for the day. The conditions are listed on the manual data-entry panel on the desk in the control room. As a rule, if conditions remain the same, the entry should be made once an hour; if a change occurs (dry to wet), the time of the change should be inserted above the notation for the change $\frac{(1416)}{\text{wet}}$.

Weather: This column coincides with Pavement Surface. Usually a change in one means a change in the other. In most instances, the time of the two changes will be the same. The Weather column should be given the same hourly treatment indicated for Pavement Surface. An hourly temperature should be noted in above the weather condition. The temperature is obtained from the Weather Bureau by calling 278-6040.

Remarks: This is a generalized column in which anything that cannot be coded should be noted. Any information which you feel may be important to an incident should be recorded in this column. Some of the instances for use of this column have already been mentioned, but there are many more. Reference to the sample log (Figure A-2) will provide some insight as to the nature of possible notations.

ADDITIONAL DUTIES OF THE OBSERVER

During the hours an observer is on duty it is possible, and in fact at times necessary, for him to perform additional tasks. These tasks can be accomplished without detracting from the effectiveness of his primary function of detecting and recording incidents. Some of the additional duties performed remove the observer from a passive role and allow him to act in response to incidents he sees or conditions of the mechanical system by operating both cameras he utilizes and the full traffic surveillance and control system.

1. Any incident which would cause a permanent reduction in the flow of traffic on the Freeway is to be reported to the appropriate maintenance service for corrective action.

2. Any incident occurring north of the television surveillance system (north of Davison to Meyers) or south of the system (south of Edsel Ford Freeway to Grand River) is to be noted on the log, as if it were a visual incident, giving all information possible.

3. The procedure for starting and shutting down the computer is explained in a manual entitled "Computer Operating Procedures"* which is kept at the desk. There will be occasions when the observer will be required to perform these functions. He therefore should be familiar with the procedures.

4. Lane signals are used for incidents involving lane blockages and for maintenance operations when it is necessary to close a lane. The lane closure signs, positioned over each lane of the Freeway, have a two-message capability. A red "X" is displayed for each closed lane and a green arrow is displayed on the remaining open lanes. In 1969 these signs are to be used only during periods of lane blockages, and the rest of the time are to be turned off rather than display green arrows for all lanes.

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*See Cook, Allen R., Pretty, Robert L., and Cleveland, Donald E., Evaluation of the Effectiveness of Ramp Metering Operations. TrS-2, Highway Safety Research Institute, Ann Arbor.

When a single lane is blocked because of an incident or maintenance work, a minimum of one red "X" is employed. If a blockage is in an area 250 feet ahead of a red "X", the next effective red "X" must also be used. The maximum distance that the red "X" is to be used is 5000 feet behind the blockage and is illustrated on the monitors by orange lines with their respective zones. When a red "X" is displayed ahead of the blockage, the distance should not exceed 150 feet.

For multiple lane blockages, the treatment is initially the same for single lane blockages using the appropate red "X"'s. If the blockage is of the short duration type, continue to use the procedures for single lane blockages. However, if in your estimation the duration will exceed five or six minutes, then close all affected lanes through the <u>entire</u> field behind the blockage until the blockage has been cleared. Any requests for the lane signal system to be activated must be referred to the Principal Investigator.

5. The ramp metering system on the Lodge Freeway is in operation from 2:30 p.m. to 6:30 p.m. on week days. During this period the observer is required to perform special tasks of observation and logging.

Cameras 3, 5, and 10 are to be panned to the right to allow visual observation of the Webb, Chicago and Seward ramp signals.

The information on the metering system typewriter is to be logged according to "Procedure for Logging Typewriter Log Information" kept on the observer's desk. Special attention should be given to accurately recording this data as the information is vital to the efficient operation of the metering system.

Finally, any malfunction in the computer controlling the metering system is to be reported to one of the programming personnel. If none of these people are present, the malfunction should be handled according to the procedure in the "Computer Malfunction Check List"* also kept on the observer's desk.

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*See Cook, Allen R., Pretty, Robert L., and Cleveland, Donald E., Evaluation of the Effectiveness of Ramp Metering Operations. TrS-2, Highway Safety Research Institute, Ann Arbor.

