Incident Management Under SCAT Adaptive Control System

FAST-TRAC Phase III Deliverable

#11. Final Report On Incident Management Under
SCATS Adaptive Control System
EECS-ITS LAB-FT98-084

William C. Taylor, PH.D
Ahmed S. Abdel-Rahim

FAST-TRAC Evaluation
Technology Planning and Evaluation Group (TPEG)
Intelligent Transportation Systems Laboratory
University of Michigan
Ann Arbor, MI 48109

Steve Underwood, Ph.D, Principle Investigator
Zakian R. Shaikh, M.E., Project Manager

Program Offices Telephone
(313) 764-433

Program Offices Facsimile
(313) 763-1764

150319

Final Report

On

Incident Management Under SCATS Adaptive Control System

Prepared by

William C. Taylor, Ph.D.,

and

Ahmed S. Abdel-Rahim

Department of Civil and Environmental Engineering
Michigan State University
East Lansing, MI 48824

April 1998

ACKNOWLEDGMENT

The authors would like to thank the Oakland county road commission (OCRC), the Michigan department of transportation (MDOT), and the federal highway administration (FHWA) for funding this study. We extend our thanks to all OCRC staff members for their continuous cooperation during all phases of this study.

ABSTRACT

The report documents the results of a study designed to test the effectiveness of ATMS and ATIS strategies to reduce delay resulting from an incident. The study had two main sections: a simulation study to test the effectiveness of several control strategies on various incident situations and a field study to validate the output of the simulation.

The simulation study was conducted using a NETSIM simulated surface street network. The network used in the simulation was configured to approximate the road network in the cities of Troy and Rochester Hills. The control strategies considered in the study were: traffic metering, traffic diversion, and signal timing strategies. The impacts of three different incident types (50 %. 85%, and 100% reduction in capacity), each with three incident durations, were examined.

The results showed that the control strategies tested had different levels of effectiveness in specific incident conditions. In a less severe incident situation, none of the control strategies resulted in improvements in traffic operations over the do-nothing case. Traffic metering reduced network travel time in a moderate incident situation; however, it did not reduce the congestion duration. Traffic diversion became more effective as the severity of the incident increased. The benefits of diversion with signal timing modification did not exceed those achieved by traffic diversion alone.

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

The field study was designed to test the concepts developed in the theoretical simulation approach. It was planned to collect and analyze field data to test the validity of the simulation results. The original plan was to stage an incident at either an intersection or at a mid-block location and determine the adaptability of SCATS to respond to such an

event. However, the cities of Troy and Rochester- Hills,-as well as the RCOC, expressed both legal and safety concerns over staging such an event. Another possible study plan considered was the collection of data by conducting a needed maintenance activity during the rush hour. However, this too was not acceptable.

The strategy ultimately adopted was to use SCATS to develop a baseline data file, and then to search for anomalies resulting from a non-staged incident. This approach envisaged selecting a few major crashes, and documenting changes in the SCATS file output. As a first step in the analysis, the network traffic data for four months was collected from the SCATS monitoring files. The green time reported in these files was used to construct a 95% confidence interval for the green time allocated for each approach for these intersections under non-incident situations. The second part of this approach involved collecting police records for traffic crashes occurring in the network during the same months. From these records crashes which appeared to have the potential to create a major impact on the network were selected. The response of the traffic signals immediately following the reported time of these selected crashes was then compared with the baseline SCATS files to determine how SCATS adapted to this disruption by changes in the control strategy. The plan was to then simulate the modified traffic flow and control pattern to determine the benefits of changes in the control strategy.

The analysis of the green time response to the eight crashes studied showed several problems that would need to be resolved before the proposed simulation validation could be conducted. The green time distribution in five of the eight crashes remained within the 95% confidence limit. For the other three crashes where there was a signal timing response. However, the response occurred prior to the reported time of the crashes. The most likely explanation for this phenomenon is that the reported time of the crashes was incorrect.

The proposal to use field data to validate the value of SCATS under an incident situation was ultimately abandoned. It was not feasible to stage an incident under peak period traffic conditions and the attempt to use historical data to construct a simulation model was unsuccessful due to the reliability of data on traffic-volumes and the exact timing of the incidents.

The green time allocation suggest that SCATS control does respond to certain incidents by extending or shortening the duration of the green time at adjacent intersections. Thus, if the data accuracy problem could be overcome, this approach may be appropriate for evaluating the benefits of an adaptive signal system. Since none of the crashes analyzed showed a long-term response and there was no identifiable response at adjacent intersections, it is not likely that any traffic diversion was involved. Thus, this approach does not appear to be useful in estimating the benefits of an ATIS system.

TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

1 INTRODUCTION

1.1 FAST TRAC

Realizing that there would never be sufficient funds to build enough roads to meet the county's economic and population growth, and to alleviate the overburdened roads, the Road Commission of Oakland County (RCOC) turned to technology. **FAST-TRAC** became operational in 1992 and over the last 5 years the system has expanded throughout Oakland County. FAST TRAC through the use of advanced traffic management technologies, responds to changing traffic patterns and helps minimize traffic delay.

An acronym which stands for Faster And Safer Travel through Traffic Routing and Advanced Controls, FAST TRAC is the world 's largest field test which combines several advanced traffic management and traveler information technologies into one system. FAST TRAC combines:

The Sydney (Australia) Coordinated Adaptive Traffic System (SCATS) for area wide traffic signal control.

The AUTOSCOPE video image processing system for detection of vehicles at intersections.

The Siemens automotive **Ali Scout** system for in vehicle route guidance.

FAST TRAC has been designed to give motorists access to reliable traffic information through a broad array of media. The ultimate aim of FAST TRAC is to develop into a complete Transportation Management System

1.2 Development of SCATS

SCATS, developed by the Roads and Traffic Authority (RTA) of New South Wales, Australia is reputed to be the world's most advanced dynamic Traffic Control System. It is a computer based area traffic signal control system. It is a complete system of hardware, software and control philosophy. It operates in real time, adjusting signal timings throughout the system in response to variations in traffic demand and system capacity. The purpose of SCATS, as with any area traffic control system, is to control traffic on an area wide basis rather than an uncoordinated intersection basis. In most modern cities traffic densities are such that uncoordinated operation of traffic signals simply cannot cope with the traffic.

The popular concept is that coordinating traffic signals is simply a matter of providing a "green wave" progression whereby a motorist traveling along a road-receives successive green signals. The principal purpose of the control system is to minimize overall stops and delays and when the traffic demand is at or near the capacity of the system, to maximize the throughput and minimize the possibility of "traffic jams" by controlling the formation of queues.

SCATS responds dynamically to changing traffic patterns by continuously adjusting signal timings cycle by cycle so that optimum traffic flow is achieved.

1.3 Research objectives and approach

1.3.1 Objectives

The objectives of this study were to assess the potential benefits of an adaptive traffic signal system in reducing congestion following an incident. The first part of the study used simulation modeling to estimate the benefits of an adaptive system, alone and in conjunction with a route guidance system, on the magnitude and duration of delay in a hypothetical network. The second part of the study used data from intersections in the FAST TRAC test area to determine the system response to incidents.

1.3.2 Description of the problem

Traffic operations can be adversely affected by the occurrence of any incident in the traffic network. The ability to manage incident congestion is therefore an important attribute of an adaptive signal system since congestion disrupts smooth traffic flow and affects the entire spectrum of traffic operations. Selecting the most appropriate traffic control strategy for incident congestion management can have a major impact on the lateral extension and duration of the resulting congestion. This topic has not been thoroughly and extensively studied in the past.

1.3.3 The research study approach

This study was designed to include both a computer simulation of various strategies in a hypothetical network, and subsequent application of the concepts developed in this approach to a field test. First, an incident analysis was conducted on a hypothetical dense grid surface street network in which mid block incidents of various duration were tested. This network was configured to approximate the existing road network in the cities of

Troy and Rochester Hills. Second, field data was collected in these cities and analyzed. In the first phase of this research study, various control strategies were tested to determine their effectiveness under 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). In the field studies, only the SCATS system logic could be tested.

1.4 Incidents and their effect on traffic

Traffic incident is a term used for an event that 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 non-recurring 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.

It is this third category of incidents that was considered in this study. These incidents generally result in traffic congestion, The magnitude and duration of the congestion is difficult to predict because neither the location, the time, nor the severity of an incident is known beforehand. Limited information on incidents can result in non-optimal choices, such as an improper route choice and ill-timed signal settings.

1.4.1 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 the 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.

The efficient use of existing capacity through traffic management is the only response applicable to nonrecurring congestion. Therefore, measures to alleviate incident congestion focus on maximizing the use of available capacity.

Actions to reduce incident congestion have been 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.

1.4.2 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, and

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 offset to maintain equal queues for conflicting movements, traffic metering to avoid blockage, and reverse progression.

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 that minimize the effect and extent of the incident. Communication through in-vehicie devices or changeable message signs is required to give the drivers incident and routing information

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.

2 The computer simulation study

2.1 Statement of the problem

Traffic control strategies aimed at reducing the consequences of incidents have not been developed and thoroughly 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 as well as the joint effect of ATMS and ATIS control strategies were determined.

2.2 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.

2.3 Research approach

This research was based on traffic simulation since this permit; 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 cities such as 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 for 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. The prime objective of this research was to investigate the effectiveness of several control strategies on various incident locations.

3 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, as well as safety, and to reduce fuel consumption. Most of the signal control policies in the past were developed for recurrent traffic conditions, for both peak and off-peak traffic. As the nonrecurring 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 traffic control system. Since then increased attention has been given to the ability of such modern traffic control systems to respond with special control strategies for incidents.

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 is 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 vph for 4-lane, 4-leg junction). When the demand is greater than 2000 vph, the basic queue control strategy is better than the others.

Many control strategies were developed for oversaturated traffic conditions at an isolated intersection. Gordon (1969) suggests that the control objective is to maintain a constant ratio among the respective storage spaces. Longley (1968) attempted to balance queue lengths on all approaches. The signal split is determined for the next cycle based on the results of queue balance determination from preceding cycles. NCHRP Report 194 shows that, although the Longley control logic yields lower delay than the off-line calculation, the queue-actuated control yields lower delay when the degree of saturation is above 0.5. The report states 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.

3.1 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 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 fully evaluated.

In the Japanese UTMS 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 SCAT system 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. Then the traffic control is done manually by the expert. 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 is 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 may 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 4 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.

3.2 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 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, modem systems utilize more 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. These systems are called Dynamic Route Guidance systems (DRG). 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, variable message signs, and in-vehicle guidance system.

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 reroute 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 in Manhattan, New York.

3.3 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 3-l.

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 3-1 Results for route affected by the incident (Hunt and Holland, 1985)

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

This study did not have a routing procedure for diverted traffic. Therefore, there is no guarantee that vehicles return to their original routes nor did the study take into account the longer journey time due to alternate routes. Therefore, the indicated reduction in delay was exaggerated.

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.

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 equi-saturation 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.

3.4 Summary

Most traffic control strategies, developed for recurrent traffic conditions and employed in current control systems, may not be effective in the 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. A limited number of studies have been conducted to evaluate the effectiveness 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 test bed. Furthermore. a number of assumptions are imposed and a detailed analysis of the impact has not been conducted.

4 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 were tested in this study, with various control strategies applied to these scenarios.

4.1 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.

4.2 Hypothetical network formulation

There is a general resistance among transport modelers 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 influence 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 4-l was constructed for this study. The network is grid system, with each intersection one-quarter mile apart. 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 4-2.

4.3 Traffic demand and initial traffic signal setting

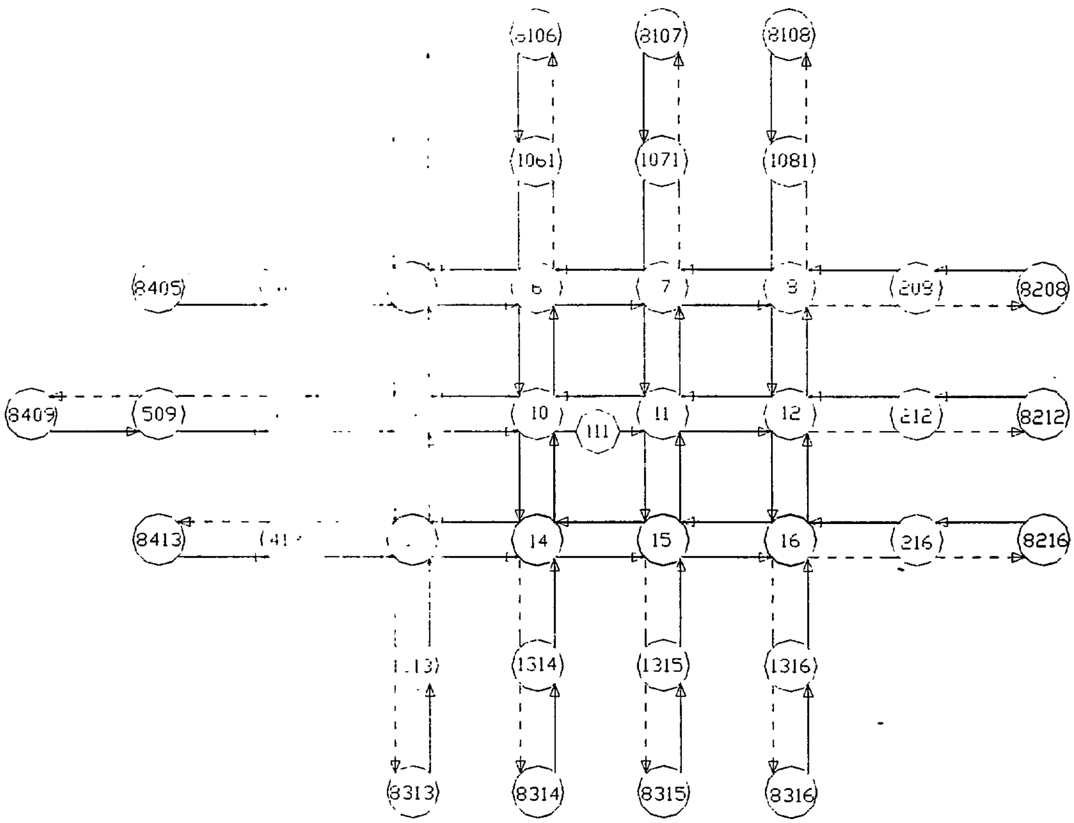
Traffic volumes were selected to be similar to the peak-hour traffic condition. The traffic volumes and the associated level of service (LOS) is shown in Table 4-l.

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 4-l Traffic demand used in this study

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

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



Incident takes place at node 111

Figure 4-l Street Network in this study

The LOS in Table 4-l 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.

4.4 Incidents

The characteristics of the incident introduced in the network must be specified. These characteristics include incident type, location, time of occurrence, frequency, and duration. 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 4-l.

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 lo-minute both-lane closure incident recover within one hour after the beginning of the simulation, while it takes about one and a half hour to recover in the 15-minute both-lane closure case.

4.5 Technological scenarios and control strategies

The study was formulated to test and compare four technologies. 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.

4.5.1 Do-nothing

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

4.5.2 ATMS oniy

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 was determined by calculating the growth of the queue. In practice, this could be accomplished by placing a special sensor situated at an upstream location on each link to detect the presence of a queue, or manual monitoring from surveillance cameras.

4.5.3 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 real time information on all possible paths and dynamic traffic assignment. To date, there is no diversion method that considers the combined effect of the adaptive signal control and dynamic traffic assignment The diversion plan in this study was determined from the results of multiple simulation runs. The percentage of the distribution to adjacent parallel arterials was set to yield the minimum total travel time.

4.5.4 ATIS/ATMS

The traffic diversion combined with the signal modification on the diversion route was selected for this category. While there are several methods to initiate a signal modification, the signal setting based on degree of saturation was selected in this 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 systm such as SCATS and SCOOT have adopted this method for their signal modification strategy.

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 produces the lowest intersection delays.

4.6 Measures of effectiveness (MOEs)

Several MOEs appropriate for characterizing the control of incident congestion were used in this study. 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 the spillbacks.

4.6.1 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.

4.6.2 Delay time

Delay 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.

4.6.3 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 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.

4.6.4 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.

4.6.5 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.

4.7 Study plan

The study scheme for this study 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 was 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 4-2.

4.8 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.

