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Strategies for Incident Management in an Urban Street Network

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Strategies for Incident Management in an Urban Street Network

by

Vikramaditya Bhide

A thesis submitted in partial fulfillment
of the requirements for the degree of
Master of Science in Industrial Engineering
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TABLE OF CONTENTS

LIST OF TABLES	iv
LIST OF FIGURES	v
ABSTRACT	vi
1. INTRODUCTION	1
2. MICROSIMULATION AND INCIDENT MANAGEMENT	4
2.1 CORSIM Simulation Software	5
2.1.1 CORSIM Capabilities and Limitations	6
2.1.2 Surface Street Input Data	7
2.1.3 NETSIM Traffic Assignment	7
2.1.4 Elements of the Traffic Environment	8
2.2 Incident Management	10
2.2.1 Traffic Flow Dynamics	10
2.2.2 Incident Management Planning	10
2.2.3 Components of Incident Management	11
3. LITERATURE REVIEW	14
3.1 Dynamic Traffic Assignment	14
3.2 Computer Simulation Techniques	15
3.3 Artificial Intelligence (AI) Methods	17
3.4 Traffic Stream Parameters	18
3.4.1 Rate of Flow or Volume	18
3.4.2 Speed and Travel Time	19
3.4.3 Density	20
3.5 Incident Management Research	20
3.5.1 Optimized Signal Timing	20
3.5.2 Actuated Signal Control	22
3.5.3 Variable Speed Limits	23

3.5.4	Real-Time Diversion	25
3.5.5	Incident Studies	26
4.	RESEARCH OBJECTIVES	28
4.1	Problem Statement	28
4.2	Network Details	28
4.3	Factors Affecting the Network	30
4.3.1	Driver Behavior	30
4.3.2	Traffic Flow or Volume	32
4.4	Model Assumptions	32
4.4.1	Links in the Network	32
4.4.2	Nodes in the Network	33
4.4.3	Driver Assumptions	33
4.4.4	Road and Driving Conditions	33
4.5	Network Enhancement Strategies	34
4.5.1	Fixed and Variable Speed Limits	34
4.5.2	Semi-Actuated Signals	34
4.5.3	Network Type	34
4.6	Measures of Effectiveness (MOEs)	35
4.6.1	Average Speed (Miles per Hour)	35
4.6.2	Average Travel Time (Seconds)	35
4.6.3	Total Delay (Vehicle Minutes)	35
4.7	Expected Results	35
5.	MODEL DEVELOPMENT	38
5.1	High Volume Corridor	38
5.2	Medium Volume Complex Corridor	40
5.3	Low Volume Corridor	41
6.	RESULTS AND ANALYSIS	45
6.1	Simulation Results	45

6.2	Design of Experiment	45
6.2.1	Results and Analysis for Average Speed	49
6.2.2	Results and Analysis for Average Travel Time	52
6.2.3	Results and Analysis for Total Delay	54
7.	SUMMARY AND CONCLUSIONS	57
7.1	Research Summary	57
7.2	Conclusions	57
7.3	Scope for Further Research	59
	REFERENCES	60

LIST OF TABLES

Table 2.1	Surface Street Modeling Capabilities of CORSIM	6
Table 2.2	Input Data for Surface Street Modeling	7
Table 4.1	Percentage Multipliers of Free Flow Speed	31
Table 5.1	Traffic Volume for High Volume Corridor	38
Table 5.2	Traffic Volume for Complex Medium Volume Corridor	41
Table 5.3	Traffic Volume for Low Volume Corridor	42
Table 5.4	Driver Behavior Configurations	43
Table 6.1	Simulation Results for Average Speed	45
Table 6.2	Simulation Results for Average Travel Time	46
Table 6.3	Simulation Results for Total Delay	47
Table 6.4	Factorial Design	49
Table 6.5	Analysis of Variance for Average Speed	49
Table 6.6	Analysis of Variance for Average Travel Time	52
Table 6.7	Analysis of Variance for Total Delay	55

LIST OF FIGURES

Figure 3.1	Simulation and DMS Actuation	16
Figure 4.1	Network Corridor in Tampa Area	29
Figure 5.1	High Volume Corridor	39
Figure 5.2	Medium Volume Corridor	42
Figure 5.3	Low Volume Corridor	43
Figure 6.1	Main Effects Plot for Average Speed	51
Figure 6.2	Interaction Plot for Average Speed	51
Figure 6.3	Main Effects Plot for Average Travel Time	53
Figure 6.4	Interaction Plot for Average Travel Time	54
Figure 6.5	Main Effects Plot for Total Delay	56
Figure 6.6	Interaction Plot for Total Delay	56

STRATEGIES FOR INCIDENT MANAGEMENT IN AN URBAN STREET NETWORK

Vikramaditya Bhide

ABSTRACT

In this research the problem of incident congestion on surface street networks is addressed. Microscopic simulation is used to simulate incident scenarios on various corridors in the Tampa Bay area. The effect of the three factors, namely, network, speed and signal strategies on the traffic flow is studied. The network performance is based on Highway Capacity Manual specified measures of effectiveness prepared by the Transportation Research Board.

Three inherently different city corridors, high, medium and low volume, are used to test the strategies developed. The strategies investigated include varying speed limits during incidents and using pre-timed and semi-actuated signals that respond to real time traffic volumes. The effectiveness measures are total delay in vehicle minutes, average speed in miles per hour and average travel time in seconds. Different facilities on a network include intersections; both signalized and unsignalized, local highways and arterials. The outputs from the simulation model is used to set up a factorial design to study the interaction between network type, signal strategy and speed strategy with the measures of effectiveness being the response variables.

This type of corridor analysis is unique and provides decision support for local transportation planning departments for making corridor enhancements. In most city, state or county planning departments road planning is merely based on projected traffic demand using existing static models and does not factor necessary adjustments for incidents. Another unique aspect of this research is that variable speed limits are tested on surface streets. Such a test is not available in the literature.

With dynamic message signs, next generation communication networks for traffic signal control and ITS technologies available, it is possible to implement the strategies suggested in this research.