APPENDIX B

INCIDENT-FREE DAYS USED FOR ANALYSIS

TABLE B-1

INCIDENT-FREE CLEAR WEATHER DAYS

DATE	DAY OF WEEK	MEAN TEMPERATURE	WEATHER
February 25	Tuesday	35°	Overcast
February 28	Friday	35°	Clear
April 24	Thursday	63°	Clear
June 5	Thursday	63°	Overcast
June 17	Tuesday	74°	Clear
August 1	Friday	80°	Clear
August 7	Thursday	85°	Clear
September 29	Monday	63°	Overcast

TABLE B-2

INCIDENT-FREE RAINY WEATHER DAYS

DATE	DAY OF WEEK	MEAN TEMPERATURE	WEATHER
March 25	Tuesday	37°	Rain
April 17	Thursday	64°	Mostly Rain
November 18	Tuesday	50°	Rain
November 19	Wednesday	33°	Rain/Snow

APPENDIX C

TEXAS TRANSPORTATION INSTITUTE INCIDENT DETECTION MODELS

APPENDIX C

TEXAS TRANSPORTATION INSTITUTE INCIDENT DETECTION MODELS

The formulas for the five Texas Transportation Institute (TTI) incident detection models are reviewed below. The following standard notations are applied throughout.

$q(j)$ = traffic flow or volume (vehicles per minute) recorded at the j^{th} detector station during the most recent minutes.

$\theta(j)$ = average percent occupancy at the j^{th} detector station during the most recent minute. Occupancy is the proportion of the time a vehicle is sensed by an overhead sonic detector on the freeway. It is generally linearly related to density (vehicles per unit distance) and is therefore used in this study as a surrogate for density.

i = upstream detector station

$i+1$ = downstream detector station.

<u>Freeway Station Models</u>

<u>Station Energy</u>: Kinetic energy, $E(i)$, is defined as the square of the volume divided by the occupancy. The nominal dimensions of kinetic energy

are vehicles^2 per minute^2 per percent occupancy (2). The kinetic energy values were normalized by dividing them by the theoretical maximum kinetic energy derived from the linear speed-density flow model (10). The values found by TTI in 1968 for maximum kinetic energy, $E_m(i)$, at each station were used in this report (10). These energy values are presented in Table C-1.

The equations for the Station Energy Model are:

$$E(i) = q(i)^2/\theta(i)$$ <u>Station Kinetic Energy</u>

$$E'(i) = E(i)/E_m(i)$$

$E'(i)$ = normalized kinetic energy

$E_m(i)$ = theoretical maximum kinetic energy

$$M_1(i) = E'(i)$$ <u>Station Energy Variable</u>

Cumulative distribution curves for the normalized kinetic energy values for clear and rainy days at the Seward and Calvert detector stations are presented in Figure C-1. It is evident from the large number of parameter values greater than one that the above normalization was only approximate. Similar results were obtained by TTI (10). Such

TABLE C-1

NORMALIZING VALUES FOR TTI DETECTION MODELS

VARIABLE	FREEWAY STATION (j)			
	SEWARD	CHICAGO	CALVERT	GLENDALE
FREE SPEED (Vehicles per minute per % occupancy) $u_f(j)$	9.5	6.4	10.0	10.4
JAM OCCUPANCY (Percent) $\theta_j(j)$	33	54	39	38
MAXIMUM KINETIC ENERGY (Vehicles^2 per minute^2 per % occupancy) $E_m(j)$	590	335	580	590

These values were developed by TTI in 1968 (10) by applying the Greenshields flow model to traffic observations recorded by the sonic detectors at the above stations.