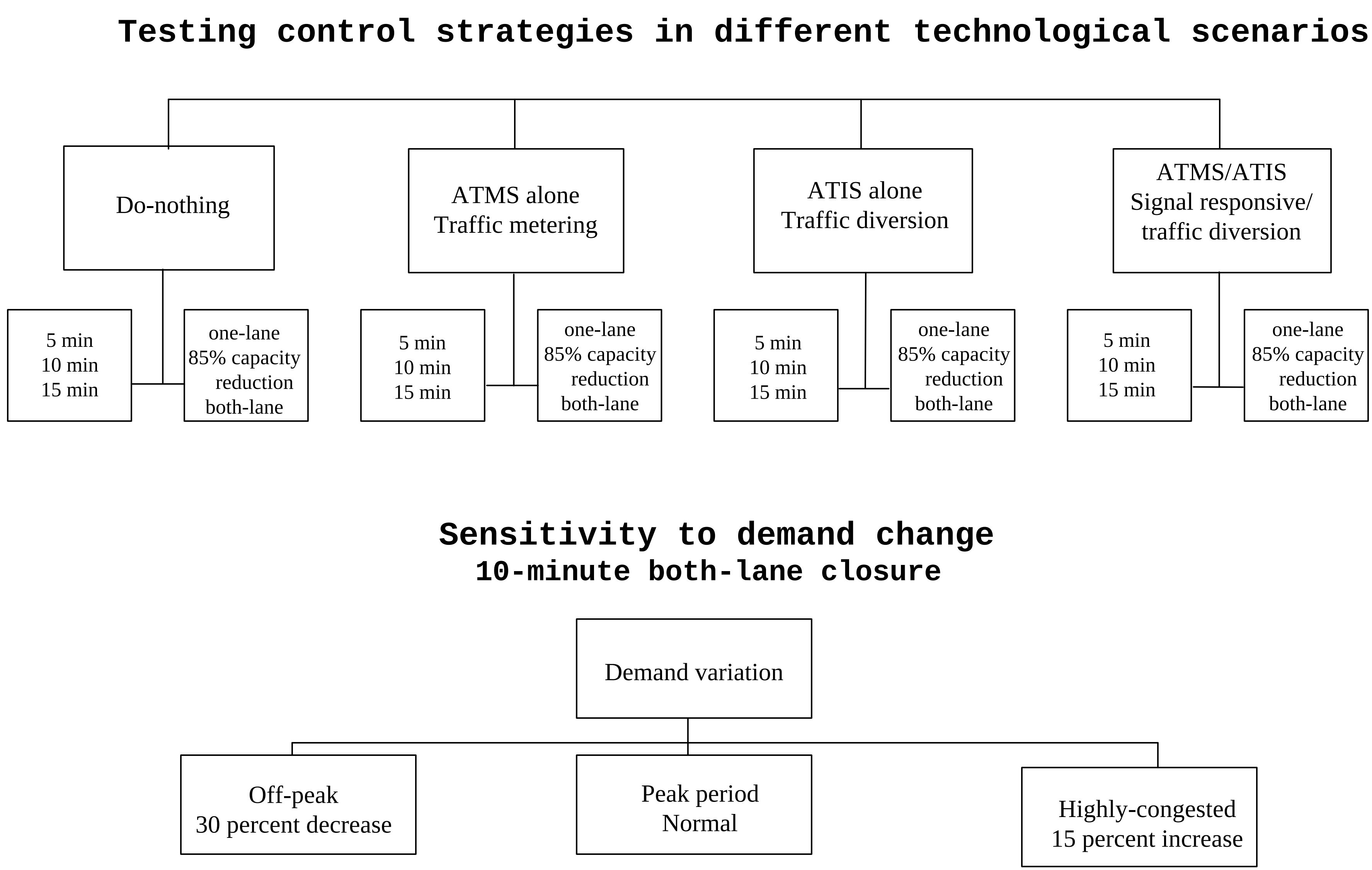


Figure 4-2 Study plan

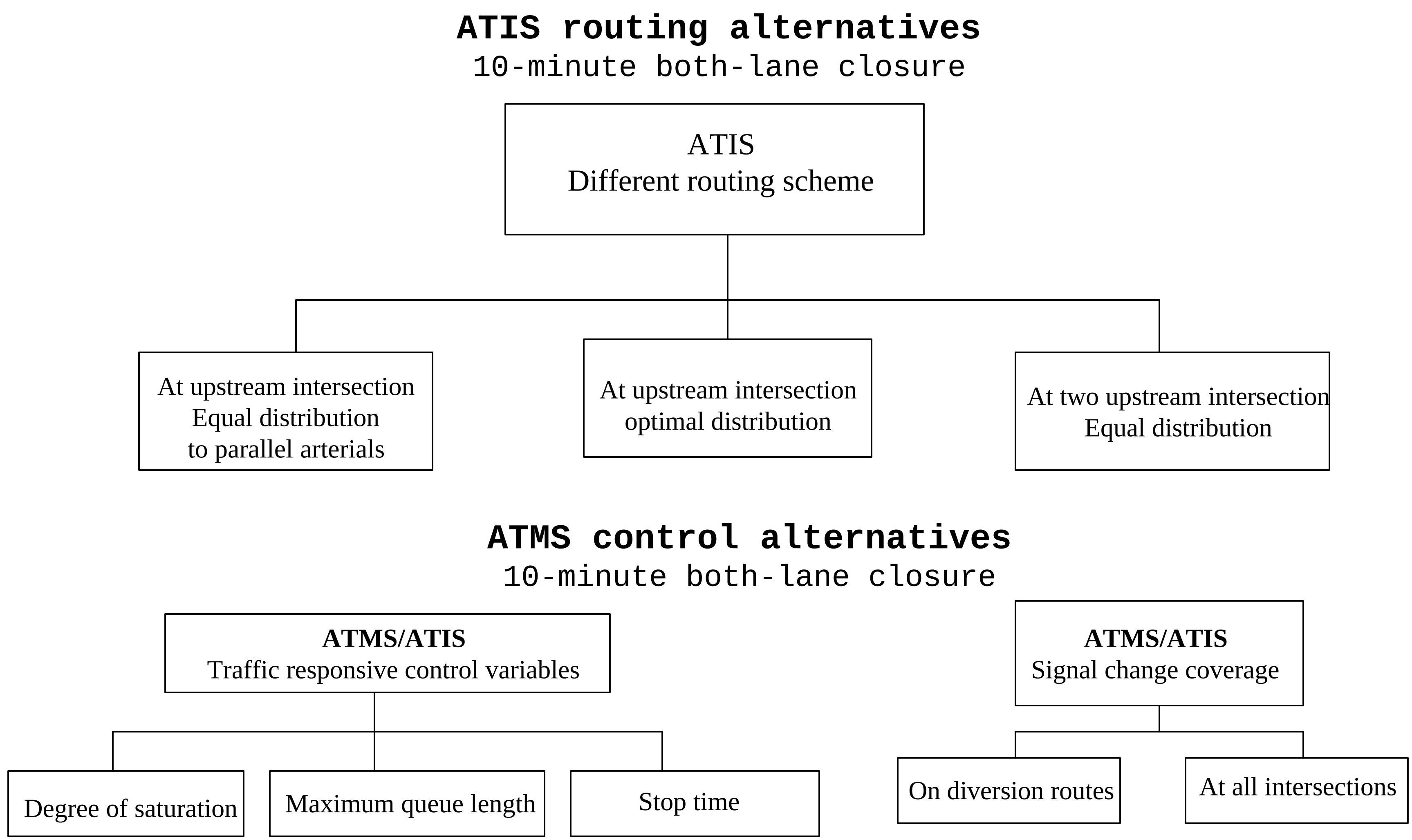


Figure 4-2 (cont'd)

5 SIMULATION 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 describes traffic conditions when incidents were introduced. Then various control strategies were tested on the same incident situations and their MOEs were compared.

5.1 Effect of type and duration of incident

Table 5-l 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.

5.1.1 Total travel time

As shown in Table 5-1, 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.

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.

Table 5-l 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

5.1.2 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 **5-2**

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 blockages at this intersection ended in 9, 3 10, 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.

Table 5-2 Start and end time of intersection blockages: Various Incident Types and Duration

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 9	326 n/a	335 n/a	326 n/a	636 n/a	326 917	936 1132
Both-lane closure						
IO 9 409 14 13	212 n/a n/a n/a n/a	337 n/a n/a n/a n/a	212 602 n/a n/a n/a	64X 725 n/a n/a n/a	212 602 879 721 824	974 1020 1089 981 898

Note: The intersections are periodically cleared during the spillback periods

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 lo-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 4-1) 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.

5.1.3 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 5-l demonstrates why delay from the standard NETSIM outputs cannot be used. This is because the delays 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 5-1, the 1 O-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 5-l was calculated from queue lengths obtained every four seconds. The queue length is illustrated in Figure 5-2. 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 5-l is 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 5-3. All incidents started at 300 seconds after the beginning of the simulation. In the 85% capacity reduction incident situation, the traffic operations returned to normal at time 400,900, and 1400 seconds after the 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 3200 seconds after the incidents were removed.

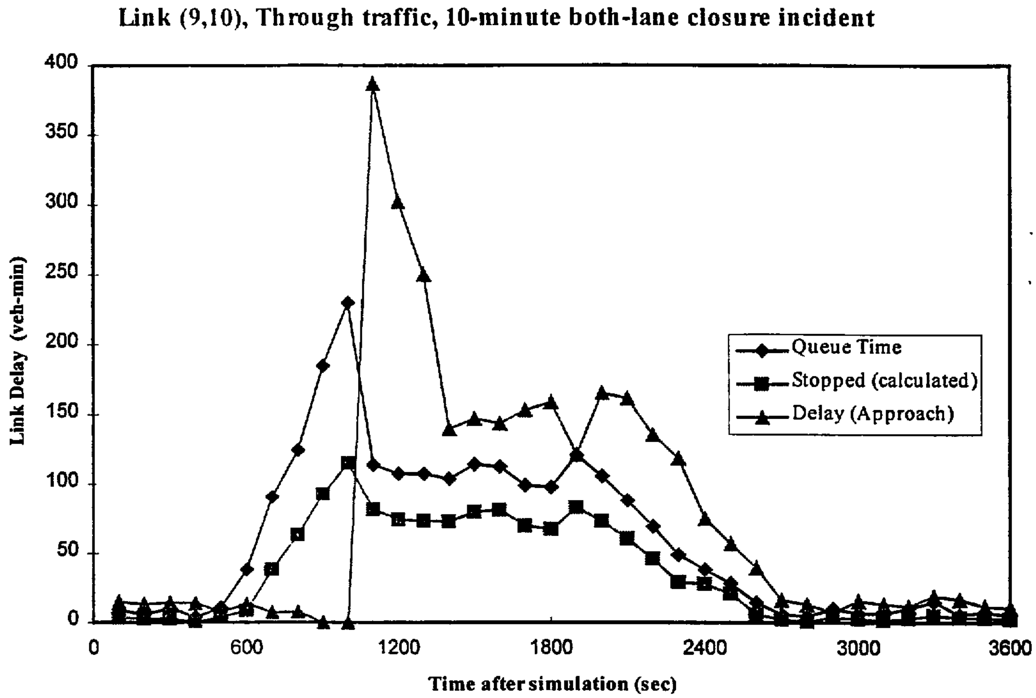


Figure 5-1 Statistics from NETSIM for determining congestion period

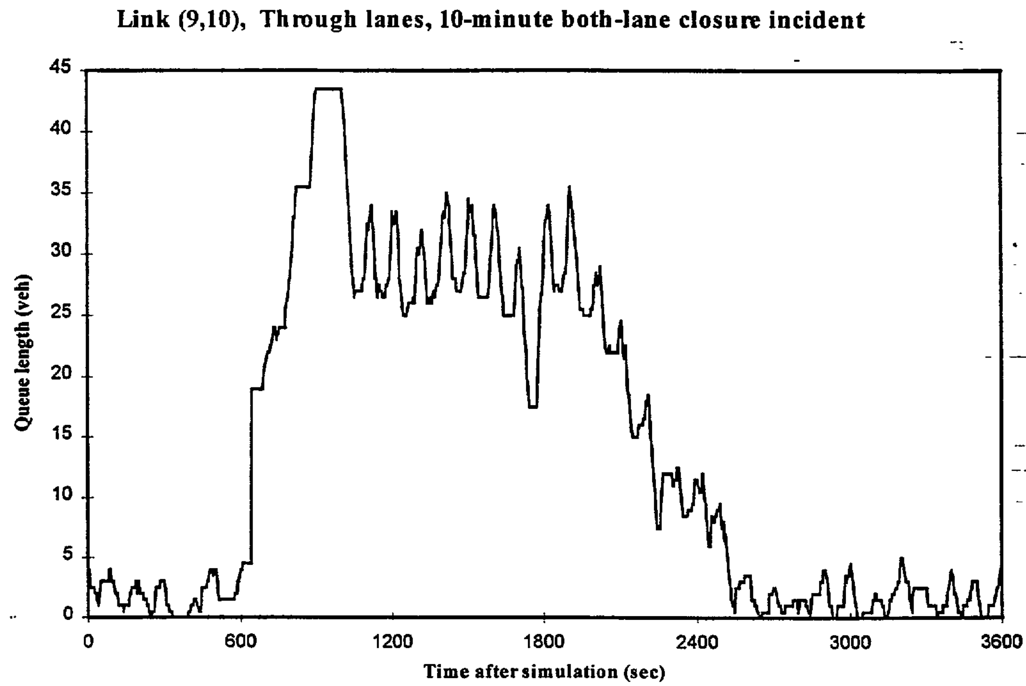


Figure 5-2 Queue length obtained every four seconds

The spread and duration of congestion in the network can be presented as illustrated in Figure 5-4. 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 lo-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 5-4a.

Figure 5-4b 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.

a. 85 percent capacity reduction incident

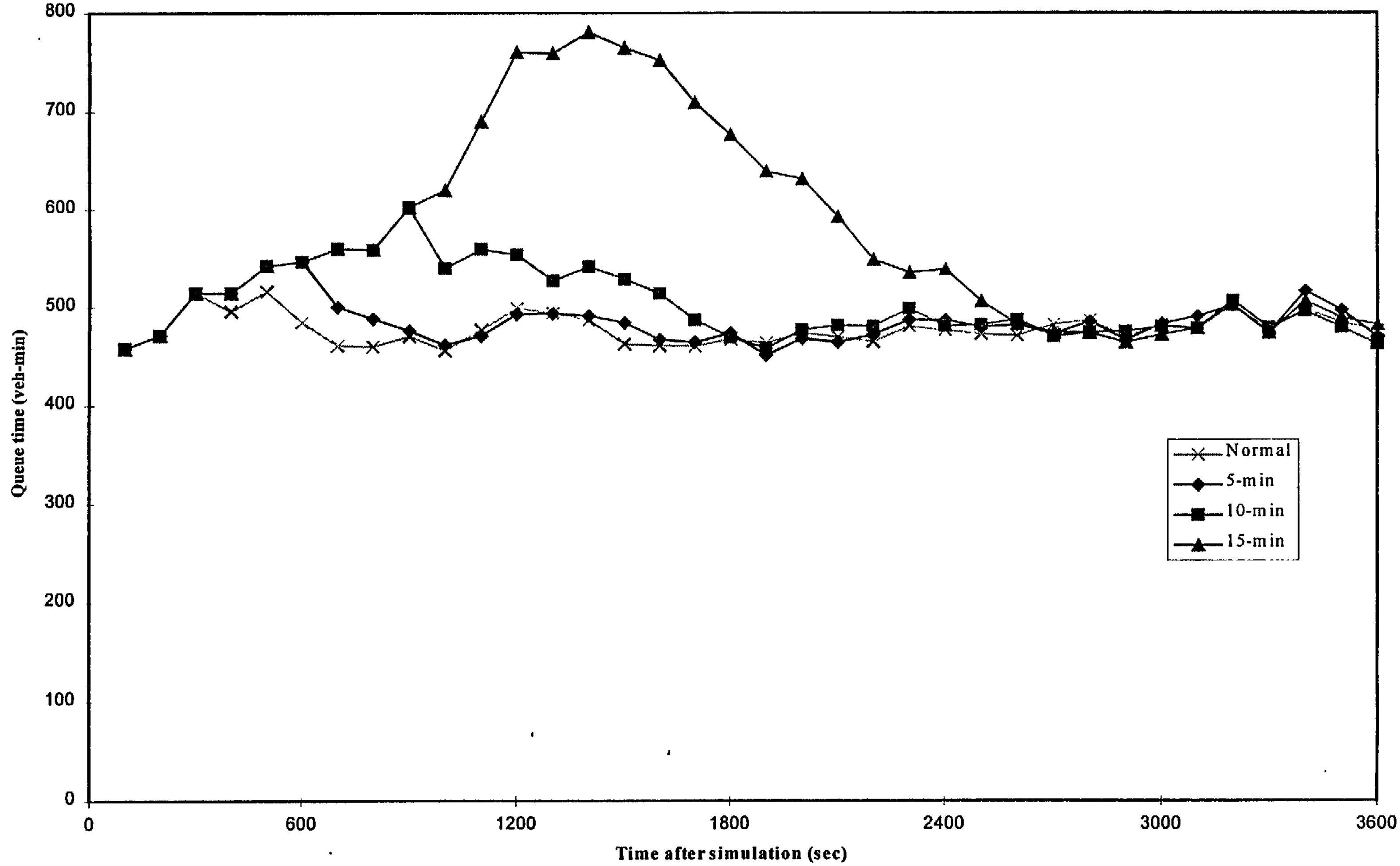


Figure 5-3 Congestion duration: no control change

b. Both-lane closure incident

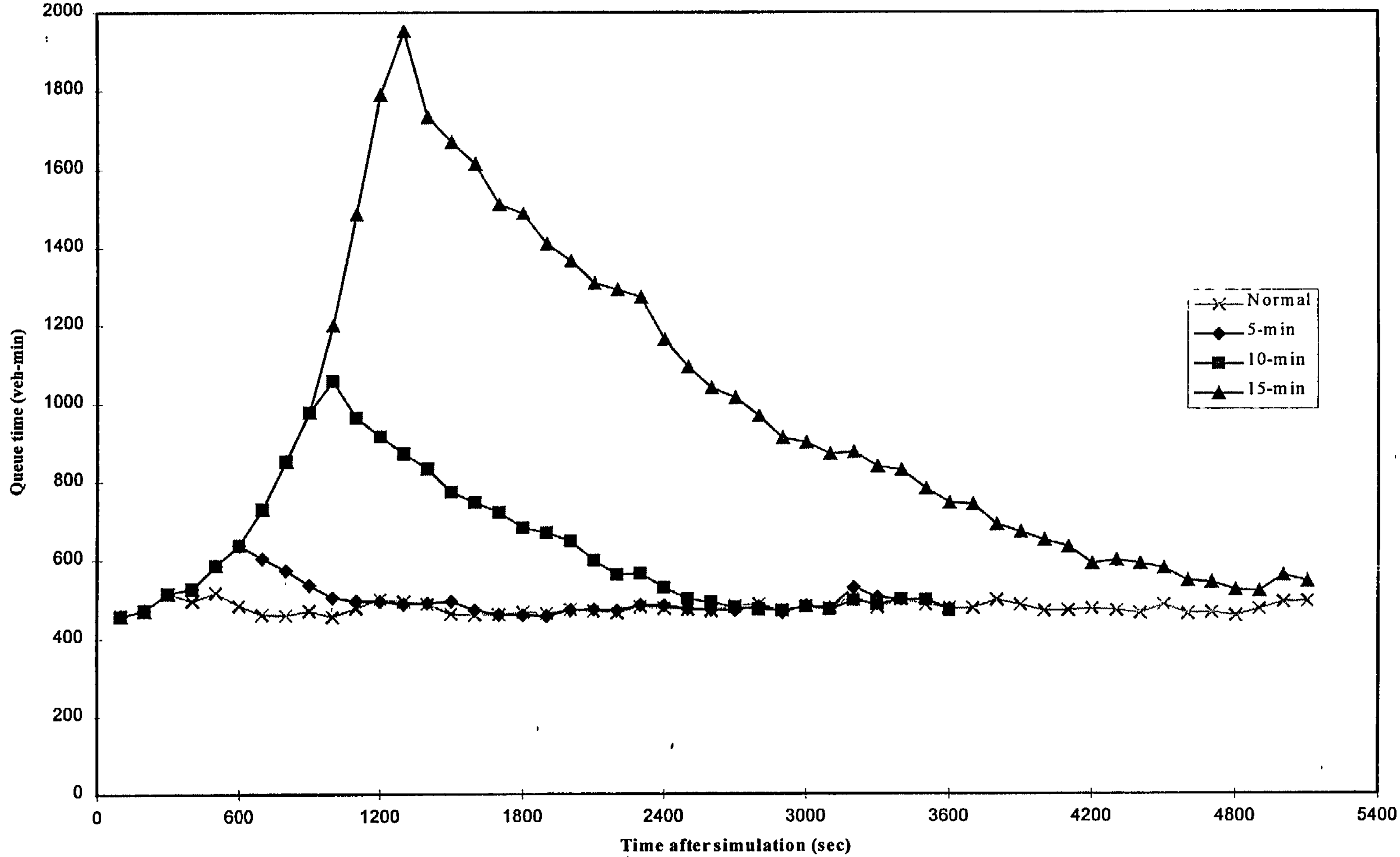


Figure 5-3 (cont'd)