1. INTRODUCTION

The demand for vehicles, road systems and support systems is on the increase. Around 8.5 million new passenger cars are bought every year in the United States, increasing traffic and causing many congestion problems, particularly in large urban areas. As an effect, it has been observed that the number of road accidents has also increased, albeit gradually in the last 3 years. According to the National Highway Traffic Safety Administration, in the year 2001, the total numbers of fatalities on the road were about 42,000. Of these, almost 40% were in urban areas in or around cities. The probability that an accident on a city arterial may result in fatalities is low. As a result, the number of crashes it takes to cause almost 16,800 deaths in urban areas is alarmingly high. Furthermore, the cost of time lost and fuel burned due to congestion is as high as \$900 per capita. According to the Texas Transportation Institute, the cost of congestion in Tampa Bay stands at \$ 745 million annually. In other cities, the cost may be as high as \$8.6 billion. Due to the shortage of development space and cost constraints in urban areas and cities specifically, it is not feasible to keep expanding and building more roads. Hillsborough County in Tampa Bay is in the process of preparing a report called the Corridor Plan wherein it will review the conditions, both road and traffic along major arteries and highways in the Tampa Bay area to earmark improvements, safety measures and repairs.

Current research focuses on optimizing the use of current available road networks by distributing traffic flow, rerouting traffic in case of recurring or non-recurring congestion and enhancing incident management systems for rapid restoration of affected road segments. New technologies like Intelligent Transportation Systems (ITS) are being developed to enhance road safety, incident management and response, and improved traffic flow for reduced congestion. ITS brings with it a lot of promise for a safer, more efficient future. It merges various disciplines of engineering, economics, communications and computer science. It is important to study the effects of incidents on the traffic stream, particularly in arterial networks and local highways in order to implement road improvements.

In this research we focus on three aspects that significantly affect the outcome of an incident on urban streets, namely network type (and hence volume and geometry), traffic signal type and speed strategy. A good understanding of incidents and their impacts on traffic flow is necessary to better appreciate remedial action in reducing them. From historical data, incidents are categorized as vehicle disablements, minor collisions and major collisions. Traffic conditions affect the impact of an incident a great deal. Congestion is highest during peak hours, usually mornings and evenings as people commute to and from business districts in urban areas. During peak hours, even a minor collision may affect the traffic stream adversely causing a lot of travel time delay. It is also difficult for response units to react quickly and clear the site during peak hours as compared to off-peak hours. The three factors mentioned above are discussed in detail in Chapter four.

In this research we will use microscopic simulation to simulate incident scenarios on various corridors in the Tampa Bay area to study the impact of the three factors mentioned above and the traffic flow. The incident scenarios will then be subject to two enhancements and study their effect on the network performance for three inherently different city corridors. These enhancements are varying speed limits during incidents and using pre-timed and semi-actuated signals that respond to real time traffic volumes. The MOEs are total delay in vehicle minutes, average speed in miles per hour and average travel time in seconds. Different facilities on a network include intersections; both signalized and unsignalized, local highways and arterials. The network characteristics are explained in detail in Chapter five. The outputs from the simulation model will be used to set up a factorial design to study the interaction between network type, signal strategy and speed strategy with the MOEs being the response variables. This type of corridor analysis is unique and provides decision support for local transportation planning departments for making corridor enhancements. Most roads planning is merely based on projected traffic demand using existing static models and do not factor necessary adjustments for incidents. With dynamic message signs, next generation communication networks for traffic signal control and ITS technologies available, it is possible to implement the strategies suggested in this research.

The report is organized as described. In Chapter 2 fundamental concepts of microscopic simulation, incident management and allied technologies are discussed.

The relevant literature in the field of traffic assignment, simulation techniques, incident management and related fields is reviewed in Chapter 3. Chapter 4 introduces the problem, the microscopic simulation model, the network and modeling assumptions. Chapter 5 describes the simulation model developed in detail. The results and analysis are included in Chapter 6. The research summary, conclusions drawn and suggestions for furthering this research are given in Chapter 7.

2. MICROSIMULATION AND INCIDENT MANAGEMENT

Road traffic microsimulation models are computer models where the movements of individual vehicles traveling around road networks are determined by using simple car following, lane changing and gap acceptance rules. They are becoming increasingly popular for the evaluation and development of road traffic management and control systems. Traditional models provide an aggregated representation of traffic, typically expressed in terms of total flows per hour. In such models, all vehicles of a particular group obey the same behavior rules.

By contrast, microsimulation models provide a better representation of actual driver behavior, vehicle response and network performance. They are the only modeling tools available with the capability to examine certain complex traffic problems (e.g. intelligent transportation systems, complex junctions, shockwaves, and effects of incidents). In addition, there is the appeal to users of the powerful graphics offered by most software packages that show individual vehicles traversing across networks that include a variety of road categories and junction types. This visual representation of problem and solution in a format understandable to layman and professional alike can be a powerful way to gain widespread acceptance of complex strategies.

If a traffic system is simulated on a computer by means of a simulation model, it is possible to predict the effect of traffic control and Automated Traffic Management System (ATMS) strategies on the system's operational performance, as expressed in terms of MOEs, which include average vehicle speed, vehicle stops, delays, vehicle-hours of travel, vehicle-miles of travel, fuel consumption, and pollutant emissions. The MOEs provide insight into the effects of the applied strategy on the traffic stream, and they also provide the basis for optimizing that strategy.

One of the most important analytical tools of traffic engineering is computer simulation. Computer simulation is more practical than a field experiment for the following reasons:

- It is less costly.
- Results are obtained quickly.
- The data generated by simulation include several measures of effectiveness that cannot be easily obtained from field studies.
- The disruption of traffic operations, which often accompanies a field experiment, is completely avoided.
- Many schemes require significant physical changes to the facility, which are not acceptable for experimental purposes.
- Evaluation of the operational impact of future traffic demand must be conducted by using simulation or an equivalent analytical tool.
- Many variables can be held constant.

The availability of traffic simulation models greatly expands the opportunity for the development of new and innovative ATMS concepts and designs. Planners and engineers are no longer restricted by the lack of a mechanism for testing ideas prior to field demonstration. Furthermore, because these models produce information that allows the designer to identify the weaknesses in concepts and design, they provide the basis for finding the optimal form of the candidate approach. The results generated by the model can form the basis for selecting the most effective candidate among competing concepts and designs, and hence the name candidate approach. With this approach, the eventual field implementation will have a high probability of success.

