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TESTING TRAFFIC CONTROL STRATEGIES FOR INCIDENT CONGESTION MANAGEMENT OF A SURFACE STREET SYSTEM

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ABSTRACT

TESTING TRAFFIC CONTROL STRATEGIES FOR INCIDENT CONGESTION MANAGEMENT OF A SURFACE STREET SYSTEM

By

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Selecting the most appropriate traffic control strategy for incident congestion management can have a major impact on the extent and duration of the resulting congestion. This research investigated the effectivenesses of several control strategies on various incident conditions. The selected control strategies representing possible ITS technologies included traffic metering (ATMS), traffic diversion (ATIS), and traffic diversion with signal timing modification (ATIS/ATMS). The analysis was conducted on a hypothetical dense grid surface street network. Mid-block incidents of various durations were tested. The results indicated that the ATIS/ATMS based solution can reduce congestion duration up to 27 minutes, with a saving of 261 vehicle-hours of delay. A sensitivity analysis was performed to obtain the effectivenesses of various control strategies under different demand levels. Several alternate diversion plans and control variables for initiating signal modification were also tested.

This work is dedicated to my parents, Mrs. Sumitda and Mr. Vicharn, my brother and sister, Mr. Noppadol and Ms. Wipawee, and all of my friends, who all dream to witness my accomplishment.

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INTRODUCTION

1.1 Description of the problem

Selecting the most appropriate traffic control strategy for incident congestion management can have a major impact on the amount and duration of the resulting congestion. With the implementation of the Intelligent Transportation System (ITS) technology, several advanced traffic control options are now available. However, this topic has not been thoroughly studied. In this study, several ITS control strategies are tested to determine their effectivenesses under various incident and control conditions.

1.1.1 Incidents and their effect on traffic

Traffic incident is a term used for a random, unplanned event which affects traffic operations. It can be a temporary reduction in roadway capacity caused by accidents, roadway maintenance, or construction activities, or a temporary increase in traffic demand as commonly occurs immediately before and after special events. Incidents, generally referred to as nonrecurrent events, can be divided into three basic categories based on their uncertainty of occurrence (Holmes and Leonard, 1993):

a. Normal and generally accepted (although not necessarily desirable)--such as on-street parking. This type of incident is usually tolerated by drivers as being part of normal traffic conditions on the network.

b. Expected and programmed--includes roadwork and maintenance activities. Their occurrence is foreseen and planned, but unexpected to motorists.

c. Unexpected--such as vehicle breakdowns and accidents. Neither drivers nor the traffic agency is prepared for this type of the incident because the occurrence is unpredictable.

Incidents generally result in traffic congestion. The magnitude and duration of the congestion is difficult to predict because, in most cases, neither the location, the time, nor the severity of an incident is known beforehand. Limited information and knowledge on incidents can result in non-optimal choices, such as an improper route choice and ill-timed signal settings.

Each incident has a unique impact on traffic operations in a network. Beaubien (1994) analyzed the effect of incidents on delay for various incident types. Similar work was also conducted in Texas (Dudek, 1976) and in London, England (Holmes and Leonard, 1993). Delay generally ranged from 15-30 vehicle-minutes due to a vehicle disablement to several vehicle-hours due to major accidents with lane blockages.

Incident management has received considerable attention since incidents are one of the most pressing traffic problems in urban areas. Lindley (1987, 1989) reported that congestion due to incidents accounted for more than 61 percent of all urban congestion in 1984, and is expected to cause more than 70 percent of the total congestion by the year 2005 (National Cooperative Highway Research Program, 1991).

1.1.2 Measures to alleviate congestion due to incidents

Incidents commonly create two types of congestion: primary and secondary. Primary congestion is caused by traffic queuing at a bottleneck. Secondary congestion arises from the blockage of other intersections by primary congestion (Longley, 1968). The goal of incident management is to restore roadway capacity as quickly as possible, so as to limit primary congestion, and at the same time avoid or reduce secondary congestion.

Incident management shares the same traffic treatment philosophy as recurrent congestion management, although different traffic control strategies may be required. Recurrent congestion occurs routinely at specific locations and times of day. An example is the peak hour traffic jam. Both short-term and long-term solutions are considered as methods to alleviate recurrent congestion. Considering the techniques for reducing recurrent traffic congestion, which can be divided into three categories (Rathi and Leiberman, 1989):

a. Increasing the capacity of the road system--through construction of additional facilities or a physical improvement to provide additional capacity.
b. Reducing traffic demand--through behavioral changes or travel demand management or traffic restraints.
c. Maximizing the use of available capacity--through traffic engineering practices aimed at minimizing the capacity reducing factors (e.g. through traffic regulation) or more efficient use of existing capacity (e.g. signal control improvement).

The first method is not appropriate for incident management. The unpredictable nature of incidents makes it infeasible to maintain excess capacity at all elements of the network. Behavioral changes are also not applicable to incident management because of the time frame involved (long-term solution). However, traffic restrictions in congested areas, such as metering and traffic diversion, may be applied to incident management. The efficient use of existing capacity through traffic management is the only response applicable to nonrecurrent congestion. Therefore, measures to alleviate incident congestion focus on maximizing the use of available capacity.

Actions to reduce incident congestion can specifically be categorized into three groups (Van Vuren and Leonard, 1994):

a. Incident control.

b. Behavioral control or demand control.

c. Network control.

Incident control deals with the initial cause of congestion. Techniques include reduction in incident duration (i.e., incident removal) and local traffic management to reduce the impact of the incident at the scene. Behavioral control includes the provision of information to motorists so that they can adjust their travel pattern to avoid the congested links through route diversion, a departure time change, a mode change, or even trip cancellation. The route change is the only response to the incident that can be applied to motorists currently on the streets. Network control is the efficient use of available network characteristics, including throughput and storage capacity. This method employs measures such as signal control alterations.

1.1.3 Strategies for incident management

Most traffic control measures attempt to improve network efficiency, i.e., reduce delay for all vehicles using the system. With this goal in mind, a criterion by which success will be measured and a technique to achieve the goal must be developed for a specific application. Such a technique is called a strategy.

In the course of incident management, traffic control strategies can be classified into two main categories:

a. Signal modification.

b. Traffic diversion.

Signal modification strategies are generally implemented at traffic control centers. Examples of signal modification strategies are longer or shorter cycle time, phase changes to reflect current demand, changes in the green splits and offsets to maintain equal queues for conflicting movements, traffic metering to avoid blockage, and reverse progression. The signal modification strategies require a signal control system that is responsive to changing traffic demand. Signal control strategies have been extensively reviewed in the literature (Wright and Huddart, 1989; Montgomery and Quinn, 1992; Quinn, 1992; OECD, 1981; McShane and Pignataro, 1978).

The strategies for driver information are pre-trip information and route guidance. These strategies attempt to provide knowledge of traffic conditions to drivers so they can make route choices which minimize the effect and extent of the incident. Communication through in-vehicle devices or changeable message signs is required to give the drivers incident and routing information. These control policies were surveyed in Van Aerde and Rakha (1989) and Van Aerde and Plum (1988).

The effectiveness of each traffic control strategy depends on demand, the network, and control characteristics. Signal alteration alone is applicable only when the demand does not exceed the total network reduced capacity after an incident occurs. Traffic metering requires some links to be designated for queue storage. The effectiveness of traffic routing depends on the availability of alternate routes and their level of congestion. Therefore, there is no single most appropriate control strategy that can be applied in all situations.

1.1.4 Intelligent Transportation Systems (ITS) and incident congestion

In the past decade, the ability to improve performance of the transportation systems has been made possible through the advancement of computer, communication, and information technologies. This effort has been pursued in many parts of the world. In the United States, Intelligent Transportation Systems (ITS), formerly Intelligent Vehicle-Highway Systems (IVHS), is a single phrase describing the use of technologies to accomplish transportation goals in many functional areas. The European community calls the program Advanced Transport Telematics (ATT) and Road Transport Informatics (RTI) (Castling, 1994).

ITS offers potential incident congestion reduction through Advanced Traffic Management System (ATMS) and Advanced Traveler Information System (ATIS). The primary feature of ATMS is the provision of real-time (dynamic) control to respond to changing traffic conditions. ATIS provides travelers with information required to ensure that their journey is as efficient and safe as possible. The combined effect of ATMS and ATIS has been studied by Rakha et. al. (1989) and Sarakki and Kerr (1994). There are several demonstration programs employing these two technologies currently underway in the United States, Europe, and Japan. Thus, the scenario of vehicles equipped with ATIS devices and circulating in a network with an ATMS traffic control is in the near future.

However, control strategies in the ITS environment need further investigation to determine the effectiveness of each strategy under various situations. The benefits of ITS deployment cannot be fully realized if inappropriate control strategies are applied.

1.2 Statement of the problem

Traffic control strategies aimed at reducing the consequences of incidents have not been thoroughly developed and tested. The research conducted for this study is original in that different control strategies developed for a variety of incident situations in an ITS environment were tested. The effectiveness of controls under each individual ITS element was obtained. The joint effect of ATMS and ATIS control strategies was also examined as benefits gained through their interaction may be lost if one of the strategies is employed.

1.3 Objective and scope of the research

This research addresses the development and testing of traffic control strategies designed to reduce the consequences of an incident. The scope of the research includes:

a. Identification of measures of effectiveness (MOEs) to indicate the impact of an incident on an urban street network;

b. Investigation of the impacts of incidents on these MOEs under various conditions;

c. Development of routing and signal control strategies to cope with the incidents; and

d. Determination of the limits of the effectiveness of these strategies by varying degrees of demand, incident severity, and incident duration.

1.4 Research approach

This research was based on traffic simulation since this permits the analysis and comparison of different control strategies on the same road network and incident. NETSIM (NETwork SIMulation) was selected for this study because it could be modified to replicate control and drivers characteristics within the ITS environment. NETSIM is a microscopic interval-based simulation model of urban traffic on a surface street network. The model was first developed in the 1970s and has periodically been enhanced. NETSIM version 5.0, which was used in this study, includes many advanced features on traffic signal, driving behavior, and turning movement descriptions and can provide data on the MOEs suitable for the analysis (Federal Highway Administration, 1995).

The research was based on a hypothetical dense grid network with demand characteristics representative of traffic conditions in the City of Troy, Michigan. When an incident was introduced into the network, the evolution and dissipation of congestion were studied. Congestion resulting from an incident in a network without ITS was used as a base case, with traffic performance analyzed for various types of incidents. For the base case, the signal timing was held constant and the impacts of the incidents on specified MOEs were determined.

Several traffic signal control and route diversion strategies were developed for each traffic situation. These strategies were then tested with the simulated network to obtain performance measures in various incident characteristics. Data for the MOEs were collected for each control scheme and the results were compared and discussed.

The effectiveness of these control strategies under different demand condition was then determined. Moreover, variations of control strategies were evaluated.

Chapter 2

LITERATURE REVIEW

Traffic control strategies have been developed and incorporated in urban traffic signal control systems since the 1960s. Along with the advancement in traffic control systems and technologies, many traffic control strategies have been developed to provide efficiency, safety, and a reduction in fuel consumption. Most of the signal control policies in the past were developed for recurrent traffic conditions, both for peak and off-peak traffic. As the nonrecurrent traffic congestion problem on urban streets increases, recent interest has shifted to traffic control strategies under incident conditions. Traffic control strategies for incident conditions were not possible until responsive traffic signal controls and communication technologies existed, due to the requirement for a prompt response to the incident.

Studies on control strategies for incidents started in the 1970s with the evaluation of responsive signal control systems and driver information systems on unexpected situations. Nonetheless, the first major work was conducted by Hunt and Holland in 1985, where an attempt was made to determine the effect of an incident in a network controlled by the SCOOT (Spilts, Cycle length, Offset Optimization Technique) traffic control system. Since then increased attention has been given to the ability of each modern traffic control systems to respond with special control strategies for incidents.

Most traffic control strategies for incidents are derived from those for recurrent congestion conditions (both undersaturated and saturated conditions). Because of this, the following section reviewed the control strategies originally developed for recurrent traffic conditions. The transferability to an incident situation was then discussed, along with the research on effectiveness of numerous control strategies on incident-caused congestion.

2.1 Theoretical traffic signal control strategies

The first generation of signal control strategies were based on off-line calculations for a fixed time signal control system. At an individual intersection, Webster and Cobbe (1958) suggest that a signal split strategy should equalize the degree of saturation (DS) of all critical approaches to approximately yield the minimum intersection delay. This control strategy can handle varying demand in a day by having separate settings for different time periods. This technique became general practice for most fixed time signal controls, in both undersaturated and saturated traffic conditions.

For arterial and network considerations, Little (1966) introduced an off-line mathematical technique to maximize the bandwidth. The principle was to maximize the number of vehicles able to successfully encounter green signals when traveling along a street. Over the years, several variations of this approach were developed. NCHRP Report 73 (1969) evaluated several of these offset strategies. Off-line control techniques investigated in this report were Yardeni's time-space design, Little's maximal bandwidth, and delay/difference-of-offset. Three responsive control strategies, namely basic queue control, cycle and offset selection, and mixed cycle mode, were also evaluated in this report. The results indicate that the cycle and offset selection method and delay/difference-of-offsets techniques rank the best for off-peak periods, whereas the mixed cycle mode and basic queue control were the best for peak periods.

Perhaps the most comprehensive and most widely-applied control strategy for fixed time control setting is based on a computer optimization method. TRANSYT (Traffic Network Study Tool) (Robertson, 1968) is an off-line program utilizing modified Webster's method to calculate green splits, and a hill-climbing optimization technique to determine offset and cycle length which minimizes a performance index. The logic for the offset calculation is similar to the delay/difference-of-offset method evaluated in NCHRP Report 73. Similar programs to TRANSYT are SIGOP (Signal Optimization program) and PASSER II (Progression Analysis and Signal System Evaluation Routine), which have slightly different calculation procedures.

The control strategies obtained from off-line calculations are effective for average traffic conditions, but are not responsive to changing traffic patterns. When a traffic pattern changes, the solutions from these programs are no longer optimal. Thus, the TRANSYT method is suitable only for recurrent traffic conditions. These methods are difficult to apply to incident conditions, where the incident alters the capacity and demand pattern.

Several traffic-responsive signal control strategies were developed for an individual intersection furnished with traffic detectors. Gazis and Potts (1964) developed a technique for time-dependent signal setting under varying demand. They used queue length as an input to minimize total aggregate intersection delay. The technique is also called "bang-bang" because the green time is set at a predetermined maximum value for the queued approach, and at a minimum value in other directions. When a queue in the first approach is cleared, the setting is reversed. This signal setting does not, in general, minimize the period during which one approach is congested. d'Ans and Gazis (1976) furthered this control method by means of linear programming. Church and Revelle (1978) formulated similar control strategies with consideration of maximum waiting time and queue length. When the maximum queue length was used as a control objective, they found that the solution tended to balance the queue lengths on the most saturated approaches of each signal phase, and the signal frequently switched between phases. Michalopoulos and Stephanopolous (1977) reported that the queue constraint was effective when the demand increases to the limiting value. The optimal control strategy at saturation is simply the balance of input-output to maintain constant queue length.

NCHRP Report 32 (1967) tested four control strategies, namely basic queue control, queue-length arrival rate control, modified space-presence control, and delay-equalization control. The results showed that the modified space-presence control strategy yielded the lowest delay under low to medium intersection demand (up to 2000 vehicles per hour for 4-lane, 4-leg junction). When the demand was greater than 2000 vehicles per hour, the basic queue control strategy was better than the others.

Many control strategies have been developed for oversaturated traffic conditions at an isolated intersection. Gordon (1969) suggested that the control objective should be to maintain a constant ratio among the respective storage spaces. Longley (1968) attempted to balance queue lengths on all approaches. NCHRP Report 194 showed that, although the Longley control logic yielded lower delay than the off-line calculation, the queue-actuated control resulted in lower delay when the degree of saturation was above 0.5. The report stated that the objective of signal control should be to avoid spillback and to provide equitable service. The report also gave some tactical control strategies to ease queue blockage at an intersection.

2.2 Signal control strategies and response to incidents in existing urban traffic control systems

Under a fixed time control system, the TRANSYT method of delay minimization is a popular method to determine signal timings (Woods, 1993). However, such timings cannot respond to unexpected incidents. Because the signal setting is fixed for a time-of-day period, there is no special control strategy for incidents.

Similar control strategies were used in the UTCS (Urban Traffic Control System) first generation control system as in the fixed time control systems, but signal plans could be changed every 15 minutes. A signal timing plan suitable for current traffic conditions is selected from a set of pre-calculated plan. The UTCS first generation system includes split adjustment for the Critical Intersection Control (CIC). The signal split is altered if oversaturation is detected, and queue control comes into place at this critical intersection.

The UTCS second generation system computes a new signal plan instead of "looking up" a selection in the plan library. Signal split and offset are then adjusted at the critical intersection. The UTCS third generation system controls intersections independently, with fully adaptive split, offset, and cycle length determination. The signals can be changed every 3-6 minutes. Because the second and third generation systems are on-line and more responsive to changing traffic patterns, they can respond to incident-related traffic but the effectiveness of these systems to an incident has not been evaluated (Kay, Allen, and Bruggeman, 1975).

In the Japanese UTMS (Urban Traffic Management System), five control strategies are selected based on the level of traffic demand. Three strategies correspond to levels before network saturation. Signals are optimized similar to TRANSYT in undersaturated conditions. In oversaturated conditions, the objective is switched to prevent blockages and to give priority to main roads by restraining access from side streets. In the case of incidents, the system keeps priority routes clear during particularly severe congestion (Woods, 1993).

The SCATS (Sydney Co-ordinated Adaptive Traffic System) of Australia also has different control strategies for various demand levels. Signal splits and offsets are selected from embedded plans calculated by an off-line program such as TRANSYT, while the cycle length is calculated every cycle. However, the system also makes use of some tactical controls at each intersection (Lowrie, 1982). Response to incidents is primarily activated by traffic operators. When the detectors are covered by traffic for certain periods of time, an alarm is signaled to the traffic operator who sets the traffic control. SCATS tactical logic itself can also respond to incident-related congestion. The logic is the same as the normal recurrent traffic operation. At each intersection, tactical control strategies include:

a. Signal split selection from a library according to degree of saturation;

b. Green time gap-out;

c. Green time early cut-off due to inefficient use of green time; and

d. Phase skip if no demand is placed in the previous cycle length.

At a "strategic" level of control, offset and cycle time are selected in response to the current traffic situation based on the plan selection process. However, the plans are not typically developed for incident situations. In principle, when an incident occurs on a link, there is a reduction in traffic at the downstream intersection. The reduction of the green time for that direction will be given to other phases by means of any of the four strategies. At an intersection upstream from the incident, if blockage exists and reduces the flow, the green split is reduced by the split plan change and the early cut-off. SCATS does not have logic to prevent intersection blockage.

The British SCOOT system is simply an on-line version of TRANSYT. The control strategies are to minimize delays and stops at all intersection in the network in all ranges of demand. Signal splits change incrementally based on current demand obtained from detectors every four seconds. Offsets and cycle times are adjusted every few minutes. The response to incidents relies on the adaptive logic of the system. In the case of an incident where the traffic demand change is so rapid that SCOOT cannot adapt to it, two methods can be imposed. The first method is that SCOOT is suspended and falls back to manual operation. The other method is to invoke a special plan run. SCOOT also has a gating feature that limits flow into a particular sensitive area.

2.3 Route guidance and access control strategies

Van Aerde and Rakha (1989) studied the potential of two route guidance strategies, namely user-optimum and system optimum assignment. The user optimum strategy follows Wardrop's first principle that a driver is assumed to choose a route which will minimize their journey time through the network, and all other drivers equipped with the route guidance instrument make their choice by the same criterion. The system optimum strategy is that each driver with the route guidance equipment is directed to the path which minimizes the overall travel time to all drivers. They concluded that system optimized routings are complex and impractical for any but the most trivial networks.

The difficulty of integrating route guidance/signal control was initially reported by Allsop and Charlesworth (1977). They suggested that the route guidance optimal strategy was dependent on signal control. In normal traffic operation, an optimal routing can be found for each signal setting. When the signal timings are changed, the optimal routing changes. This effect is also reported by Charlesworth (1978) and Maher and Akcelik (1975).

Although optimal route guidance control is difficult to obtain, modern systems utilize advanced communication systems to obtain real-time traffic data from individual vehicles. The real-time travel time data are then used to determine the optimal path. The systems are based on the user optimal strategy. Each equipped vehicle is provided with information on the shortest time to its destination, based on current travel time on each road section. The systems include EURO-SCOUT, CACS, SOCRETES (Castling, 1994).

Various techniques can also be used to disseminate traffic information to motorists. These include radio broadcasting, police control, variable message signs, and pre-trip planning.

The concept of access control can be applied to incidents if a route guidance system is available. In an incident situation, access to the area is controlled by means of traffic diversion. Traffic is diverted to other routes to avoid the obstruction. For a wider area, where there are numerous alternative routes, access control can be done through the use of route guidance to re-route traffic to non-congested routes.

Traffic metering (gating) is another technique to control access. The traffic is screened at an entry point to limit the number of vehicles allowed into the congested area. Many countries have applied this technique for peak-hour congestion (May and Westland, 1979). Rathi (1991) conducted a comprehensive study on the traffic metering on a grid network of Manhattan, New York, which the overall travel time reduction in the order of 20 percent was obtained.