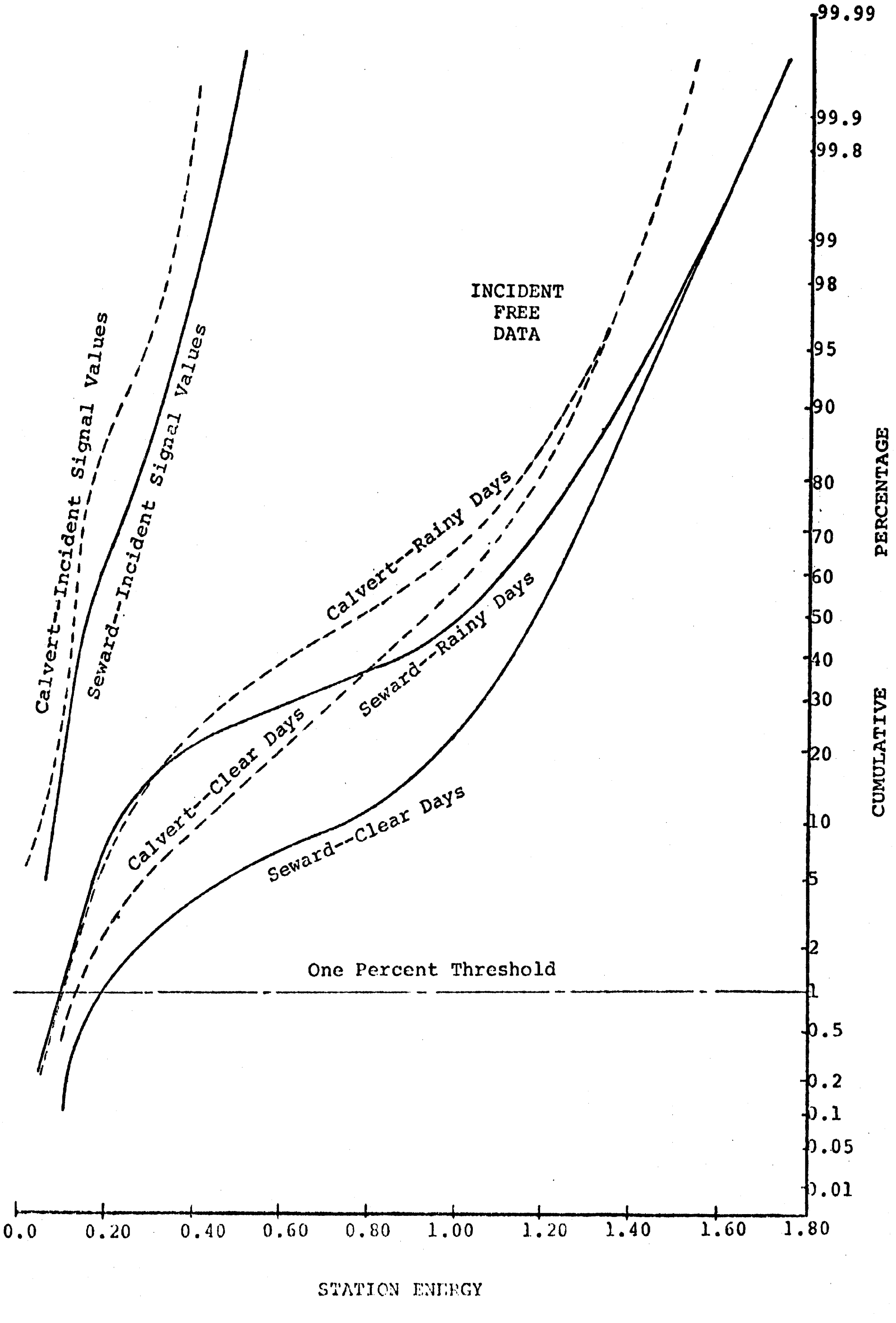


FIGURE C-1

STATION ENERGY VARIABLE FOR CLEAR AND RAINY CONDITIONS AT SEWARD AND CALVERT STATIONS results are inevitable when historical normalizing factors are used, especially when they are theoretical, rather than the largest values actually observed. The use of normalized energy values in this model is actually redundant, but was done for convenience as they were also used for the Subsystem Energy Model. In the latter case, normalization makes the energy values at different stations comparable.

<u>Station Discontinuity Model</u>: Kinetic energies are computed for each lane at the detector station. The smallest lane energy, $E_s(i)$, is found and the station discontinuity, $M_2(i)$, computed as follows:

$$M_2(i) = \frac{2\ E_s(i)}{E_a(i) + E_b(i)}$$ <u>Station Discontinuity Variable</u>

$E_a(i)$, $E_b(i)$ = The other two lane energy values

This variable can take values ranging from zero to one. Smaller values indicate an imbalance in the lane energies caused either by lane blockage or disproportionately fewer vehicles in one lane. The computation above accentuates this imbalance as compared to the more straight-forward ratio total of all three lanes. Cumulative distribution curves for the station discontinuity variable at the Seward and Calvert detection stations on dry and rainy days are presented in Figure C-2.

Freeway Subsystem Models

Subsystem Shock Wave Model: The subsystem shock wave variable, $M_3(i)$, is calculated as the difference between the downstream volume and the upstream volume. Thus, for subsystem i:

$$M_3(i) = q(i) - q(i+1)$$ Subsystem Shock Wave Variable

Subsystem Energy Model: Analogous to the Subsystem Shock Wave Model, this variable is the difference in normalized kinetic energy values between upstream and downstream detector stations. For subsystem i the equation is as follows:

$$M_4(i) = E'(i) - E'(i+1)$$ Subsystem Energy Variable

Subsystem Discontinuity Model: The variable in this model measures the discontinuity in flow within a subsystem as the difference in speed-density states at the upstream and downstream stations.