2.1 CORSIM Simulation Software

Corridor Simulation Software (CORSIM) was developed by FHWA (2003) at the Turner-Fairbank Highway Research Center. It has been enhanced for more user-friendliness and better graphical interface over the last four versions. The newest version, version five consists of an integrated set of two microscopic simulation models that represent the entire traffic environment. NETSIM represents traffic on urban streets and FRESIM represents traffic on freeways. Microscopic simulation models represent movements of individual vehicles, which include the influences of driver behavior. In a multiple-model network, each of the component models of CORSIM simulates a different sub-network. The interfacing of adjoining sub-networks is accomplished by defining interface nodes that represent points at which vehicles leave one sub-network and enter

another. Nodes of this type are assigned special numbers to distinguish them from other nodes in the network. The terms "entry interface links," which receive traffic from the adjoining sub-networks, and "exit interface links," which carry traffic exiting the sub-network to adjoining sub-networks, are used to describe links at the boundaries of the sub-networks.

2.1.1 CORSIM Capabilities and Limitations

The following tables list many elements of modern traffic systems. CORSIM can model most of these elements explicitly. Many of the other features can be approximated using the basic elements of CORSIM, along with engineering judgment and creativity. The tables are Surface Street systems and show CORSIM capabilities and the types of input data that CORSIM uses to model those systems as shown in table 1.

Table 2.1 Surface Street Modeling Capabilities of CORSIM

Modeling Capabilities	Yes/No	Modeling Capabilities	Yes/No
Bottlenecks	Yes	Unsignalized intersections	Yes
Complex intersections	Yes	All-way stops	Yes
HOV lanes	Yes	Roundabouts	No*
On-street parking	Yes	Fixed-time signals	Yes
Two-way left turn lanes	No*	Actuated signals	Yes
Over saturation	Yes	Signal coordination	Yes
Time-varying demand	Yes	Surveillance	Yes
Incidents	Yes	U-turns	No*
Pedestrians	Yes	Transit signal priority	No
Work zones	Yes	Bus operations	Yes

These features are not modeled explicitly by CORSIM, but can be modeled using basic CORSIM elements. Some of them require using both surface street elements and freeway elements.

2.1.2 Surface Street Input Data

The following table describes the input data required for modeling surface streets.

Table 2.2 Input Data for Surface Street Modeling

Input Data	Input Data
Node coordinates	Time-varying turn percentages
Link length	Traffic composition
Grade	Vehicle occupancy
Number of lanes	O-D table
Lane channelization	Signal timing plan
Turn pockets	Surveillance detectors
Pedestrian traffic	Single ring actuated control
Free flow speed	Dual ring actuated control
Turn percentages	User-defined driver characteristics

2.1.3 NETSIM Traffic Assignment

Two optimization techniques are used in the traffic assignment model, the user equilibrium assignment and the system optimal assignment. The criterion for determining when user equilibrium has been reached is that no driver can reduce his journey time (or impedance) by choosing a new route. The criterion for the system optimization is the minimum total cost of the entire network. A given origin-destination demand matrix is assigned over the specified network. The results of the traffic assignment are then transformed into link-specific turn percentages as required by the simulation models, which commence operation following the assignment process.

The impedance function employed by the traffic assignment model is the FHWA formula and modified Davidson's queuing functions that relate link travel time to link volume and link characteristics (capacity and free-flow travel time). Traffic assignment is performed on a transformed path network that represents the specified turn movements in the original network. The algorithm that is used is a Frank-Wolfe decomposition variation that generates all-or-nothing traffic assignments for every iteration using the

link impedances produced by the previous iteration. For every iteration, a minimum path tree is constructed for each specified origin node to all other network nodes, using a label-correcting algorithm. The network cost function is evaluated at the end of the iteration, and a line search is conducted for the improved link flows that minimize the cost function. The iterative procedure terminates when convergence is attained or when a pre-specified upper bound on the number of iterations is reached.

2.1.4 Elements of the Traffic Environment

The traffic environment, which must be specified by the user, consists of:

- Topology of the roadway system (in the form of a link-node diagram)
- Geometry of each roadway component
- Lane channelizations (such as left-turn only and buses only lanes)
- Traffic volumes entering the roadway system
- Turn movements or origin-and-destination data
- Intersection Approach Geometry
- Stop and Yield Signs
- Pre-timed Signal Control
- Actuated Signal Control
- Freeway Ramp Metering Control
- Incidents and Temporary Events
- Traffic Surveillance Systems
- Fleet Components (buses, carpools, cars, and trucks)
- Load Factors (the number of passengers/vehicle)
- Turn Movement Distributions
- Bus Operations (paths, flow volumes, stations, dwell times, and routes)
- HOV Lanes (buses, carpools, or both)
- Queue Discharge Distribution on surface streets
- Lane Changing Parameters
- Variations in Driver Aggressiveness
- Reaction points for upcoming geometric changes on freeways

A network comprised of nodes and unidirectional links represents the physical environment. The links generally represent urban streets or freeway sections, and the nodes generally represent urban intersections or points at which a geometric property changes (such as a change in grade).

Another important feature of CORSIM is that characteristics that change over time, such as signal timings and traffic volumes, can be represented by dividing the simulation into a sequence of user-specified time periods, during which the traffic flows, the traffic controls, and the geometry are held constant. Therefore, the morning rush hour might be simulated with one time period representing pre-rush hour, a second representing rush-hour timing, and a third representing the post-rush-hour flows. These time periods are further divided into time intervals. CORSIM also includes a traffic assignment program, which is designed to expand the applicability of traffic simulation modeling to transportation planners. The program internally translates the origin-and-destination data, which is readily available to the planning community into a form suitable for use by the simulation models.

The traffic assignment model interfaces with the NETSIM component of CORSIM only and uses conventional traffic assignment techniques, along with user equilibrium and system optimization capabilities. The purpose of including a traffic assignment model in CORSIM is to extend the potential user group for this program to include planners and traffic engineers. The planner usually has sufficient information available to produce a table of origin-and-destination volumes that represent traffic demands over an area for a specified period of time. For this information to be useful as input in the NETSIM model, it must first be transformed into link-specific turn percentages. The mechanism for performing this transformation is the traffic assignment model. The interfacing logic is designed to perform data manipulation internally, thus freeing the user to focus attention on providing the origin-and-destination table. This logic will read and check the data and then perform the necessary data organization to provide the traffic assignment program with its data requirements. Subsequently, it will create turn percentages and entry volumes for input into the NETSIM model.

2.2 Incident Management

This section deals with incident management, its components and the theory of incident management studies conducted.