2.4 Effectiveness of control strategies for incidents

Hunt and Holland (1985) studied the effect of a SCOOT control strategy and traffic diversion on the reduction in congestion due to an incident on a hypothetical network. A key assumption in the study was that the flows were chosen so that during the road closure there was no oversaturation under fixed time control. This implies that any increase in delay is due to lack of responsiveness, rather than lack of capacity. In the "before" case, demand which created a degree of saturation of 42 percent at any intersection on the major arterial was selected to conform to the assumption. The volume level was selected to resemble off-peak traffic in Coventry, England. Each junction had a simple two-phase signal. The control strategies in this study were modifications of green split and offsets as a result of the SCOOT embedded adaptive control logic and traffic diversion. All traffic was obliged to turn away from the incident at an upstream intersection onto one parallel arterial then return to the original route at an intersection downstream of the incident. The results from the simulation are shown in Table 2.1.

The results indicate a large incident delay reduction for adaptive signal control over the fixed time system. However, the assumptions on the treatment of right turns on the diverted route (vehicles are operated on the left side of the road in England) are questionable. The assumption was made that there was no opposing traffic for the right turners and thus there was no waiting time for this traffic. The parallel arterials, which received the diverted traffic, did not connect to other links and thus the need to retain progression on the adjacent arterials with the outside network was not considered.

Table 2.1 Delay and journey time for routes affected by the incident (Hunt and Holland, 1985)

Scenario	Route/Control	Delay		Journey time	
		Seconds per veh	Increase over normal before case (%)	Seconds per veh	Increase over normal before case (%)
Before incident	Direct route	28.4	-	84.4	-
	Diverted route	61.0	115	145.0	72
After incident (diverted route)	Fixed time control	105.6	271	189.6	125
	SCOOT responsive control	44.4	56	128.4	52

Roberg (1995) investigated several dynamic strategies for controlling and dispersing traffic jams on an idealized one-way grid network. The strategies include the application of restricted movements on a number of critical junctions in the network. An incident was placed on a link in the network to study traffic congestion evolution and migration. Control strategies in this study were a combination of turn bans, ahead bans, and gating. Traffic was not allowed to turn into selected links to avoid gridlock. An ahead ban was imposed around the envelope of the congested area to reduce input into the critical sections of road. The ahead ban forced traffic to reroute away from the jam. In some experiments, instead of forcing vehicles to turn away from the congested region via ahead ban, vehicles were queued on the approaches to the jam without being diverted. This technique is called gating or external traffic metering.

Roberg and Abbess (1994) reported that gating generally yields higher delay than rerouting because traffic, which is stored on the approach links, may create some secondary gridlock.

The results of the study indicate the operational domain, in which the chosen strategies have successfully eliminated the jam, with respect to different levels of demand, turning percentage, and lane utilization at the intersection. The increase in delay from the normal situation was presented.

This study did not have a routing procedure for diverted traffic and there was no guarantee that vehicles returned to their original routes. The study also neglected to account for the longer journey time due to alternate routes and thus the indicated reduction in delay was exaggerated.

Van Vuren and Leonard (1994) studied four scenarios of different control strategies on incident congestion; signal optimization, gating, diversion, and demand restraint. They tested these techniques on an irregular shaped network of Kingston-upon-Thames. A congestion index, defined as the ratio of the travel time to the free-flow travel time, was used as a measure of effectiveness. The signal downstream of the incident was timed so that all approaches had equal saturation. Two main entry points to the incident were metered and gated traffic was stored in the peripheral region. Drivers were diverted to alternate routes when they faced an unexpected queue, either primary or secondary, based on travel time along the links. This means the drivers had no prior knowledge of congestion on the diverted routes. In this study, traffic was forced to reroute at selected intersections.

The results show that the equisaturation policy at intersections downstream from the incident lowers the congestion index, a surrogate measure of delay, by 14 to 22 percent. Benefits from the gating strategy were estimated to be up to 7 percent. The result suggests that rerouting before reaching the congested area has substantial potential benefit. This however depends on the incident location, demand pattern, position of traffic signals in the system, and link storage capacity. The secondary jam due to stored vehicles was not addressed. It was implied that diversion becomes potentially damaging when the overall level of recurrent saturation in the network increases.

Rakha et. al. (1989) examined the interactions between route guidance and signal control strategies on a freeway with a parallel signalized arterial. Traffic demand is assumed to be 1800 vehicles per hour on the 4-lane freeway and 150 vehicles per hour on the 2-lane arterial, in the direction incidents are introduced. The spacing between junctions on the arterial is approximately 2300 meters. Two types of incidents were investigated, one was a one-lane blockage on the freeway and the other was a blockage of 0.75 of a lane on the arterial. The authors did not consider oversaturation and total blockage during the analysis. Two signal control strategies were evaluated, namely an off-line signal optimization by holding the signal setting as it was, and an on-line signal optimization by adjusting signal timings at periodic intervals. For the on-line signal optimization strategy the signal splits and the cycle length were optimized as isolated intersections every three minutes without considering signal offset.

Table 2.2 displays the results from this study for the arterial incident scenarios. In the no incident situation, the on-line signal optimization reduced the average trip travel time over the off-line control by four percent. However, signal optimization increases trip time when a higher percentage of vehicles with route guidance capability is assumed. The

Table 2.2 Percentage average trip time relative to base case: arterial incident (Rakha et. al., 1988)

Scenario (Duration of incident)	Percentage of route guidance (%)					
	0	20	40	60	80	100
No signal optimization						
No incident	100	82	79	79	79	79
5 minutes	102	83	80	79	79	79
10 minutes	105	85	81	80	79	79
15 minutes	109	88	82	81	79	79
On-line optimization						
No incident	96	81	79	79	79	79
5 minutes	96	82	82	80	80	80
10 minutes	98	87	82	82	80	79
15 minutes	100	89	83	81	81	79

authors gave the reason that the signal optimizer was set to calculate timings based on the non-incident flow rates rather than the reduced flow rates following the incident. The conclusion of this study was that the combined effect of this signal optimization strategy and route guidance was not positive on arterial incidents because the signal control strategy failed to improve traffic performance.

2.5 Summary

Most traffic control strategies, developed for recurrent traffic conditions and employed in current control systems, may not be effective in an incident situation. Incident congestion requires a responsive signal control system that can adapt the signal to changing traffic patterns during the incident. Moreover, other alternatives, such as traffic restraints and traffic diversion, can be applied to alleviate the congestion. Limited number of studies were conducted to evaluate the effectivenesses of these traffic control strategies for incidents. The primary focus of the previous studies was to estimate the impact of one control type on incident congestion. Although various signal control policies, as well as routing procedures were tested, they have not been tested in the same street network. Furthermore, a number of assumptions were imposed and a detailed analysis of the impact of these assumptions has not been conducted.

Chapter 3

DESIGN OF STUDY

This study was designed to test different traffic control strategies under a controlled environment using the NETSIM traffic simulation program. The testing was based on a hypothetical network with a base demand. The normal traffic operations were assumed to be similar to a peak traffic period, with the optimal signal timing plan developed by an off-line calculation. Three types of incidents were considered; a one-lane closure, a two-lane closure, and a reduction of the two-lane capacity to 15 percent of the original capacity. Three incident durations with various control strategies applied to these scenarios were tested.

3.1 NETSIM simulation model

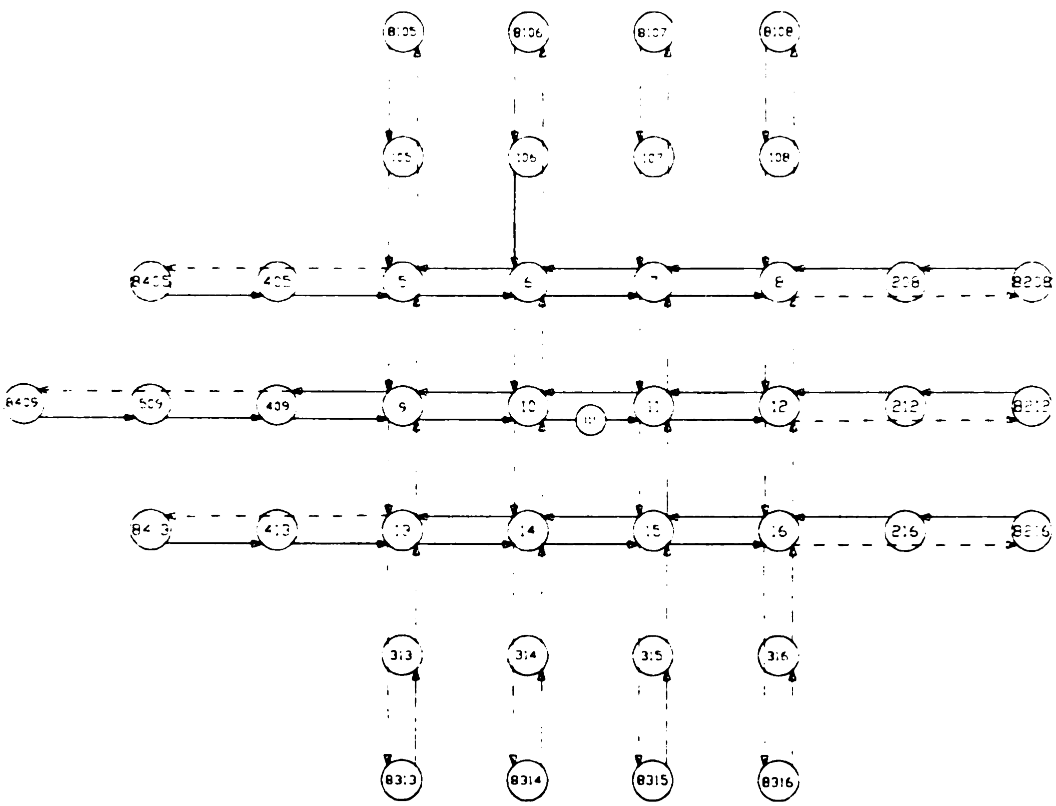
Simulation is a standard tool of engineers in studying existing systems and in predicting the behavior of projected systems (Gerlough, 1965). Traffic simulation provides the mechanism for testing theories, modeling concepts, control strategies, and new ideas prior to field demonstration. For this research, given that incidents are rare and unplanned event, it is impossible to study the effect of traffic control strategies empirically. Therefore, simulation is suitable for this research in that it provides an opportunity to experiment with possible policies under predetermined incident and controlled traffic conditions.

The NETSIM traffic simulation model was chosen for this study. NETSIM was developed by the Federal Highway Administration for simulating traffic operations on a surface street system. This microscopic model is based on the behavior of individual vehicles, and the newest version (5.0) includes detailed features on signal and routing controls. The model is accepted as an official tool for traffic analysis. The model has recently been modified to incorporate advanced signal and routing control logic, although these options are not yet available for public use.

3.2 Hypothetical network formulation

There is a general resistance among transport modellers to use hypothetical networks for simulation work because of the potential for introducing unrealistic features (Van Vuren and Leonard, 1994). Nonetheless, a theoretical network is essential when the objective is to test a series of options, including interactions among features which have not been applied in an existing network. The network can be designed to obtain a direct measure of the effect of a change by controlling other characteristics that might impact on the designated measure. The network thus can be used to obtain performance measures under certain characteristics for several control strategies. Moreover, the results of one case can directly be compared with another because the network environment is identical.

A postulated surface street network system shown in Figure 3.1 was constructed for this study. The network is grid system, with each intersection one-quarter mile apart.



Incident takes place at node 111

Figure 3.1 Street Network in this study

Streets are all two-way with a left turn pocket of 200 ft at each intersection approach. Specification of the network and demand is illustrated in Figure 3.2.

3.3 Traffic demand and initial traffic signal setting

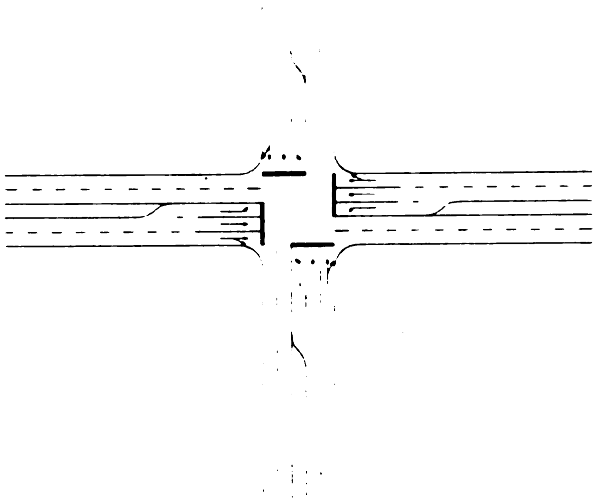
Traffic volumes were selected to be similar to the peak-hour traffic condition. The traffic volumes and the associated level of service (LOS) is shown in Table 3.1.

The initial traffic signal settings were determined from the TRANSYT signal optimization program. The program selected signal splits, offsets, and cycle length which minimizes a performance index. The performance index for this study was system-wide delay in the network. These initial signal conditions represent the optimal signal setting for normal traffic condition using the off-line technique.

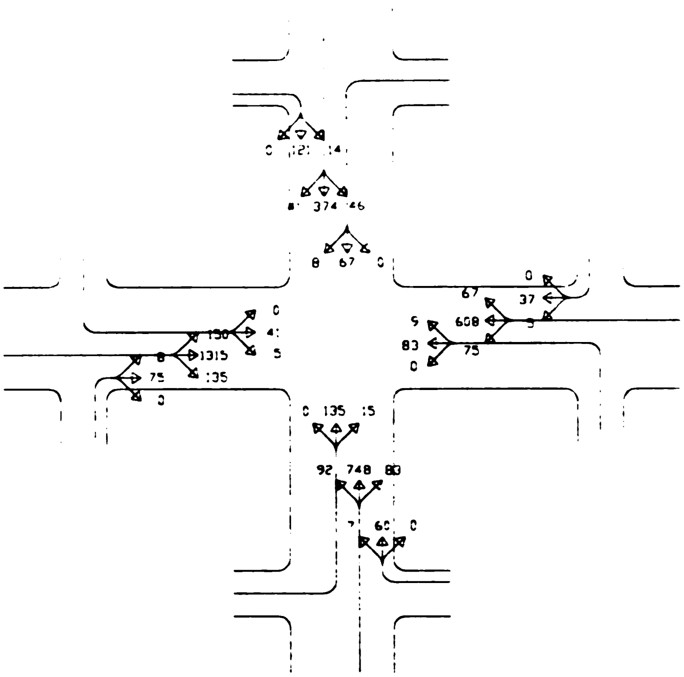
Table 3.1 Traffic demand

Traffic direction	Traffic volume (vph)	Level of service* (Intersection 10)
East Bound (EB)		
- Thru and Right turn	1350	B
- Left turn	150	E
West Bound (WB)		
- Thru and Right turn	675	D
- Left turn	75	C
North Bound (NB)		
- Thru and Right turn	900	B
- Left turn	100	E
South Bound (SB)		
- Thru and Right turn	450	B
- Left turn	50	D

Note: Levels of service are determined at optimal progression based on Synchro 2.0™ program (1995) and Highway Capacity Manual (1994).



a. Typical intersection geometry



b. Volumes at typical intersections (approximate)

Figure 3.2 Intersection geometry and volume

The LOS in Table 3.1 were determined with this optimal signal timing in place. The LOS is a qualitative indicator describing operational conditions within the traffic stream, as perceived by motorists/passengers (Highway Capacity Manual, 1985). For signalized intersections, the average stopped delay is used as a criterion for determining LOS. The delays were obtained from the Synchro™ traffic software. This model has a major advantage over the standard Highway Capacity Manual calculation method in that the model automatically determines arrival patterns resulting from the signal timings and network configuration.

3.4 Incidents

The characteristics of the incident introduced in the network must be specified. ·se characteristics include incident type, location, time of occurrence, frequency, and ..·ation. The type of incident determines the severity of the incident and thus the impacts on traffic performance. The types of incident, for example, include accidents, stalled vehicles, and minor or major roadway maintenance. The incident location characterizes the storage capacity on the street section and the time it takes to affect the adjacent intersections. The time of occurrence would change the effect because of the changing demand pattern over the day, with the most serious impact being during peak hour traffic. The duration of incident affects the congestion because it extends the time period of reduced capacity of the system.

Incidents with one-lane closure, an 85 percent reduction of the street capacity, and both-lane closure at a mid-block location were selected for study. The one-lane closure incident represents illegal parking, stalled vehicles, or one-lane roadway maintenance in the curb lane. The incident with an 85 percent reduction in the roadway capacity blocks one traffic lane and reduces traffic in the other lane. This might be a characteristic of an accident. The traffic in both lanes is assumed to pass the incident location on a first-in-first-out basis. The discharge during the incident is determined from the maximum flow at the bottleneck. The both-lane closure incident represents some serious accidents or major roadway activities which require total blockage. The range of the type and severity of the incident offers the opportunity to investigate the different impacts of selected control strategies. The location of the incident in the network is shown in Figure 3.1.

Three durations of the incident were planned for the analysis, namely 5, 10, and 15 minutes. The duration of the incidents was limited by the recovery time to normal traffic operation in the most severe case, the 15-minute both-lane closure. With this size and configuration of the network, level of demand, and location of the incident, traffic operations in the 5 and 10-minute both-lane closure incident recover within one hour after the beginning of the simulation, while it takes about one and a half hours to recover in the 15-minute both-lane closure case.

3.5 Technological scenarios and control strategies

The study was formulated to test four technologies in addition to the normal operations. The four options were:

a. Do-nothing--no special control strategies applied;

b. ATMS only--traffic metering;

c. ATIS only--traffic diversion; and

d. ATIS/ATMS--combined traffic diversion and signal timing modification.

3.5.1 Do-nothing

The do-nothing case means there is no diversion and no new control strategy applied during the incident. The signal timing remains the same as before the incident occurred.

3.5.2 ATMS only

Traffic metering was chosen to represent the ATMS only scenario. It is assumed that signals on the main arterial are responsive to the queue length. The traffic signal timing at an intersection is modified when there is a possibility that this intersection will be blocked in the next cycle. With the signal modification, traffic is released to approach the incident at the same rate that traffic is discharged at the incident location. This technique ensures that the queue on the link does not result in intersection blockage. In the both-lane blockage incident, traffic is prohibited from entering that link. The time to implement this control is determined by calculating the growth of the queue, a special sensor situated at an upstream location on the link to detect the presence of queue, or manual monitoring from surveillance cameras.

3.5.3 ATIS only

Traffic diversion represents the ATIS only scenario. Traffic diversion is a method to reduce the demand approaching an incident-caused congested area by rerouting traffic away from the incident. Diversion is the only demand restriction solution that can be applied to traffic already on the street at the time an incident takes place.

There are many mediums to implement traffic diversion. The route information can be disseminated via a dynamic route guidance system, a changeable message sign, or even police regulation. With a dynamic route guidance system, the percent of compliance to the information is one major issue. However, an assumption of 100 percent compliance is used in this study.

The diversion paths can be determined in many ways. If no information on travel time on possible diversion routes is available, then traffic can be equally distributed to parallel arterials. The simplest point of diversion is at an intersection upstream to the incident. A more sophisticated method includes the calculation of dynamic travel time on all possible paths and dynamic traffic assignment. However, this method requires information on dynamic signal controls. To date, there is no known diversion method that considers the combined effect of the adaptive signal control and dynamic traffic assignment. The diversion plan can also be determined from the results of simulation runs. . percentage of the distribution to adjacent parallel arterials can be set to yield the minimum total travel time.

3.5.4 ATIS/ATMS

The traffic diversion combined with the signal modification on the diversion route is selected for this category. While there are several methods to initiate a signal modification, the signal setting based on degree of saturation is chosen in the initial case. The degree of saturation control variable is a well-accepted method of signal control setting. In theory, Webster used this criterion for his signal split determination. In practice, several urban traffic control systems such as SCATS and SCOOT have adopted this method in their signal modification.

At each intersection green splits can be determined independently according to the local demand. In many "reactive" traffic controllers such as the SCATS strategic control level, local traffic patterns in a previous cycle are used to determine the split settings. Traffic counts are then translated to the degrees of saturation (DS). The degree of saturation is the ratio of the actual amount of green time utilized by traffic to the ideal (minimum) amount of green time which could serve the same amount of traffic. The DS can also be viewed as a measure of unused green time and the minimization of the unused green time means the lowest intersection delays.

3.6 Measures of effectiveness (MOEs)

Several MOEs that are appropriate for use in characterizing the control of incident congestion were used. To be useful, the MOEs must be understandable and easy to obtain. Moreover, the MOEs must reflect the objectives.

Indicators related to stops, delays, travel time, and productivity are used for this incident congestion management. These MOEs can be drawn from general MOEs suggested by Pignataro et. al. (1978).

The MOEs used in recurrent and nonrecurrent traffic conditions are different due to different desired objectives. The incident congestion also requires some MOEs which may not be the same as recurrent conditions.

The MOEs selected for this study are:

a. Total travel time;

b. Delay time;

c. Queue time;

d. Time to dissipate the congestion; and

e. Duration of spillbacks.

3.6.1 Total travel time

Total travel time is the sum of the travel time for all individuals completing their trips. This measure considers number of motorists, distance of travel, speed, and delay associated with the travel. In the diversion versus non-diversion cases, this MOE can be used to determine whether the time saved due to lower delay on the diversion route exceeds the increased travel time due to the longer distance on the diversion route. The total travel time may be the most appropriate indicator for a system operator, who seeks the minimum overall system-wide travel time.