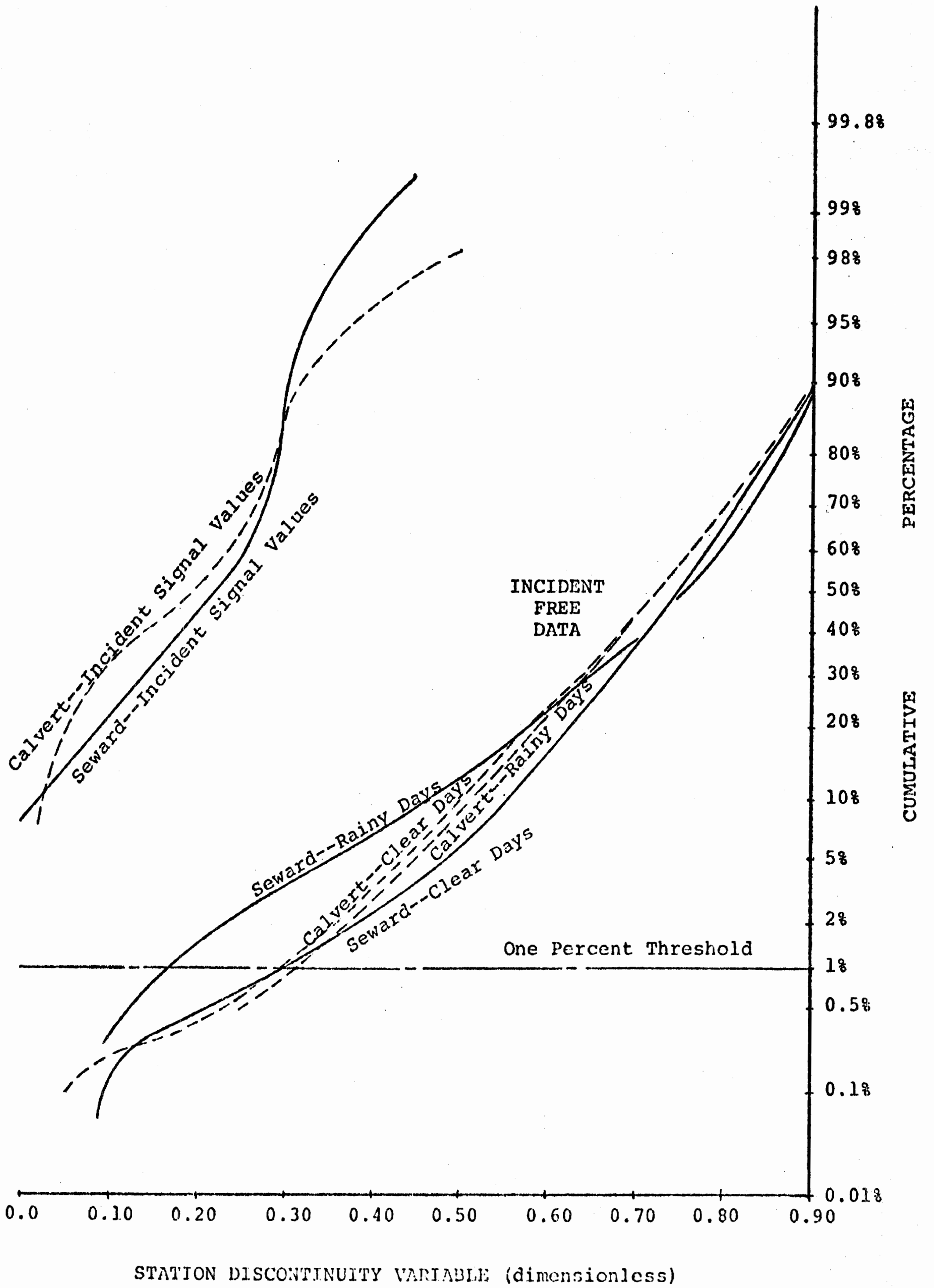


FIGURE C-2

STATION DISCONTINUITY VARIABLE FOR CLEAR AND RAINY CONDITIONS AT THE SEWARD AND CALVERT FREEWAY DETECTOR STATIONS

This is the distance $\overline{BA}$ in Figure 12. Occupancy is used as the estimate for density. The speed, u(i), is estimated from volume and occupancy as follows:

$$u(i) = q(i)/\theta(i)$$

Station Speed
(Vehicles per minute per percent occupancy)

The computed speed values are normalized by dividing by the theoretical free speed, $u_f(i)$, at the station (Table C-1). Similarly, the occupancy values are normalized by dividing by the theoretical jam occupancies, $\theta_j(i)$ (Table C-1). The values for free speed and jam occupancy developed by TTI in 1968 and presented in Table C-1 were used in this report (10). This normalization was not done by TTI for this model, but is necessary to make the data at each station comparable. The speed-occupancy relation is thus the same at each station as depicted in Figure 12.