2.2.1 Traffic Flow Dynamics

It is important to understand the characteristics of traffic flow before, during, and after an incident have occurred on a roadway. The traffic flow prior to an incident can be described as the demand flow. The demand flow consists of the traffic volume that is normally present on the roadway at a given time. After an incident has occurred on the roadway, the traffic flow, now referred to as incident flow, is significantly decreased because of physical reductions (lane blockages) and the effects of rubbernecking, which is a term describing drivers passing the incident and slowing down to observe the incident scene. The reduction in traffic flow results in added delay and increased travel times. The amount of delay that results from the incident depends on the duration of the incident and the timeliness of its detection, response, clearance, and recovery to normal flow. The amount of delay experienced during an incident is shown in Figure 2.1 and is normally expressed in vehicle-hours. After the traffic passes the incident, motorists attempt to regain some of the lost time and tend to increase their speed. This increase in speed causes an increase in traffic flow levels, commonly referred to as getaway flow. Finally, after the recovery period is over, traffic will resume to its original demand flow. The intent of an Incident Management System (IMS) is to reduce the negative effects caused by an incident occurrence. Incident management systems attempt to reduce the detection, response, and clearance times of incident duration, thereby reducing the delay time experienced by motorists passing through the incident location. Incident management will also provide traveler information to warn motorists that an incident is ahead and to take an alternative route if one is available. The diverted traffic will reduce the demand on the road segment where the incident occurred, causing less delay to the motorist on this segment.

2.2.2 Incident Management Planning

Incident management is a coordinated and planned program that controls, guides, and warns the motorists of traffic problems in order to optimize the safe and

efficient movement of people and goods. Incident management involves the cooperation of multiple agencies, such as government officials, police, highway patrol, fire and rescue, emergency medical services, hazardous material crews, and towing services, to facilitate nonrecurring congestion problems on freeway.

2.2.3 Components of Incident Management

Incident management can be described as an array of activities that take place during four main stages: detection, response, clearing, and recovery. The main elements of incident management include the following:

- Incident detection
- Incident verification
- Response selection
- Incident removal
- Traffic management
- Traveler information

Each of these elements, individually and collectively, impacts the efficiency and success of the IMS. Detailed, well-organized management systems or plans have proven beneficial in communities that implement them by reducing delay and creating more predictable travel.

Incident Detection. The early detection of incidents is very important to the effectiveness of an IMS. Typically, major incidents are detected within 5 to 15 minutes of the occurrence. On the other hand, minor traffic accidents, which comprise of a majority of the total traffic incidents, may go undetected for up to 30 minutes. During off-peak traffic conditions, each minute that a lane is blocked due to an incident causes four-to-five minutes of additional travel delay. During peak hour traffic, the additional delay created by an incident is much greater. One report stated that when traffic flow is near capacity, an incident that causes a 40 percent reduction in capacity would create a backup of traffic at a rate of 8.5 miles per hour. Therefore, by the time even a minor accident is removed from the freeway, a traffic backup of 6.5 to 8.5 miles can occur. The decrease in capacity caused by an incident is mainly attributed to lane blockages; however,

rubbernecking can lead to further congestion and delays. For example, if one lane of a three-lane freeway is blocked, the reduction in capacity should only be 33 percent. However, a study conducted on the Gulf Freeway in Houston, TX, determined that a stalled vehicle and a non-jury accident, which both blocked one lane of a three-lane freeway, would reduce the capacity of the roadway by 48 percent and 51 percent (Reiss and Dunn, 1991). Therefore, rubbernecking can significantly contribute to the capacity reduction caused by an incident and reinforces the need for early detection of an incident.

Incidents may be detected using a variety of methods including reports by motorists using communication means (emergency call boxes, cellular phones, citizen-band (CB) radios, etc.), automatic vehicle detectors (loop detectors, video-image detectors, closed circuit television, etc.), or patrolling units (law enforcement, service patrols, etc.).

Incident Verification. After an incident has been detected and reported, it must be verified before formulating a response. This confirmation is necessary because some reports may not be true or may not be severe enough to justify a response. Closed circuit television and patrolling units can make verification. Specific and accurate reports are important for the selection of the appropriate response strategy. Response can be defined as “the activation, coordination, and management of appropriate personnel, equipment, communication links, and motorist information. The time needed to formulate a response of an incident is very important for the recovery of the traffic flow to its original state. Studies have shown that even if an incident blocks just one lane of traffic, a two-minute decrease in response time can cause a savings of over 400 vehicle-hours of delay Dudek (1987). Depending on the severity of the incident, various responses may be implemented. Minor incidents, such as flat tires, loss of vehicle fluids, and fender benders, can be dealt with by service patrols or by law enforcement agencies that contact the appropriate service requesting assistance at the site of the incident. On the other hand, major traffic incidents require the coordination of several agencies for an effective response. Therefore, it is essential to have preplanned protocols and procedures for specific types and severities of incidents. Each agency involved in the management team must be aware of its responsibility and role in each situation.

Incident Removal. The removal process involves the safe and timely handling of the incident, which restores the traffic flow to its normal conditions. This operation may include tow truck operations, the removal of wreckage, the cleanup of material spills and debris, rerouting of traffic, etc. The removal process should implement the preplanned procedures of the response selection. As stated earlier, it is essential that effective communication and cooperation be conducted prior to and during an incident occurrence. This practice will also determine the authoritative responsibilities during the removal process. Another factor in expediting the removal of an incident is driver cooperation in promptly moving their vehicles off the road after being involved in an incident.

Traffic Management. Traffic management is the process of implementing traffic control measures at or near incident locations. Roadway capacity can be increased by allowing traffic to use the road shoulder as a lane; adjusting upstream ramp meter timings or closing them down; or diverting the traffic before it is allowed to approach the incident site. Diversion schemes are often an effective method to move traffic past an incident and should be a preplanned part of the incident management plan. Different scenarios on each road section should be evaluated to achieve the possible or recommended alternative routes for traffic diversions. Steps must be taken on the alternative routes; such as changing the signal timing plans to allow the effective passage of diverted traffic. If these additional steps are not taken, freeway congestion and delay will be passed onto another route and will not benefit the traffic network as a whole.

3. LITERATURE REVIEW

For solving a traffic assignment problem in an ITS environment, considerable literature was reviewed in the areas of shortest path algorithms, routing methods, dynamic traffic assignment techniques and simulation. Additional literature reviewed included:

- Approaches to assign and model traffic
- Related topics and problems relevant to proposed methodology

The material reviewed in this Chapter is directly related to our problem and sets a background of the research work and rationale for opting the method selected. A detailed justification based on several parameters is given along with a head to head comparison of available research and proposed methodology.