a. 10-minute both-lane closure incident

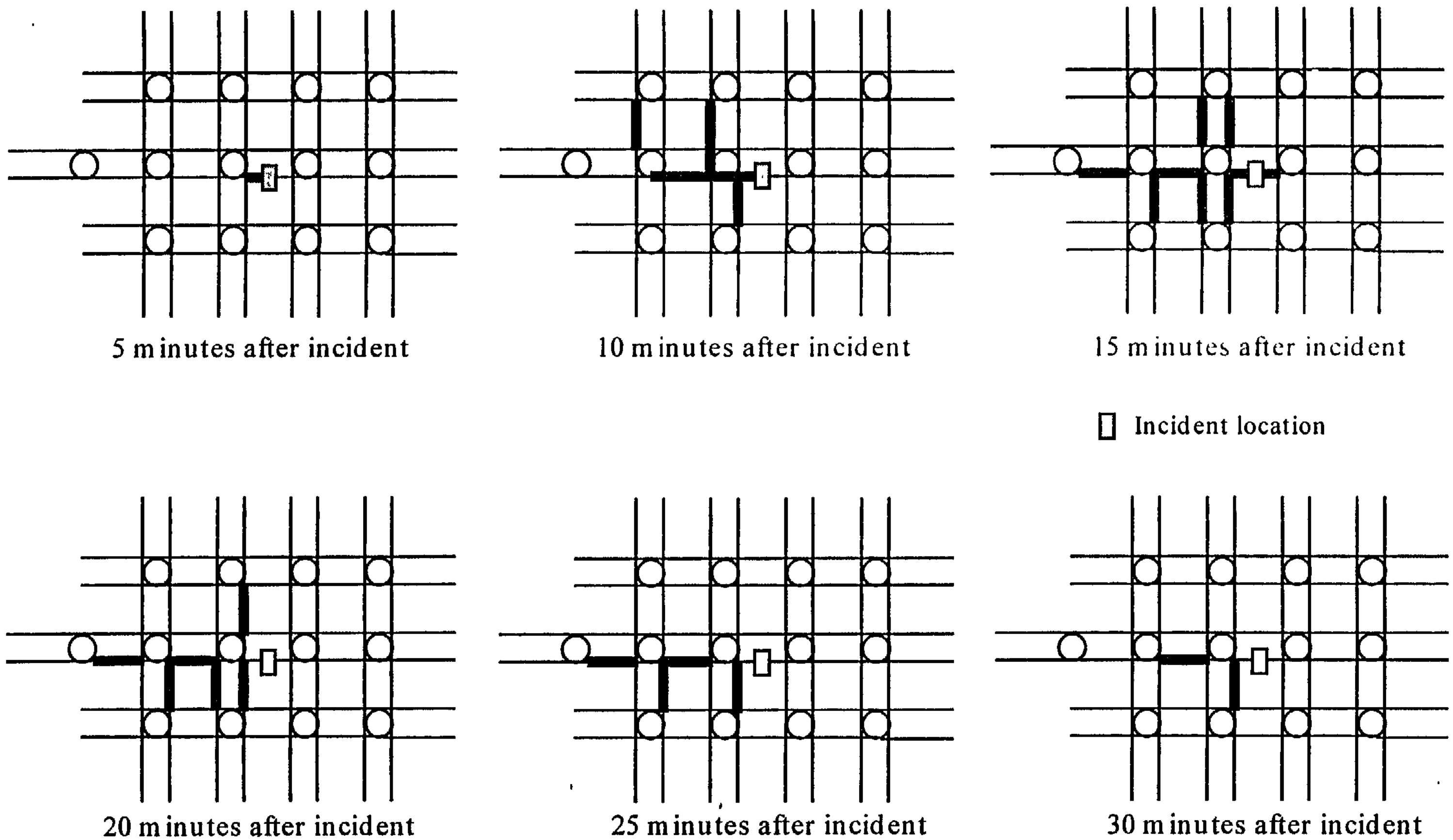


Figure 5-4 (a) Affected links and duration of congestion: no control change

b. 15-minute both-lane closure incident

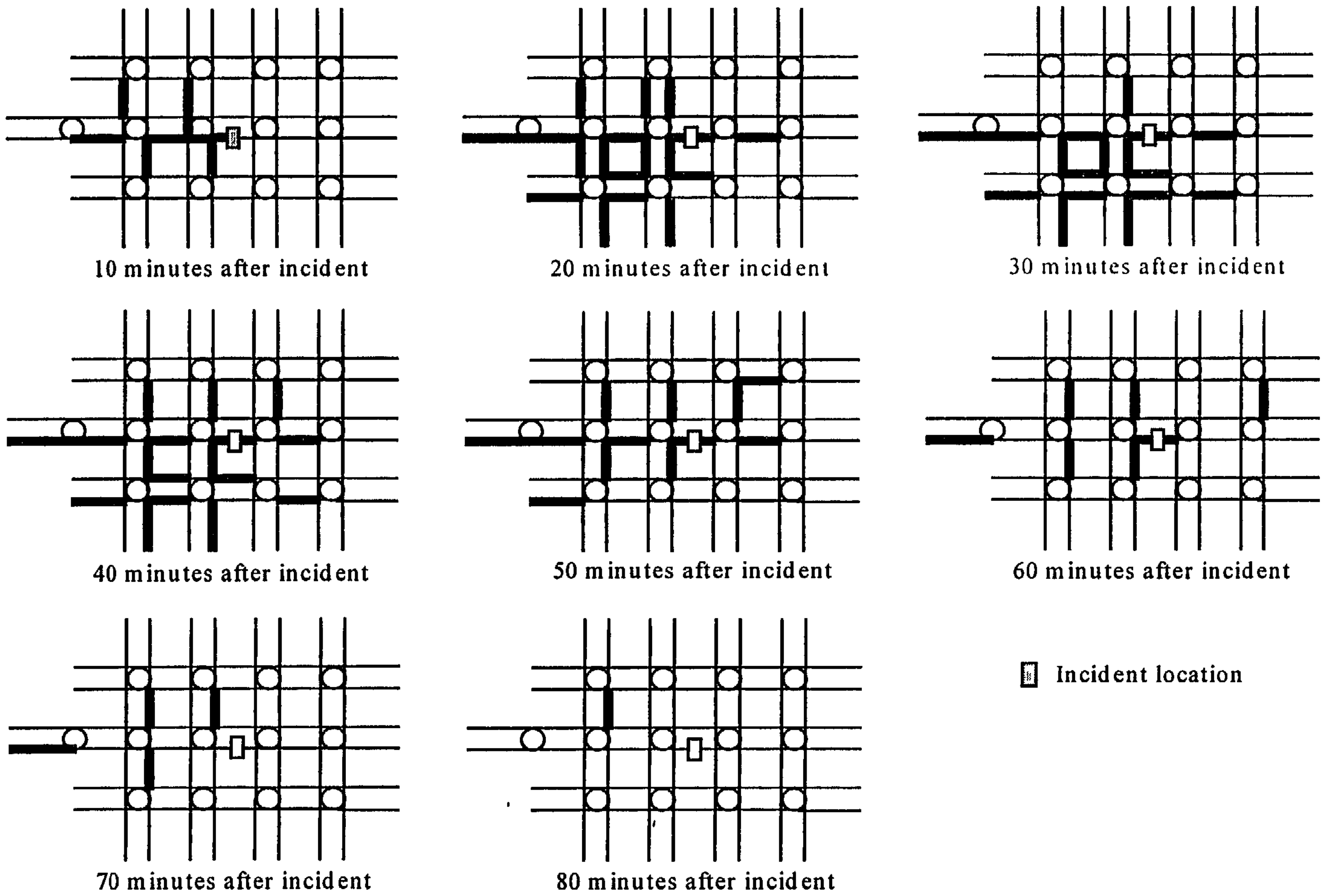


Figure 5-4 (b)

5.1.4 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 5-3 shows total travel time of through traffic on the path approaching the incident. The results reveal the same trend as Table 5-l with travel time increasing as the incident duration increases. However, there was some difference in the impact on this traffic stream versus the impact on the entire network. Table 5-3 indicates that the journey time on this through route in the lo-minute 85% capacity reduction incident situation is lower than the journey time for a 5-minute both-lane closure incident (77.3 veh-hrs compared with 78.7 veh-hrs). However, the total travel time of all traffic in the lo-minute 85% capacity reduction incident situation (793.8 veh-hrs) is higher than that of the 5-minute both-lane closure incident (788.3 veh-hrs). This means that the lo-minute 85% 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 5-3, 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.

Table **5-3 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	42.4	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

5.2 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.

5.2.1 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 5-4.

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 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.

Table 5-4 Total travel time for four control strategy scenarios

a. 85% 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	826.0 1	869.76
ATIS/ATMS: traffic diversion with signal change (equalization of degree of saturation)	794.96	839.75	93 1.83

ATIS traffic diversion is the assignment of traffic to adjacent arterials to avoid the incident. In this analysis, traffic was 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 5-4a 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 a 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 lo-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 lo-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 lo-minute incident situations, changing signal timing causes higher delay than the no-control change scenarios.

For the both-lane closure incident (Table 5-4 b), traffic metering improves the traffic operations over the no control change situation. The 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 lo-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.

5.2.2 Intersection blockage

All traffic control strategies eliminated intersection blockage.

5.2.3 Congestion duration

The duration of congestion is another measure used to express the impacts of these control strategies. As discussed in the preceding section, 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 the increased travel distance in the diversion control strategies should be taken into account, the total travel time was used to determine the congestion periods 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 5-5.
In the 1 O-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

a. 10-minute both-lane closure incident

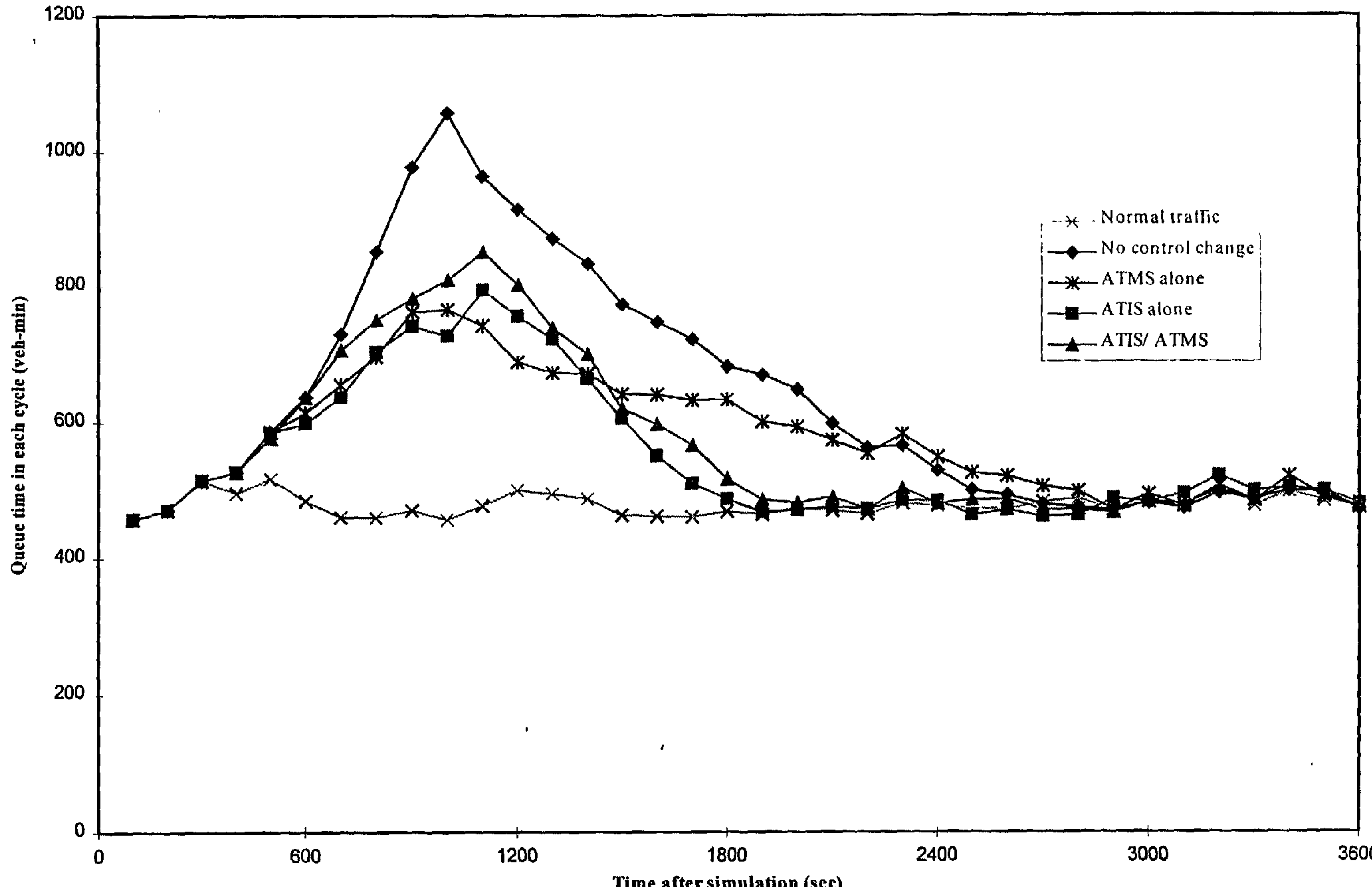


Figure 5-5 Congestion duration: different control strategies

b. 15-minute both-lane closure incident

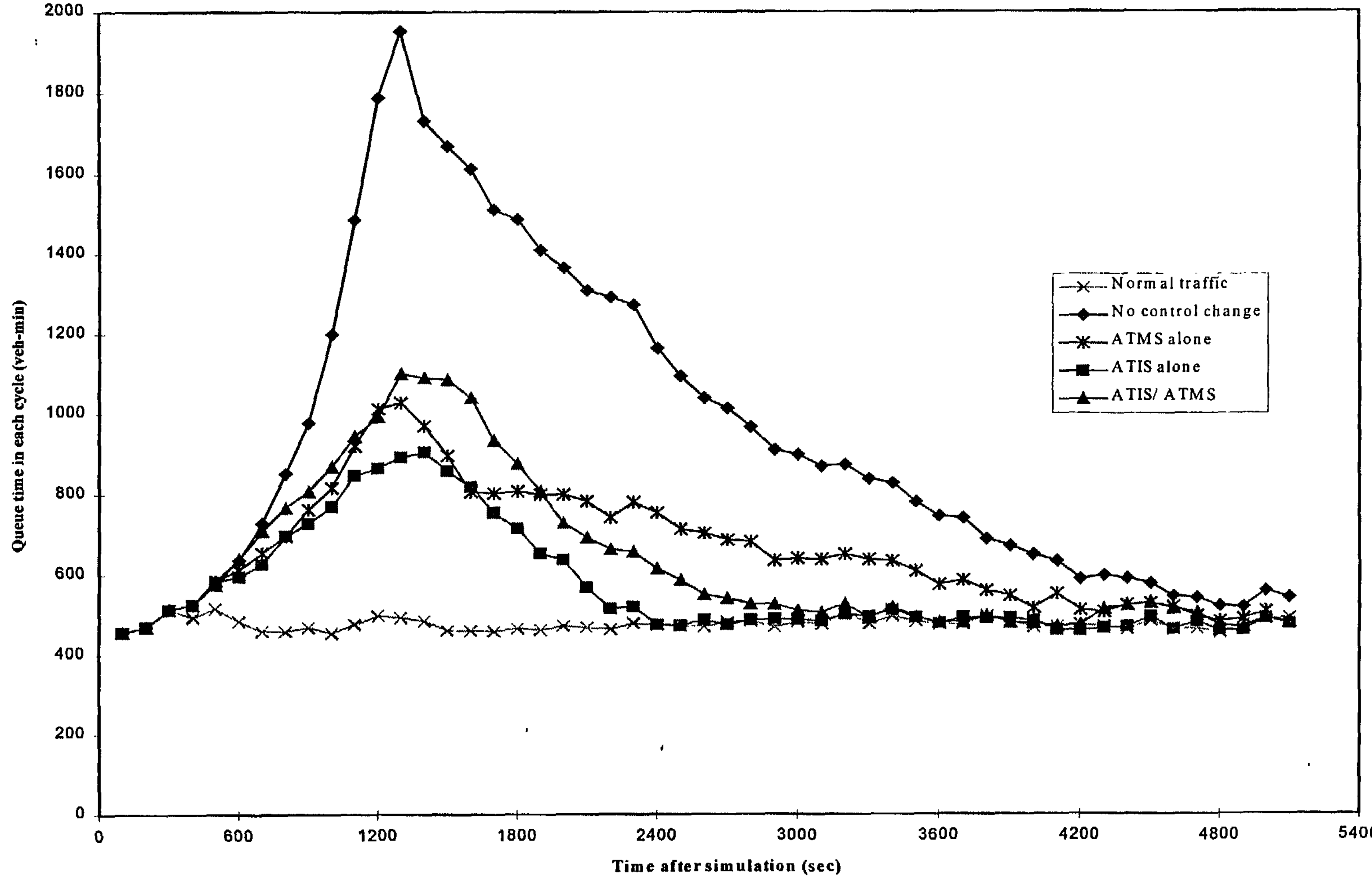


Figure 5-5 (cont'd)

the do-nothing case by 700 seconds. The ATIS/AT-&IS 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 5-6. The lo-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 5-6a). Traffic diversion creates heavier traffic on diversion routes during the rerouting, but the duration is much shorter, as noted earlier (Figure 4-6 b). 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 routes. The termination of signal modification after the incident is cleared creates heavy traffic on the downstream links at rerouted intersections (Figure 5-6c).

5.2.4 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.

a. Traffic metering

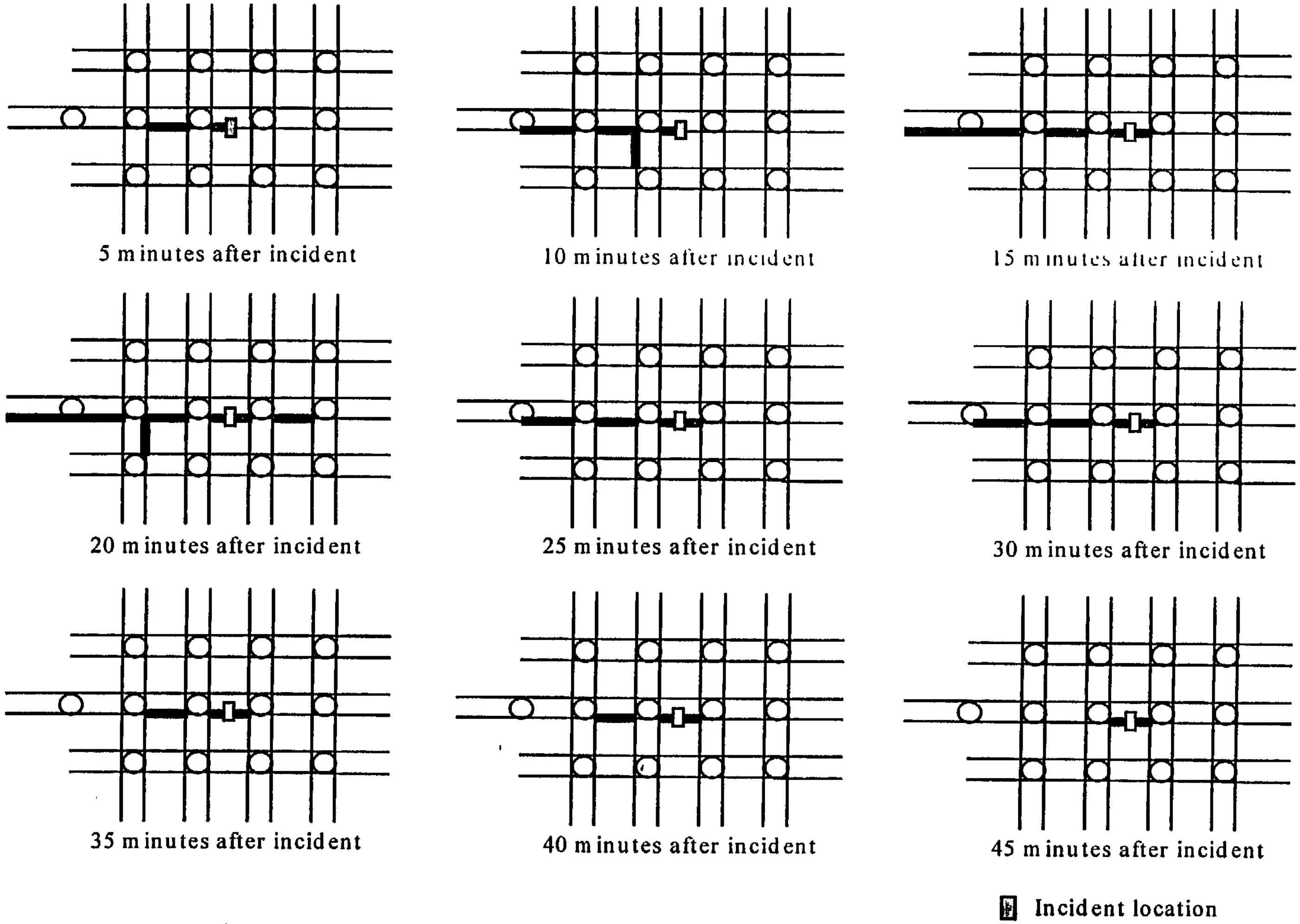


Figure 5-6 (a) Affected links and duration of congestion: different control strategies

b. Traffic diversion

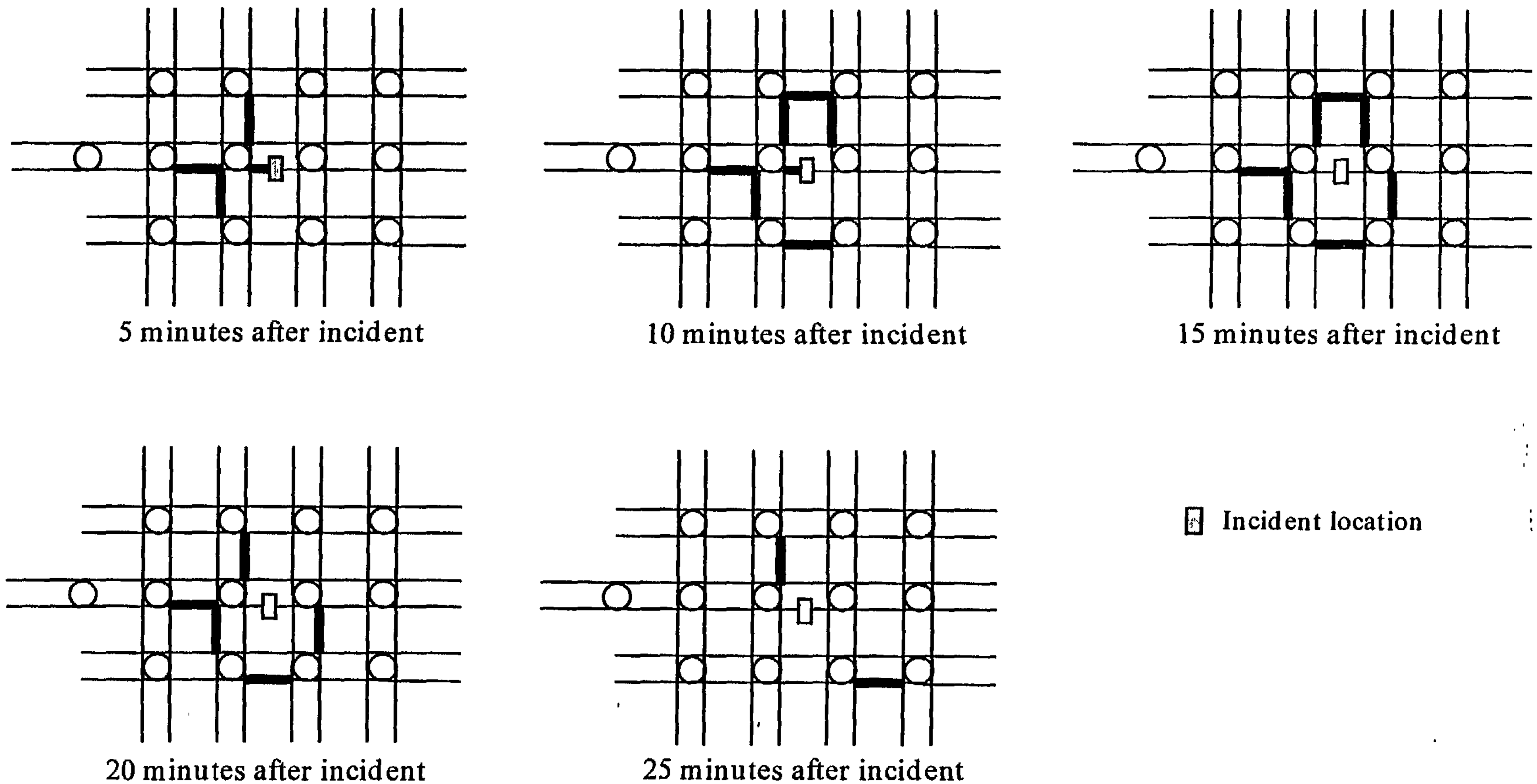


Figure 5-6 (b) Affected links and duration of congestion: different control strategies