The variable, $M_5(i)$, is estimated by subtracting the vector distance $\overline{AC}$ from the vector distance $\overline{BC}$.

$$M_5(i) = \sqrt{\left(\frac{u_f(i) - u(i)}{u_f(i)}\right)^2 + \left(\frac{\theta(i)}{\theta_j(i)}\right)^2} - \sqrt{\left(\frac{u_f(i+1) - u(i+1)}{u_f(i+1)}\right)^2 + \left(\frac{\theta(i+1)}{\theta_j(i+1)}\right)^2}$$

<u>Subsystem Discontinuity Variable</u>

$u_f(i)$ = theoretical free speed derived from linear speed-density theory.

$\theta_j(i)$ = jam occupancy derived from linear speed-density theory.

All of these models were investigated by TTI in 1968 (10). Comparisons of the thresholds for incident detection found in the 1969 studies for dry and rainy weather and in the 1968 studies are presented in Tables C-2, C-3, and C-4. Tables C-5, C-6, C-7, C-8, and C-9 contain additional results from the 1969 analysis. These include the mean, standard deviation, and range of the variables observed. The tables are discussed in Chapter Two of this report.

TABLE C-2

THRESHOLD VALUES FOR DETECTION (ONE PERCENT LEVEL) BY THE STATION ENERGY AND STATION DISCONTINUITY MODELS

FREEWAY STATION	STATION ENERGY			STATION DISCONTINUITY		
	DRY WEATHER		RAIN	DRY WEATHER		RAIN
	1968 (4 peak periods)	1969 (8 peak periods)	1969 (4 peak periods)	(4 peak periods)	(8 peak periods)	(4 peak periods)
Seward	.17	.20	.09	.232	.30	.16
Chicago	.20	.24	.18	.321	.33	.25
Calvert	.19	.14	.10	.513	.31	.30
Glendale	---	.19	.12	---	.23	.28

TABLE C-3

THRESHOLD VALUES FOR DETECTION (0.5 PERCENT LEVEL) BY THE SUBSYSTEM SHOCK WAVE MODEL

FREEWAY SUB-SYSTEM	STORAGE DECREASE			STORAGE INCREASE		
	DRY WEATHER		RAIN	DRY WEATHER		RAIN
	1968 (4 peak periods)	1969 (8 peak periods)	1969 (4 peak periods)	1968 (4 peak periods)	1969 (8 peak periods)	1969 (4 peak periods)
1. Seward-Chicago	-32	-33	-29	38	43	39
2. Chicago-Calvert	-29	-32	-26	35	31	26
3. Calvert-Glendale	-29	-33	-35	31	38	35

TABLE C-4

THRESHOLD VALUES FOR DETECTION (ONE PERCENT LEVEL) BY THE SUBSYSTEM ENERGY AND SUBSYSTEM DISCONTINUITY MODELS

FREEWAY SUB-SYSTEM	SUBSYSTEM ENERGY			SUBSYSTEM DISCONTINUITY		
	DRY WEATHER		RAIN	DRY WEATHER		RAIN
	1968 (4 peak periods	1969 (8 peak periods)	1969 (4 peak periods)	1968 (4 peak periods)	1969 (8 peak periods)	1969 (4 peak periods)
1. Seward-Chicago	-.77	-.71	-.73	---	.68	1.00
2. Chicago-Calvert	-.53	-.33	-.30	---	.30	.25
3. Calvert-Glendale	-.42	-.76	-.68	---	.71	.55

TABLE C-5

STATION ENERGY MODEL STATISTICS

STATION	DRY WEATHER		EXTREME VALUES OBSERVED			
	Mean	Std. Dev.	Max.	Min.	a	b
Seward	1.13	.67	1.72	.08	.20	.00
Chicago	1.07	.79	1.77	.09	.24	.00
Calvert	.89	.82	1.56	.06	.14	.08
Glendale	1.00	.75	1.68	.09	.19	.08

STATION	RAIN			EXTREME VALUES OBSERVED			
	Mean	*	Std. Dev.	Max.	Min.	a	b
Seward	.89	S.	.84	1.68	.06	.09	.01
Chicago	.87	S.	.73	1.60	.08	.18	.11
Calvert	.76	S.	.81	1.56	.04	.10	.02
Glendale	.82	S.	.75	1.68	.07	.12	.00

a : Threshold Values for Detection

b : Extreme Minimum Values Observed During an Incident

* : Significantly (S.) or Not Significantly (N.S.) Different (.05 Level of Confidence) Mean from Dry Weather Mean