3.1 Dynamic Traffic Assignment

In dynamic assignment trips may be considered as a combination of route choice and departure time, hence flow rates and travel times are time dependent and stochastic in nature. Alfa (1986) presented a review of dynamic traffic assignment (DTA) models, most considering only one Origin-Destination (OD) pair. The model was developed for local area assignment in normal conditions. Ben-Akiva (1985), considered one OD pair for several parallel routes. Mahmassani and Yi-Chang (1987) considered several origins but only one destination for traffic assignment.

A whole link model, rather than path based models, was developed by Merchant and Nemhauser (1978), and later improved by Carey and McCartney (2002). This model analyses assignment for steady state and stochastic travel demand conditions. It assumes shorter links and a queue type congestion following FIFO principles. Based on Ran et al (1996), Han (2003) developed a queuing model with discrete time windows for dynamic user equilibrium, which states that after a long period all drivers tend to follow paths of minimum disutility. It updates a link flow pattern rather than path based using

DYNASTOCH algorithm. Many research efforts analyze both travel times (flows) as well as driver perceptions. Liu, Ban and Mirchandani (2002) modeled a DTA solution for probabilistic travel time and random traveler perception using Variational Inequalities.

The models described in this section can all be used for modeling our problem with some modification. Our research is being done for an Automated Traveler Information Systems (ATIS) and Traffic Management Center (TMC), so travel demand need not be modeled, as it will be available in real time. Furthermore, our research deals more with Local Area Traffic management in case of a known incident and assignment needs to be done over a smaller area.

3.2 Computer Simulation Techniques

Traffic models can be very well depicted using simulation techniques. Much traffic simulation software is available for modeling routing strategies. These include Arena (using Visual Basic technology), Siman, Paramics, Integration, DynaSmart, CORSIM (which is a powerful and detailed traffic simulation tool) and many more.

When simulating traffic network and traffic behavior, inputs are taken either from a travel demand projection model, ramp meter readings which are explained in detail in the ITS section or real time data based on onboard GPS systems in cars (also known as probe cars) or cameras. These inputs then generate a graphic simulation of traffic behavior in the congestion scenario making it easy for traffic control technicians to allocate appropriate messages on the Variable Message Signs (VMS). Communication systems requirements for this process are delved into the section on ITS related technologies. Refer to Figure 3.1 for a full schematic description.

The limitations to simulation models are that almost always feedback times are high. Also, it is very difficult to get data in real time. Many models use Traffic Demand Models that are good for Transportation planning, signal design but fall short for real time congestion management. The advantage with simulation models is that they are very portable and scalable, and can be transferred to communication interfaces like VMS, or wireless communication devices easily. Many simulation programs have add-on features like ConnectPlus, which enable email, wireless and digital signal communication.

Simulation studies carried out by Fraser and Nicol (2001) in the City of Edinburgh in England showed significant improvement in traffic flow and better traffic control and access in the city's center. The tool used was Paramics program with an embedded network of Central Edinburgh. The inputs to the Paramics program were travel demand models and forecasts made by the city council. The study also showed reductions in carbon monoxide and carbon dioxide levels in central Edinburgh. The study however, does not consider congestion by incidents and rerouting techniques.

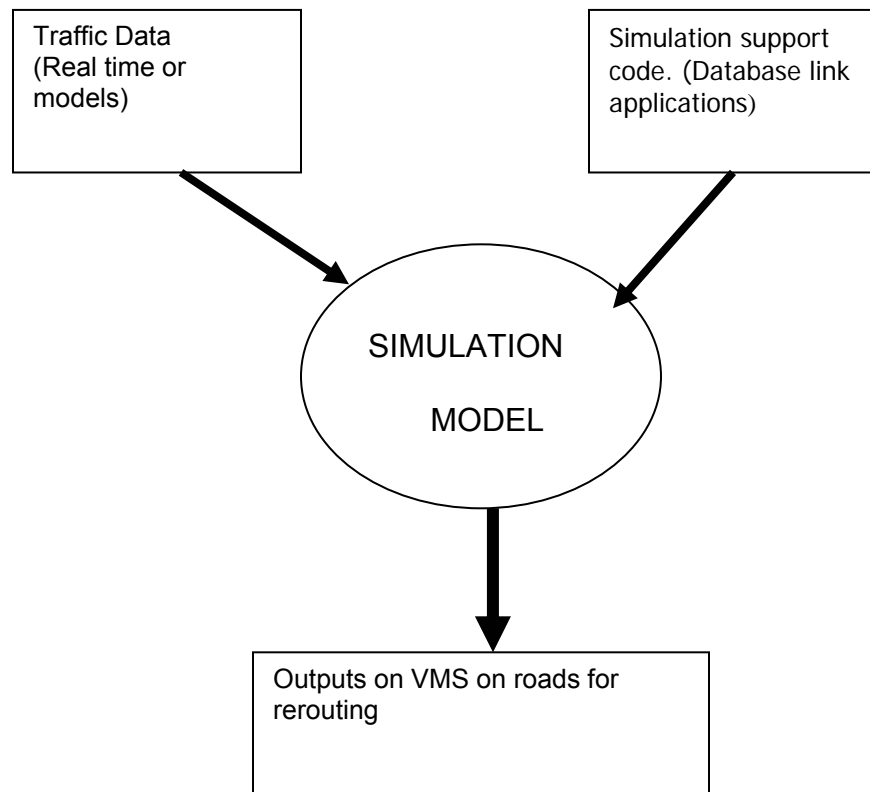


Figure 3.1 Simulation and DMS Actuation

Some simulation studies have been conducted considering in-vehicle ATIS, with the vehicle having full access to road, congestion and route information. These vehicles are called 'enabled' vehicles. Simulation studies carried out on Santa Monica freeway

corridor by Gardes and May (1993) using Integration program use various simulation tools for modeling. Santa Monica studies included ramp metering, signal optimization and dynamic route selection. Enabled vehicles selected routes dynamically, and those not enabled were given a distortion factor of 20% and lag. It was seen that during congestion, travel time reductions were observed for enabled vehicles by up to 6.2% in cases of saturated congestion levels.

The DynaSmart model, used by Jayakrishnan et al (1997), shows that enabled vehicles follow paths based on instantaneous travel times generated by the ATIS whereas unequipped vehicles travel on either judgment or delayed information. In some cases, travel times in enabled vehicles were observed to be higher, as information available through the ITS is real time, and hence travel time projections are instantaneous and constantly changing, while a route choice decision may be made at a time when the ATIS did not completely reflect the congested situation accurately. Dynasmart currently has two versions, developed at the University of Texas, Austin used for travel demand prediction and actual assignment using DTA. It was an initiative started by Mahmassani and Yi-Chang (2001) during his work on DTA. Currently, the FHWA is in the process of standardizing Dynasmart Simulation for future traffic assignment models. All developments are posted on the FHWA DTA website.