c. Signal timings modification and traffic diversion

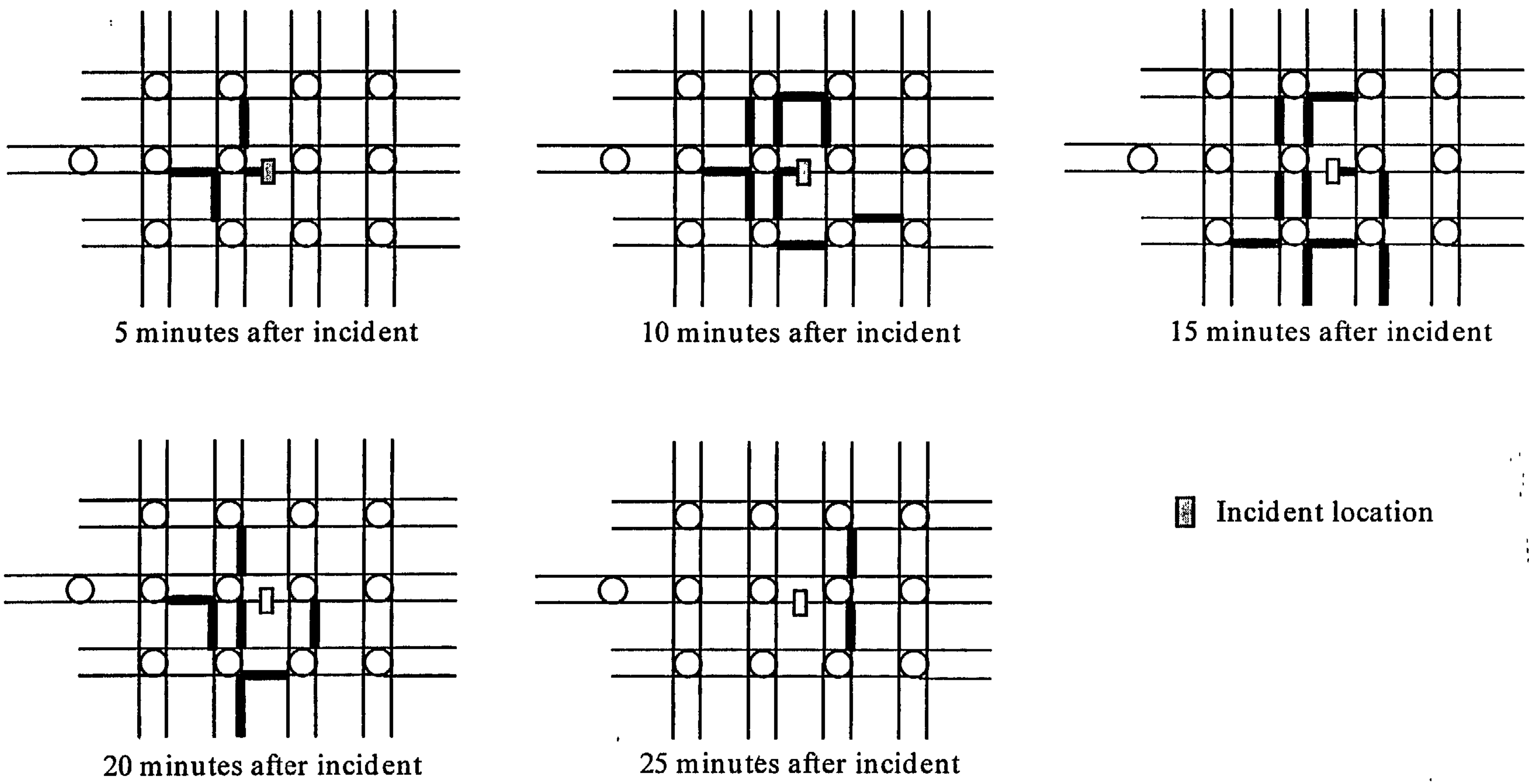


Figure 5-6 (c) Affected links and duration of congestion: different control strategies

The traffic was divided into three groups, based on the potential to have different impacts from the control strategies. They are:

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 5-5 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 suffers higher delay due to the interruption of progression caused by the signal adaptation. This interruption 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.

Table 5-5 Total travel time of particular traffic groups: Both-lane closure incident

Link Group	Travel time in one hour (veh-hrs)					
	Incident duration (minutes)					
	5-minute		10-minute		15-minute	
	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

5.3 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 traffic streams 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 lo-minute 85 percent capacity reduction, and the 5-minute both lane closure incident situation. Although this control 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.

6. MODEL VALIDATION STUDY

6.1 The Traffic Network in Troy and Rochester Hill

The Cities of Troy and Rochester Hills are located in the southwest comer of Oakland County. Like the rest of Oakland County, these cities are experiencing considerable commercial and residential development and resulting increases in traffic congestion. The road network in these two cities is arranged in a perpendicular grid system of primary roadways spaced at approximately one-mile intervals. The majority of the traffic is carried on the main arteries comprising this grid. The local street network is also arranged in an approximate grid layout with a density, as is common, considerably greater than the primary road system. A subset of these two cities, consisting of the street network in a three-mile square area was used in this analysis. The three main streets running east/west are Auburn Road, South Blvd. and Square Lake Road. The north/south streets are Rochester, Livemois and Crooks Roads, Figure 6-l.

There are nine signalized intersections within the road network considered in this analysis. The installation, operation, and maintenance of these signals are under the jurisdiction of the Road Commission for Oakland County. Originally, all of these signals operated on a well-coordinated pre-timed basis. The Oakland County ATMS project involved the conversion of all nine signals to SCATS control.

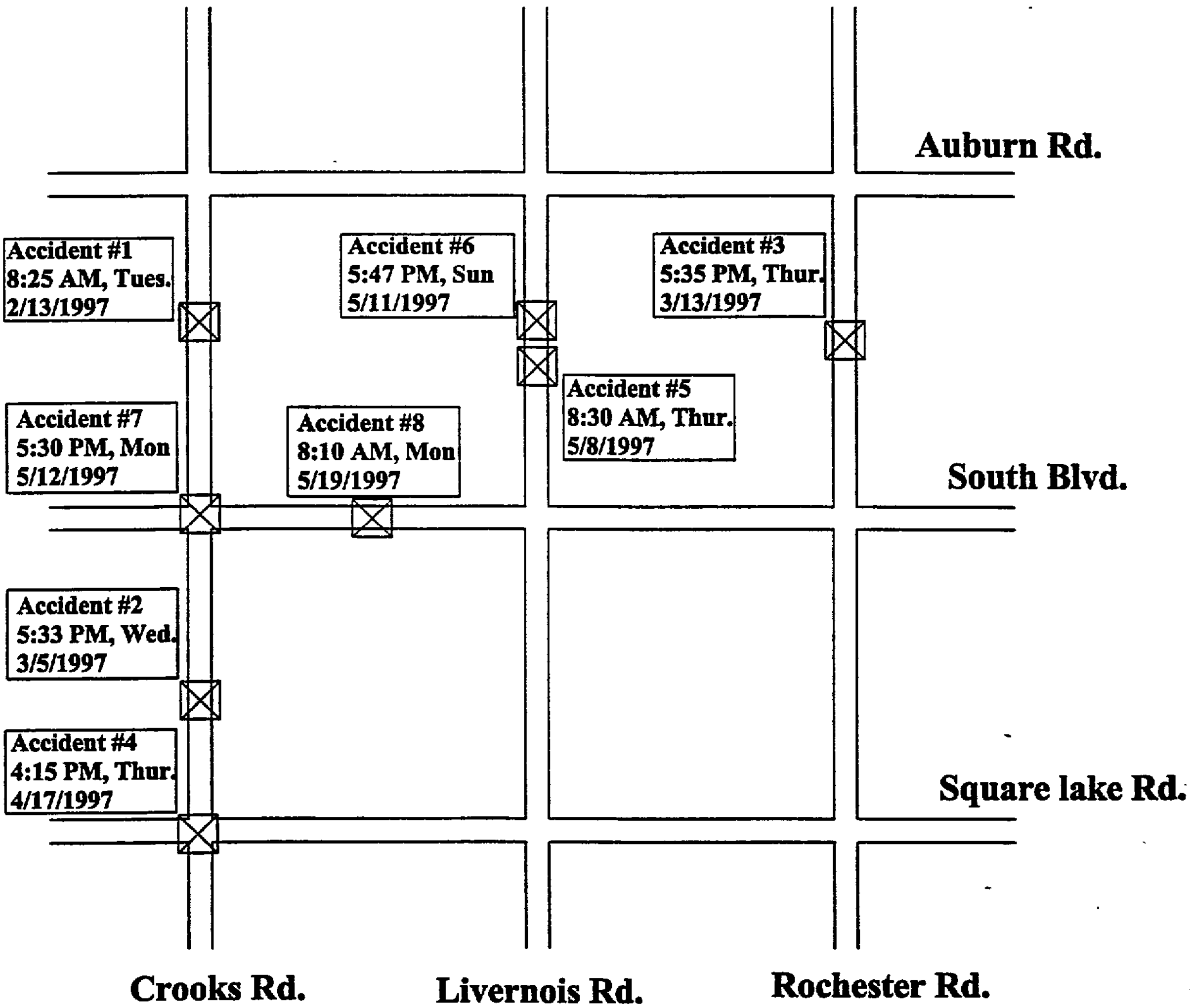


Figure 6-1 Street Network and Crash Locations

6.2 The Research Study Approach

The study was originally designed to test the concepts developed in the theoretical simulation approach described in the first part of this report. The network used in the simulation was configured to approximate the road network in the cities of Troy and Rochester Hills. After having obtained some insight from the theoretical concept it was planned to collect and analyze field data to test the validity of the simulation results.

6.2.1 The Field Study Approach Adopted

The original plan was to stage an incident at either an intersection or at a mid-block location and determine the adaptability of SCATS to respond to such an event. However, the cities of Troy and Rochester Hills, as well as the RCOC, expressed both legal and safety concerns over staging such an event. Although these agencies were willing to participate in such a study, they did not consider it appropriate or feasible to have this event staged during the peak period. This was, however, self-defeating, as the simulation had already shown that if the volumes are too low, the queue generated will not result in a blockage of the intersection.

Another possible study plan considered was the collection of data by conducting a needed maintenance activity during the rush hour. However, this too was not acceptable. This study plan was abandoned because staging such an event or observing a maintenance activity in the non-peak period would not require the signal system to respond.

The strategy ultimately adopted was to use SCATS to develop a baseline data file, and then to search for anomalies resulting from. a non-staged incident. As a first step in the analysis, the network traffic data for four months was collected from the SCATS monitoring files. The SCATS files contain information on the green time, volume, degree of saturation, marriage /divorce of the intersection, and the phase and link plans deployed at each intersection. The second part of this approach involved collecting police records for traffic crashes occurring in the network during the same months. From these records crashes which appeared to have the potential to create a major impact on the network were selected. The response of the traffic signals immediately following the reported time of these selected crashes was then compared with the baseline SCATS files to determine how SCATS adapted to this disruption by changes in the control strategy. This approach envisaged selecting a few major crashes, and documenting changes in SCATS file output. The plan was to then simulate the modified traffic flow and control pattern to determine the benefits of changes in the control strategy.

6.2.2 Selection of Crashes

The accident records over the study period (Feb. 97 to May 97) were collected from the Police Department and analyzed. A number of mid-block (segment) and intersection crashes were selected for analysis. The selection of the crashes was based on their potential impact on the traffic network,

The study was designed to determine if there was a relationship between the occurrence of a crash and the traffic flow and the green time allocation in the period immediately subsequent to the occurrence of the crash. The cycle-by-cycle green time duration for 20 minutes before and 20 minutes after each reported. crash time was studied to determine the extent of the impact of the particular incident on the green time and volume.

Crashes occurring at the following eight (8) locations as shown in Figure 6.1 were studied:

1) North of Crooks Road/ South Blvd. intersection on Crooks Road.
2) North of Crooks Road/ Square Lake Road intersection on Crooks Road
3) North of Rochester Road/ South Blvd. intersection on Rochester Road
4) Square Lake Rd/ Crooks Rd intersection
5) North of Livemois Road/ South Blvd. intersection on Livemois Road.
6) North of Livemois Road/ South Blvd. intersection on Livemois Road.
7) South Blvd. /Crooks Road intersection
8) Between South Blvd. / Crooks Road and South Blvd. / Livemois Road intersections on South Blvd.

6.2.3 Establishing Green Time Confidence Interval

The green time allocation at the nearest intersection to the crash location was monitored immediately after the reported time of the crash and compared with the green time allocation in the twenty minutes prior to the crash to determine whether SCATS changed the control strategy as a result the incident. To determine whether any observed changes was statistically significant, a confidence interval for the green time allocated for each approach to the intersection being monitored was constructed based on SCATS data reported for the four month period. The 95% confidence interval was used to determine whether the green time allocation tits within the "normal" range of the green time for this approach. The green time allocation before and after the incident was then determined and compared to these confidence limits. The green time confidence interval for each of the intersections is shown in Figures 6-2 through 6-9.

6.3 Analysis of Green Time Response

6.3.1 Crash # 1

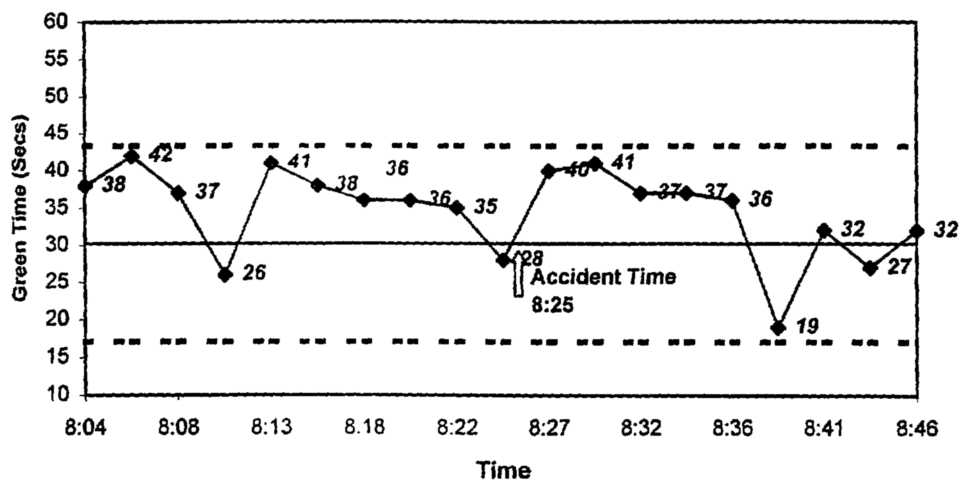
This crash occurred on Crooks Road, north of the Crooks Road / South Blvd. intersection at a mid-block location. The crash occurred at 8:25 a.m. The green time variations on this day are depicted in 6-2.

There was a decrease in the green time in the EW direction from 35 seconds to 28 seconds one cycle prior to the reported time of the incident. The green time then increased from 28 seconds to 40 seconds in the first cycle after the incident indicating there was probably some response to the incident. However, both within the 20 minutes prior to this incident and within the 20 minutes after the incident there was a larger variation in green time. The change in green time allocation in all three instances ‘was within the confidence limits established for this intersection.

In the NS direction there was little response after the incident occurrence, as shown in Figure 6-2. The graph indicates a normal pattern, as if there had been no change due to the occurrence of the crash.

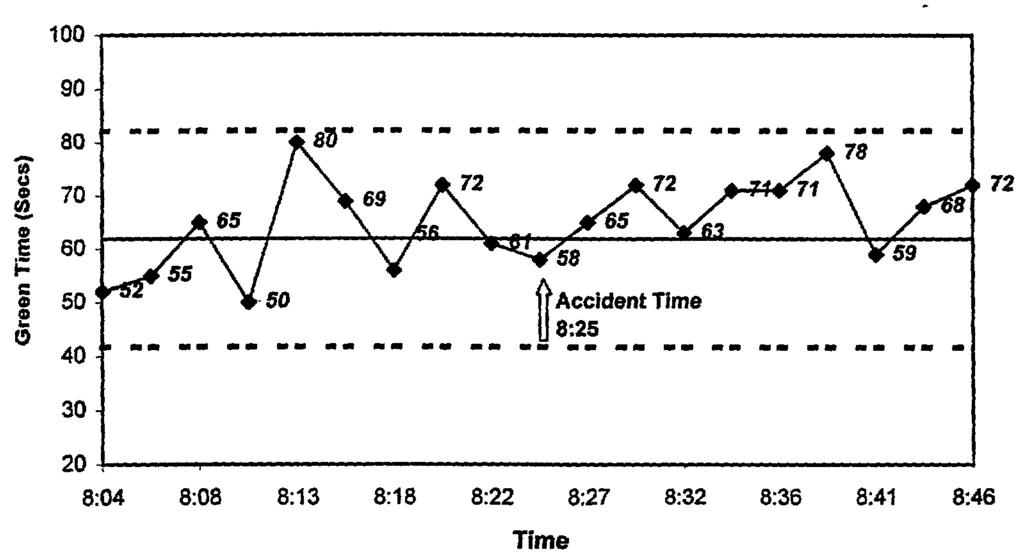
Figure 6-2 Green Time Response for Crash #1

Green Time for Eastbound/Westbound Traffic (South Blvd. & Crooks Rd. Intersection)



Average green time over 4 months period = 30.2 secs, SD = 6.7 secs

Green Time for Northbound/Southbound Traffic (South Blvd. & Crooks Rd. Intersection)