TABLE C-6

STATION DISCONTINUITY MODEL STATISTICS

STATION	DRY WEATHER		EXTREME VALUES OBSERVED**			
	Mean	Std. Dev.	Max.	Min.	a	b
Seward	.74	.37	1.00	.07	.30	.00
Chicago	.63	.30	.91	.09	.33	.00
Calvert	.71	.39	1.00	.00	.31	.02
Glendale	.72	.44	1.00	.05	.23	.00

STATION	RAIN			EXTREME VALUES OBSERVED**			
	Mean	*	Std. Dev.	Max.	Min.	a	b
Seward	.72	N.S.	.45	.99	.05	.16	.01
Chicago	.56	S.	.33	.99	.08	.25	.04
Calvert	.71	N.S.	.39	.99	.12	.30	.00
Glendale	.71	N.S.	.41	.99	.19	.28	.00

a : Threshold Values for Detection

b : Extreme Minimum Values Observed During an Incident

* : Significantly (S.) or Not Significantly (N.S.) Different (.05 Level of Confidence) Mean from Dry Weather Mean

** : Variable Range Restricted To From 0.0 To 1.0

TABLE C-7

SUBSYSTEM SHOCK WAVE MODEL STATISTICS

Sub-System	DRY WEATHER		EXTREME VALUES OBSERVED					
	Mean	Std. Dev.	Max.	a^+	b^+	Min.	a^-	b^-
1	4.08	36.9	50	43	72	-40	-33	-52
2	-4.38	28.7	51	31	27	-44	-32	-16
3	1.48	33.3	55	38	60	-47	-33	-43

Sub-System	RAIN			EXTREME VALUES OBSERVED					
	Mean	*	Std. Dev.	Max.	a^+	b^+	Min.	a^-	b^-
1	5.57	N.S.	33.9	45	39	44	-42	-29	-61
2	-2.22	S.	24.0	35	26	--	-30	-26	--
3	-0.39	S.	30.2	43	35	68	-44	-35	-37

a^+, a^- : Threshold Values for Detection

b^+, b^- : Extreme Values Observed During Incidents

* : Significantly (S.) or Not Significantly (N.S.) Different (.05 Level of Confidence) Mean from Dry Weather Mean

TABLE C-8

SUBSYSTEM ENERGY MODEL STATISTICS

Sub-System	DRY WEATHER		EXTREME VALUES OBSERVED			
	Mean	Std. Dev.	Max.	Min.	a^-	b^-
1	.05	.84	1.24	-.98	-.71	-1.14
2	.18	.62	1.12	-.54	-.33	- .57
3	-.11	.72	1.02	-1.02	-.76	-1.03

Sub-System	RAIN			EXTREME VALUES OBSERVED			
	Mean	*	Std. Dev.	Max.	Min.	a^-	b^-
1	.02	N.S.	.73	.86	-.99	-.73	-1.11
2	.10	S.	.49	.90	-.54	-.30	---
3	.07	N.S.	.61	.90	-1.01	-.68	-.77

a^- : Threshold Values for Detection

b^- : Extreme Minimum Value Observed During an Incident

* : Significantly (S.) or Not Significantly (N.S.) Different (.05 Level of Confidence) Mean from Dry Weather Mean

TABLE C-9

SUBSYSTEM DISCONTINUITY MODEL STATISTICS

Sub-System	DRY WEATHER		EXTREME VALUES OBSERVED			
	Mean	Std. Dev.	Min.	Max.	a^+	b^+
1	-.06	.64	-1.07	1.15	.68	1.89
2	-.10	.39	- .84	.40	.30	.68
3	.11	.51	- .62	1.16	.71	1.28

Sub-System	RAIN			EXTREME VALUES OBSERVED			
	Mean	*	Std. Dev.	Min.	Max.	a^+	b^+
1	.05	S.	.76	-.91	1.18	1.00	1.87
2	-.05	S.	.38	-.76	.58	.25	---
3	.06	S.	.51	-.83	.81	.55	.80

a^+ : Threshold Values for Detection

b^+ : Extreme Maximum Values Observed During an Incident

* : Significantly (S.) or Not Significantly (N.S.) Different (.05 Level of Confidence) Mean from Dry Weather Mean

APPENDIX D

CALIFORNIA INCIDENT DETECTION MODEL

APPENDIX D

CALIFORNIA INCIDENT DETECTION MODEL

The California incident detection model consists of three successive "tests" involving occupancy changes in time in a subsystem (41). The tests are conducted once every 20 seconds. The flow chart on the following page (Figure D-1) details the model logic.