3.6.2 Delay time

Delay is a very good MOE in that it reflects the traffic operation as perceived by system users. Overall delay over a period of time reflects the efficiency of the system without considering the impact on individuals. Some control strategies such as gating are designed to sacrifice some traffic movements in order to yield higher overall productivity and the impact of this strategy can be reflected in this MOE. This MOE, however, may not be appropriate for comparing diversion and non-diversion control strategies as the total delay does not consider the increased distance on the diversion routes.

3.6.3 Queue Time

Queue time is similar to delay time except it considers only the period of time vehicles spend in a standing or moving queue. Normally the queue time is a proportional to the delay time. However, in NETSIM, queue time is recorded at any time whereas the delay time is collected only when a vehicle departs a link. With this reporting characteristic, the queue time is a good representation of the congestion currently on the streets.

3.6.4 Time to dissipate congestion

This MOE is useful for describing the effect of congestion on traffic conditions as a whole. One of the objectives of congestion management is to clear the congestion as soon as possible. This indicator reflects the impacts of a control strategy on congestion duration. However, this MOE is very difficult to measure in the field due to the fact that it depends on how congestion is defined. In the NETSIM model, this MOE is not directly available but a surrogate measure can be determined from the increased queue time on each link. The queue time as a result of an application of a control strategy can be compared with the queue time under normal traffic condition to find the duration of congestion due to the incident and control strategy.

3.6.5 Duration of spillbacks

The duration of spillbacks roughly indicates the duration time of the congestion. When spillbacks occur following an incident situation, these cause a breakdown in the system. Spillbacks generate intersection blockages and make the congestion spread very quickly. The end of spillback duration in the system is a measure of the quickness of the action to relieve congestion.

3.7 Study plan

The study scheme for this research was designed to test the impact of the control strategies under technological scenarios and variations in traffic flows. A set of control strategies were selected to represent the technological groups and a detailed analysis of the effect of these controls on the traffic were performed. Subsequently, alternate signal control strategies as well as diversion alternatives were included in the experiment to seek better results under selected incident situations. Sensitivity analyses of the base case traffic parameters were conducted to determine the impact of these controls on changing traffic characteristics. The study plan is shown in Figure 3.3.

3.8 Summary

The experiment was designed to test control strategies on a hypothetical network using the NETSIM program. The base traffic demand represents the peak period, with the approximate overall network LOS C. The normal traffic was operating with optimal signal timing obtained from an off-line calculation. Incidents at mid-block with one-lane closure, both-lane closure, and two-lane closure which reduces the capacity to 15 percent of its original were introduced in this experiment. Four technological scenarios depicting no-change in traffic control, the deployment of ATMS alone, ATIS alone, and the combined ATMS and ATIS were studied. Traffic metering, traffic diversion, and traffic responsive control strategies were designed in the analysis.

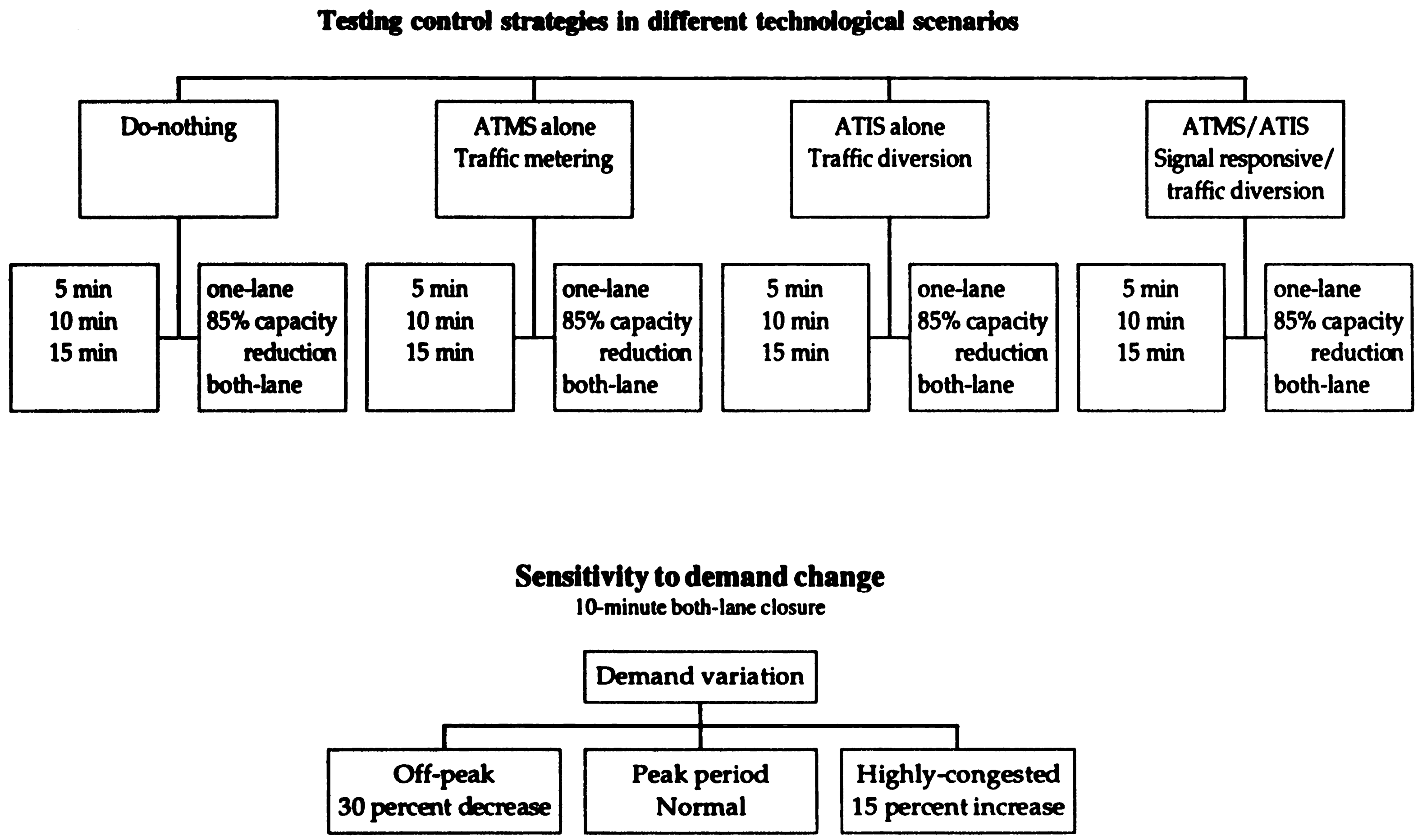


Figure 3.3 Study plan

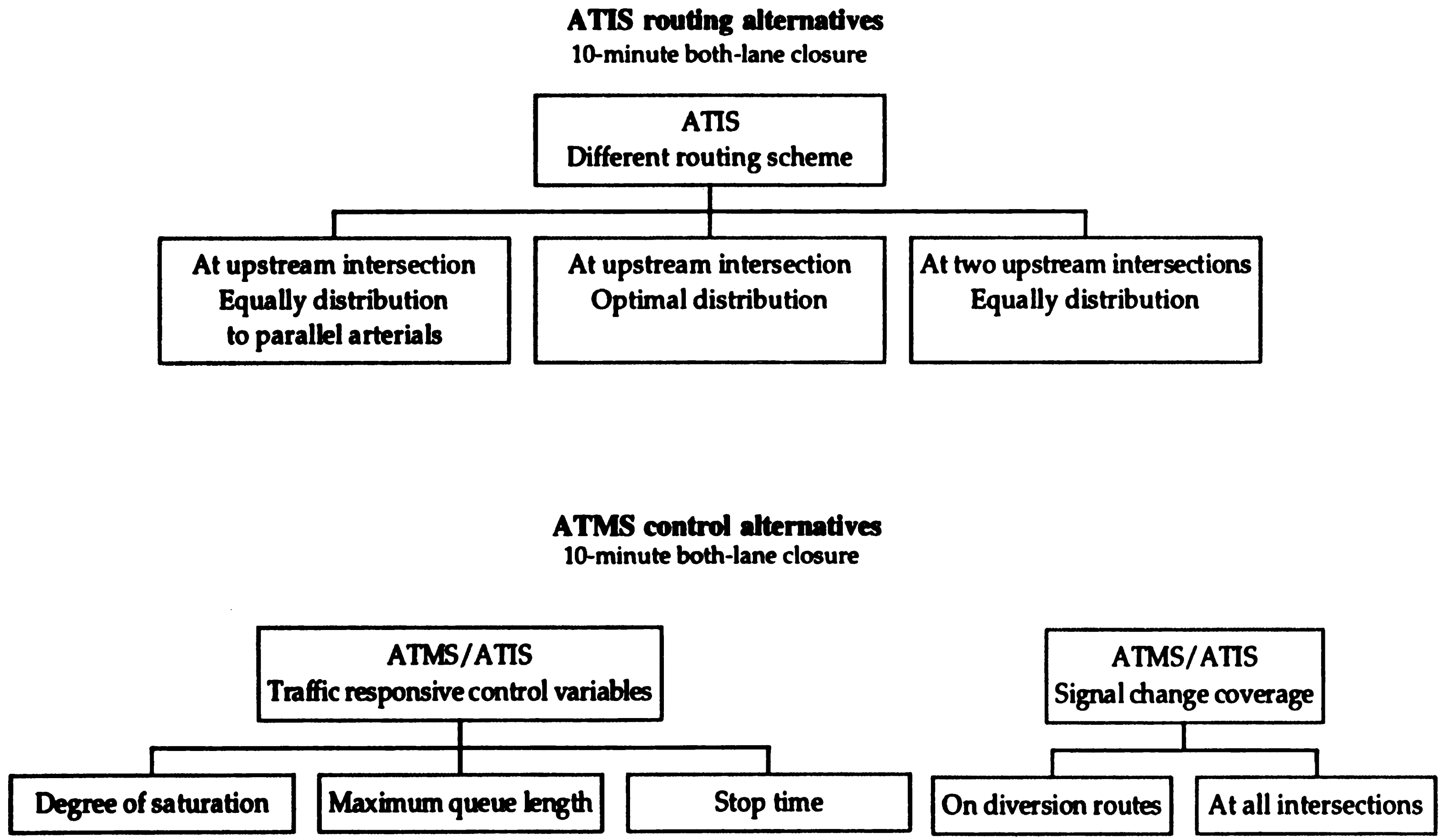


Figure 3.3 (cont'd)

Chapter 4

SIMULATION ANALYSIS AND RESULTS

The NETSIM model was used to simulate traffic conditions under several control scenarios. Measures of effectiveness (MOEs) from the program were collected and compared. The first section described traffic conditions when incidents were introduced. Then various control strategies were tested on the same incident situations and their MOEs were compared.

4.1 Effect of type and duration of incident

Table 4.1 shows the effect of different types and durations of incidents on traffic operations when there is no change in traffic control. The three types of incidents have a significant difference in their effect on traffic congestion as measured by travel time, intersection blockage and congestion duration. They also have different impacts on different traffic streams.

4.1.1 Total travel time

As shown in Table 4.1, the one-lane closure incident produces no discernible impact on traffic operations at this demand level because traffic on the blocked lane is able to switch to the other lane.

Table 4.1 Total travel time in the network under incidents

Incident type	Total travel time in one hour (veh-hrs)			
	Incident duration (minutes)			
	0 (no incident)	5	10	15
One-lane closure	774.3	774.3	774.2	774.3
85% reduction in capacity	774.3	779.2	793.8	841.4
Both-lane closure	774.3	788.3	882.5	1193.3

In the 85 percent reduction of capacity and both-lane blockage situations, total travel time increases exponentially as the duration of the incident increases. Traffic passing an incident which reduces the capacity at the bottleneck to 15 percent of its original capacity must stop and wait in a queue before proceeding past the incident. Traffic proceeding through the both-lane closure incident must stop until the incident is cleared.

As expected, traffic experiences longer delay when the duration and severity of an incident increase.

4.1.2 Intersection blockage

The increase in total travel time is exacerbated by spillback (intersection blockage) on approaching links and adjacent arterials. The spillbacks and durations are shown in Table 4.2.

In the 85 percent capacity reduction incident situation, an intersection blockage occurred at the nearest upstream intersection at 326 seconds after the incident started. The

Table 4.2 Start and end time of intersection blockage: various incident types and durations

Intersection number	Time of spillback occurrence after incident (sec)					
	Incident duration (minutes)					
	5		10		15	
	Begin	End	Begin	End	Begin	End
85% reduction in capacity*						
10	326	335	326	636	326	936
9	n/a	n/a	n/a	n/a	917	1132
Both-lane closure						
10	212	337	212	648	212	974
9	n/a	n/a	602	725	602	1020
409	n/a	n/a	n/a	n/a	879	1089
14	n/a	n/a	n/a	n/a	721	981
13	n/a	n/a	n/a	n/a	824	898

Note: * The intersections are periodically cleared during the spillback periods.

blockages at this intersection ended in 9, 310, and 610 seconds after the initial blockage for 5, 10, and 15-minute incidents respectively. Blockage at the prior upstream intersection also occurred in the 15-minute incident situation, starting at 917 seconds after the incident was introduced and lasting for 215 seconds. However, these upstream intersections were intermittently clear as traffic was released at the incident location or at the downstream intersection. The total duration of blockage was 8, 118, and 237 seconds at the nearest intersection for 5, 10, and 15-minute incidents and 46 seconds at the second nearest intersection for the 15-minute incident situation.

In the 5-minute both-lane closure incident situation, the blockage at the nearest upstream intersection started at 212 seconds after the incident was introduced, and lasted for 125 seconds. In the 10-minute incident situation, the blockage started at the nearest upstream intersection at the same time as in the 5-minute incident situation but lasted for 436 seconds, and the blockage at the prior upstream intersection began at 602 seconds after the incident started and ended 123 seconds later. The blockage at the nearest upstream intersection in the 10-minute incident situation lasted longer than in the 5-minute incident situation because of the presence of the traffic queue waiting at the entry of the link.

The 15-minute both-lane closure incident caused spillbacks on five road sections, three of which were located on the street where the incident occurred and two of which were situated on a parallel arterial. On the arterial leading to the incident, the blockages were initiated at 212, 602, and 879 seconds after the incident, and lasted for 762, 418, and 210 seconds, respectively from the nearest to the furthest intersection. One intersection on a side street (intersection 14 in Figure 3.1) was blocked starting 721 seconds after the incident and lasting for 260 seconds. This secondary congestion is the result of the blockage at the nearest upstream intersection to the incident (intersection 10). One intersection on a parallel arterial (intersection 13) experienced spillback caused by the blockage at intersection 14. The blockage on this intersection started 824 seconds after the incident and lasted for 74 seconds.

4.1.3 Congestion duration

The time period and lateral extent of congestion in the network can be determined from an analysis of queue time statistics available from the standard NETSIM outputs. While delay is the primary MOE used in this analysis, the output from the NETSIM model is not suitable for using this measure as a basis for tracking the spread of congestion through the network. Figure 4.1 demonstrates why delay from the standard NETSIM outputs cannot be used. This is because the delay for individual vehicles are collected when they leave a link. Thus, during an incident that closes a link, the delay would go to zero, even though vehicles are queued on that link. This output attribute results in high delay being reported after the incident is cleared. As shown in Figure 4.1, the 10-minute both-lane closure incident was cleared at 900 seconds after the simulation started. The incident caused a blockage at the downstream intersection and hence no traffic departed the link between the 902nd and 1020th second after simulation. The delay was reported when the spillback dissipated as shown by the high delay between the 1000th and 1500th second. Travel time from NETSIM also has the same reporting characteristic as the approach delay.

A more appropriate measure for determining the spread of congestion is stopped delay. The stopped delay curve in Figure 4.1 was calculated from queue lengths obtained every four seconds. The queue length is illustrated in Figure 4.2. The queue time from the standard NETSIM output is found to be highly correlated with the queue length and stopped time delay and thereby suitable for identifying the congestion period. It is noted that the shape of the three curves shown in Figure 4.1 are different because of their definitions.

The effect of incident type and duration on the length of the network-level congestion periods is shown in Figure 4.3. All incidents started at 300 seconds after the beginning of the simulation. In the 85 percent capacity reduction incident situation, the traffic operations returned to normal at time 400, 900, and 1400 seconds after the