3.3 Artificial Intelligence (AI) Methods

These are relatively newer methods, and are widely used nowadays in academic research. In most Artificial Intelligence (AI) or Neural Network (NN) methods, the system designed is self-learning. In this case, a rerouting model would have a longer reaction time initially, but when a similar situation of congestion arises again, the model will refer to history and react appropriately faster. This saves the need to recalculate routes and reduces processing time considerably. The system is in constant state of learning and applying, so the more the system is used or broken into, the better it becomes. Some limitations of AI programs are that it takes a long time for them to be effective, which is they have to undergo thousands of runs in different scenario in order to be computationally efficient.

Modeling time-varying, flow rate dependant traffic flows is very important in assessing routing strategy, as the objective function in modeling is invariably to

maximize flow or reduce time/distance. Subrahmanian and Carey (2000) modeled traffic realistically using dynamic traffic assignment, assuming that FIFO property of entering traffic holds true until a large increase in vehicles or congestion.

Realistic studies by Sadek, Smith and Demetsky (2001) for a Case Based Reasoning match/retrieve model for a Virginia highway showed that traffic routing can be done realistically using this approach, although certain refinements were required for more congested networks. The inputs for this study were taken from CCTV and inductive loop sensors embedded in road surface. The match/retrieve algorithm uses previous experience to match current congestion and retrieve appropriate solution based on how well it fits, otherwise, a DTA model is used to process new routes.

Fuzzy and NN systems are effective for short-term prediction, and also adjust well to stochastic nature of traffic flow. In addition, NN systems are self-learning and get more accurate over multiple runs. System developed consists of two models, gate network (GN) and expert network (EN). Defining a non-linear and stochastic relationship between upstream and downstream traffic flow is used for setting the model up. The down-stream traffic flow for a link between two nodes is measured using meters/sensors, in addition to this the function between upstream and downstream is considered and the fuzzy-neural model is developed for prediction. Once flows are predicted, traffic can be routed appropriately during road incidents or recurring congestion.

3.4 Traffic Stream Parameters

Traffic streams are defined macroscopically using three main characteristics namely speed, flow and density. There are many mathematical forms available to describe the relationships between these characteristics that we will later use in this research.

3.4.1 Rate of Flow or Volume

Traffic volume is defined as the number of vehicles passing through a point on the highway or given lane during a specified time interval. Depending on the application of the data, volumes may be measured on daily, hourly or sub-hourly basis.

Daily volumes are generally used for highway planning purposes and may be measured as average annual daily traffic, average annual weekly traffic or simply average daily traffic (volume per day). Daily volumes are not differentiated by direction or lane, and in case of arterials are generally the total volumes passing a particular intersection in a 24-hour period.

Volume varies considerably during a full day and for the purpose of operational analysis, as in the case of our research, hourly traffic volumes are preferred. In most cases, volumes are considerably higher during the peak hour than at other times. All operational analysis and assignment must consider both direction and peak hour volumes. Highways must be designed to accommodate peak hour volumes in peak direction of flow.

For measuring very short-term fluctuations volumes may be counted over fifteen minute intervals called sub-hourly volumes. Such volumes are generally collected for signal warrant analyses, when a decision whether to signalize a particular intersection is to be made.

3.4.2 Speed and Travel Time

Speed is defined as rate of motion in distance per unit time (mph or fps). Mean speeds can be calculated as time mean speed or space mean speed. Time mean speed is a point measure, and is defined by the Highway Capacity Manual (1994) as average speed of all vehicles passing a point on the highway. Space mean speed is measure relating to a length of highway or lane and is defined by the Highway Capacity Manual (1994) as average speed of all vehicles occupying a given section of a highway over a specified time. Mathematically, both can be described as follows:

$$TMS = (\sum d/t_i) / n \quad \dots\dots\dots (3.1)$$

$$SMS = n*d / \sum t_i \quad \dots\dots\dots (3.2)$$

where, TMS = time mean speed (mph or fps)

SMS = space mean speed (mph or fps)

d = distance traversed (ft or mi)

n = number of travel times observed

t_i = travel time for the *i*th vehicle (sec or hours)

For this research, space mean speeds are a more accurate measure of stream characteristics for measurement of travel times. Travel time is defined as the total time to traverse a given highway segment. Running time is defined as the time over a given segment that the vehicle is in motion. As running time does not consider stopped delays, whether due to signalization or incidents, it is not useful for us in this research.

3.4.3 Density

Density is defined the number of vehicles occupying a given length of highway or lane is expressed as vehicles per mile (vpm) or vehicles per mile per lane (vpmpl). Even in a scenario where ITS deployments are complete density may be difficult to measure directly and is hence computed from speed and volume by the relation:

$$v = S * D \quad \dots\dots\dots (3.3)$$

where,
 v is rate of flow (vph), S is space mean speed (mph) and D is density (vpm)

3.5 Incident Management Research

Some of the incident management research works are reviewed and briefed below.

3.5.1 Optimized Signal Timing

This section outlines the need to use alternate strategies to mitigate incident related congestion using optimized signal times. Most areas use signal timing plans that correlate to specific times of day, such as morning and evening peak periods. Signal timings plans, however, are inflexible and do not change during each of these time-of-day intervals and are hence called "fixed-time" plans. Some more progressive systems use actuated-coordinated, which allows unused side street green time to be returned to the main street. This provides more capacity to the main street, but results in less efficient coordination, as the offsets do not adjust in real-time to the early platoon arrival at downstream intersections. Even these more progressive actuated systems do not adjust the cycle and therefore a single peak period is controlled by a constant cycle length. This implies that peak period traffic conditions remain relatively constant

otherwise the "fixed-time" systems are less than optimal from cycle to cycle. All plan-based signal timings are known as "fixed-time" systems. Often this term is confused with "pre-timed," which is a rigid timing plan that does not incorporate actuation. Fixed-time refers to a generic condition of either pre-timed or actuated-coordinated signal control. Incidents on arterials raise another concern for congestion. Since fixed-time control does not respond to real-time traffic demand changes, they do adjust to reduced capacity.