Test One*: $\theta(i,j) - \theta(i+1, j) \geq K1$

*Not used in this research

Test Two: $\dfrac{\theta(i,j) - \theta(i+1,j)}{\theta(i,j)} \geq K2$

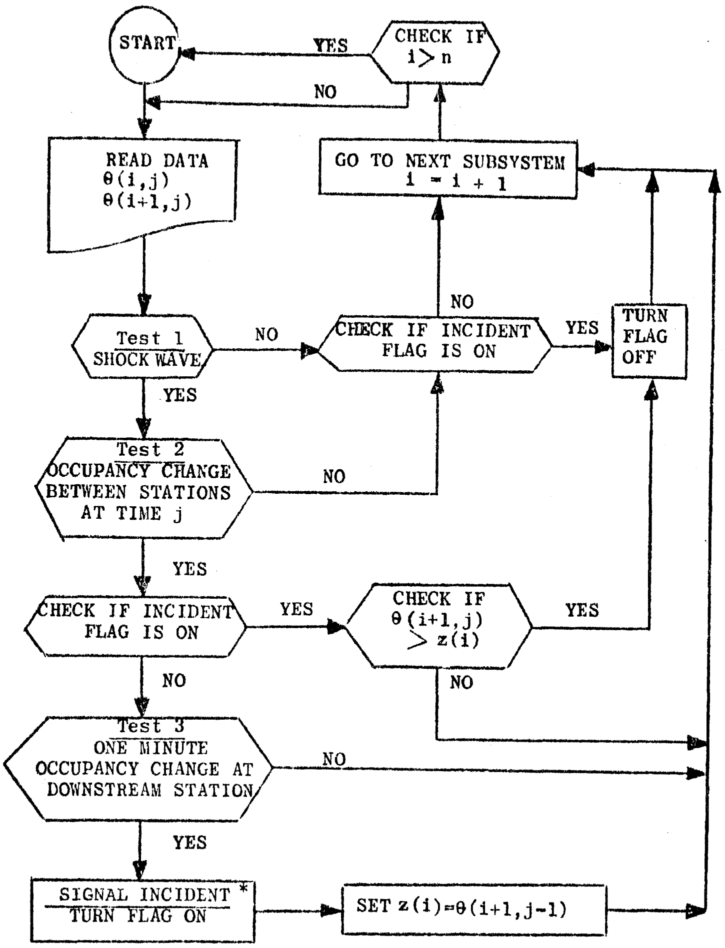
Test Three: $\dfrac{\theta(i+1, j-1) - \theta(i+1,j)}{\theta(i+1, j-1)} \geq K3$

Where: $\theta(k,j)$ = average occupancy at k^{th} detector station during minute j (one minute average)

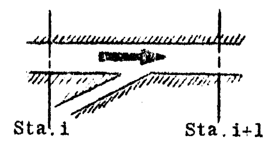
i = upstream detector station

i+1 = downstream detector station

j = time in one minute increments.



*Declaration must be confirmed by Test 2 in succeeding minute.



Freeway Subsystem

KEY

j	=	Time in one minute increments
i	=	Station number
θ(i,j)	=	One minute average lane occupancy at station i, time j
n	=	Number of subsystems
z (i)	=	Threshold value for determining termination of incident

FIGURE D-1

CALIFORNIA INCIDENT DETECTION FLOW CHART

A tentative incident declaration is made after all three (or the last two) critical K parameters are exceeded in order, their values being predetermined from historical traffic characteristics. The declaration is confirmed in the succeeding minute when the second test again passes. The third test is expected to signal only once, or at most twice. The end of the incident is signaled when either the K2 parameter returns to a level below control for the first time, or the downstream occupancy for the first time exceeds the occupancy level immediately preceding the incident declaration. Table 3 presents the results of a preliminary study of the performance of the model. Changes in the K1 parameter did not affect these results.

APPENDIX E

DOUBLE EXPONENTIAL SMOOTHING MODEL

APPENDIX E

DOUBLE EXPONENTIAL SMOOTHING MODEL

The exponential smoothing model gives a prediction of a traffic stream variable for the coming minute based on a linear combination of all past observations. Past observations are discounted geometrically. The most recent value in this research was given weight 0.3, and previous values were thus weighted 0.21, 0.147, 0.1029, etc. The double exponential smoothing modification to account for trend in the data stream is essentially a smoothing of the smoothed data stream. The following exponential smoothing formulas are taken from Brown (7).

$S_1(t) = a\,x(t) + (1-a)\,S_1(t-1)$ <u>Exponential Smoothing</u>

$S_1(t)$ = smoothed value of variable.

a = smoothing constant (0.3).