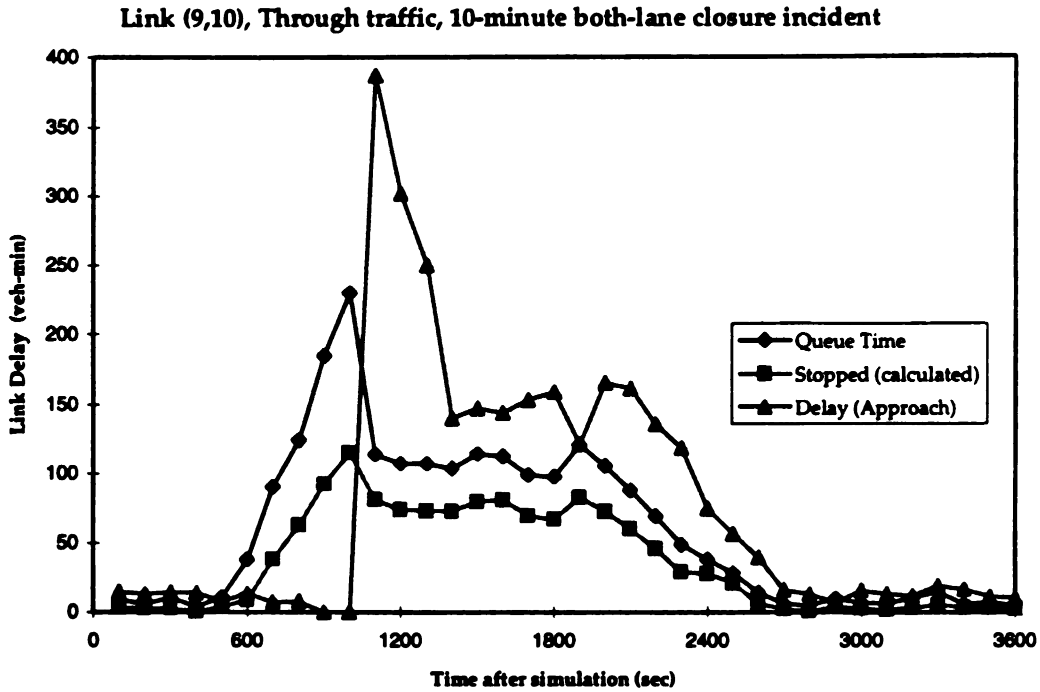


Figure 4.1 Statistics from NETSIM for determining congestion period

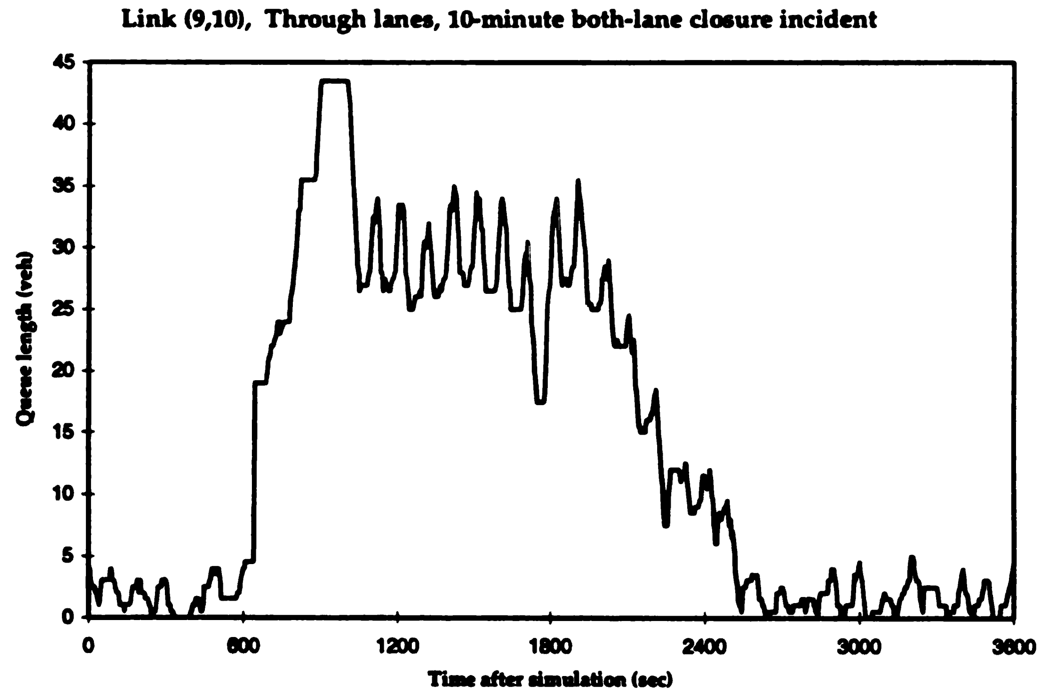


Figure 4.2 Queue length obtained every four seconds

a. 85 percent capacity reduction incident

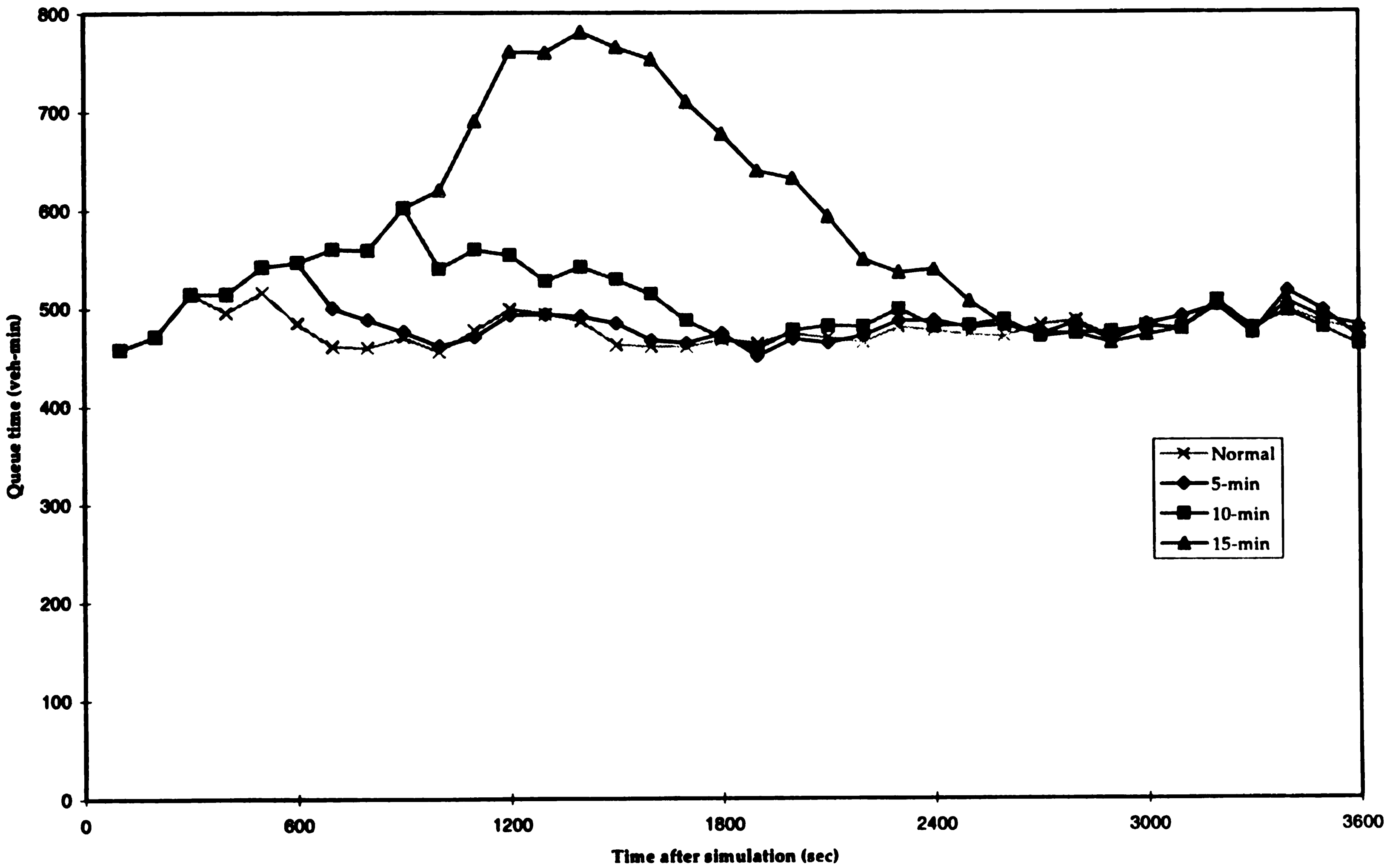


Figure 4.3 Congestion duration: no control change

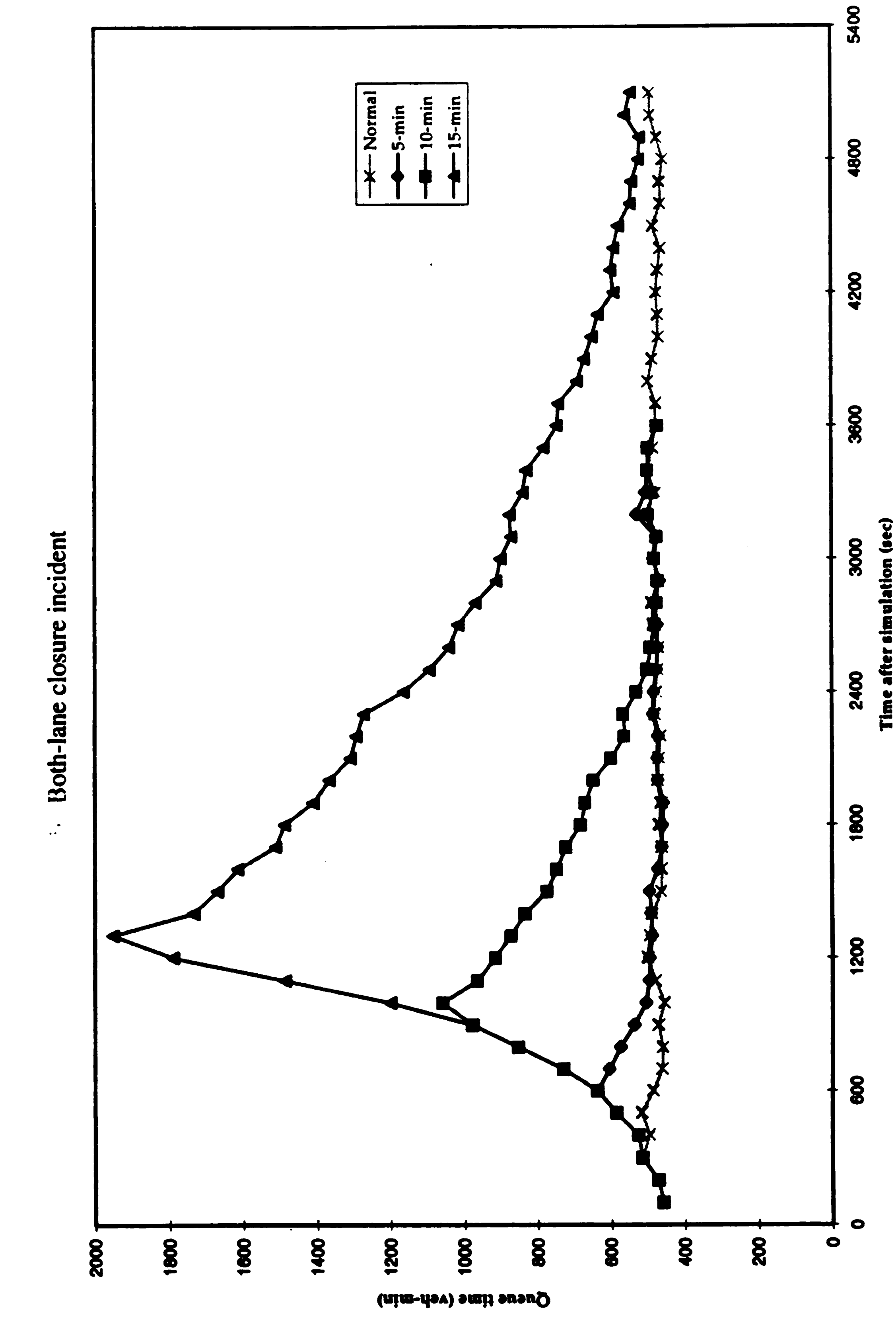


Figure 4.3 (cont'd)

incident was cleared, for the 5, 10, and 15-minute incident respectively. With the same order of incident duration, the both-lane closure incident congestion periods lasted 600, 1900, and 3900 seconds after the incidents were removed.

The spread and duration of congestion in the network can be presented as illustrated in Figure 4.4. The queue time of all vehicles in a link is used to determine the congestion period. The congested links in the network are plotted over time to determine the congestion coverage and duration. In the 10-minute both-lane closure incident situation, intersection blockages created congestion on both the street where the incident occurred and the nearby north-south streets. After the incident is cleared and the spillback dissipated, links downstream from the congested links receive heavy traffic and become congested. This is illustrated in Figure 4.4a.

Figure 4.4b shows the congestion caused by the 15-minute both-lane closure incident. Congestion occurs on the mainstream approaching the incident as well as on a parallel arterial. Although the congestion starts to dissipate on the upstream links within 5 minutes after incident is cleared, the spillbacks produce major congestion on approaching links as well as downstream links well after the incident is cleared. The congestion in the network lasted for 80 minutes after the incident was introduced.

4.1.4 Delay on different traffic streams

To better understand the effects of the various lane blockages, an analysis was made to determine the relative delay to various traffic streams in the network. This information is essential in determining the control strategies to be used in reducing the impact of an incident. Table 4.3 shows total travel time of through traffic on the path

a. 10-minute both-lane closure incident

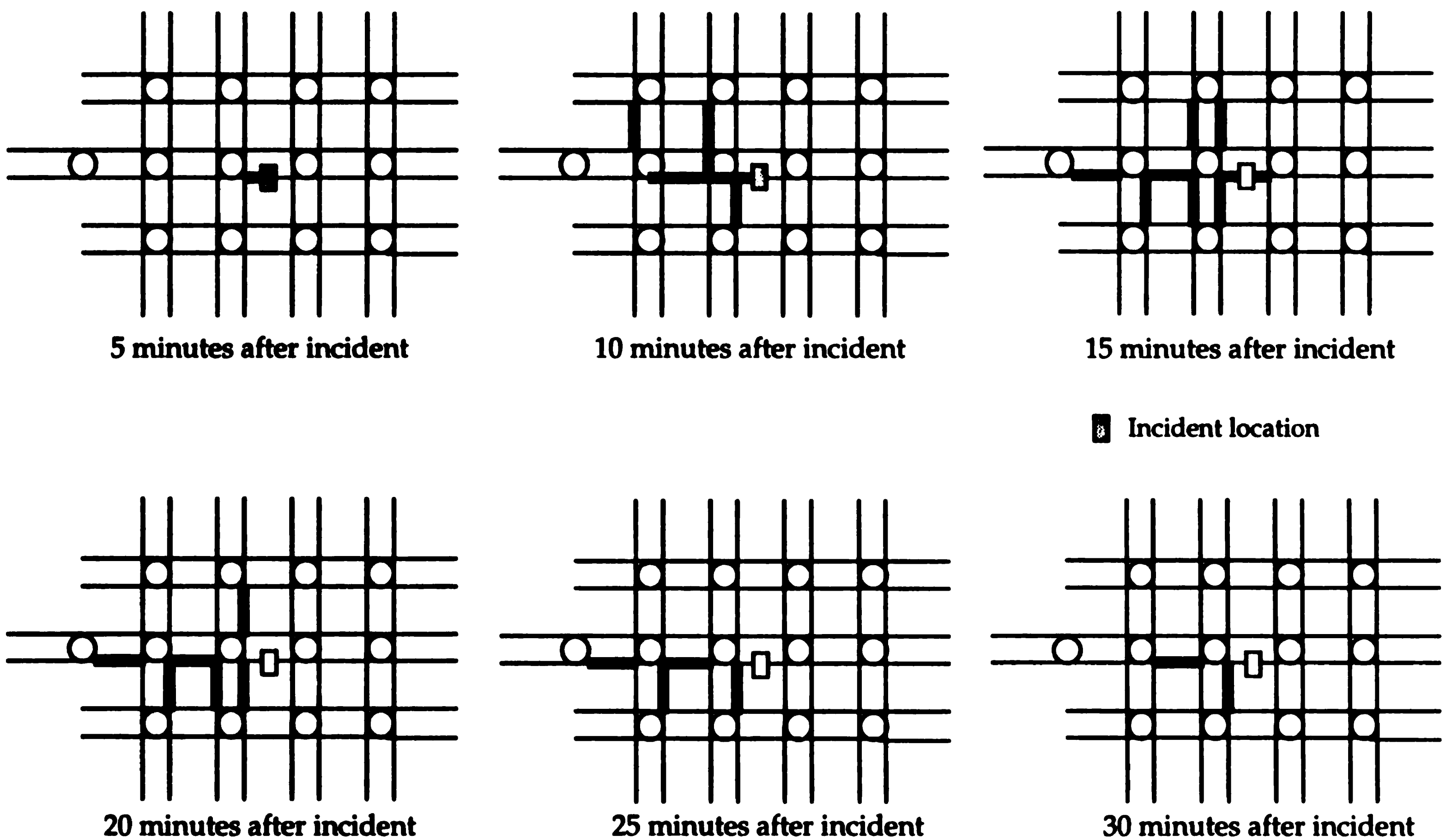


Figure 4.4 Affected links and duration of congestion: no control change

b. 15-minute both-lane closure incident

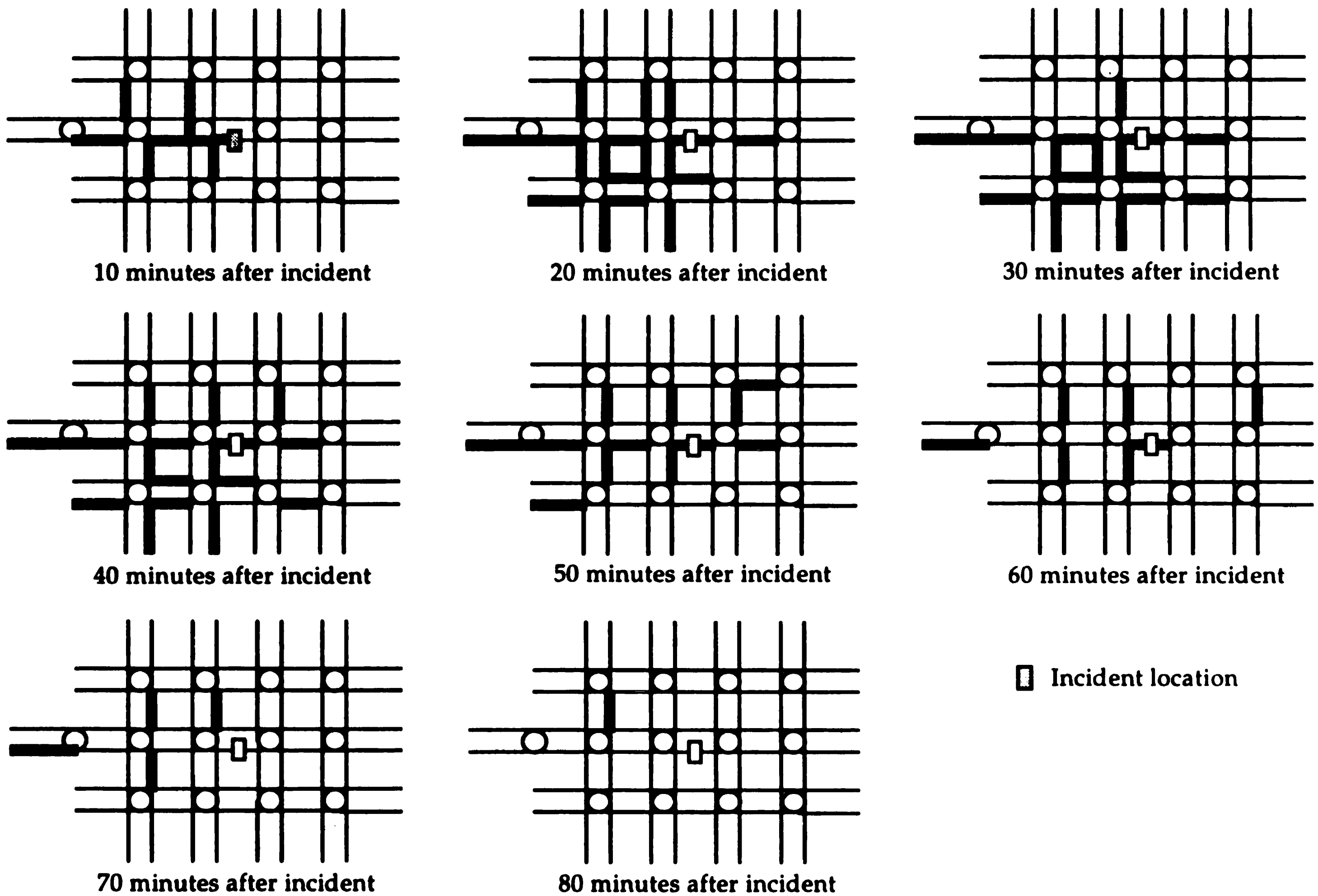


Figure 4.4 (cont'd)

Table 4.3 Total travel time of traffic passing the incident
(traffic heading from intersection 409 to intersection 12)

Incident type	Total travel time in one hour (veh-hrs)			
	Incident duration (minutes)			
	0 (no incident)	5	10	15
One-lane closure	62.4	62.4	62.3	62.4
85% reduction in capacity	62.4	64.9	77.3	102.7
Both-lane closure	62.4	78.7	115.7	152.8

approaching the incident. The results reveal the same trend as Table 4.1 with travel time increasing as the incident duration increases. However, there were some differences in the impact on this traffic stream versus the impact on the entire network. Table 4.3 indicates that the journey time on this through route in the 10-minute 85 percent capacity reduction incident situation is lower than the journey time for a 5-minute both-lane closure incident (77.3 vehicle-hours compared with 78.7 vehicle-hours). However, the total travel time of all traffic in the 10-minute 85 percent capacity reduction incident situation (793.8 vehicle-hours) is higher than that of the 5-minute both-lane closure incident (788.3 vehicle-hours). This means that the 10-minute 85 percent capacity reduction incident causes greater traffic interruption in non-affected traffic streams than the 5-minute both-lane closure incident, although the spillback duration in the first situation is shorter.

As shown in Table 4.3, the 15-minute both-lane closure incident creates widespread congestion in the network. For this incident, the increase in travel time on the path passing the incident contributes a smaller proportion of the overall network travel time than in the other cases.

4.2 Effect of different control strategies

After determining the effect of an incident on traffic with no change in traffic control, different types of control strategies were tested and the impacts were measured. This simulation experiment allows the testing of these control strategies alone as well as the combination of two or more controls. In this study, the impact of the control strategies in three different ITS technological groups were determined. The experiments were performed on several incident types and durations.

The 85 percent capacity reduction and both-lane closure incidents were selected as the base cases for determining the effect of different control strategies because they cover a wide range of congestion levels and offer the opportunity to experiment with various controls. Since one of the objectives of this study is to compare alternative control strategies without traffic diversion, with diversion alone, and a combination of diversion and traffic control, total travel time is a good indicator of performance because it includes the effect of longer route distances resulting from diversion.

4.2.1 Total travel time

Four major traffic control scenarios were tested and compared. The total travel time of all links in the network for these different scenarios is shown in Table 4.4.

Traffic metering in the partial lane closure incident situation consists of gating at the intersection immediately upstream from the incident. Traffic is released to approach the incident at a rate equal to 15 percent of the link capacity so that no growing queue

Table 4.4 Total travel time for four control strategy scenarios: 10-minute both-lane closure incident

a. 85 percent capacity reduction incident

Scenario	Total travel time in one hour (veh-hrs)		
	Incident duration (minutes)		
	5	10	15
No traffic control change	779.30*	793.80	841.40
ATMS: traffic metering	781.79	792.99*	821.74
ATIS: traffic diversion	783.56	803.99	820.00*
ATIS/ATMS: traffic diversion with signal change (equalization of degree of saturation)	789.19	804.76	823.27

b. Both-lane closure incident

Scenario	Total travel time in one hour (veh-hrs)		
	Incident duration (minutes)		
	5	10	15
No traffic control change	788.30	882.50	1193.30
ATMS: traffic metering	787.55*	847.68	942.20
ATIS: traffic diversion	788.45	826.01*	869.76*
ATIS/ATMS: traffic diversion with signal change (equalization of degree of saturation)	794.96	839.75	931.83

Note: * indicates the lowest total travel time for an incident situation developed. In the total-lane closure incident, traffic metering is set at a rate which keeps the intersection from being blocked by a queue. The green phase is skipped when the queue stored on any receiving link is full.

ATIS traffic diversion is the assignment of traffic to adjacent arterials to avoid the incident. Traffic is distributed equally between two adjacent parallel routes at the nearest upstream intersection to the incident. The middle through lane can be used by both left and right-turn traffic. No signal adjustment is made in this scenario.

In the ATIS/ATMS scenario, signals along the diversion routes are modified every cycle, using traffic data of the previous cycle. The signal control change in the ATIS/ATMS scenario attempts to equalize degrees of saturation of all approaches at each intersection. This logic is similar to a SCATS network with no system level control. No offset change was made in these initial simulation runs.

The results from Table 4.4a indicate that traffic metering control yields longer total travel time than the do-nothing condition in the 5-minute incident situation. The increase in travel time is caused by the fact that gated traffic has to wait at the upstream link for approximately one cycle (100 seconds), while the spillback occurs for only 9 seconds (Table 4.2). In this situation, it is better to let the spillback occurs for a short time period. Traffic metering in the 10 and 15-minute incident situations results in an improvement over the do-nothing cases.

The traffic metering strategy in the 5 and 10-minute incident situation gives shorter travel time than traffic diversion. This implies that the longer travel distance caused by the diversion is greater than the time waiting in the queue at the upstream link. In the 15-

minute incident situation, the traffic metering gives slightly higher travel time than traffic diversion alone.

In the 85 percent capacity reduction incident cases, traffic diversion in the 5 and 10-minute incident situations does not improve the overall travel time. This is because the diverted traffic has a greater increase in total time than the delay savings to the traffic impacted by the incident if they had remained on their original travel path in these incident situations. Since traffic can be partially released at the incident location, the system performs better if vehicles wait to get through the incident than if they reroute to adjacent streets. Although the 5 and 10-minute incidents create periodic blockage at the upstream intersection(s), spillbacks are relatively short. The rerouting produces traffic disruption at other intersections, creating higher delays to traffic on the diversion paths, and on overall network performance. In the 15-minute incident, however, diversion leads to lower network travel time as the blockage and waiting time to pass the incident adversely affect the network operation.