Average green time over 4 months period = 61.9 secs, SD = 10.3 secs

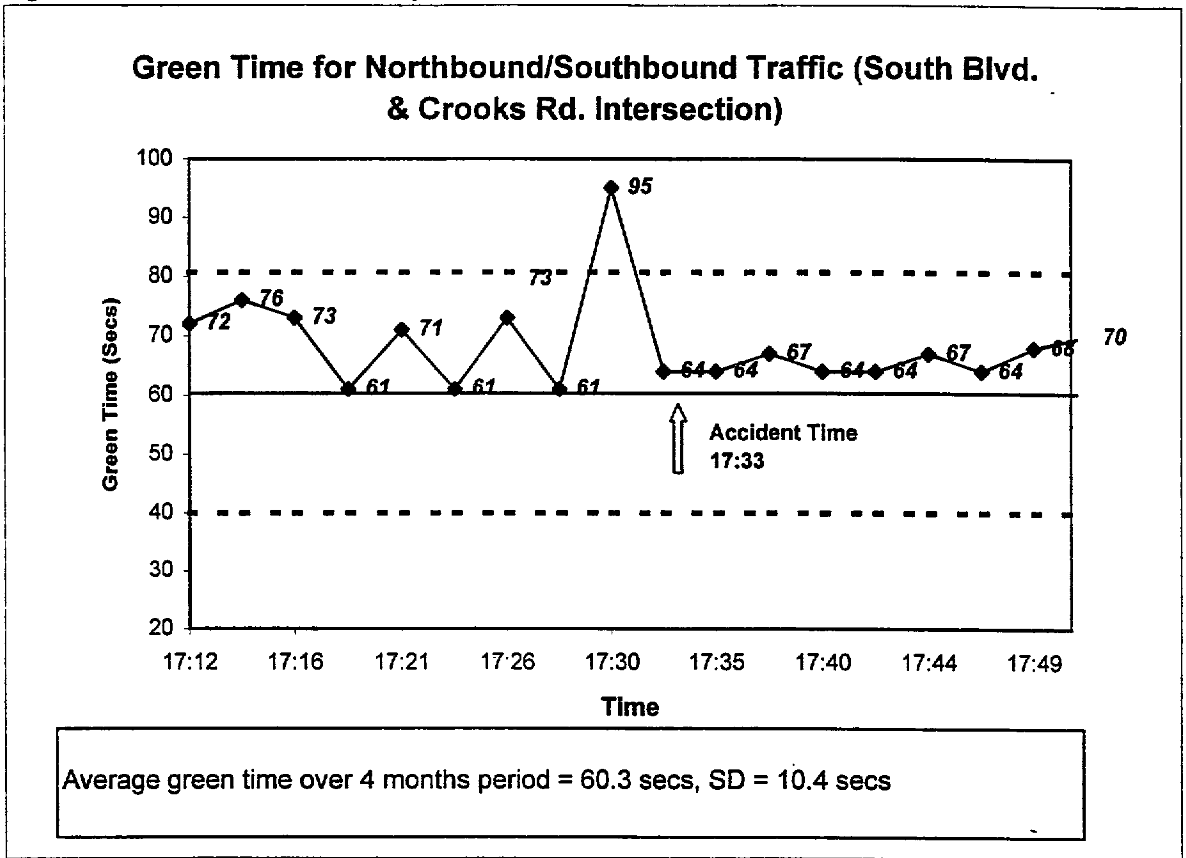
6.3.2 Crash # 2

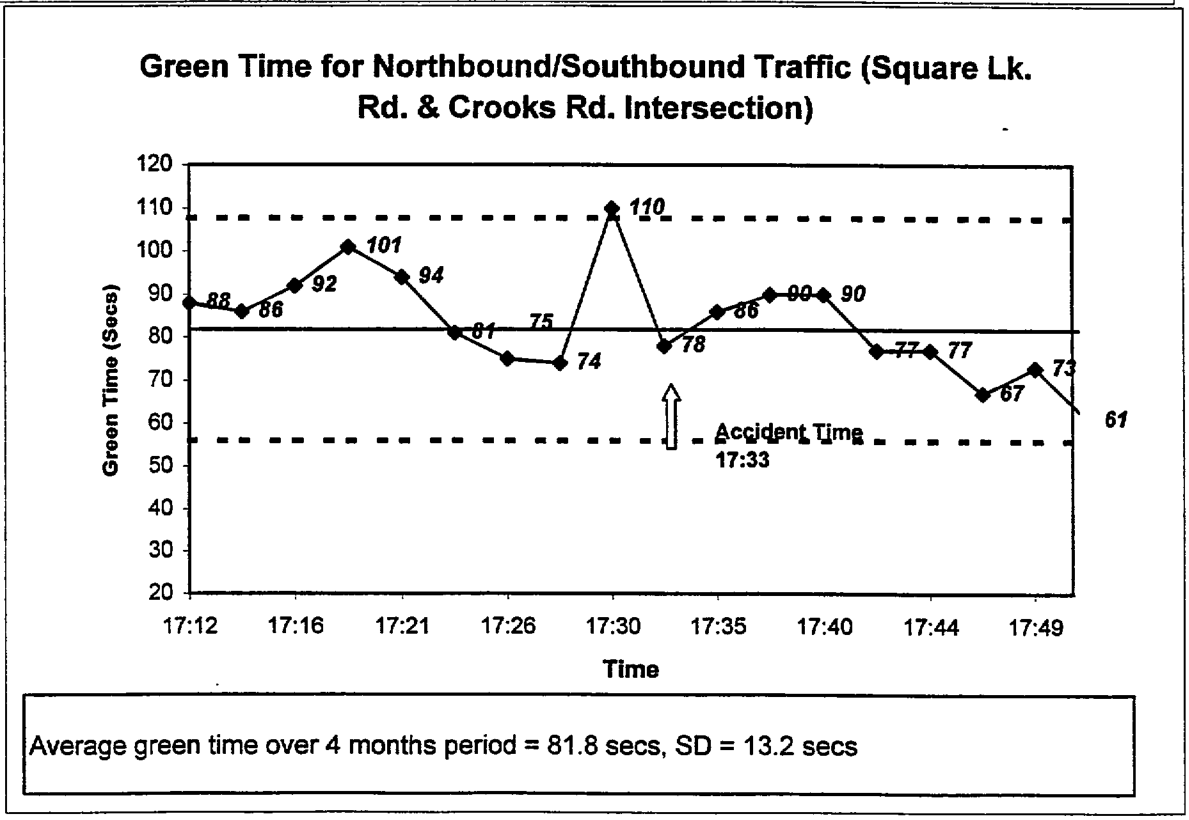
This incident occurred at 17:33 on Crooks Road north of the Crooks Road / Square Lake Road intersection at a mid-block location. The variation in green time at both the Crooks Road/South Blvd. intersection and Crooks Road/Square Lake intersection are shown in Figure 6-3. These were studied to determine if there was any significant change in green times due to the above incident.

In the NS direction at the Crooks Road/South Blvd. intersection, the green time increased from 61 seconds to 9.5 seconds immediately prior to the reported time of the crash. The green time dropped from 95 seconds to 64 seconds in the cycle immediately after the incident, and remained nearly constant for the 20-minute period after the incident.

At the intersection just south of the incident (Crooks Road/Square Lake Road intersection), there was an increase from 74 seconds to 110 seconds for one cycle, and then a decrease in green time from 110 seconds to 78 seconds in the cycle immediately following the incident. After this cycle, however, there were no abrupt changes in the green time. This represents a case where there was a clear response to the incident, as both intersections exhibited a green time variation outside the 95% confidence interval.

Figure 6-3 Green Time Response for Crash #2





6.3.3 Crash #3

This incident occurred at 17:35 on Rochester Road north of the Rochester Road/South Blvd. intersection. The green time variations are shown in Figure 6-4. There were no noticeable changes in the green time in either the EW direction or the NS direction. It appears the incident did not cause the SCATS control logic to respond.

6.3.4 Crash #4

This crash occurred at 16: 15 at the intersection of Square Lake Road and Crooks Road. The green times for this intersection as well as the adjoining intersection of Square Lake Road and Livemois Road are shown in Figure 6-5.

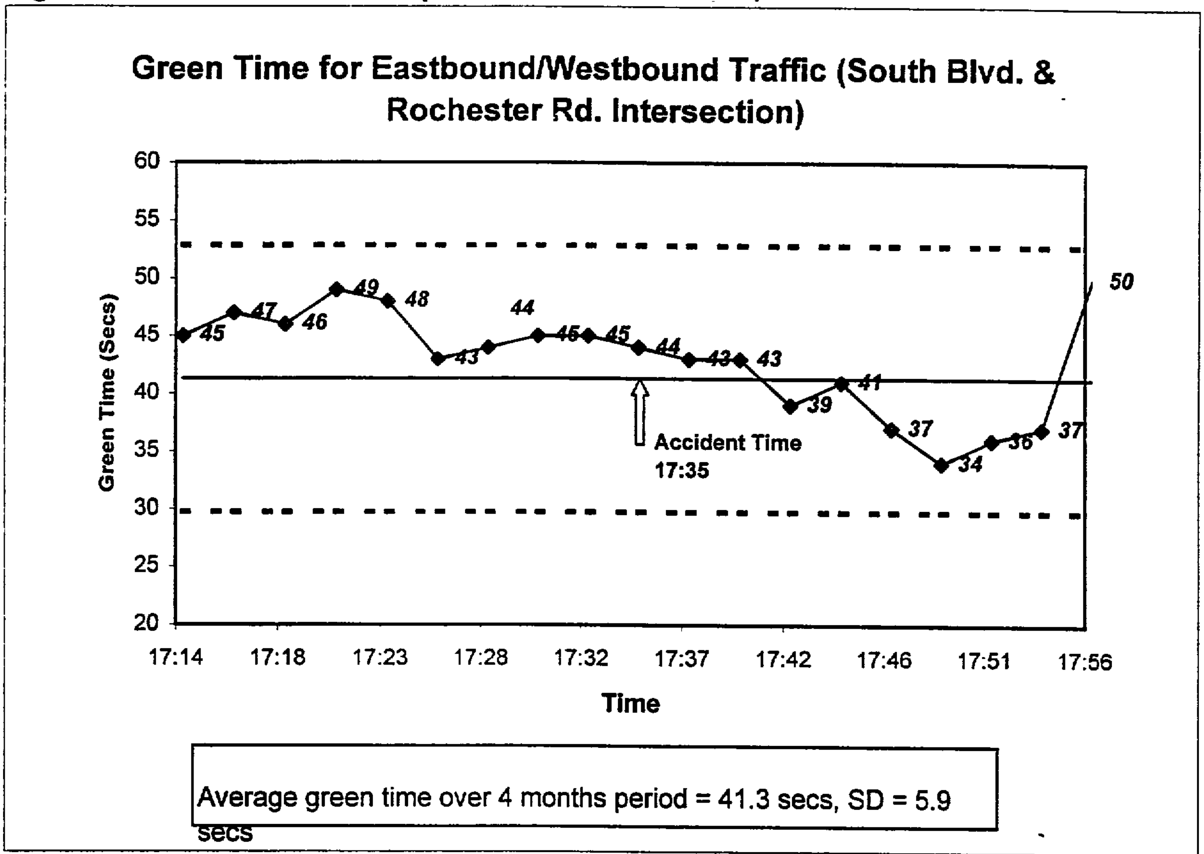
At the Crooks Road/Square Lake Road intersection, where the incident occurred, in the EW direction the green time experienced only a marginal increase from 25 seconds to 29 seconds in the cycle immediately following the incident. After this cycle, the green time decreased in the next cycle to 22 seconds. Both of these changes were well within the confidence limit in the figures. In both 20-minute periods, there were green time changes larger than that exhibited at the time of the incident.

In the NS direction, the response was more pronounced, but still mostly within the confidence limits established for this intersection. The green time decreased from 80 seconds to 63 seconds in the cycle immediately after the incident. In the subsequent two cycles there is a further decrease to 61 and 54 seconds. The green time then increased from 54 seconds to 93 seconds in the fourth cycle after the incident. After remaining steady around 92 to 94 seconds there is again a drop-in the green time from 92 seconds to 73 seconds, at which time it remains nearly constant.

At the adjoining intersection (Square Lake Road/Livernois Road), a less pronounced green time variation was observed at the reported time of the crash. In the NS direction, immediately after the reported time of the incident, there was an increase in the green time from 49 seconds to 52 seconds, and then an immediate decrease to 43 seconds in the next cycle. The green time variation in both the 20-minute period before and the 20-minute period after the incident showed larger variations. In the EW direction, the green time was relatively constant around the reported time of the incident.

The green time allocation at this intersection was less than the lower limit of the confidence band for both the EW and NS directions several minutes before the reported time of the crash. This may be an example of an error in reporting the time of the crash. The signal at this intersection apparently responded to some incident that occurred at 16:01, but did not respond at the reported time of this crash, which was 16: 15.

Figure 6-4 Green Time Response for Crash #3



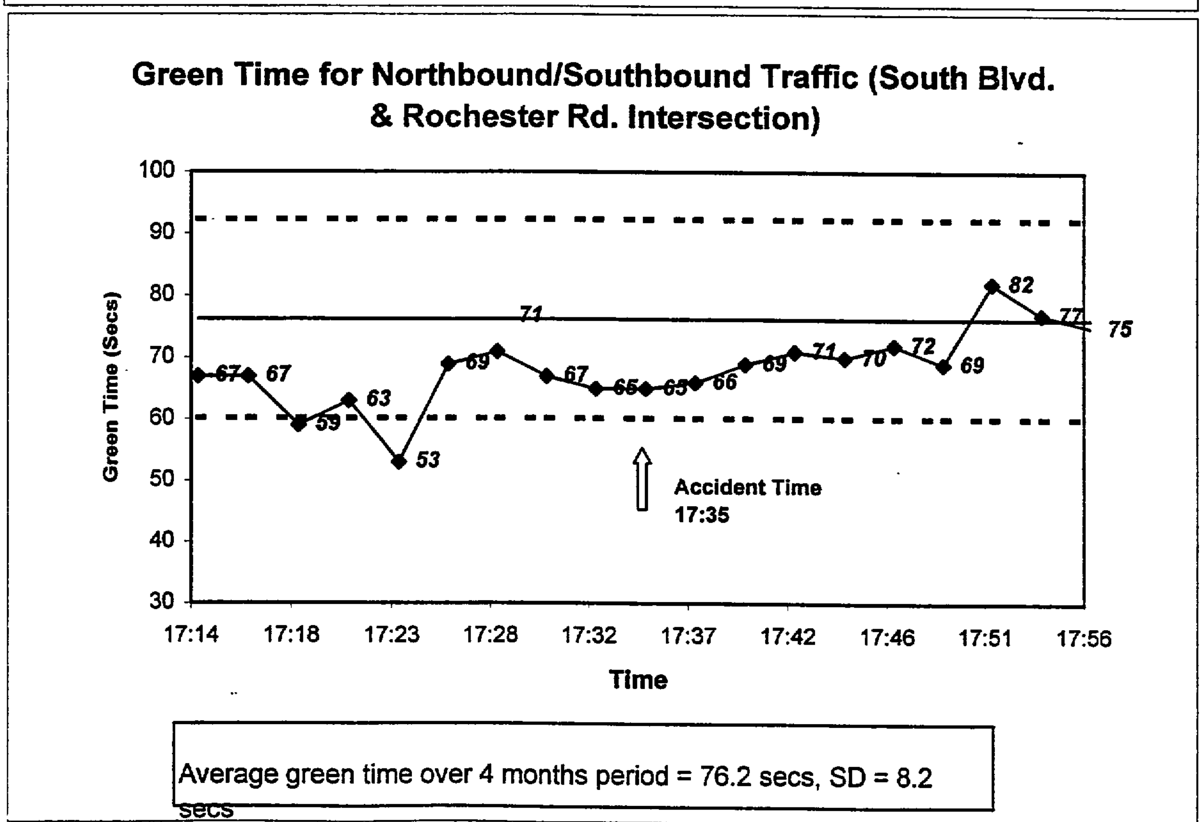
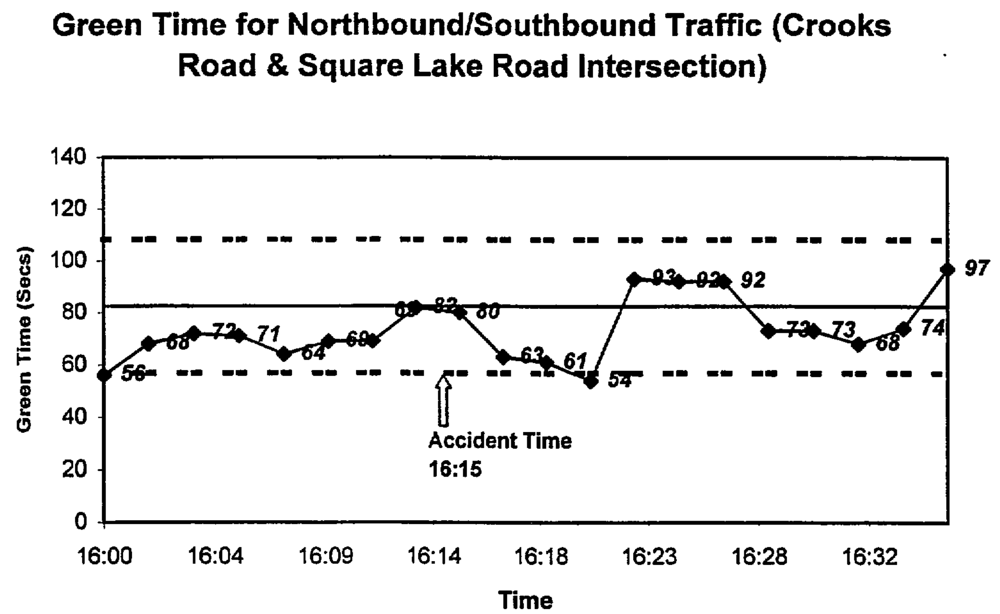
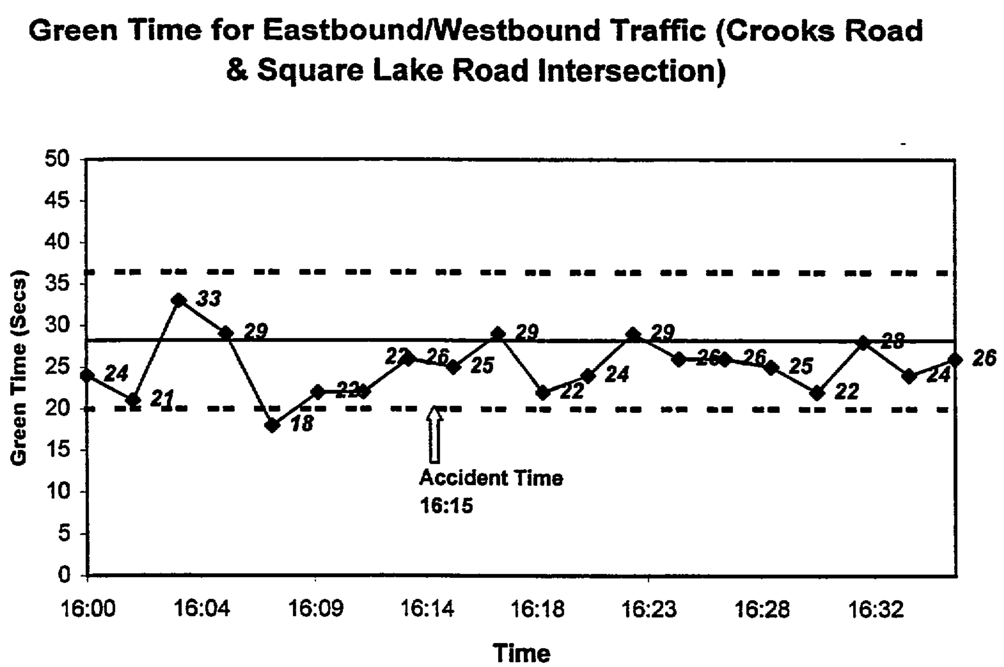


Figure 6-5 Green Time Response for Crash # 4



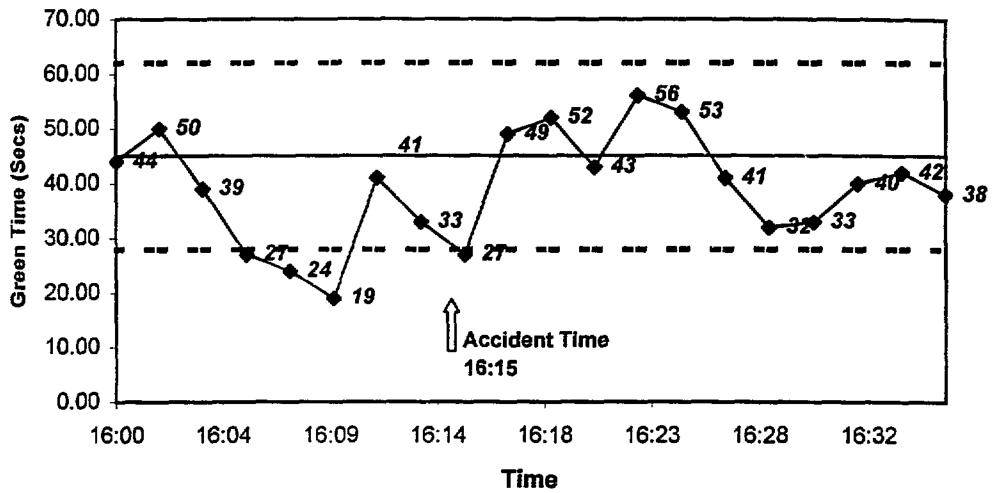
Average green time during this time period over 4 month period = 82.5 secs. with SD=13.1 secs.



Average green time during this time period over 4 month period = 28.2 secs. with SD=4.2 secs.