There are three main types of traffic signals. Two similar types of signals are semi-actuated signals and fully actuated signals. The timing of these systems is dependent on detecting the vehicles at the intersection. Semi-actuated signals usually base their timing on traffic volumes from one specific approach. Consider the situation where there is an intersection with heavy main street traffic volumes and a seldom-used side street. If there were no traffic lights, vehicles would never be able to get across the main street from the side street. When a vehicle comes to an intersection from a side street, a video camera or magnetic-loop detectors in the pavement detect it. After a few seconds, the side street gets the green light for a short time. The side street then stays red until the next vehicle approaches or until a certain time elapses. Fully actuated signals detect vehicles on all approaches and change the light based on demand. Fully actuated signals are often used when traffic flow varies greatly during the day at isolated intersections. The third type is a pre-timed signal where timing is fixed over specified time periods and does not change in response to changes in traffic flow at an intersection. This type of signal is widely used currently where there are predictable traffic volumes and pedestrians. In this case, the cycle length, green time, and red time have been pre-determined based on statistical evidence. The cycle length is the amount of time for a light to go from green to red and back to green again.

In case of incidents, traffic volumes are not predictable and this poses a challenge for traffic control using pre-timed signals since quite obviously the links affected by the incident require more green time in order to improve traffic flow. In such conditions, actuated controllers that respond to changes in traffic in real time are useful and may enhance the performance of the network if used correctly. As such, there is no single proven signalization strategy that has proven more successful than other strategies. Signalization strategy is unique to every intersection. In our research, we

attempt to test actuated signals for traffic control once the incident is detected. There are many actuation models available, of which we test the PASSERS model incorporated in CORSIM.

3.5.2 Actuated Signal Control

Each actuated signal has the following features that must be set on the controller:

- *Minimum green time.* Each phase has a minimum green time.
- *Passage time interval.* Passage time interval allows the vehicle to travel from the detector to the stop line. It also defines the maximum gap between vehicles arriving at the detector to retain a given green phase. If actual passage time is too short for defining maximum gap, the passage time maybe be increased in the controller of the signal.
- *Maximum green time.* Each phase has a maximum green time. After this time, the green will arbitrarily terminate, assuming there is a requirement for green on another phase.
- *Recall switch.* Every phase has one recall switch. When turned 'on' the green is recalled from the terminating phase with existing green. When it is 'off', green is retained on the previous phase until a call for service is received.
- *Clearance or 'all red' interval.* This is an interval allowed for vehicles entering the intersection legally on a yellow to clear the intersection before giving green to a conflicting movement. Hence at the phase changeover, all lights are red momentarily to avoid collisions. This interval depends on intersection geometry as well as pedestrian movements and volumes at that intersection.

One way to deal with diversion of traffic during incident scenarios is by adjusting the signal timings in arteries (optimal signal timings) to accommodate for the incident. In general, this is not a good strategy for major incidents, in which delay might be up to a couple of hours. Also, certain optimal signal timing applications, such as the real-Time Adaptive Control Strategies (RT-TRACS) project developed by ITT Industries tested in Fairfax County and partly funded by FHWA in 1997 show that stop delay and travel times are actually increased in certain cases. Furthermore, these studies are not entirely

accurate at peak hours or heavy congestion; hence traffic diversion is a better option. The RT-TRACS project is still under development. Another signal control system is Sydney Co-coordinated Adaptive Traffic System (SCATS) developed in Australia. SCATS originally was developed for the New South Wales Roads and Traffic Authority for application in Sydney and other Australian cities. Currently it has been installed in more than 50 cities worldwide. Similar to SCOOT, SCATS adjusts cycle time, splits and offsets in response to real-time traffic demand to minimize overall stops and delay. However, it is not model based but has a library of plans that it selects from and therefore relies extensively on available traffic data. It can loosely be described as a feedback control system.

3.5.3 Variable Speed Limits

The steady increase of traffic demand during the past decades has led to a high rate of congestion. Many intelligent transportation systems (ITS) are being designed to reduce congestion and ensure safer, quicker, less expensive, and more-energy-efficient travel. Variable Speed Limits (VSL) as one type of ITS technologies have been widely adopted to provide appropriate speed on the basis of real-time traffic, environment and roadway conditions by means of variable message signs. However, there are very few studies on the real-time VSL control strategies designed for achieving control objectives such as reducing congestion and improving safety.

Speed limits are established to encourage uniform driving behavior and meet specific objectives: improve safety; reduce congestion (improve travel times and/or maximize throughput); and reduction of emissions and energy conservation. Static speed limits effectively fulfill this duty when the factors influencing vehicle speeds are time-invariant, but tend to underachieve in a rapidly changing environment. To account for changing conditions, speed limits need to be adjusted so that the posted speed limits reflect the resulting conditions. Although speed is often assumed to be the greatest contributing factor in crashes, many studies indicate that speed is more important as a determinant of crash severity but not of crash occurrence. Instead, speed variance is associated with higher crash rates. Disrupting the smooth flow of traffic increases the probability of accidents. Higher speed variance means more frequent passing or lane changing and many crashes happen during such actions. In addition, weaving, frequent

lane changing and passing reduce the stability of the traffic stream by increasing the number of short headways, which in turn could lead to congestion and traffic breakdown.

On a low-density highway vehicles are generally far apart. Drivers move at their desired speeds, and maneuver freely from lane to lane. As density increases there are increasingly fewer opportunities to maneuver and car following behavior dominates the movement of many vehicles, which in general decreases the average speed. As long as the arrival rate to the facility is less than the capacity, traffic moves steadily at reduced speed. If the arrival rate increases beyond the maximum flow the facility can accommodate, queues develop in front of the section with the smallest capacity—the bottleneck section. Incidents generally are a cause of these bottlenecks. Upstream from the bottleneck section traffic conditions will quickly deteriorate due to a progressive shockwave effect.

While the two types of traffic described here, typically characterize most roadways, researchers have claimed that there is a third traffic state called synchronized traffic flow. In synchronized flow, all of the vehicles travel at the speed close to average speed and the vehicles become highly dependent on one another, in other words, their behaviors are correlated Kerner (1998). The synchronized state is characterized by almost pure car following conditions, since very little passing can occur. Under free-flow conditions, car following may occur, but only if the driver chooses to follow the preceding vehicle. Under congested conditions, drivers have little choice about following the lead vehicle closely.

Unstable traffic conditions are associated with stop-and-go behavior and severe congestion. Using microscopic traffic simulation we can show that with small average time headway, disturbances generated at the head of the car stream cannot be damped as they propagate upstream. This is not hard to explain since at a small headway some drivers in the stream cannot react to the disturbance in time. If the disturbance cannot be damped, stop-and-go phenomena will occur or even worse, collisions may take place somewhere upstream.