Traffic diversion alone yields the lowest travel time for the 15-minute incident. The addition of ATMS control increases total travel time slightly over the traffic diversion only case.

The ATIS/ATMS control creates higher total network travel time than traffic diversion alone for all three incident durations. In fact, in the 5 and 10-minute incident situations, changing signal timing causes higher delay than the no-control change scenarios.

For the both-lane closure incident (Table 4.4b), traffic metering improves the traffic operations over the no control change situation. The level of improvement increases as the duration of the incident increases.

Traffic diversion does not lower total travel time for the 5-minute incident situation. However, for the 10-minute and 15-minute incident, this control decreases the total travel time. The reduction is 27 percent from the no-control change situation for the 15-minute incident since the diversion eliminates all intersection blockages.

The addition of ATMS to the ATIS does not reduce the total travel time for any of the incident durations.

4.2.2 Intersection blockage

All traffic control strategies eliminated intersection blockage. The traffic metering at the upstream intersection cut off the green light of the congested direction before the back of the queue reached. In the diversion situation, traffic was re-routed before the queue blocked the upstream intersection.

4.2.3 Congestion duration

The duration of congestion is another measure used to express the impacts of these control strategies. As discussed in Chapter 3, the queue time was an appropriate measure to identify the beginning and the end of the congestion period for the no control change scenarios. However, because there is increased travel distance in the diversion control strategies, queue time may be the best measure to determine the congestion period, but the total travel time is a measure of traffic efficiency for these control strategies.

The 10 and 15-minute both-lane closure incidents were selected for this analysis. The effect of different control strategies on congestion duration is shown in Figure 4.5. In the 10-minute incident, the overall congestion ends 1900 seconds after the incident is cleared if there is no control change. Traffic metering causes longer congestion duration than the no control change situation by 200 seconds. This is because traffic metering, although it successfully eliminates the spillback , stores traffic in the network to postpone the surge of heavy congestion. It spreads the congestion peak but does not reduce the congestion duration. On the other hand, the ATIS alone and the ATIS/ATMS control strategies alleviate the congestion 800 seconds sooner than the do-nothing case.

In the 15-minute incident, the no control change creates congestion until 3500 seconds after the incident is removed. The traffic metering shortens the congestion duration over the do-nothing case by 700 seconds. The ATIS/ATMS shortens the congestion period by 1600 seconds over the no control change case. Diversion alone eliminates the congestion period 500 seconds sooner than the ATIS/ATMS, or 2100 seconds sooner than the do-nothing case.

The extent of the congestion is shown in Figure 4.6. The 10-minute both-lane closure is chosen in the analysis. The traffic metering strategy produces heavy traffic on the link approaching the incident, as these links are designated to store the spillback (Figure 4.6a). Traffic diversion creates heavier traffic on diversion routes during the rerouting, but the duration is much shorter, as noted above (Figure 4.6b). The diversion with signal modification produces higher delay on approaches to the intersections on the diverted paths because green time is taken away from other direction for the diversion

a. 10-minute both-lane closure incident

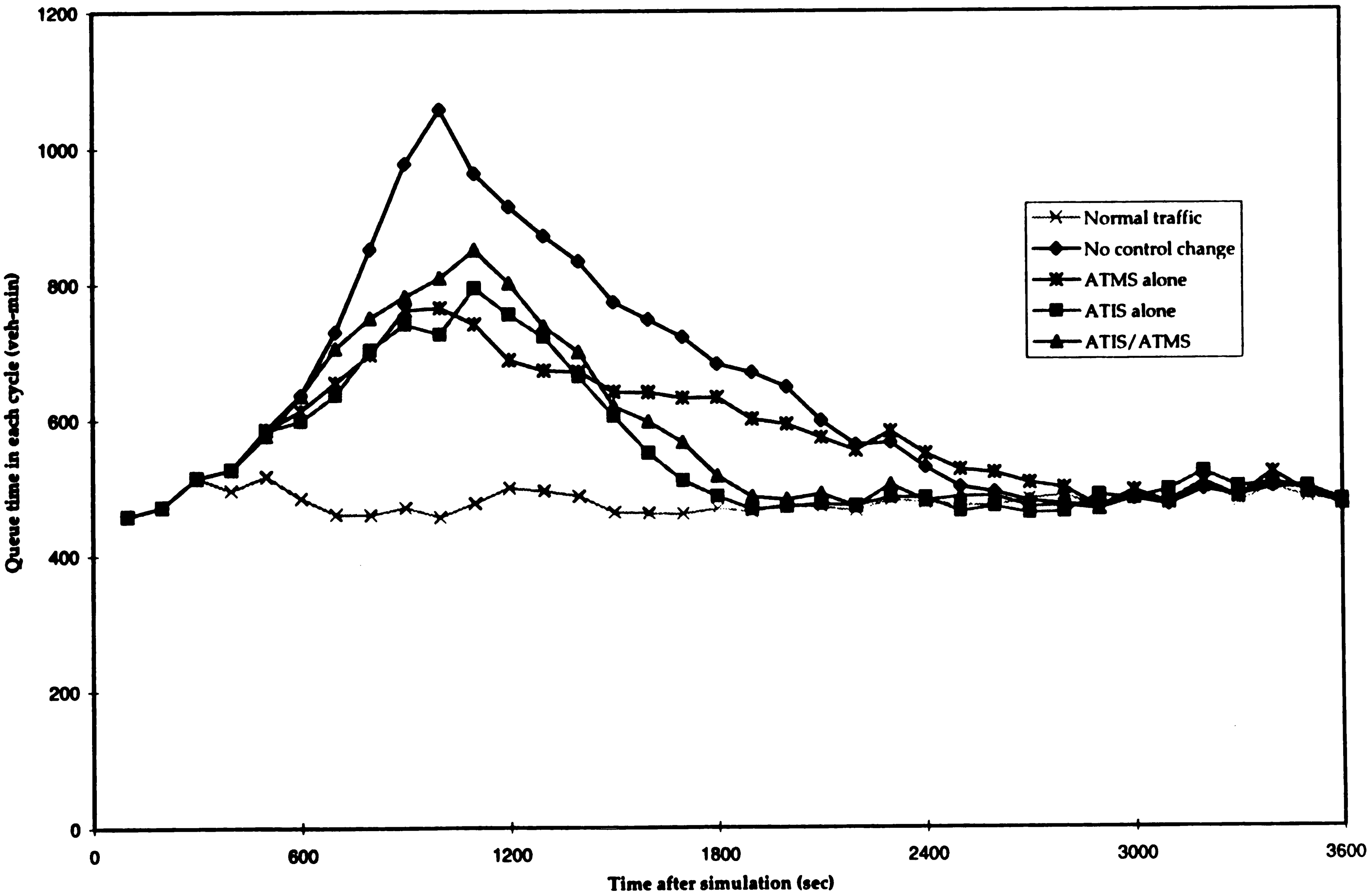


Figure 4.5 Congestion duration: different control strategies

b. 15-minute both-lane closure incident

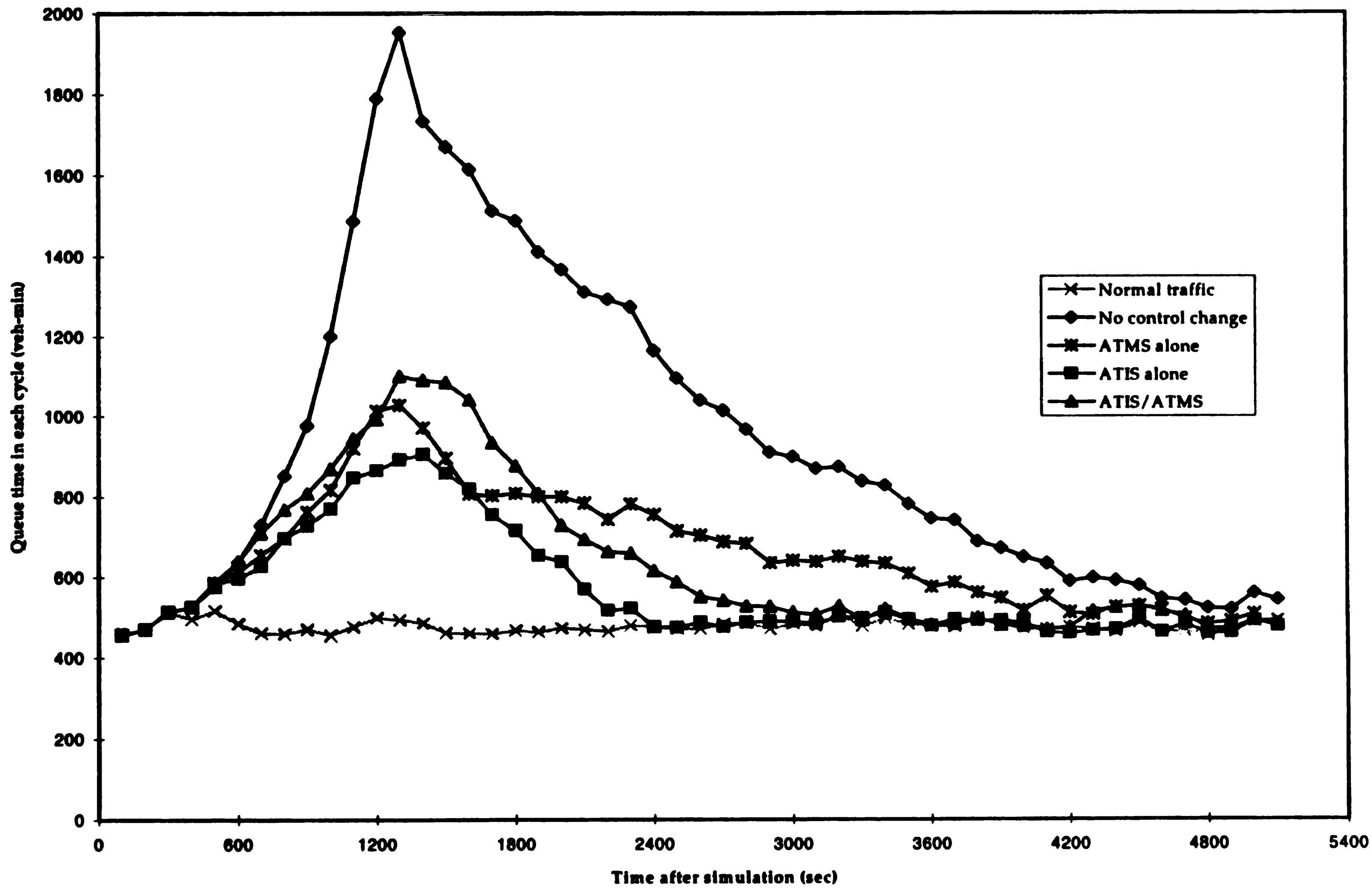


Figure 4.5 (cont'd)

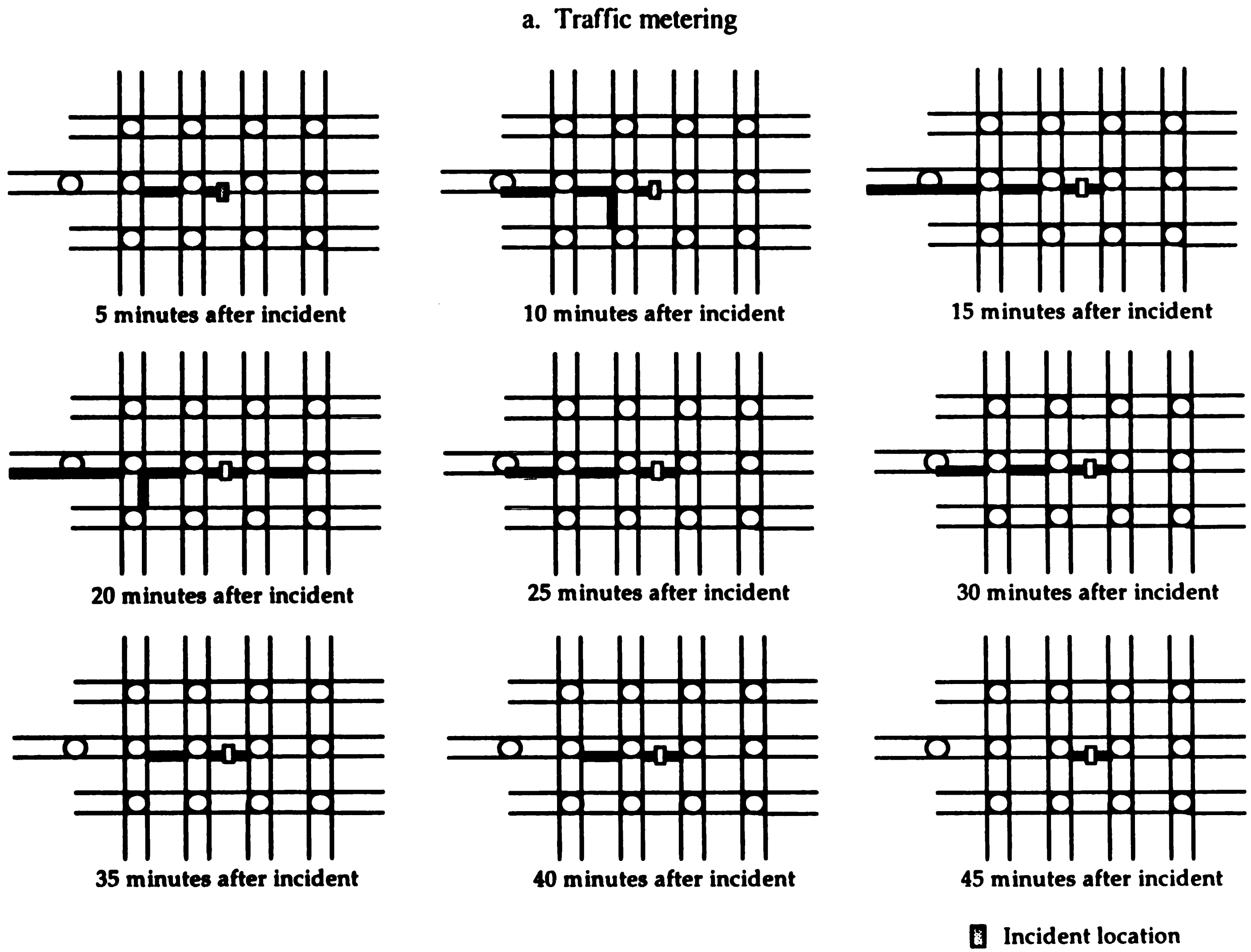


Figure 4.6 Affected links and duration of congestion: different control strategies

b. Traffic diversion

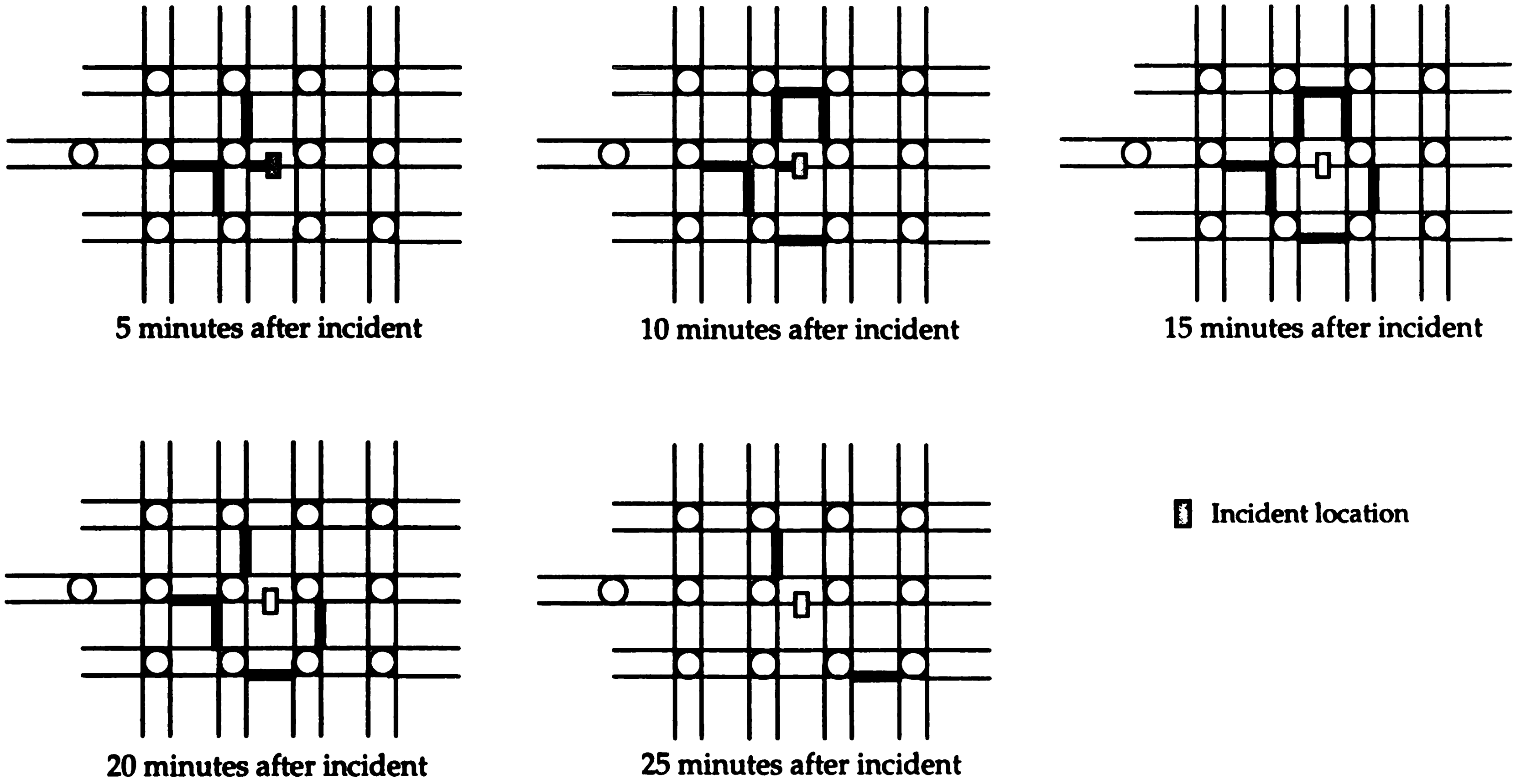


Figure 4.6 (cont'd)

c. Signal timings modification and traffic diversion

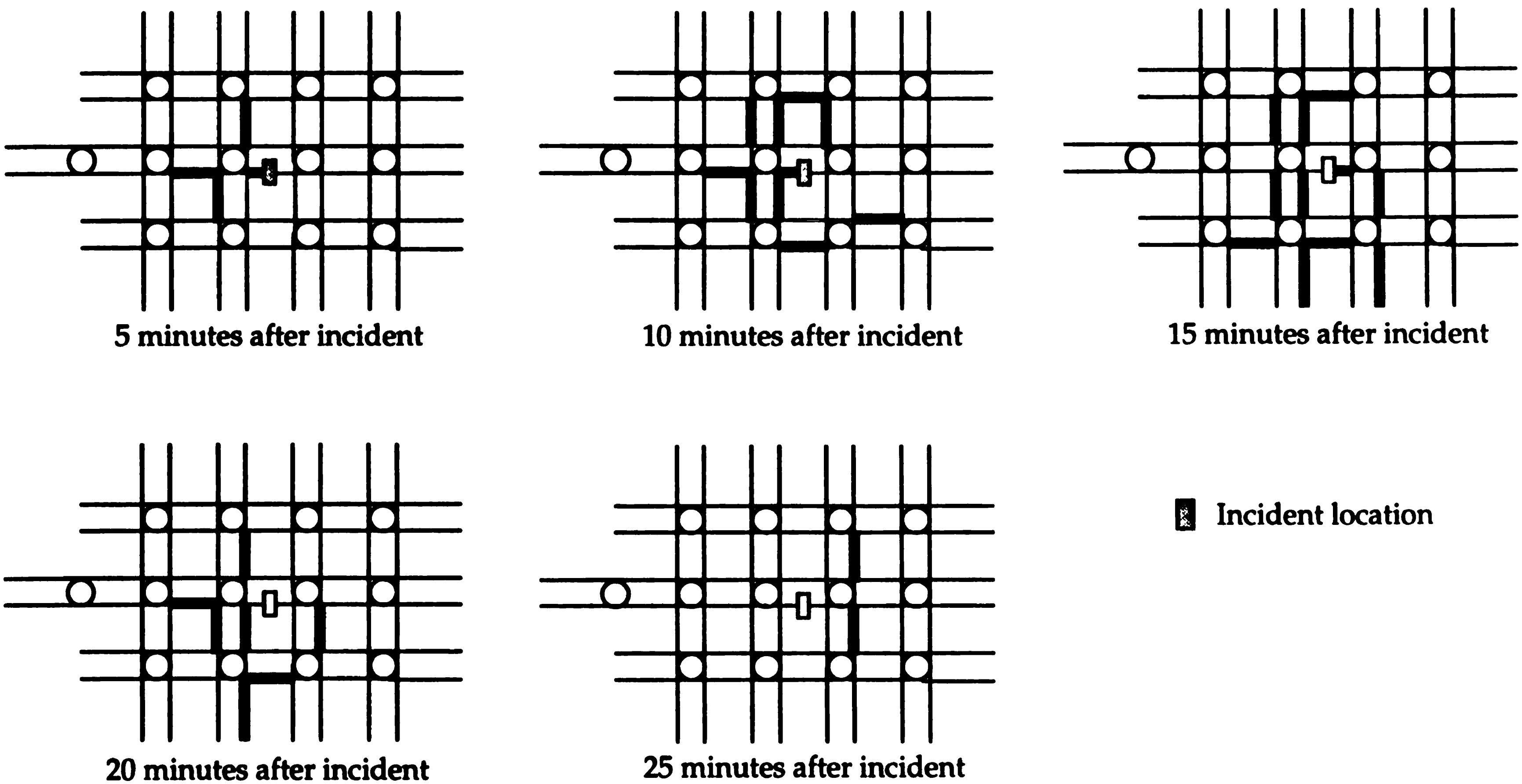


Figure 4.6 (cont'd)

routes. The termination of signal modification after the incident is cleared creates heavy traffic on the downstream links at rerouted intersections (Figure 4.6c).