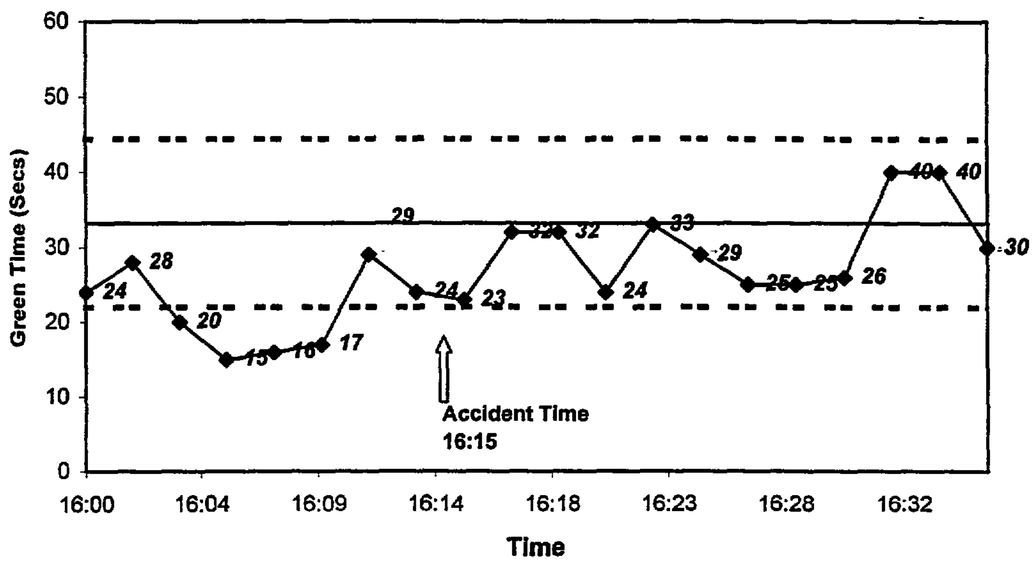
Figure 6-5 (Cont.) Green Time Response for Crash # 4

Green Time for Northbound/Southbound Traffic (Crooks Road & South Blvd. Intersection)



Average green time during this time period over 4 month period = 45secs. with SD=8.7 secs.

Green Time for Eastbound/Westbound Traffic (Crooks Road & South Blvd. Intersection)



Average green time during this time period over 4 month period = 32.2 secs. with SD=5.7 secs.

6.3.5 Crash # 5

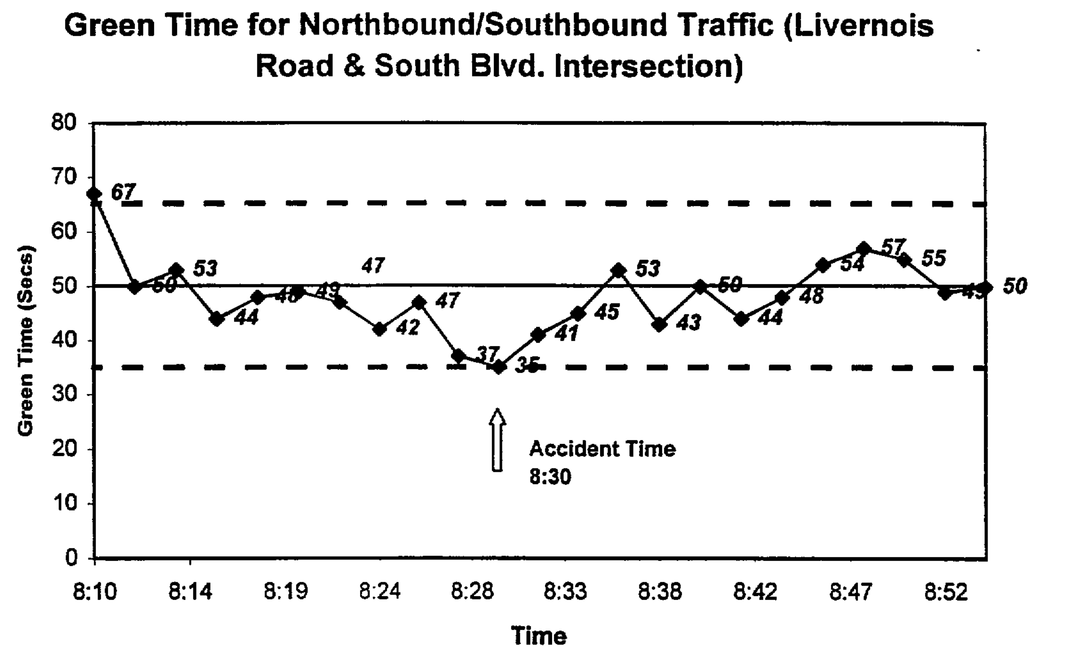
This incident occurred at 8:30 am, on Livernois Road in the mid-block location north of the Livemois Road/South Blvd. intersection. The green time variations in the NS and EW directions are shown in Figure 6-6. The green time allocated to each direction in the following cycles stayed within the confidence limits established for the intersection. However, for approximately five minutes prior to the reported time of the crash, the green time in the EW direction was outside the confidence limit band established for the intersection.

6.3.6 Crash # 6

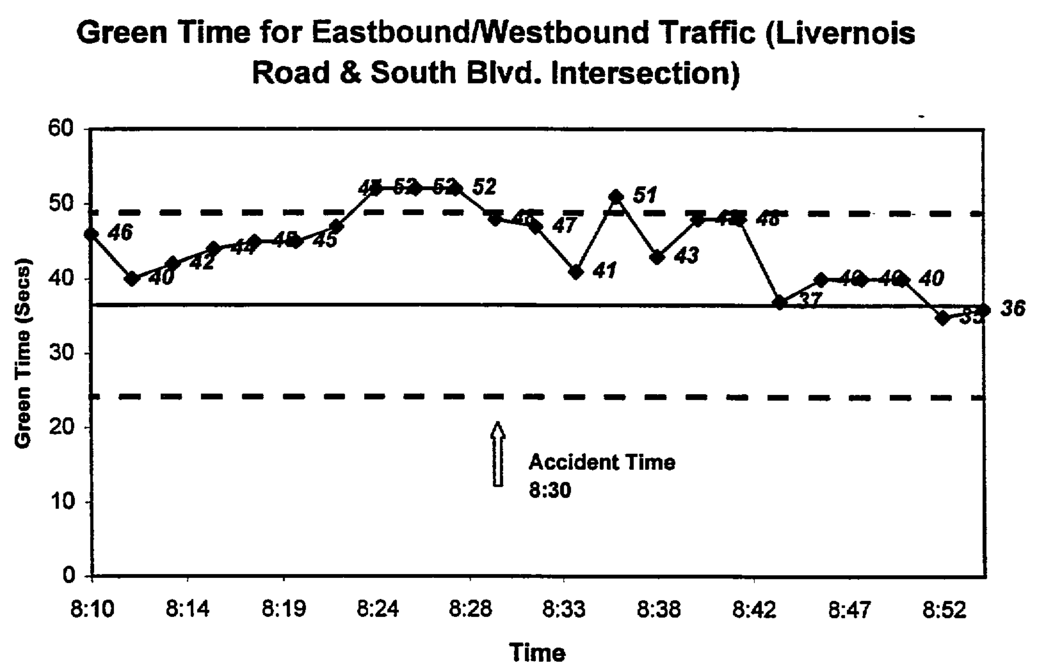
This incident occurred in the mid-block location on Livemois Road north of the Livemois Road/South Blvd. intersection at 17:47. Being a Sunday, it is assumed that there would be no peak hour traffic, and no signal response.

The variations in green times in both the NS and EW directions are shown in Figure 6-7. As expected, there were only small changes observed in the cycles immediately after the incident in either direction.

Figure 6-6 Green Time Response for Crash # 5

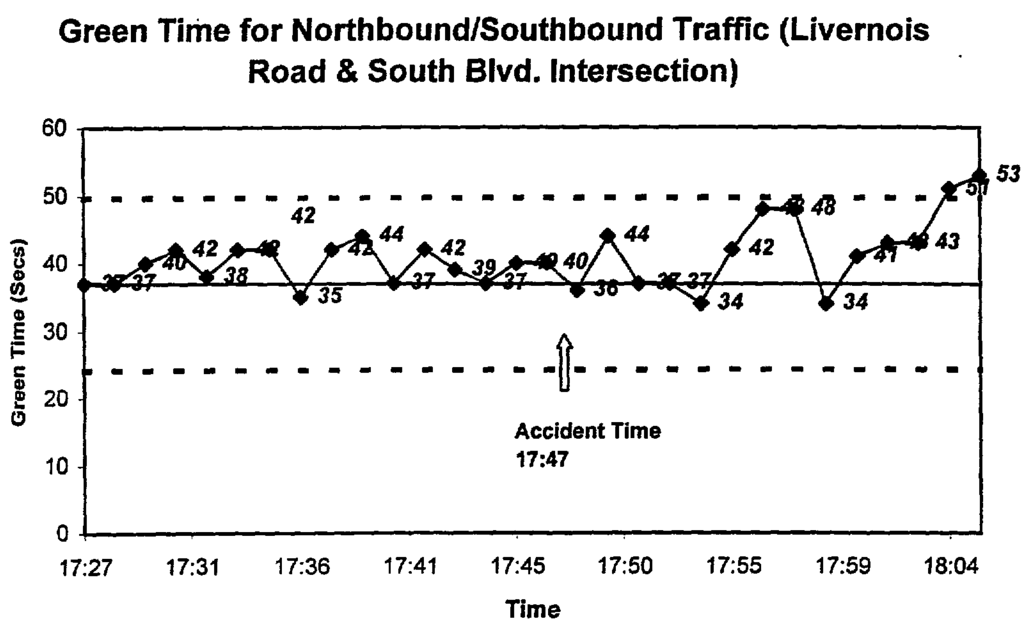


Average green time during this time period over 4 month period = 50.1 secs. with SD=7.7 secs.

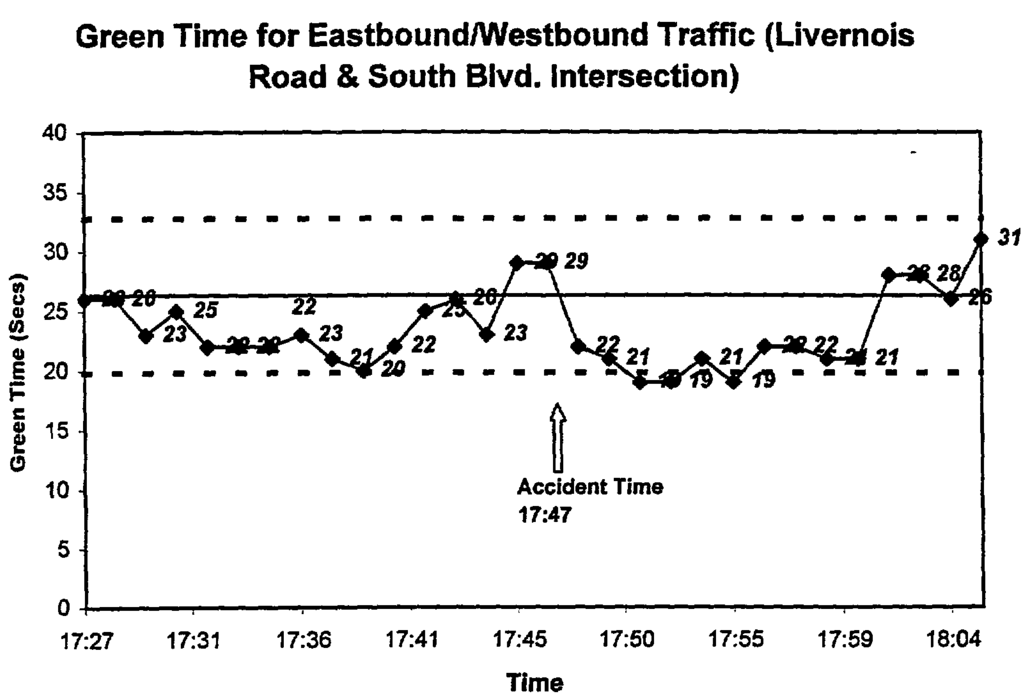


Average green time during this time period over 4 month period = 36.5 secs. with SD=6.3 secs.

Figure 6-7 Green Time Response for Crash # 6



Average green time during this time period over 4 month period = 36.9 secs. with SD=6.5 secs.



Average green time during this time period over 4 month period = 26.3 secs. with SD=3.3 secs.

6.3.7 Crash #7

This incident occurred at 17:30 at the intersection of South Blvd. and Crooks Road. The green time variations at this intersection are shown in Figure 6-8. As this incident could also affect the adjoining intersections of Crooks Road/Square Lake Road, and South Blvd./Livernois Road, the variations at these intersections were also studied. The green time variations at these two intersections are also shown in Figure 6-8.

At the South Blvd./Crooks Road intersection where the crash occurred, the green time in both the EW the NS directions remained in the normal range following the reported time of the incident. This was also true for the adjoining intersections, where all variations in green time were within the expected range.

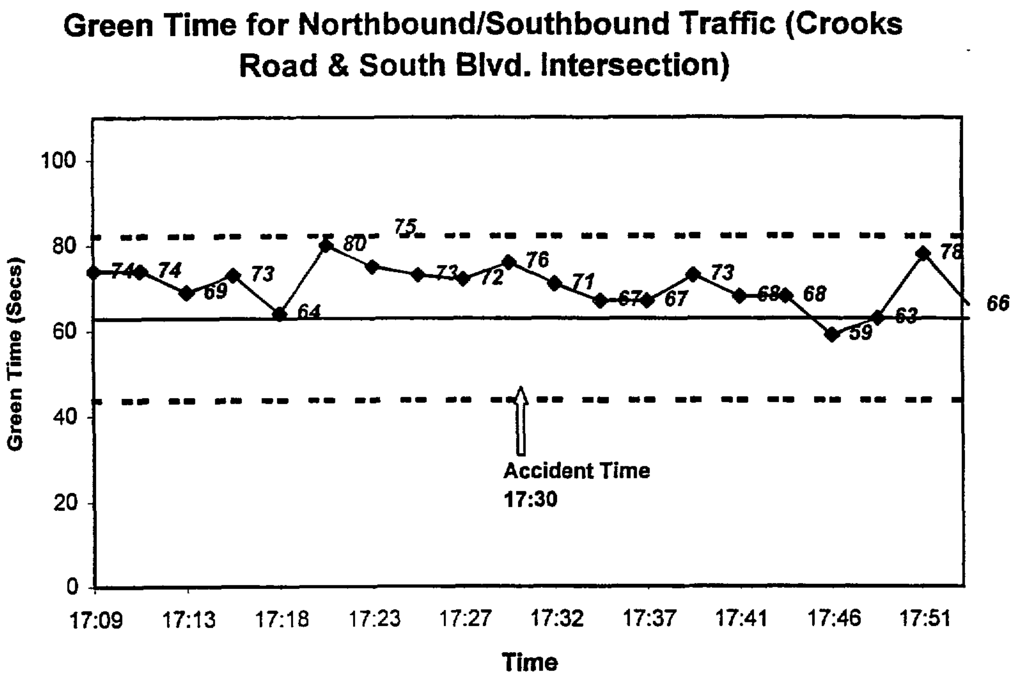
6.3.8 Crash # 8

This incident occurred at 8:10 am on South Blvd., between the two intersections of South Blvd./Crooks Road and South Blvd./Livernois Road. The green time variations for these two intersections are shown in Figure 6-9. At the South Blvd./Crooks intersection, in the NS direction the green time increased from 59 seconds to 75 seconds immediately before the reported time of the crash, then reduced to 56 seconds before increasing again to 67 seconds in the cycle immediately following the incident. After that, it dropped in the next two cycles to 61 and 60 seconds and continues to decrease to a low of 43 seconds. In the 20-minute period after the incident, after this drop in green time to 43 seconds it increased in the immediate next cycle to 69 seconds, and kept increasing to 82 seconds. Thus, there appear to have been a response to this incident in the signal timing plan, but because the variation in the signal timing over the. four month observation period was large, the response did not fall outside the confidence limits.

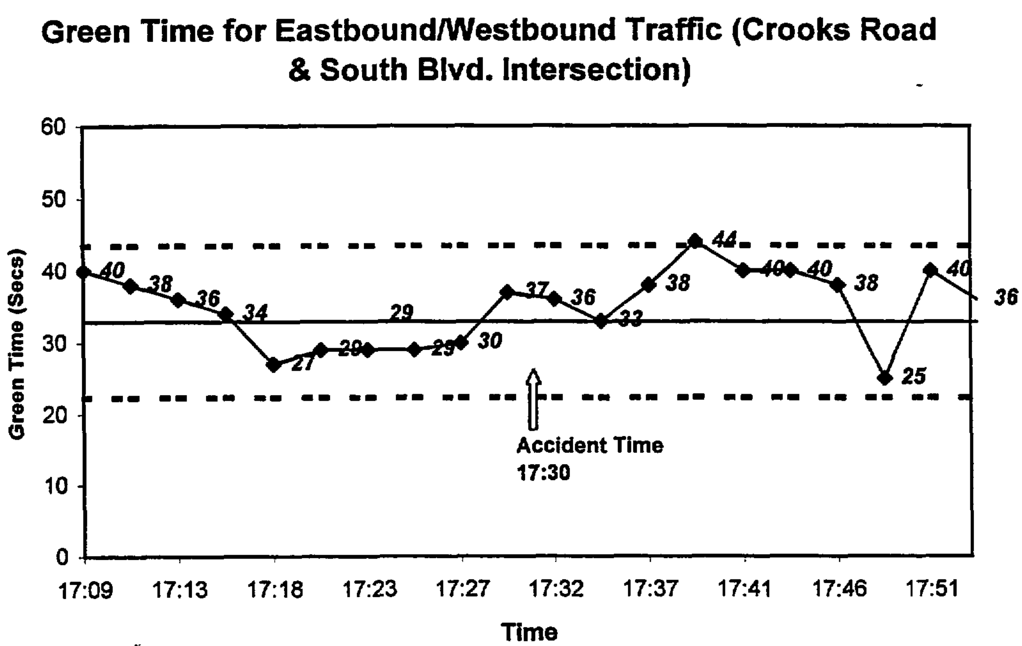
In the EW direction. there was only a small increase in green time from 39 seconds to 42 seconds in the cycle immediately following the reported time of the crash. There was a larger variation in the three cycles just prior to the reported time of the crash indicating that the reported time of the crash might be in error.

For the intersection at South Blvd. and Livemois Road, there was no significant change in the green time in either direction following the incident.

Figure 6-8 Green Time Response for Crash # 7

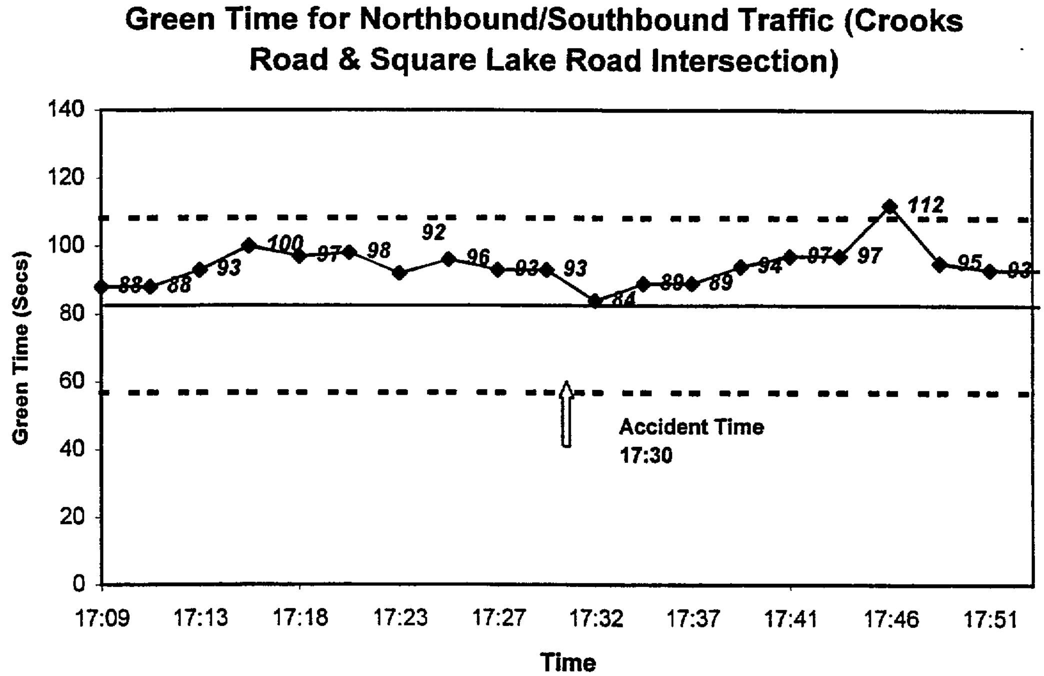


Average green time during this time period over 4 month period = 62.9 secs. with SD=9.8 secs.