$x(t)$ = traffic variable value.

t = current minute of observation.

$S_2(t) = a\,S_1(t) + (1-a)\,S_2(t-1)$ <u>Double Exponential Smoothing</u>

The prediction for the coming minute is developed from the above smoothed values by means of the following equations. As derived by Brown, they are the means by which the model corrects for trend in real-time.

$$\hat{x}(t+1) = A(t) + B(t)$$ <u>Parameter Prediction</u>

Where:

$$A(t) = 2\, S_1(t) - S_2(t)$$ <u>Coefficient "A"</u>

$$B(t) = \frac{a}{(1-a)} (S_1(t) - S_2(t))$$ <u>Coefficient "B"</u>

Exponential smoothing is computationally efficient. The file of historic information for each detector station consists of the two smoothing values, $S_1(t)$ and $S_2(t)$. The computation of the standard deviation from the data stream is a fairly involved process that is greatly simplified by using the mean absolute deviation as an estimate. Brown showed that the mean absolute deviation is proportional to the standard deviation, and that the constant of proportionality is approximately 0.8 for the normal and several other distributions. In this study, the mean absolute deviation, MAD, was obtained by single exponential smoothing of the absolute values of the deviations of the actual parameter value with the predicted value.

$$MAD(t) = a\,|E(t)| + (1-a)\,MAD(t-1)$$ <u>Mean Absolute Deviation</u>

$E(t)$ = error of prediction; $x(t) - \hat{x}(t)$.

a = smoothing constant. Taken as 0.1 in this report.

Incident detection was accomplished by means of the tracking signal which is the cumulative sum of the prediction errors divided by the current mean absolute deviation.

$$TS(t) = Y(t) / MAD(t)$$ <u>Tracking Signal</u>

Where: $$Y(t) = Y(t-1) + E(t)$$ <u>Cumulative Errors</u>

$Y(t-1)$ = past cumulative error.

$E(t)$ = current error of prediction.

Both the mean absolute deviation and the tracking signal require the storage of only one bit of historic information. An incident was detected when the tracking signal deviated beyond the range that could be attributed to random variation in the observations. In this report the range of the tracking signal was tentatively set at plus or minus six.

The exponential model requires initial estimates of the above smoothing values, $S_1(t-1)$ and $S_2(t-1)$. In this report this was accomplished by setting both values equal to the mean value of the first ten parameter observations. The mean absolute deviation was estimated from the standard deviation of the first ten observations with the following equation, assuming the parameter to be normally distributed.

$$MAD(t-1) = \sqrt{2/\pi}\left[\sqrt{2/(2-a)}\right]\sigma_x \qquad \underline{\text{Initial MAD Estimate}}$$

In practice the exponential smoothing model promptly compensates for inaccuracies in the initial estimates. The estimates should be reasonable enough that false detections do not occur in the first minute of operation as a result of inaccuracy.

APPENDIX F

PROJECT STATEMENT

APPENDIX F

"Excerpts From"

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Highway Research Board
National Academy of Sciences-National Research Council

FY '67

Project Statement

Research Project Title:

Optimizing Freeway Corridor Operations Through Traffic Surveillance, Communication, and Control

General Problem Area:

Special Projects

Research Problem Statement:

To meet present and future traffic demands, the combined freeway and surface street system must operate more efficiently. Freeways through heavily developed areas have limited right-of-way which prevents, on an economic basis, their reconstruction for increased capacity. Practical measures for increasing operational efficiency of these facilities through heavily traveled corridors should be developed by judicious application of traffic surveillance, communication, and control.

Urban freeways comprise a major portion of the traffic-carrying capacity of the total vehicular route system in American cities. It is believed that surveillance, communication, and control of traffic on freeways as well as on the supplemental street systems can be improved, resulting in better service to the motoring public as a whole.

It is desired to apply the best traffic surveillance, communication, and control techniques in a typical urban freeway corridor and to study the results. Innovations that may be expected to enhance the operational efficiency should be explored.

The National Proving Ground for Freeway Surveillance Control and Electronic Traffic Aids located on the John C. Lodge Freeway in Detroit has been extensively equipped for freeway surveillance, and this freeway and the adjacent corridor is designated as the study site to develop and evaluate improved surveillance, communication, and control techniques.

Objectives:

1. Determine method(s) for increasing the effectiveness of the system which involves the freeway and the adjacent surface street network within the corridor. Evaluate the methods on the study site with or without the use of additional hardware.

2. Recommend equipment configurations (that is, type and location) for the improved system which will represent the optimum balance in cost-effectiveness.