4.2.4 Delay on different traffic streams

An analysis of the impact of these control strategies on different traffic groups was performed since each control strategy provides different treatments to traffic groups. It is possible that a control treatment would give an advantage to a specific traffic group and sacrifice others, and total travel time alone cannot distinguish the impact on different traffic groups. Therefore, the data for MOEs of specific traffic groups were obtained and analyzed.

The traffic was divided into three groups, based on the potential for different impacts resulting from the control strategies. They were:

a. Rerouted traffic;

b. Traffic competing with the rerouted traffic on diversion route(s); and

c. Traffic at other intersections.

MOEs for these traffic groups were measured to determine the impact of ATIS/ATMS and ATIS only control strategies. Table 4.5 displays the results of this analysis. As expected, the delay in making left turns for the diverted traffic is reduced under ATMS control as the queue of these vehicles increased the degree of saturation for this movement, resulting in an increased allocation of green time. However, the delay to traffic in other directions, which are competing with the diverted traffic, increases as a result of this reallocation of green times. Traffic in other locations also suffer higher delay due to the interruption of progression caused by the signal adaptation. This interruption

Table 4.5 Total travel time of particular traffic groups: both-lane closure incident

Link Group	Total travel time in one hour (veh-hrs)					
	Incident duration (minutes)					
	5		10		15	
	Diversion only	With signal change on diversion routes	Diversion only	With signal change on diversion routes	Diversion only	With signal change on diversion routes
Links on diversion routes where traffic makes						
Left turn	9.03	8.93	18.82	15.33	38.29	24.71
Right turn	7.85	8.42	11.33	11.55	17.55	19.69
All links approaching intersections at which traffic is diverted	342.17	347.62	377.53	379.59	376.55	447.67
All other links	429.40	429.98	418.33	433.28	437.37	439.76
Total	788.45	794.96	826.01	839.75	869.76	931.83

of traffic in other directions is the main contributor to longer overall travel time in the ATIS/ATMS scenario than in the ATIS alone scenario.

4.3 Summary

With the initial traffic and network condition in this study, the one-lane closure did not affect traffic performance because the level of the demand was well below the reduced capacity at the incident location. However, the 85 percent capacity reduction and the both-lane closure did affect traffic operations. The longer the incident duration and the more severe the incident, the more impact on the network travel time. The traffic stream passing the incident had the greatest increase in delay, although other directions were delayed by the spread of congestion.

Control strategies tested in this research had different effects on the incident-based congestion. Traffic metering reduced travel time in the both-lane closure incident situation and the longer duration of the 85 percent capacity reduction scenario. However, this control did not have a major impact on the reduction in the length of the congestion period.

Traffic diversion did not improve the traffic operation in the incident situations which had short duration (5 and 10 minutes in the 85 percent reduction, and 5 minutes in the both-lane closure). Traffic diversion was effective in the 15-minute partial lane closure, and the 10 and 15-minute both lane closure scenarios. It reduced the network total travel time despite the fact that some vehicles had to travel longer distances. Diversion shortened the congestion period compared to the do-nothing case.

The traffic diversion with signal change along the diversion routes was not effective in the 5 and 10-minute 85 percent capacity reduction, and the 5-minute both lane closure incident situation. Although this control tended to favor the diverting traffic and resulted in an improvement in total travel time over the no control change scenario in other scenarios, it did not provide congestion reduction beyond the traffic diversion alone strategy.

Chapter 5

SENSITIVITY ANALYSIS

The analyses in the previous chapter were based on a common set of traffic parameters and a specified set of control strategies. In this chapter, the impact of the control strategies under different traffic conditions and control concepts were investigated. The traffic volumes were altered to depict higher demand, as might be found in the peak period, as well as a low demand scenario representing the off-peak period. Alternate diversion schemes were developed and examined. Different treatments for signal timing, including the use of different variables (other than degree of saturation) as a basic for modifying the phase plan, were considered. Finally, the number of signals considered in the ATMS strategies were varied.

5.1 Sensitivity to traffic demand change

To determine the effectiveness of the control strategies under diverse traffic demand conditions, two traffic volumes were introduced to represent the traffic demand in a highly-congested peak period and an off-peak period. The new traffic volumes and levels of service (LOS) are shown in Table 5.1. A 15 percent increase in traffic volume was used to represent a higher traffic demand and more congested network condition. A 30 percent decrease in traffic volume was selected to represent an off-peak traffic condition.

Table 5.1 New traffic demand used in the sensitivity analysis

a) Low demand--off-peak period

Traffic direction	Traffic volume (vph)	Level of service* (intersection 10)
East Bound (EB)		
- Thru and Right turn	945	A
- Left turn	105	E
West Bound (WB)		
- Thru and Right turn	472	C
- Left turn	53	D
North Bound (NB)		
- Thru and Right turn	630	B
- Left turn	70	D
South Bound (SB)		
- Thru and Right turn	315	B
- Left turn	35	E

b) High demand--highly-saturated system

Traffic direction	Traffic volume (vph)	Level of service* (intersection 10)
East Bound (EB)		
- Thru and Right turn	1553	F
- Left turn	172	E
West Bound (WB)		
- Thru and Right turn	776	B
- Left turn	86	D
North Bound (NB)		
- Thru and Right turn	1035	D
- Left turn	115	E
South Bound (SB)		
- Thru and Right turn	517	C
- Left turn	58	C

Note: Levels of service are determined at optimal progression based on Synchro 2.0™ program (1995) and Highway Capacity Manual (1994)

For each demand case, signal timings were recalculated using the TRANSYT program. The optimal signal timings were then used for normal signal operations.

The new demand levels were input into the NETSIM model. A 10-minute both-lane closure incident was selected for this analysis.

5.1.1 Impact on total travel time

The impacts on travel time of new volumes are shown in Table 5.2. In all traffic volume conditions with the 10-minute both-lane closure incident, traffic metering reduces the travel time over the no traffic control change. The metering is more effective in the high demand situation, reducing 56 percent of the increased travel time due to incident under heavy traffic, compared to 36 percent in the low demand situation.

Table 5.2 Total travel time for three volume scenarios: 10-minute both-lane closure incident

Scenario	Total travel time in one hour (veh-hrs)		
	Volume scenarios		
	30% decrease (off-peak)	Normal (peak)	15% increase (highly-congested)
Normal traffic (no incident)	486.79	774.30	1005.10
No traffic control change	523.29	882.50	1287.95
ATMS: traffic metering	510.24	847.68	1128.66
ATIS: traffic diversion	502.36*	826.01*	1115.09
ATIS/ATMS: traffic diversion with signal change (equalization of degree of saturation)	505.84	839.75	1076.09*

Note: * indicates the lowest total travel time for an incident situation

Traffic diversion alone also improves traffic operations over the do-nothing situation in all demand ranges. However, in the off-peak and normal peak period, the ATIS/ATMS strategy does not increase the benefits. In fact, modification of signal timing increases the travel time by 3.48 vehicle-hours in the off-peak demand case. In the highly congested traffic condition, the addition of traffic signal control modification reduces the travel time over diversion only, from 1115 vehicle-hours to 1076 vehicle-hours.

The results shown in Table 5.2 suggest that signal timing modification along with the diversion is desirable in high traffic demand conditions. This may be because the high volume of rerouted traffic contributes to longer overall delay in the diversion only situation. The benefits of signal timing modification favoring the rerouted traffic exceeds the increase in delay incurred on other directions, thereby reducing the overall delay in this scenario.

5.1.2 Impact on intersection blockage

The three traffic demand levels created diverse results when measured by intersection blockages. The results were shown in Table 5.3.

Spillback occurs at all demand levels for the no control change scenarios. The traffic volume determines the start time and duration of the spillback(s). The higher the volume, the sooner the blockage begins. The start time of the blockage at intersection 10 starts at 248, 212, and 208 seconds after the incident occurs for off-peak, peak, and highly-congested traffic conditions, respectively. The incident in the highly-congested condition creates intersection blockages on the north-south arterial, as the result of the spillback on the arterial on which incident occurs. All control strategies successfully

Table 5.3 Start and end time of intersection blockages: various traffic demand levels, 10-minute both-lane closure incident

Intersection number	Time of spillback occurrence after incident (sec)					
	Traffic demand level					
	Off-peak		Normal peak		Highly-congested	
	Begin	End	Begin	End	Begin	End
10	248	634	212	648	208	631
9	n/a	n/a	602	725	554	1015
14	n/a	n/a	n/a	n/a	497	710
13	n/a	n/a	n/a	n/a	1075	1086

Note: The intersections are periodically cleared during the spillback periods.

eliminate the intersection blockages.

5.1.3 Impact on congestion duration

The congestion durations as determined from the queue time are illustrated in Figure 5.1. Control strategies in each of the traffic demand ranges have similar potential in reducing the congestion duration. The traffic metering strategy does not have much effect on congestion duration over the do-nothing cases. Two diversion options, with and without signal timing modification, have similar impacts. In the highly-congested traffic condition, however, diversion with signal modification clears the congestion 300 seconds sooner than the diversion alone.

A comparison of the reduction in the congestion period for various traffic demand levels is shown in Figure 5.2. The congestion duration in the highly-congested condition is projected from Figure 5.1(c) because the simulation approached the NETSIM maximum number of vehicles in the system. Figure 5.2 shows that the application of control

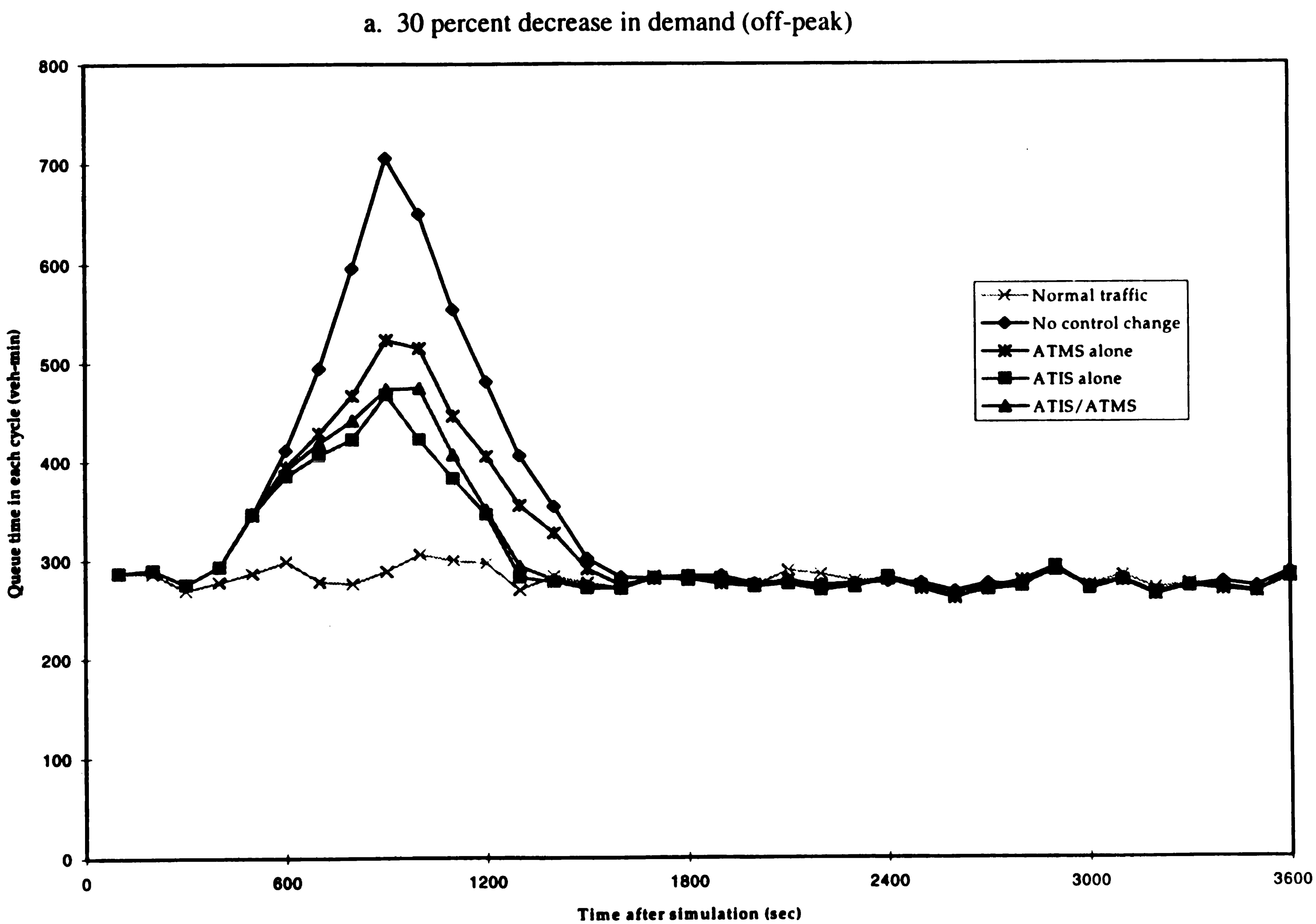


Figure 5.1 Congestion duration: different demand levels

b. Normal (peak) (same as Figure 4.5a)

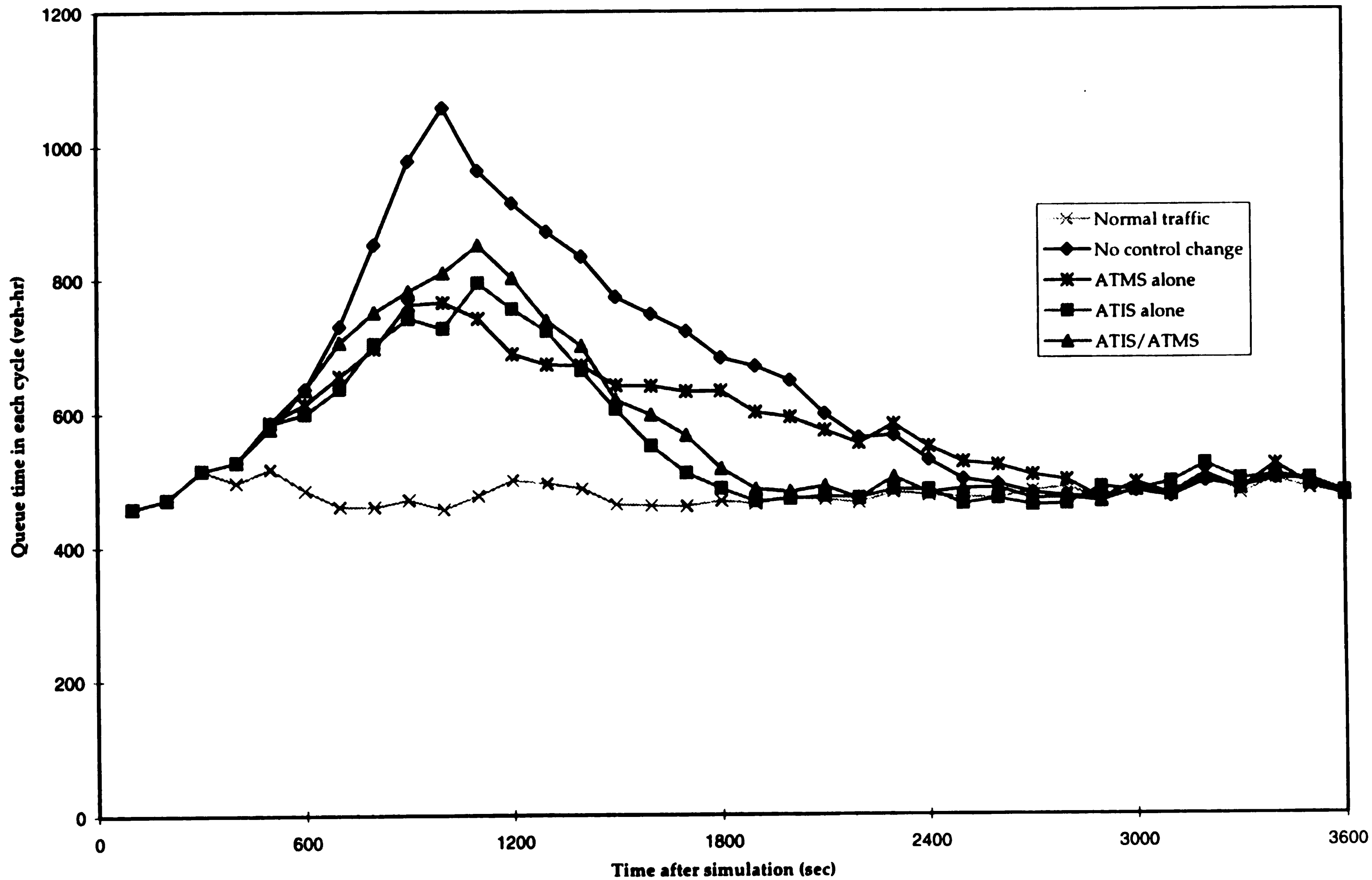


Figure 5.1 (cont'd)

c. 15 percent increase in demand (highly-congested)

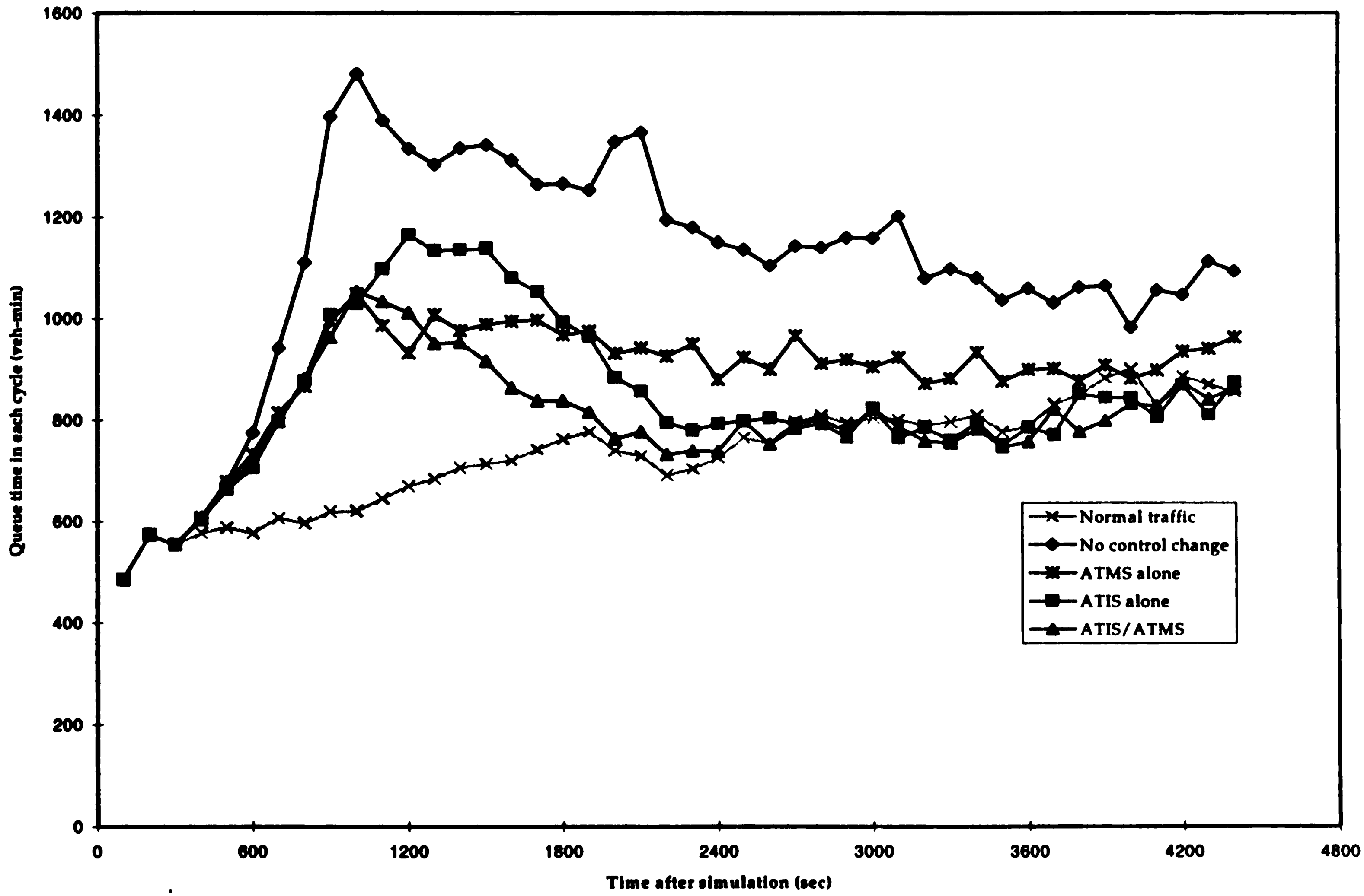


Figure 5.1 (cont'd)

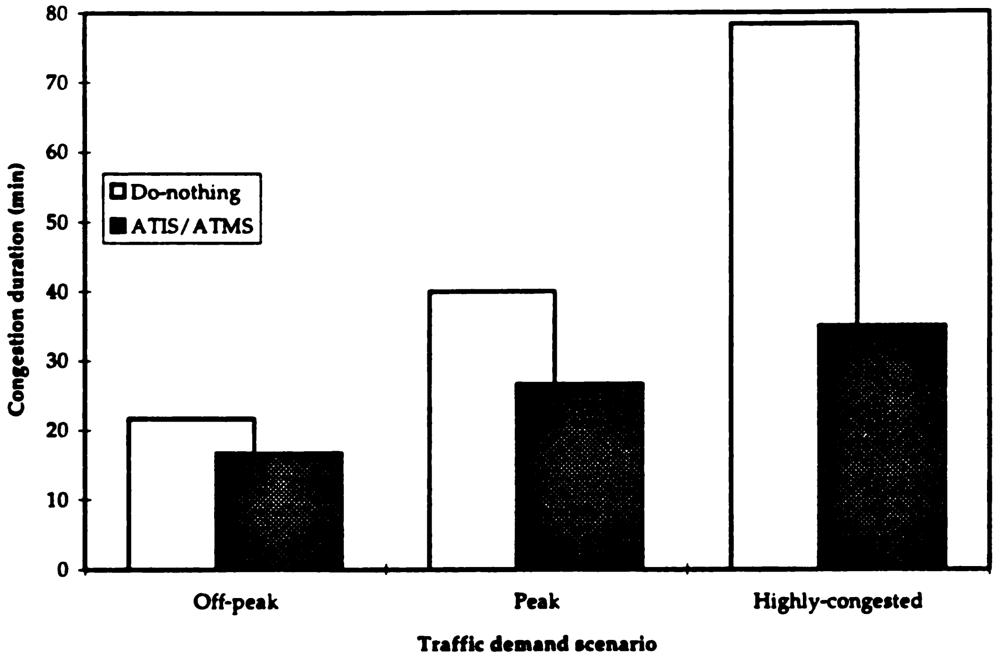


Figure 5.2 Comparison of reduction in congestion duration in different demand levels

strategies is more effective in reducing the congestion period at higher demand levels. The ATIS/ATMS control reduces the congestion period to less than a half of the time required under the no control change scenario.