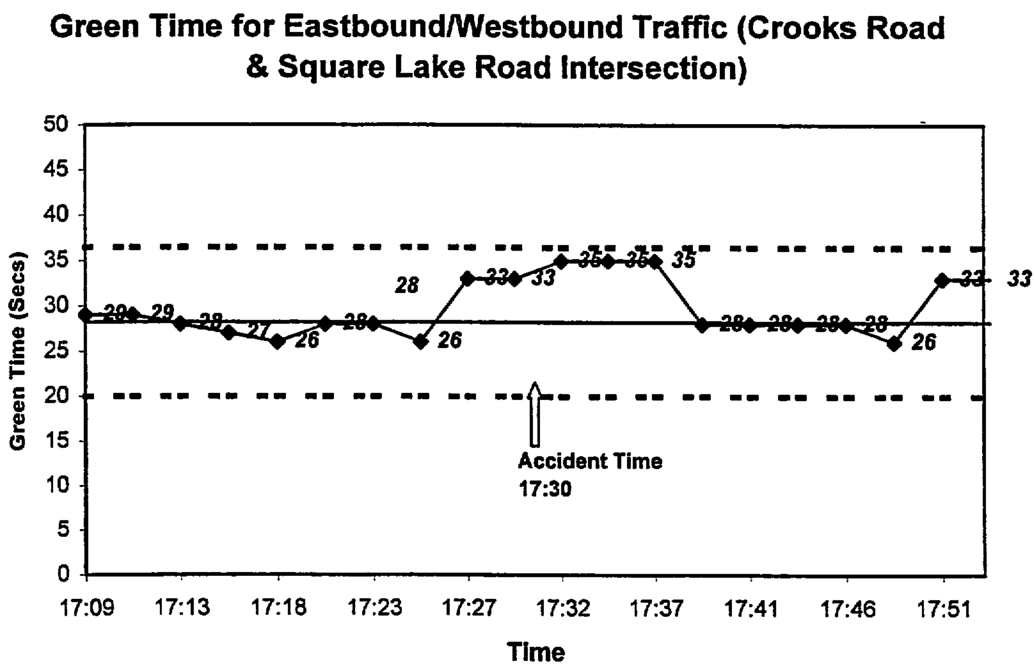


Average green time during this time period over 4 month period = 32.9 secs. with SD=5.4 secs.

Figure 6-8 (Cont.) Green Time Response for Crash # 7

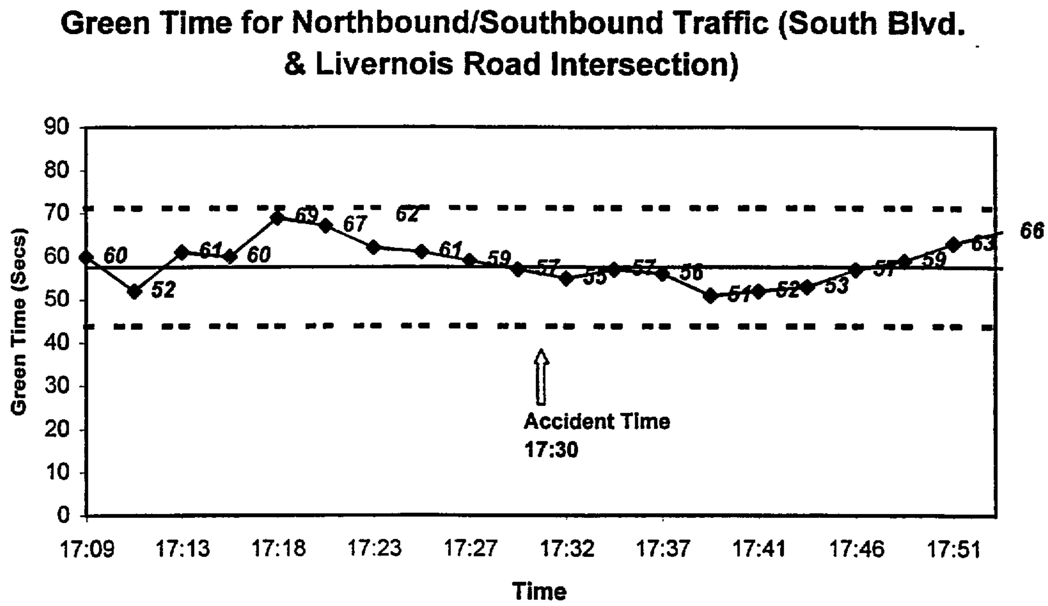


Average green time during this time period over 4 month period = 82.5 secs. with SD=13.1 secs.

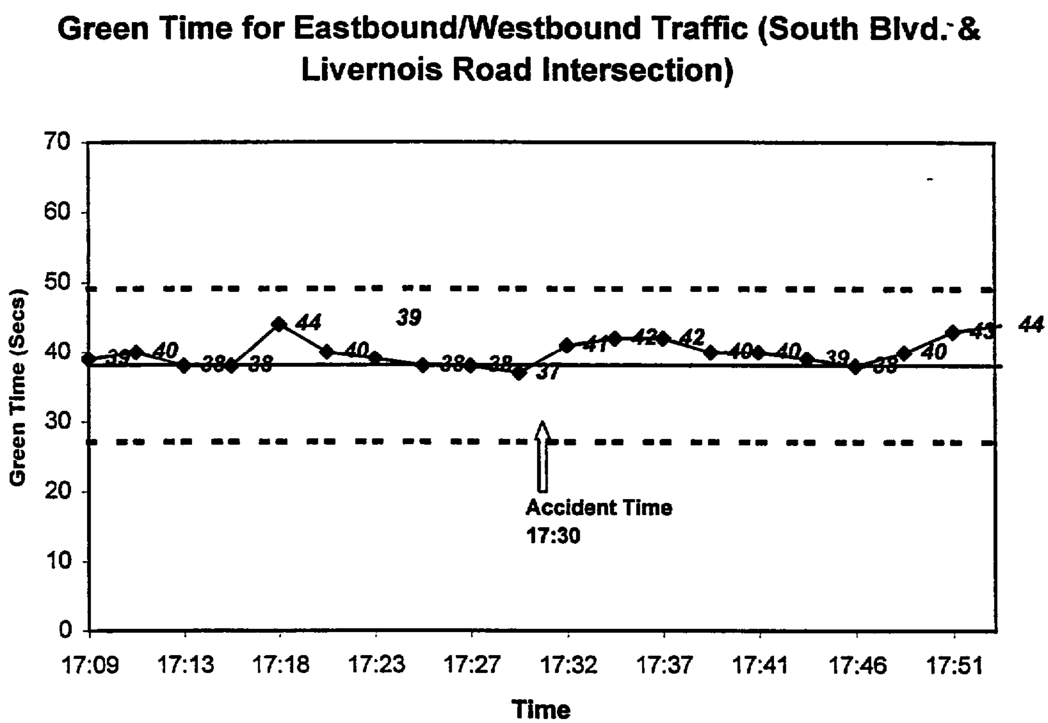


Average green time during this time period over 4 month period = 28.2 secs. with SD=4.2 secs.

Figure 6-8 (Cont.) Green Time Response for Crash #.7



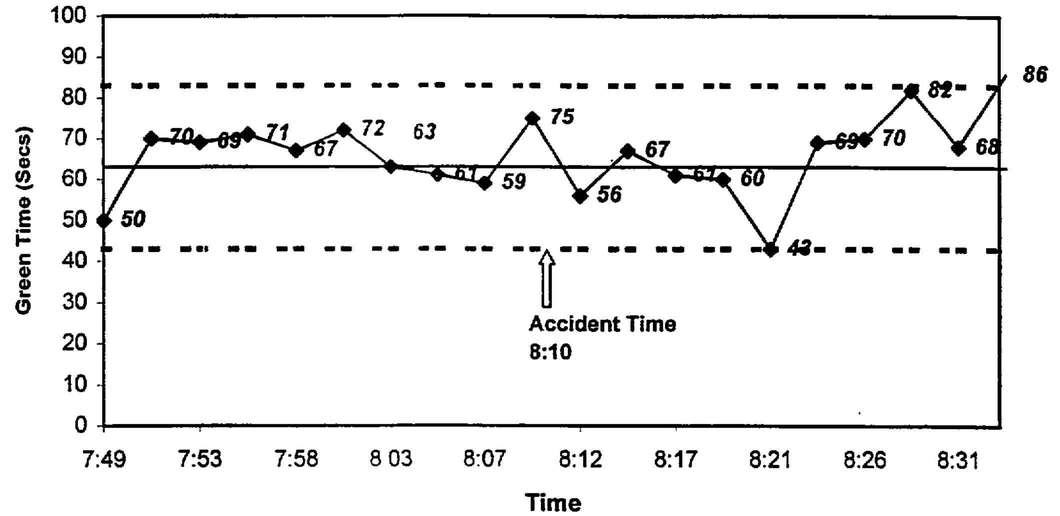
Average green time during this time period over 4 month period = 57.5 secs. with SD=7.0 secs.



Average green time during this time period over 4 month period = 38.1 secs. with SD=5.6 secs.

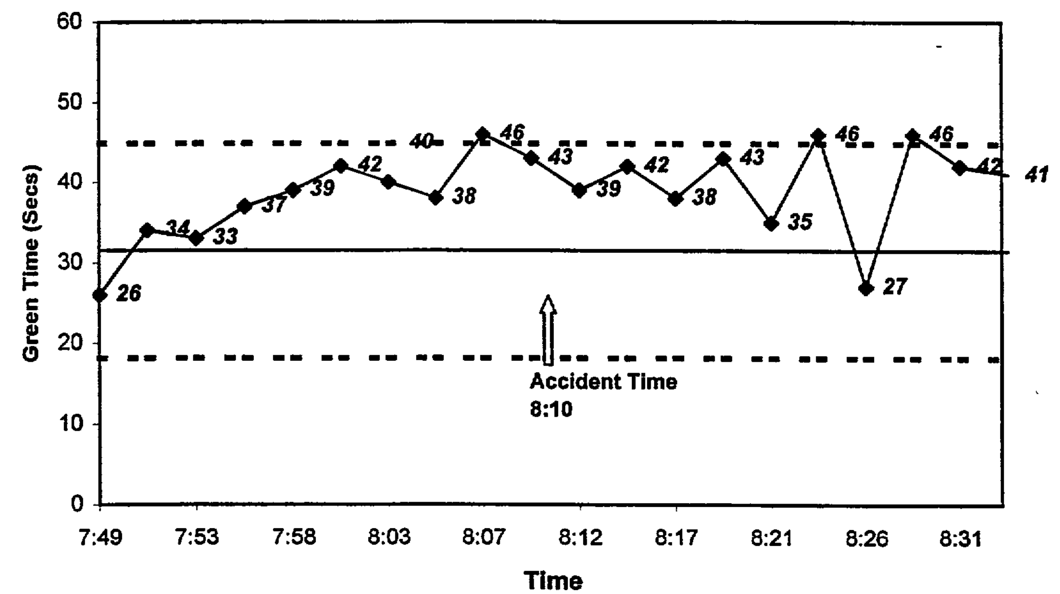
Figure 6-9 Green Time Response for Crash # 8

Green Time for Northbound/Southbound Traffic (South Blvd. & Crooks Road Intersection)



Average green time during this time period over 4 month period = 63.0 secs. with SD=10.2 secs.

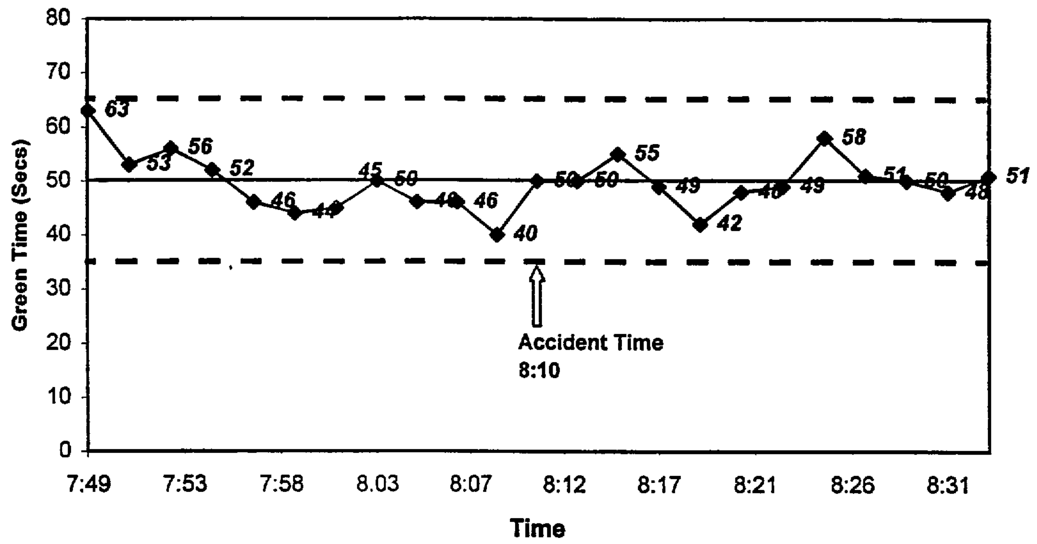
Green Time for Eastbound/Westbound Traffic (South Blvd. & Crooks Road Intersection)



Average green time during this time period over 4 month period = 31.5 secs. with SD=6.8 secs.

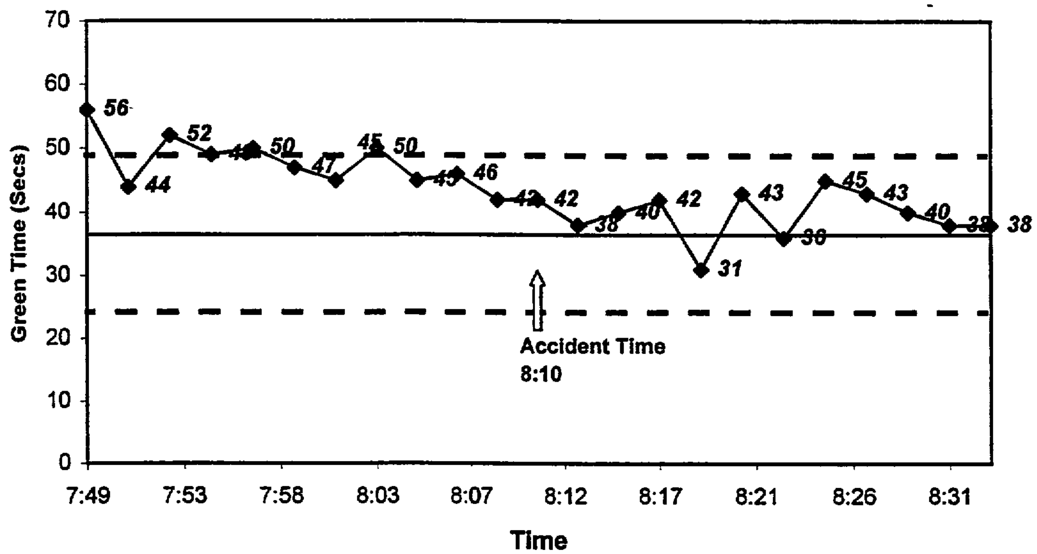
Figure 6-9 (Cont.) Green Time Response for Crash # 8.

Green Time for Northbound/Southbound Traffic (South Blvd. & Livernois Road Intersection)



Average green time during this time period over 4 month period = 50.1 secs. with SD=7.7 secs.

Green Time for Eastbound/Westbound Traffic (South Blvd. & Livernois Road Intersection)



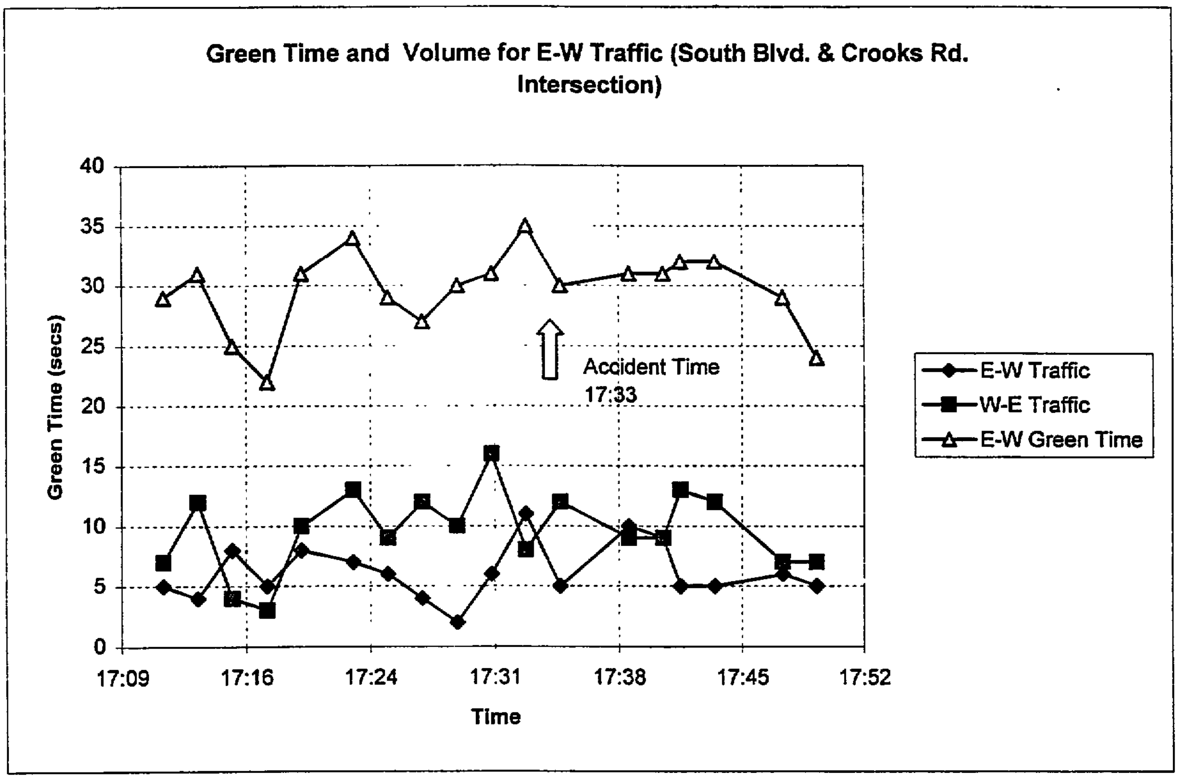
Average green time during this time period over 4 month period = 36.5 secs. with SD=6.3 secs.

6.4 Analysis of Volume Response

Figures 6-10 and 6-l 1 show the volumes and the green time variation for two of the crashes that showed signal timing responses (crash #2, and crash#4, respectively). In crash #2, the signal response occurred one cycle prior to the reported time of the crash. There was a sudden increase in both northbound and westbound traffic at this cycle. In crash #4, the response occurred 3 cycles before the reported crash time, with a sudden increase in the westbound traffic from 4 vehicles/cycle to 12 vehicle/cycle prior to the signal response. No significant changes in northbound/southbound volumes were observed. A more likely explanation to the inappropriate response time is that the reported time of the crashes was somehow incorrect.

One of the necessary inputs to the simulation program is volume on each of the arterial roads at the time of the incident. Correct volume data is essential to the proposed validation. These data do not seem to be available. Some of the critical volume data, especially prior to or after the reported time of the crashes, were missing. Besides, in some cases, the system reported departure volumes that appear to be invalid. The reliability of data on traffic volumes and the exact timing of the incidents prevented the validation of the results using the simulation model.