5.2 Sensitivity to diversion control alternatives

The analyses in the preceding chapter were based on diverting traffic equally onto the two adjacent parallel arterials at the nearest upstream intersection. Two new diversion plans were developed and compared in this section. Three diversion alternatives considered here were:

a. Traffic diversion at the nearest upstream intersection, equally distributed to two adjacent arterials (the alternative plan from Chapter 4);

b. Traffic diversion at the nearest intersection, optimal distribution to the arterials; and

c. Traffic diversion at the two nearest intersections, equally-distributed.

Under alternative b, the diversion percentage is chosen to yield the lowest network travel time. This distribution was obtained by trial-and-error, because NETSIM does not have internal logic for dynamic traffic assignment. The optimal distribution sent 56 percent of eastbound through traffic at intersection 10 to the north arterial (passing through intersections 10-6-7-11) and 44 percent of the traffic to the south arterial (passing through intersections 10-14-15-11). The last alternative was to divert half of the traffic at each of the two nearest upstream intersections. At each intersection the traffic was equally distributed to the two parallel arterials.

5.2.1 Impact on total travel time

The total travel time employing these diversion plans is shown in Table 5.4. The optimal distribution plan gives the shortest travel time, although the reduction is only 5.18 vehicle-hours or 0.6 percent of the total travel time from the equal distribution diversion plan. The diversion at two upstream intersections gives only a slight improvement over the equal diversion at the nearest intersection.

5.2.2 Impact on congestion duration

Figure 5.3 shows the congestion duration of the three diversion procedures. All three diversion plans create similar incident durations. However, the two-intersection diversion has 200 seconds longer congestion than each of the one-intersection diversions.

Table 5.4 Total travel time of alternate diversion plans
10-minute both-lane closure incident

Diversion plan	Total travel time in one hour (veh-hrs)
Equally distributed at the nearest upstream intersection	826.45
Optimal distribution at the nearest upstream intersection	821.27
Equally distributed at two upstream intersections	825.20

In contrast with the congestion duration, the spread of the congestion on the network was significantly different. The effect of congestion spread is illustrated in Figure 5.4. The optimal distribution diversion results in a slightly longer congestion period on the north parallel arterial, to which more traffic is assigned, and a slightly shorter congestion period on the diversion route passing the south parallel arterial. The two-intersection diversion causes congestion at the second upstream intersection. The congestion at the nearest upstream intersection clears sooner than the one-intersection rerouting since less traffic is approaching this intersection (half of the through traffic is diverted at the prior intersection).

5.2.3 Impact on different traffic streams

To understand the impact of the control on different traffic movements, traffic was arranged into three groups. The first group was the traffic on the diversion routes including the paths passing the second nearest intersection. The second group was the traffic competing with the diversion traffic, at the intersections on which the diverted

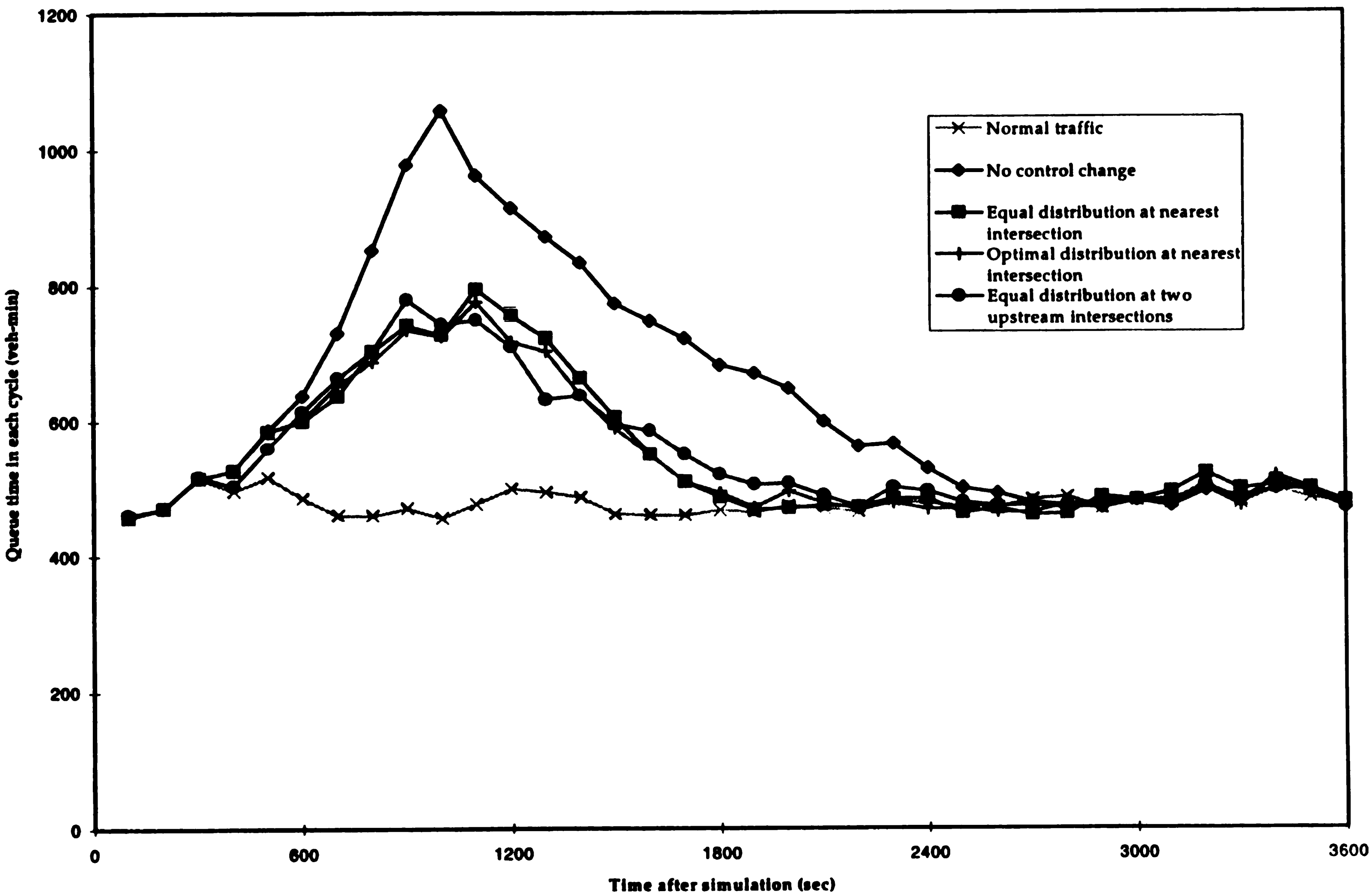


Figure 5.3 Congestion duration: alternate diversion plans

a. Equal distribution at the nea[illegible] upstream intersection (same as Figure 4.6b)

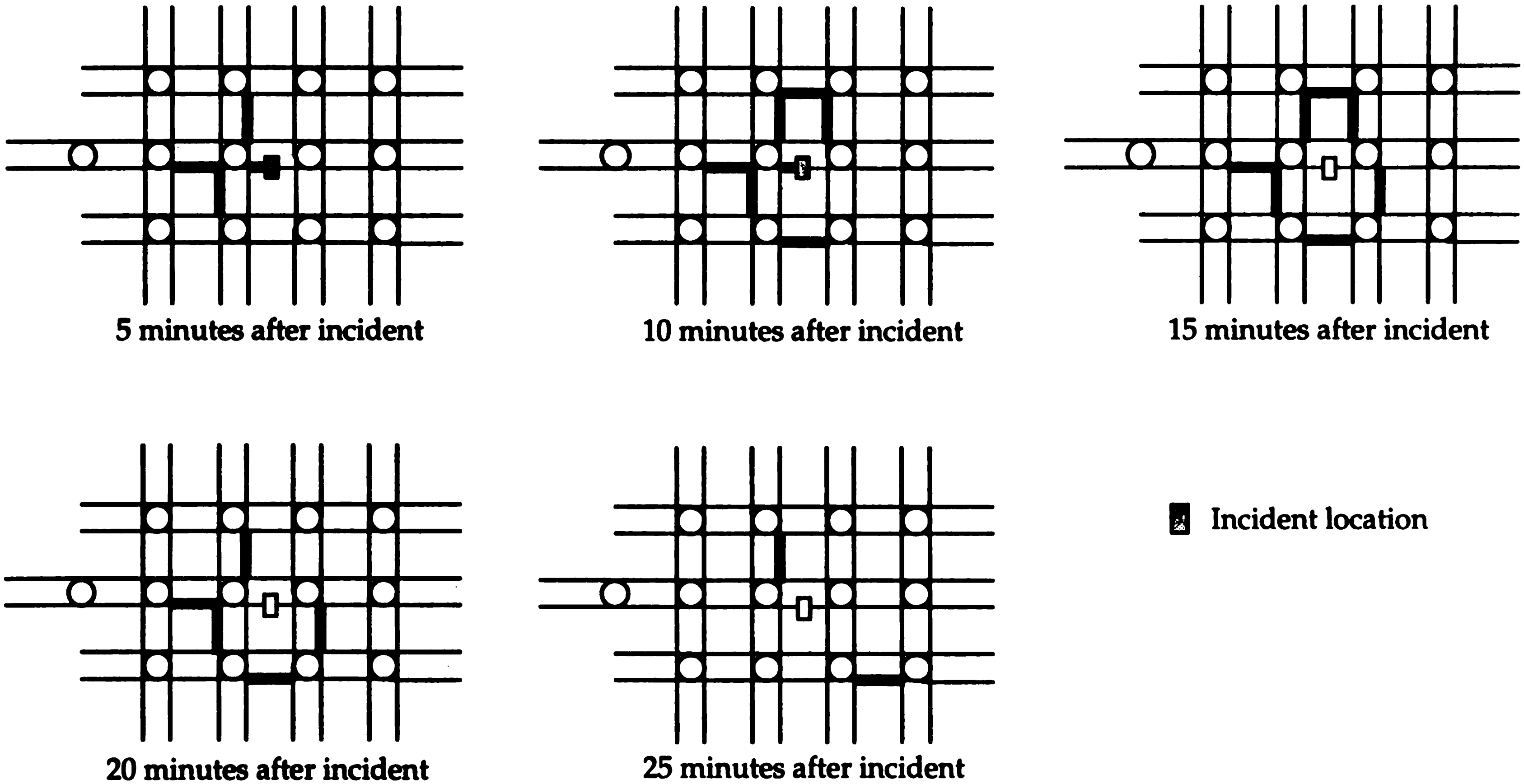


Figure 5.4 Affected links and duration of congestion: alternate diversion plans

b. Optimal distribution at the nearest upstream intersection

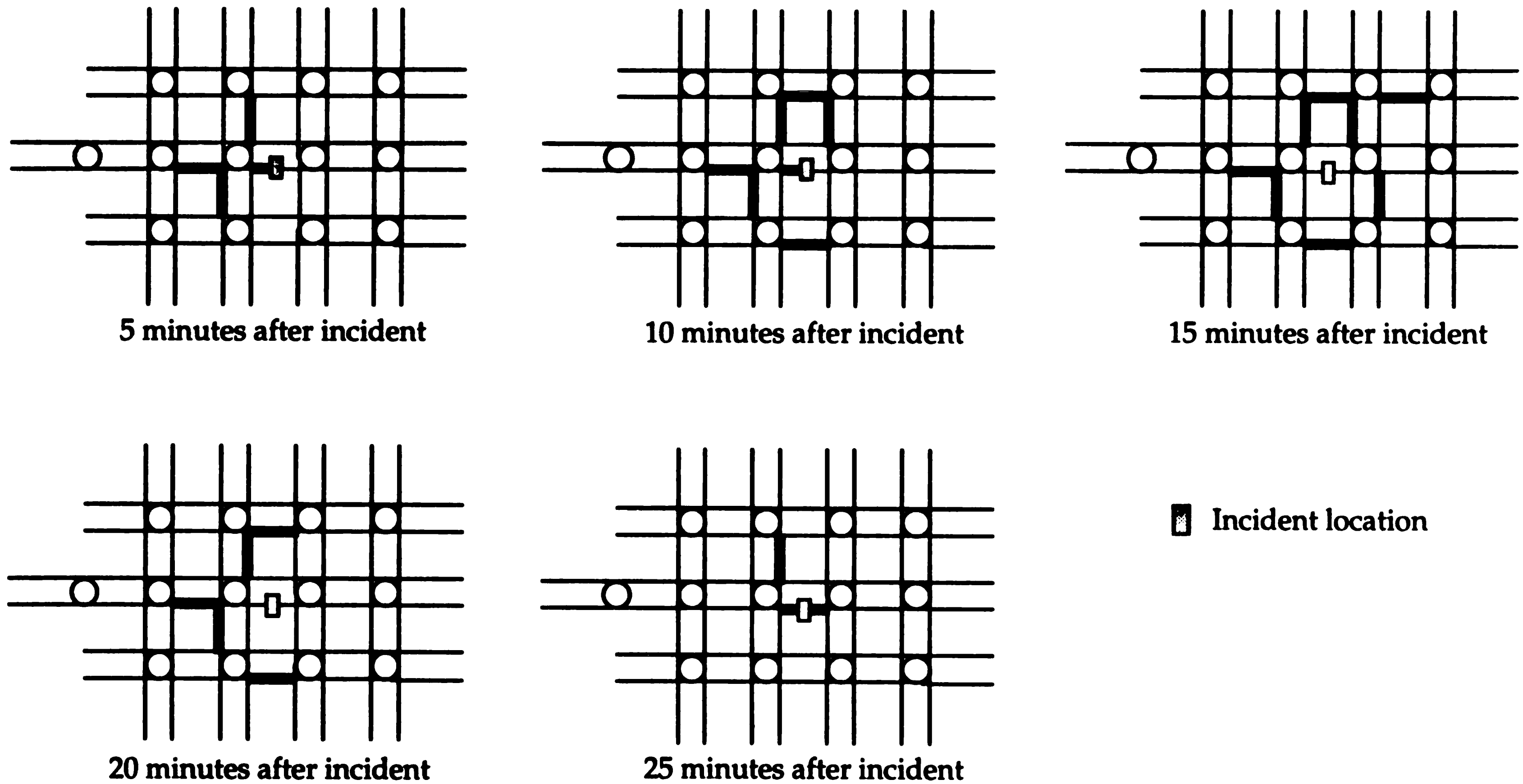
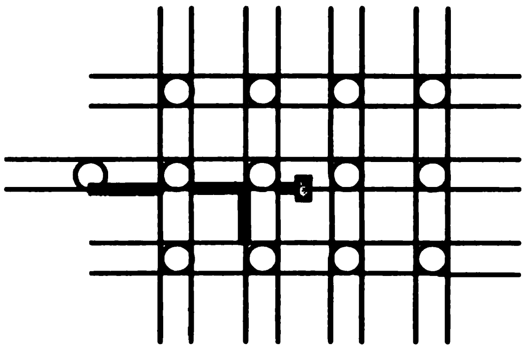
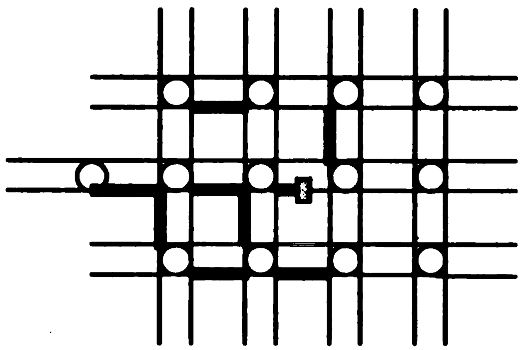


Figure 5.4 (cont'd)

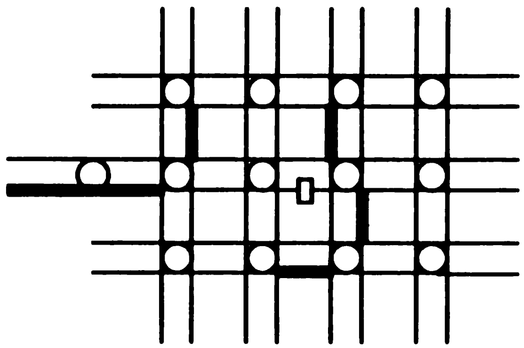
c. Equal distribution at two upstream intersections



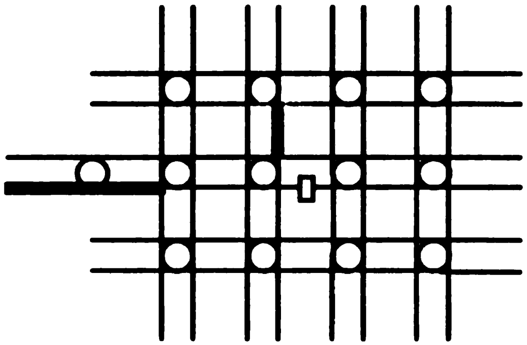
5 minutes after incident



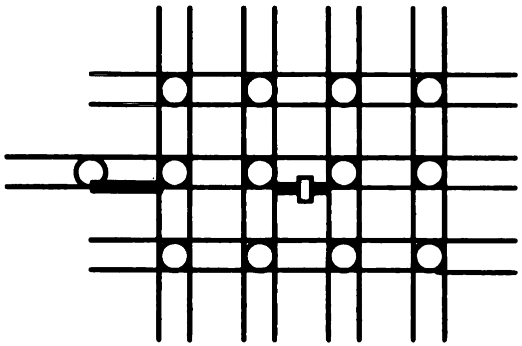
10 minutes after incident



15 minutes after incident



20 minutes after incident



25 minutes after incident

Incident location

Figure 5.4 (cont'd)

traffic traversed. The last group was all other traffic. The effect of the alternate diversion plans on different traffic groups is shown in Table 5.5.

Comparing the alternate rerouting plans at the nearest intersections, the optimal distribution plan results in lower travel time on the diversion routes. Moreover, the optimal plan produces the minimal interruption to other traffic directions competing with the diversion routes. By sending more traffic to the north arterial, the rerouting produces less impacts on traffic in other directions as traffic diverting to the north arterial makes two right turns, compared with two left turns on the south arterial diversion path.

Comparing the equally-distributed diversion at the nearest intersection and the diversion at two upstream intersections, the latter plan produces lower travel time (delay) on the diversion routes. The travel time of diverted traffic is shorter by 3.58 vehicle-hours in the two-intersection diversion case. The two intersection diversion results in lower congestion at each intersection. Although the two-intersection diversion creates higher delay in non-diverted traffic, the overall travel time (delay) is shorter by 1.65 vehicle-hours.

5.3 Sensitivity to signal control variable alternatives

In the previous analysis, the equalization of degree of saturation was used as a criterion for signal modification. In this section, two other control variables were introduced and tested. The control parameters were maximum queue length and stop time.

Table 5.5 Total travel time of traffic streams in alternate diversion plans: 10-minute both-lane closure incident

Link Group	Total travel time in one hour (veh-hrs)		
	Diversion plan		
	Equally distributed at the nearest upstream intersection	Optimal distribution at the nearest upstream intersection	Equally distributed at two upstream intersections
Links on diversion routes[1] where traffic makes			
Left turn	25.57	24.51	23.05
Through	38.19	38.01	37.88
Right turn	15.24	16.24	14.49
All links approaching intersections at which traffic is diverted[2] (except the diverted traffic direction)	513.62	507.08	515.27
All other links[3]	233.83	235.43	234.51
Total	826.45	821.27	825.20

Note: 1. This traffic group contains intersection 5, NB-RT
intersection 6, EB-THRU, NB-RT
intersection 7, EB-RT
intersection 9, EB-LT, EB-RT
intersection 10, EB-LT, EB-RT
intersection 11, SB-LT, NB-RT
intersection 13, SB-LT
intersection 14, EB-THRU, SB-LT
intersection 15, EB-LT

2. This traffic group contains all traffic directions at intersection 5, 6, 7, 9, 10, 11, 13, 14, 15 excluding diverted traffic movements above
3. This traffic group contains all traffic except the two traffic groups above.

The maximum queue length in each traffic movement is a good indicator of traffic demand at the intersection. The signal setting strategy used in this case is to balance the maximum queue lengths in all approaches, which leads to the postponement of spillback and the elimination of secondary congestion. The spillback can be either left-turn queue overflow to the through traffic lane or the intersection blockage at an upstream intersection.

The maximum queue length in each cycle is not provided in the NETSIM standard output. However, it can obtained by collecting queue data every four seconds from the NETSIM intermediate statistics.

The stop time delay is another possible control variable available from NETSIM. .e equalization of stop time delay in all competing approaches implies equality of the level-of-service (LOS), as defined in the Highway Capacity Manual, in all directions.

5.3.1 Impact on total travel time

Table 5.6 shows the total travel time for the three signal control alternatives. The signal setting by equalizing of the stop time yields the lowest total travel time. It improves

Table 5.6 Total travel time of alternate signal control variables: 10-minute both-lane closure incident

Signal control variable	Total travel time in one hour (veh-hrs)
Degree of Saturation	839.75
Maximum Queue length	833.33
Stop time	819.53

this MOE by 2.4 percent of the total travel time beyond the setting by degree of saturation for the 10-minute both-lane closure scenario.

5.3.2 Impact on congestion duration

The congestion duration for each of these three signal control settings is shown in Figure 5.5. The signal settings using the degree of saturation and stop time alleviate the congestion 300 seconds sooner than that using the maximum queue length. The control based on the stop time, however, produces the least time in queue during and after the incident, as reflected in the minimum total travel time measure.

5.3.3 Impact on different traffic streams

Table 5.7 shows the effect of these signal settings on different traffic groups. Among these three controls, the equalization of stop time concept is the best because it reduces travel times at intersections on the diversion routes over the degree of saturation and the maximum queue length criteria. The reduction in travel time on diversion routes is greater than the increase on other links, resulting in the lower overall travel time.

5.4 Sensitivity to signal control coverage

A further investigation was made to explore the effect of the boundary of the signal control modifications. In the previous analyses, the signal modification was limited to the intersections on diversion routes. In this analysis, signals at all internal intersections in the network were modified. The simulation was then performed and data on MOEs were obtained. The signal timing for this experiment were controlled using the degree of saturation as in the preceding chapters.

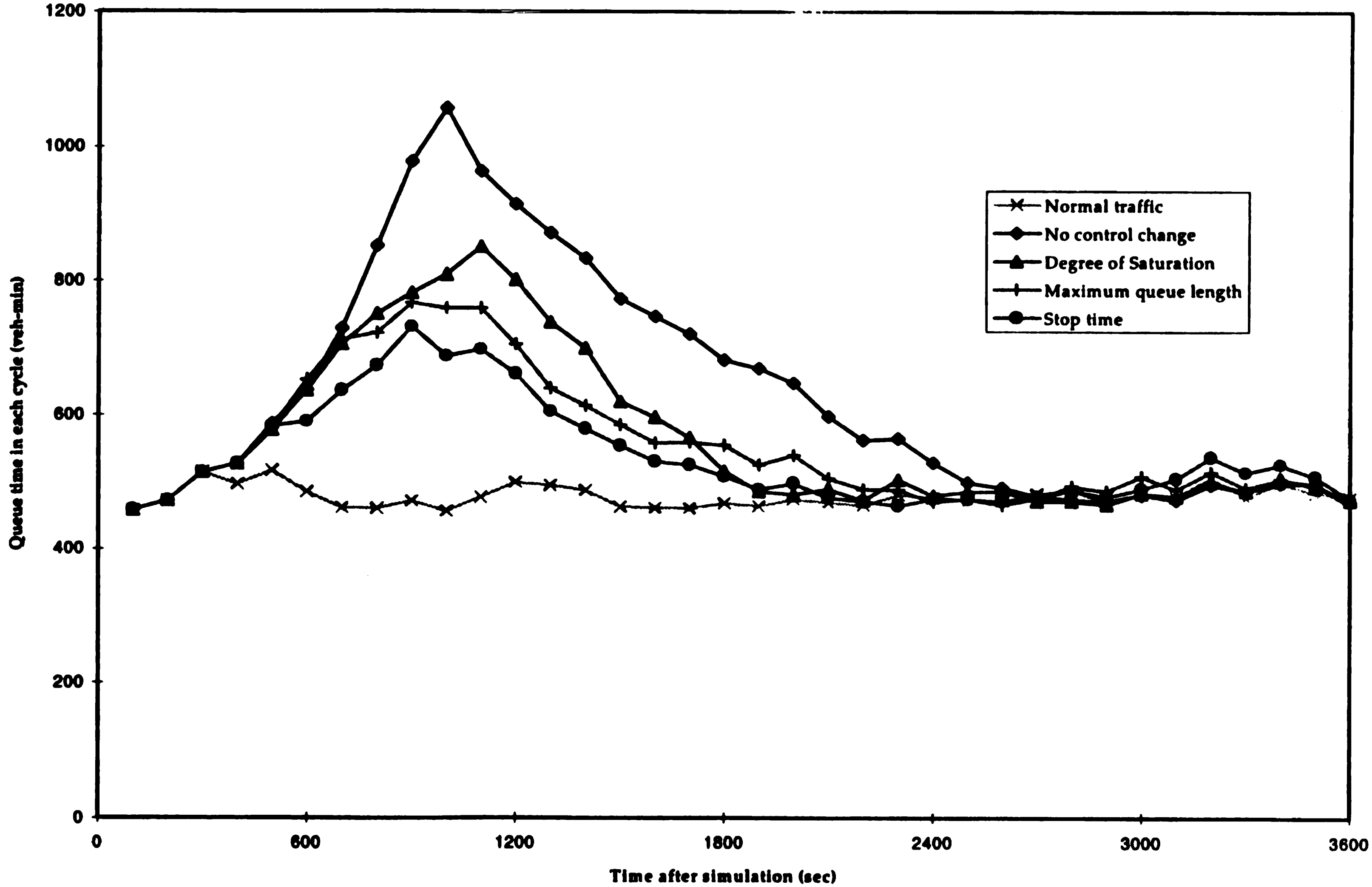


Figure 5.5 Congestion duration: alternate signal control variables

Table 5.7 Total travel time of traffic groups of alternate signal control variables: 10-minute both-lane closure incident

Link Group	Total travel time in one hour (veh-hrs)		
	Signal control variable		
	Degree of Saturation	Maximum Queue Length	Equalization of Stop time
Links on diversion routes where traffic makes			
Left turn	15.33	14.46	13.44
Right turn	11.26	10.26	9.98
All links approaching intersections at which traffic is diverted	379.88	374.44	360.72
All other links	433.28	433.87	435.39
Total	839.75	833.33	819.53

5.4.1 Impact on total travel time

Table 5.8 shows the total travel time for two scenarios with different signal coverage. The modification of signal timings at all intersections results in lower total travel time. By making the signals at these intersections more responsive to the traffic, it results in better progression and lower total travel time.

5.4.2 Impact on congestion duration

Figure 5.6 shows the congestion durations of these two signal coverage alternatives. Although the signal modification at all intersections produces slightly lower

Table 5.8 Total travel time of alternate signal control coverage
10-minute both-lane closure incident

Signal control coverage	Total travel time in one hour (veh-hrs)
On diversion routes	839.75
All intersections	826.48

delay (queue time) than the signal change on diversion route case, the network recovers from congestion at the same time.

5.4.3 Impact on different traffic streams

The preceding section shows that the larger coverage area of signal modification yields better traffic operation, as indicated by shorter overall travel time. The analysis of travel time on particular traffic streams reveals that the benefit comes from the lower delay at competing approaches on the diversion routes. The results are shown in Table 5.9. On the diversion route, the signal modification at all intersections slightly reduces the travel time in the diverted traffic directions. However, most of the delay reduction occurs on traffic in other directions, e.g. through traffic on the parallel arterials. This is because the adaptation of signals at intersections upstream and downstream from the intersections receiving diversion traffic results in more response to the cycle-by cycle traffic situation, leading to better progression on these parallel arterials. The signal modification at all intersections reduces the delay of competing movements to diverted traffic from 379.88 vehicle-hours to 361.74 vehicle-hours, although it increases the travel on other links from 433.28 vehicle-hours to 438.43 vehicle-hours.

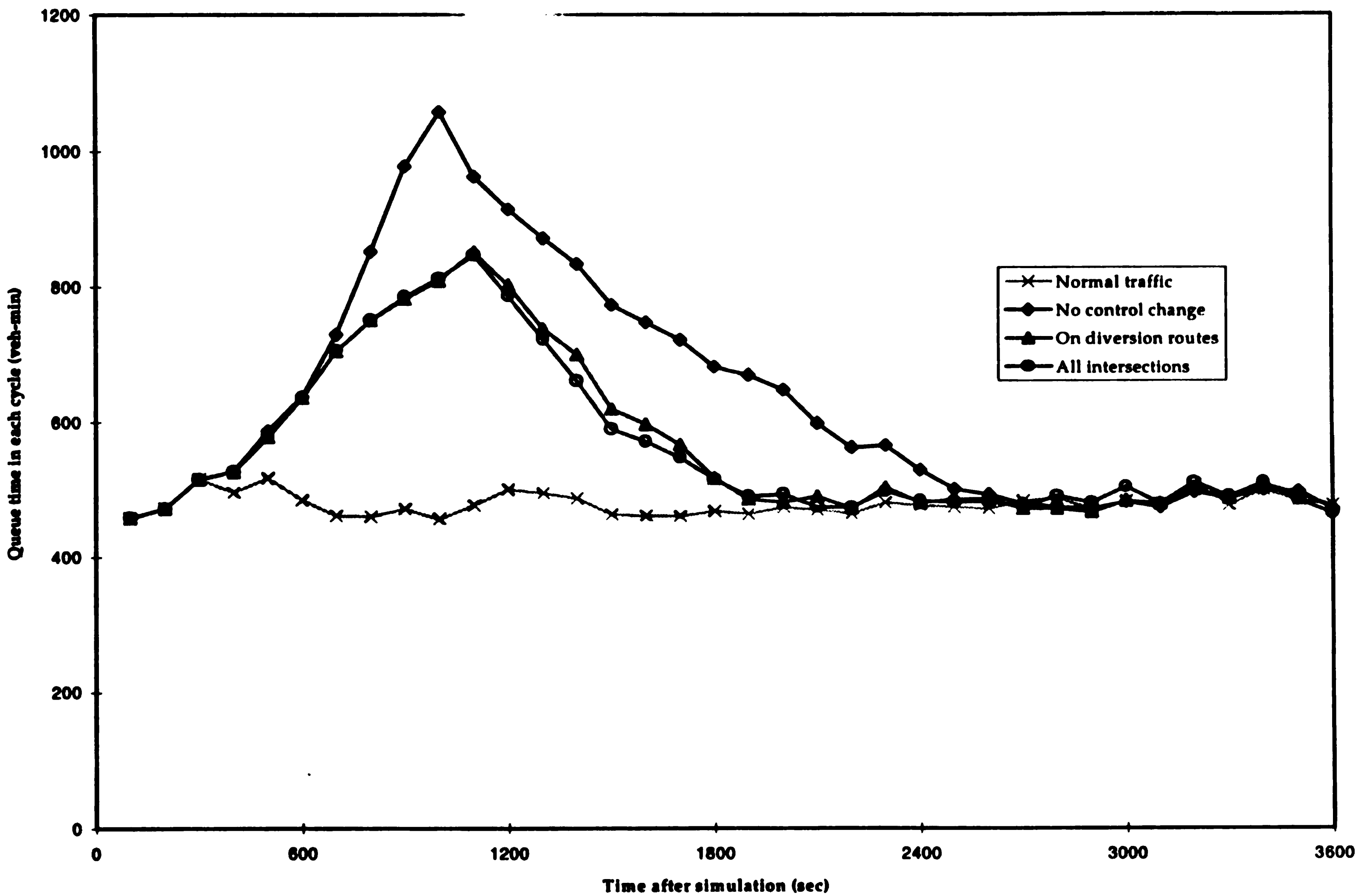


Figure 5.6 Congestion duration: alternate signal coverage

Table 5.9 Total travel time of traffic groups of alternate signal control coverage 10-minute both-lane closure incident

Link Group	Total travel time in one hour (veh-hrs)		
	Diversion only	With signal change on diversion routes	With signal change at all intersections
Links on diversion routes where traffic makes			
Left turn	18.82	15.33	15.05
Right turn	11.33	11.26	11.26
All links approaching intersections at which traffic is diverted	377.93	379.88	361.74
All other links	418.33	433.28	438.43
Total	826.01	839.75	826.48

5.5 Summary

The control strategies used in Chapter 4 were tested to determine their effectivenesses under different demand conditions. The "traffic metering" and "diversion only" alternatives were based on the optimal fixed time signal plans for each demand level. The impact of these control strategies under traffic demand representing off-peak, peak, and highly-congested conditions were obtained for the 10-minute both-lane closure incident situation. The traffic metering produces lower total travel time (delay) than the no control change in each demand range. However, the traffic metering does not have much impact on the congestion duration. Traffic diversion is more effective than traffic metering, and diversion with signal control change is the most effective at the high demand level. For both diversion with and without signal modification, the reduction in congestion period increases as the traffic demand increases.

Three different diversion and signal control setting alternatives were analyzed. The optimal distribution at the nearest upstream intersection yields the lowest delay. The distribution at two upstream intersections creates less congestion for each intersection but in a wider area. The duration of overall congestion in the three diversion plans lasts approximately the same. The optimal distribution produces minimum interruption to traffic competing with the diverted traffic directions.

Signal control modifications using three control variables were tested. The signal setting using the stop time produces the lowest total travel time, although it does not shorten the congestion period beyond the setting using degree of saturation. The reduction in delay occurs at intersections along diversion routes. Analysis on signal control coverage indicates that the signal modification at all intersections results in lower delay than the signal change on diversion routes since it increases progression on the parallel arterials.

Chapter 6

CONCLUSION AND RECOMMENDATION

6.1 Conclusion

This research examined the effectivenesses of several control strategies on various incident conditions. The aim of these controls was to alleviate the congestion caused by these incidents. In this study, the control strategies considered were traffic metering, traffic diversion, and signal timing modification. The research was conducted using the NETSIM simulation program. A hypothetical network of a surface street system was used. Using the same platform, several incident situations as well as control strategies were tested. The measures of effectiveness used to identify the performance of each control strategy were total travel time (delay and queue time), congestion duration, and spillback duration.

The impacts of three incident types, each with three incident durations, were studied under the assumption of no control change in traffic control system. The investigation showed that, in the severe incident conditions, the congestion lasted up to 68 minutes and produced 419 vehicle-hours of delay if no special control strategy was applied.

The impact of the control strategies on the various incident situations was analyzed. It was found that different control strategies had different levels of effectivenesses in specific incident conditions. These results are shown in Table 6.1. In a less severe incident situation, such as the one-lane closure and the 5-minute 85 percent reduction in capacity, none of the control strategies offered any improvement in traffic operations over the do-nothing case. In the 10-minute partial-lane and 5-minute both-lane closure incidents, only the traffic metering strategy reduced network travel time. In the 10-minute partial-lane closure situation, traffic metering did not have a major impact on the congestion period.

Traffic diversion was effective when the severity of the incident increased (15-minute 85 percent capacity reduction, and 10 and 15-minute both-lane closure). This control strategy substantially reduced the length of the overall congestion period. Although diversion results in an increase in congestion on the diversion routes for a short time period, it reduces the congestion on the affected traffic and the overall network. The diversion with signal timing modification strategy did not offer any improvement over traffic diversion alone.

The limits of effectiveness of these control strategies were examined by conducting a sensitivity analysis on their effectiveness at different demand levels. The control strategies were tested using volumes representing off-peak, peak, and highly-congested traffic conditions. The results indicated that, when the demand level increases, the control strategies are more effective in reducing both total travel time and congestion duration.

Table 6.1 Impact of alternative control strategies on various incidents

a. Difference in total travel time from the no control change scenarios (percent)

Control strategy	Incident type and duration					
	85 percent capacity reduction			Both-lane closure		
	5 minutes	10 minutes	15 minutes	5 minutes	10 minutes	15 minutes
ATMS: traffic metering	+ 50*	- 4*	- 29	- 6*	- 32	- 60
ATIS: traffic diversion	+ 85	+ 52	- 32*	+ 1	- 52*	- 77*
ATIS/ATMS: traffic diversion with signal timing modification	+198	+ 56	- 27	+ 48	- 40	- 62

b. Difference in congestion duration from the no control change scenarios (percent)
(both-lane closure incident)

Control strategy	Incident duration	
	10 minutes	15 minutes
ATMS: traffic metering	+ 8	- 16
ATIS: traffic diversion	- 32*	- 36*
ATIS/ATMS: traffic diversion with signal timing modification	- 32*	- 25

Note: 1. the negative signs indicate the improvement over the no control change
2. bold numbers indicate the situations where the control strategies are effective
3. the * means this control strategy produces the greatest improvement in that incident type and duration.

Moreover, in the highly-congested condition, diversion with signal modification became the most effective. The results are shown in Table 6.2.

Three diversion plans were compared; equal distribution at the nearest intersection, optimal distribution at the nearest intersection, and equal distribution at two upstream intersections. As shown in Table 6.3, the optimal distribution diversion plan results in a slight improvement over the equal distribution plan.

For each control strategy, variations in the techniques to accomplish the controls were studied. For the signal timing modification (ATMS), three control variables were used to modify the signal timing; the degree of saturation, the maximum queue length, and the stop time. The use of stop time yielded the lowest total travel time. The results of this analysis are shown in Table 6.4.

The signal coverage experiment indicated that the signal modification at all intersections was better than only changing the signal on the diversion routes.

6.2 Recommendation

This research has contributed to the understanding of the impact of several control strategies on incident congestion. It also identifies several areas where there is a need for further research. The study can be extended to cover additional incident types and durations under various levels of demand. This could be used to develop a set of rules to make real time decisions on alternative control strategies depending on the traffic condition existing at the time of the incident and the severity of the incident.

The same study framework can be used to experiment the impact of the incident on different network geometric configuration to uncover an absolute effectiveness of a

Table 6.2 Effectiveness of the control strategies under different demand levels

a. Difference in total travel time from the no control change scenarios (percent)
(10-minute both-lane closure incident)

Control strategy	Demand level		
	Off-peak	Peak	Highly-congested
ATMS: traffic metering	- 36	- 32	- 56
ATIS: traffic diversion	- 57*	- 52*	- 61
ATIS/ATMS: traffic diversion with signal timing modification	- 48	- 40	- 75*

b. Difference in congestion duration from the no control change scenarios (percent)
(10-minute both-lane closure incident)

Control strategy	Demand level		
	Off-peak	Peak	Highly-congested
ATMS: traffic metering	+ 0	+ 8	- 21
ATIS: traffic diversion	- 23*	- 32*	- 49
ATIS/ATMS: traffic diversion with signal timing modification	- 23*	- 32*	- 55*

Note: 1. the negative signs indicates the improvement over the no control change
2. the * means this control strategy produces the greatest improvement in that demand situation.

Table 6.3 Comparison of alternate diversion plans
10-minute both-lane closure incident

Measure of effectiveness	Diversion plan		
	Equally distributed at the nearest upstream intersection	Optimal distribution at the nearest upstream intersection	Equally distributed at two upstream intersections
Difference in total travel time from the no control change	- 52	- 57	- 53
Difference in congestion duration from the no control change	- 32	- 32	- 24

Table 6.4 Comparison of alternate signal control policies for signal modification
10-minute both-lane closure incident

Measure of effectiveness	Control variables for signal timing modification		
	Degree of saturation	Maximum queue length	Stop time
Difference in total travel time from the no control change	- 40	- 45	- 58
Difference in congestion duration from the no control change	- 32	- 20	- 32

control strategy under different network circumstances, in addition to the different volume and incident conditions.

The control strategies should be incorporated into a complete simulation analysis tool. One of the limitations of this research is the lack of simulation tools which integrates control strategies. Although the NETSIM simulation program was used in this study, it lacks of capability to incorporate an adaptive signal logic as well as dynamic traffic routing. The development of these features will be a valuable contribution to the extension of these experiments on control strategies.

Since the study was designed to test certain selected control strategies for a wide range of incident conditions and one incident situation was selected for the sensitivity analysis, the results from the sensitivity analysis demonstrate the effectivenesses of various control strategies only in that situation. A full factorial analysis of these control strategies may be only way to reveal their effectivenesses in all range of traffic and incident conditions. It is recommended that the full factorial design of the experiment should be conducted to determine the most appropriate control strategy for a particular incident and traffic condition.

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