Figure 6-10 Volumes For Crash #2



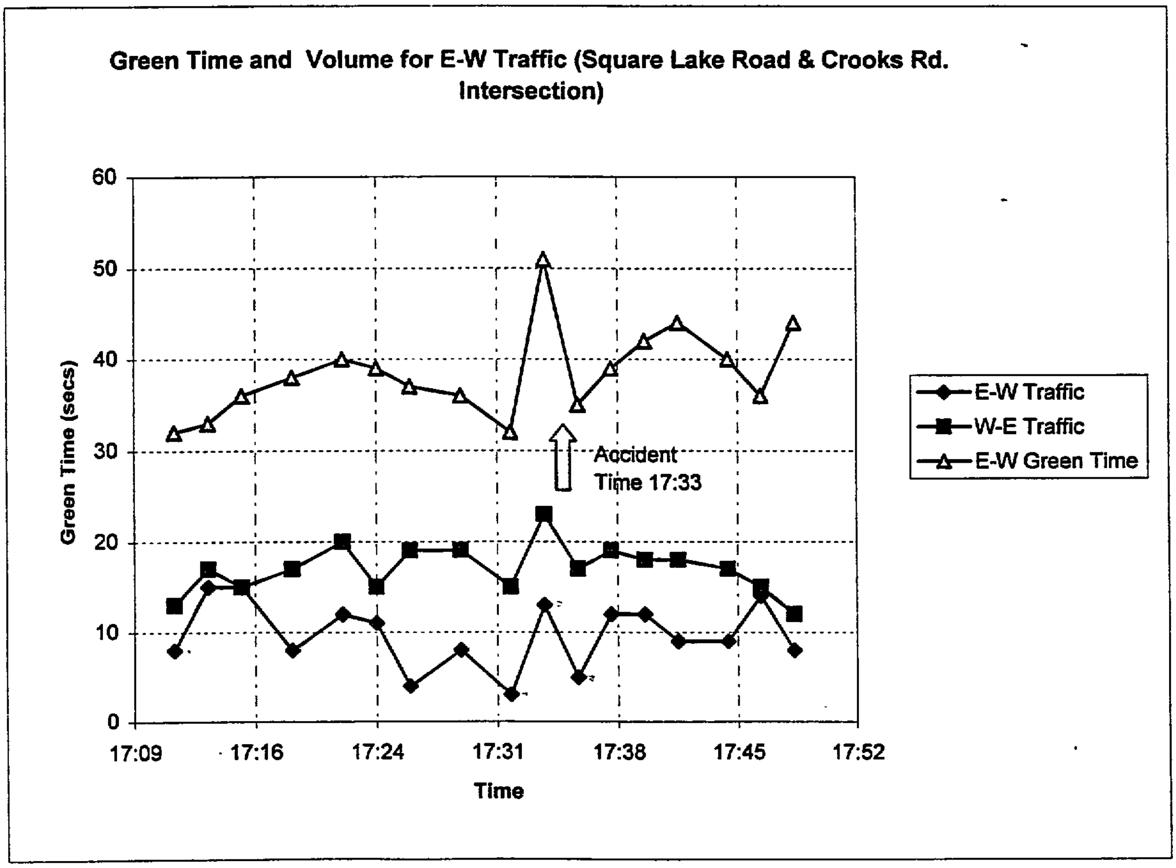
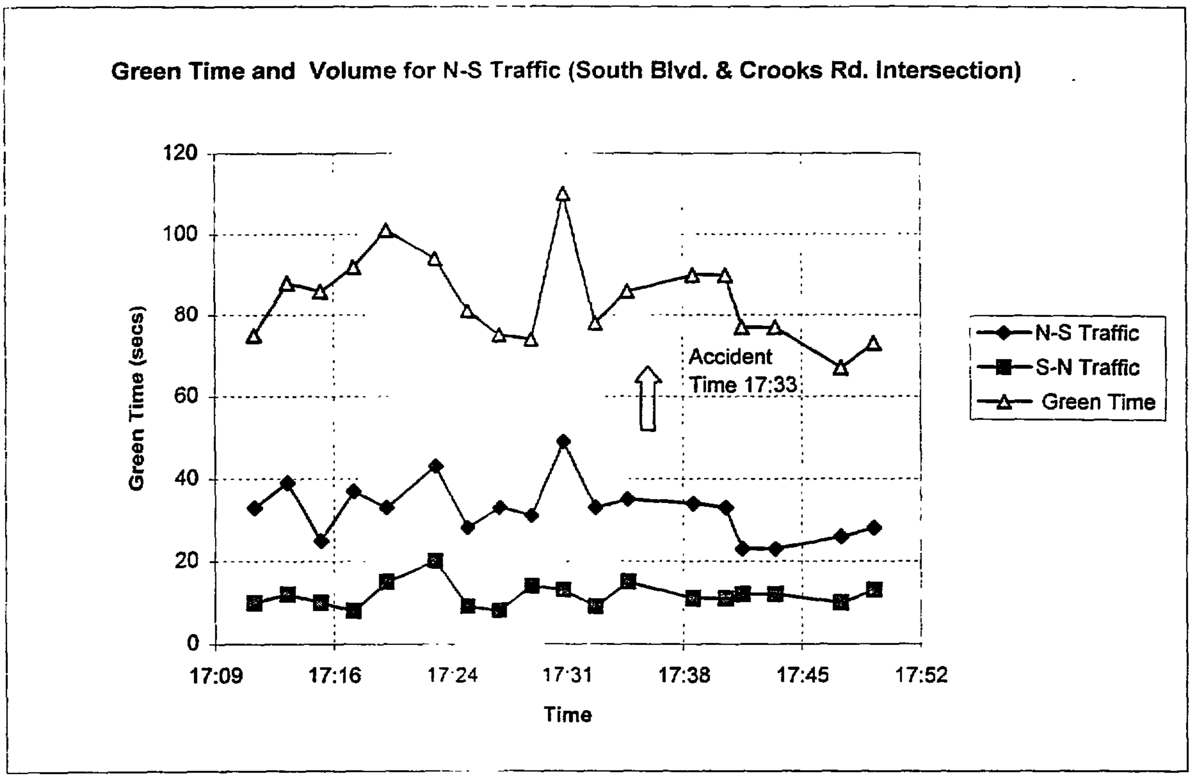


Figure 6-10 (Cont.) Volumes For Crash #2



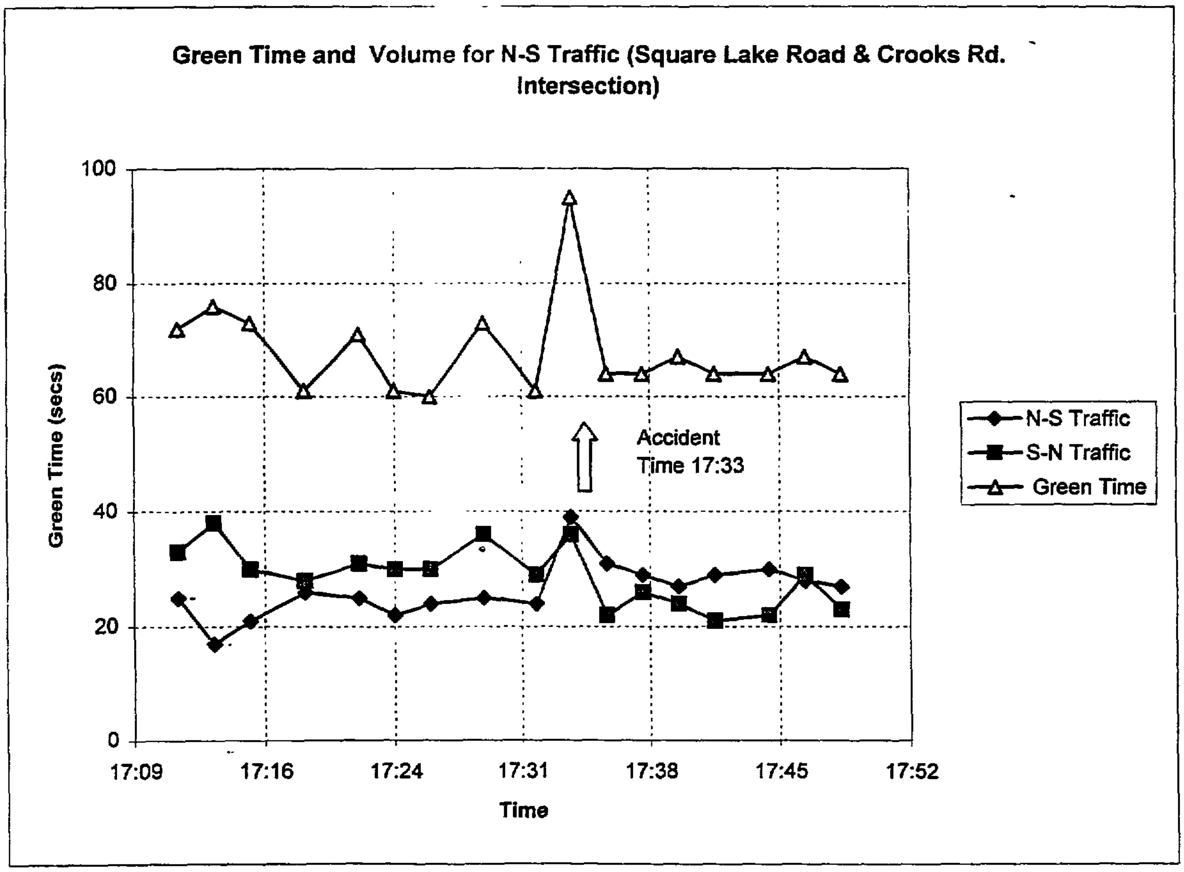
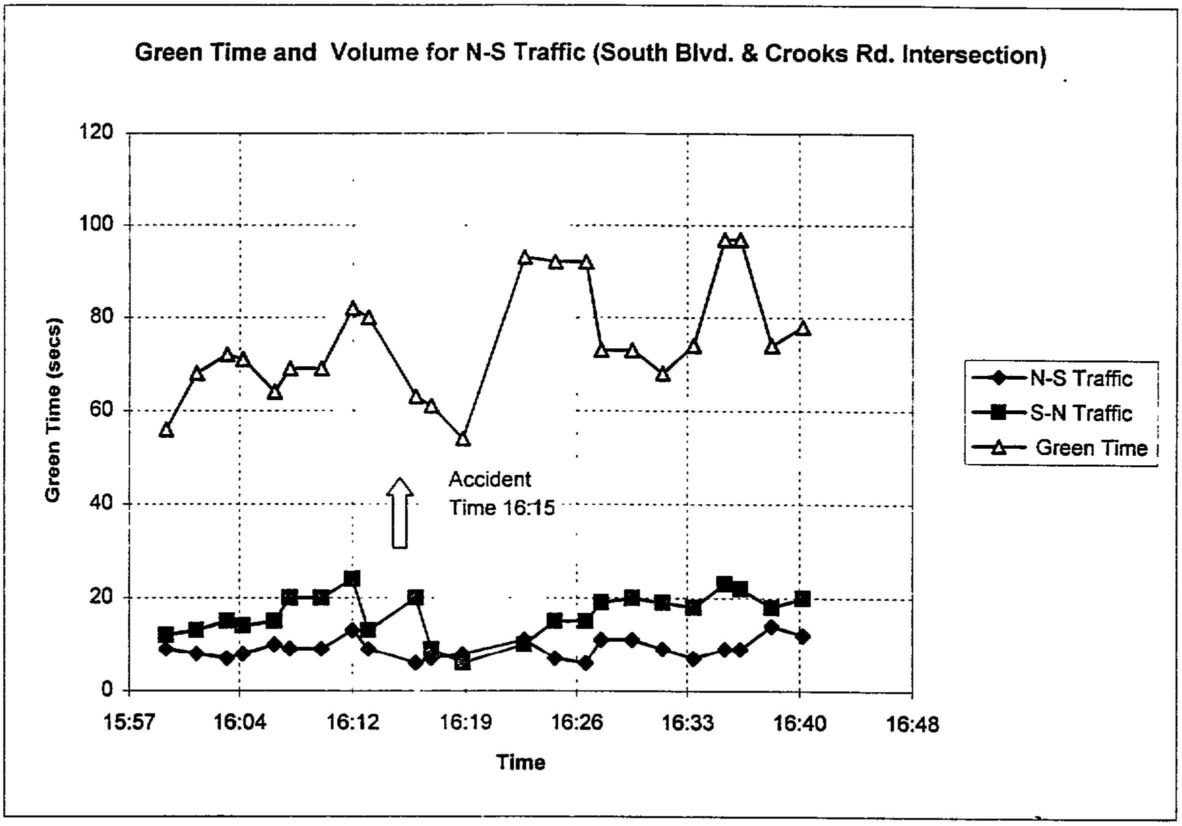
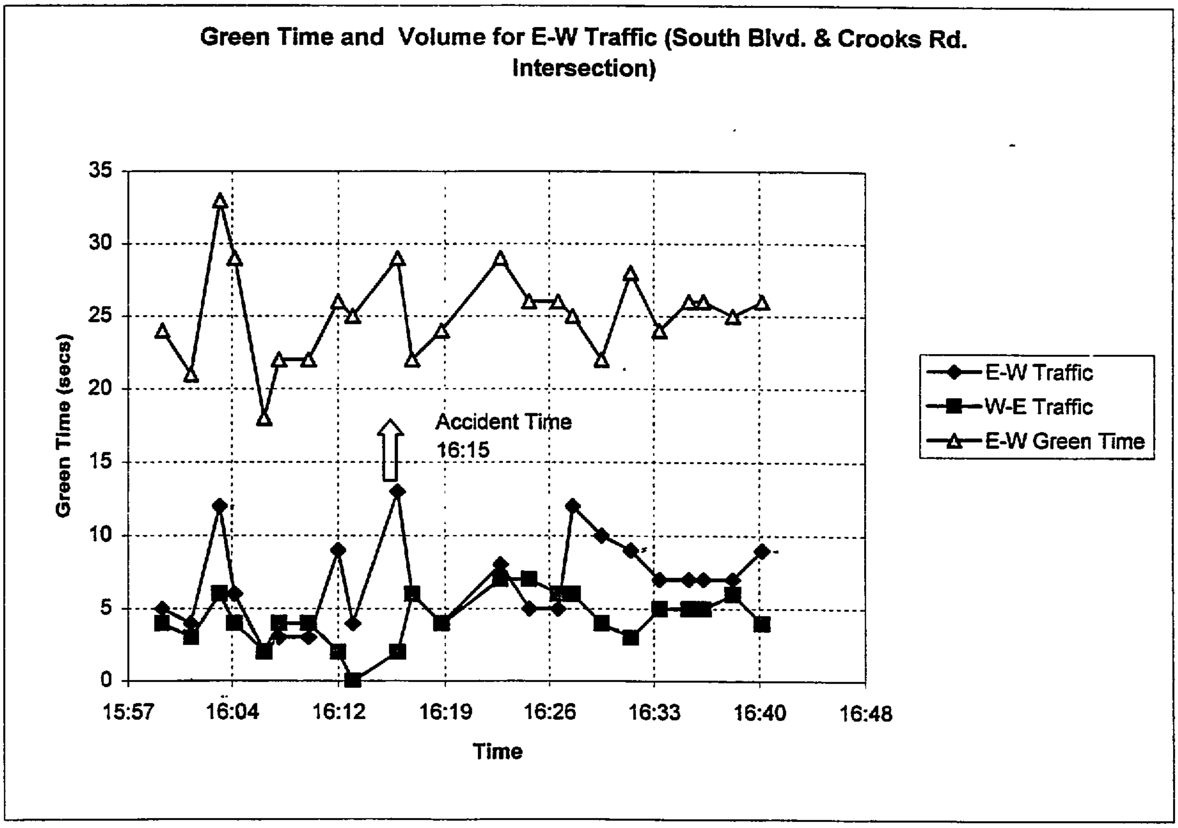


Figure 6-11 Volumes For Crash #4





6.5 Results and Discussion

The analysis of the green time response to the eight crashes studied showed several problems that would need to be resolved before the proposed simulation validation could be conducted.

a) The green time distribution in five of the eight crashes remained within the 95% confidence limit. Thus, the simulation of these incidents would be identical for SCATS and the fixed time control strategies except for the random variation in the green time allocated under SCATS control.

b) For the three crashes where there was a signal timing responses, the response occurred prior to the reported time of the crashes (crashes number 2,4, and 5). In one case, the response was only one cycle prior to the incident, but in the other two cases the response was at least two cycles prior to the reported time of the crash. If we were to simulate the network operation using the data available, the response would appear to be inappropriately timed, when the more likely explanation is that the reported time of the crashes was incorrect.

The departure volumes, in addition to the exact time of the incidents, required for the simulation study, appear to be invalid. Some of the volume data were missing. Besides, some of the reported volumes seemed to be unrealistic. Since one of the necessary inputs to the simulation program is volume on each of the arterial roads at the time of the incident, correct volume data is essential to the proposed validation. These data do not seem to be available.

6.6 Conclusion

The proposal to use field data to validate the value of SCATS under an incident situation was ultimately abandoned. It was not feasible to stage an incident under peak period traffic conditions and the attempt to use historical data to construct a simulation model was unsuccessful due to the reliability of data on traffic volumes and the exact timing of the incidents.

The green time allocation as shown in Figures 6-3, 6-5 and 6-6 suggest that SCATS control does respond to certain incidents by extending or shortening the duration of the green time at adjacent intersections. Since none of the crashes analyzed showed a long-term response, and there was no identifiable response at adjacent intersections, it is not likely that any traffic diversion was involved. Thus, this approach to the research project does not appear to be useful in estimating the benefits of an ATIS system.

6.7 Bibliography

Allsop, R.E. and J.A. Charlesworth (1977) Traffic in a signal-controlled road network: an example of different signal timings inducing different routing. *Traffic Engineering and Control* May, pp. 262-267.

d'Ans, G.C. and D.C. Gazis (1976) Optimal control of oversaturated store-and-forward transportation networks. *Transportation Science,* Vol 10 1, pp l-19.

Castling, I. (1994) *Advanced technology for road transport: IVHS and* ***ATT. Artech*** House, Boston.

Church, R. and C. Revelle (1978) Modeling an oversaturated intersection. *Transportation Research A,* Vol 12. pp 185-l 89.

Federal Highway Administration (1995) *TRAF user reference guide. Office* of Safety and Traffic Operations, March.

Gazis, D.C. (1964) Optimum control of a system of oversaturated intersections. *Operations Reearch* Vol 12, pp 8 15-83 1.

Gerlough, D.L. (1965) Simulation as a tool in traffic control system evaluation. *Traffic control: Theory and instrumentation,* Instrument Society of America, Plenum Press, NY, pp 71.

Gordon, R.L. (1969) A technique for control of traffic at critical intersections. *Transportation Science,* Vol 3, No 4, pp 279-288.

Holmes, G.N., and D.R. Leonard (1993) "The frequency and importance of incidents which cause congestion in urban areas.", *Transport Research Laboratory,* Contractor Report 342.

Hunt, P.B. and T.R. Holland (1985) The effects of an incident in SCOOT system - in simulation and on-street. *Traffic Engineering and Control,* February, pp 55-58.

Little, J.D.C. (1966) The synchronization of traffic signals by mixed-integer linear programming. *Operation Research,* Vol 14, No 4, pp 568-594.

Longley, D. (1968) A control strategy for a congested computer-controlled traffic network. *Transportation Research,* Vo12, pp 391-408.

Lowrie, P.R. (1982) Sydney co-ordinated adaptive traffic control system-Principle, methodology, algorithm. *International Conference on Road Traffic Signaling,* Institute of Electrical Engineers, Conference Publication No 207, pp 67-70.

Lowrie, P.R. *(1990) SCATS - Sydney co-ordinated adaptive traffic system: A traffic responsive method of controlling urban traffic.* Roads and Traffic Authority, Sydney.

Maher, M.J. and R. Akcelik (1975) The re-distributional effects of an area traffic control policy. *Traffic Engineering and Control,* September, pp 3 83-3 85.

May, A.D. and D. Westland (1979) Transportation system management TSM-type projects in six selected European *countries. Traffic Engineering and Control,* February, pp 18-20.

Michalopoulos, P.G. and G. Stephanopoulos (1977a) Oversaturated signal systems with queue length constraints-I: Single intersection. *Transportation Research A,* Vol 11, pp. 413-421.

Michalopoulos, P.G. and G. Stephanopoulos (1977b) Oversaturated signal systems with. queue length constraints-II: Systems of intersections. *Transportation Research A,* Vol 11, pp 423-428.

National Cooperative Highway Research Program (1967) *improved criteria for traffic signals at individual intersections.* Report No 32, Highway Research Board, Washington, DC.

Rathi, A.K. (199 1) Traffic metering: An effectiveness study. *Transportation Quarterly,* July, pp 421-440.

Roberg, P. and C.R. Abbess *(1994) Diagnosis and treatment of congestion problems in central urban areas.* Presented at EURO 13/OR Conference, Strathclyde.

Van Aerde, M. and H. Rakha (1989) Development and potential of system optimized route guidance strategies. VNIS'89, *IEEE-VTS-V399,* pp 304-309.

Van Vuren, T. and D. Leonard (1994) Urban congestion caused by incidents. *Traffic Engineering and Control,* Vol 35, No 7/8.

Wood, K. (1993) *Urban traffic control, systems review.* Project Report 41, Transport Research Laboratory, Crowthome, UK.