Disturbances always lead to flow decreases, and it is difficult to recover from such decreases in high traffic density. It is assumed that drivers judge their following distances in terms of time to respond to the change in speed of the vehicle ahead. This is reflected in the driver behavior modeling in Section 4.3. Some drivers like to follow

closely at perhaps a minimum safe driving distance, whereas others like to leave a comfortable cushion, so both time headway and standstill spacing are expected to vary considerably from one vehicle to the other.

To keep traffic stable and maximize traffic flow at the same time, it is necessary to maintain the average time headway above the critical value (below which the traffic is not stable) and minimize the variance in headway. If we lower the speed limit all instead of only some of the vehicles slow down (assuming that the compliance level to speed limit is very high). Thus a large speed variance will be avoided and the traffic flow will be steady and relatively high if not the maximum. This makes it possible to “force” a traffic stream to move at relatively high flow and high density.

However, the ability of variable speed limit to maintain high traffic flow at high density is limited. As density increases, to maintain the critical average time headway, the speed limit must be lowered again and again. Still, variable speed limits can at least delay the occurrence of low traffic flow, and most important of all, make the traffic more stable and less prone to secondary collisions. In effect, this would delay or avoid stop and go conditions.

3.5.4 Real-Time Diversion

Several research and development projects are underway to develop rerouting strategies. Using dynamic traffic assignment techniques Mahmassani (1994) attempts to address many situations including traffic diversion during incidents, traffic routing under recurring congestion and roadway planning.

Another initiative by Papageorgiou (1990) conducted for Virginia Department of Transportation uses offline traffic simulation studies for a two-alternative route system for managing congestion, not necessarily incident-caused but also applicable to it.

Expert systems have been used to develop a model for post-incident traffic control by Ketselidou (1989). The aim of the study is to demonstrate successful traffic diversion in a network with available alternate routes using expert systems. The model is developed based on pre-determined weights assigned to links depending on time of day and historical traffic volumes. Points of diversion and potential destinations are also predetermined. Three rules are used for determining best diversion strategy. First rule, keeping link demand lower than capacity. Secondly, unused capacity is preferred.

Finally, diversion is terminated when neither rule 1 or 2 is violated. Other criteria include proximity to main corridor routes, impact on adjoining land use, jurisdictional problems. As this is an academic work and was never tested, the impact of the model is as yet unknown, but the model results were compared with traffic simulation (TRAFLO) results and were found to be consistent. One drawback of this model is the pre-selection process, that is, diversion points are selected before incident information is known. Unexpected congestion on a pre-selected route, or roadwork renders the model ineffective.

3.5.5 Incident Studies

Jha, Ben-Akiva and Cuneo (2002) at MIT conducted traffic experiments for the Central Artery/Tunnel (CA/T) network in Boston and used a microscopic traffic simulator to test and evaluate the traffic control design. The advantage of this microscopic simulation laboratory is that it simulates the interaction of individual vehicles with other vehicles, network geometry, and traffic control devices, thus providing a detailed analysis of the impact of traffic control. Two case studies were presented. One placed an incident in a weaving section and used control designs comprised of lane control signs (LCS), variable speed limit signs (VSLS), ramp meters, and route diversion for incident management. The other case placed an incident in a tunnel, and used controls comprised of LCS, VSLS, and route diversion to a parallel tunnel. Total travel time and average travel times per OD were used to measure the network performance. Both experiments were performed for PM peaks and varying volume demands. This research shows that using different controls, traffic diversion may actually reduce travel times. It also showed the necessity to explore scenarios using microsimulation for corridor studies, as naïve implementation of ATMS may adversely affect the network performance.

Our research attempts to conduct traffic studies using microsimulation and varying incident conditions over demand and utilizing strategies to test if network performance is enhanced. Our research has particular relevance because limited research and studies are available on arterials and local highways, as most research tends to focus either on freeways or tunnel/freeway corridors. In this research, we attempt a new approach to surface street studies by conducting simulation experiments

for various factors and setting up a factorial design to study their interaction in the planning process for major corridor or road enhancements.

In this chapter we reviewed literature pertinent to the objectives of this research. The main components, namely algorithms, traffic assignment techniques, simulation and AI techniques were reviewed. Incident management research, strategies to enhance networks subject to incident conditions using actuated signals and variable speed limits are also reviewed. In the next chapter we explain the research problem, set up the network, the assumptions made for developing the simulation model and introducing the implementation of network enhancement strategies. Model design goals and a solved example to display the model working are also included.

4. RESEARCH OBJECTIVES

In this chapter, the problem of studying the effects of incidents on a realistic road network is stated. All major assumptions made are discussed and main objectives of the research are stated. Furthermore, strategies to enhance incident-affected networks are also tested.

4.1 Problem Statement

When conducting a corridor study for a particular network in order to meet traffic demands and suggest future improvements, it is necessary to understand the impacts of incidents and the factors affecting incidents on the network. The factors considered in this research are signals, speed strategy and incident type. A real-life scenario can be created using existing road information, traffic volumes and traffic control devices and simulated generating results based on certain Measures of Effectiveness (MOEs) criteria for the network. Once the model for existing conditions is prepared, we add incident management strategies to the model to see if significant improvements in the MOEs (average speed, total delay and average travel time according to Highway Capacity Manual) are possible during an incident. The strategies adopted will be fixed and variable speed limits, pre-timed and semi-actuated signal operation, network type depending on peak hour volumes and their combined effects. We approach the problem by testing each strategy and designing an experiment to study the effects of each strategy and the interaction between them. Another contribution of this research is to test the viability of variable speed limits, which has proven successful on freeway corridors in incident scenarios. Development of the model is discussed in detail in Chapter 5.

4.2 Network Details

A network is defined as a directed graph $G = (N, A)$ consisting of a set N of nodes and a set A of arcs or links with associated numerical values, such as the number of nodes, $n=|N|$, the number of arcs, $m=|A|$, and the length of an arc connecting nodes i and j , denoted as $l(i,j)$.

The network considered for this research consists of twenty-four nodes and thirty-three links. Of these, there are seven pseudo nodes and seven pseudo links used for simulation purposes of entering and exiting traffic volumes. Geographically, the network is bound between four major roads in the Tampa Bay area, namely Dale Mabry Highway (N-S), Hillsborough Avenue (E-W), Fletcher Avenue (E-W) and 50th Street (N-S) as shown in Figure 4.1. All the streets within the network are either arterials or local highways connecting major interstates within the Tampa Bay area.

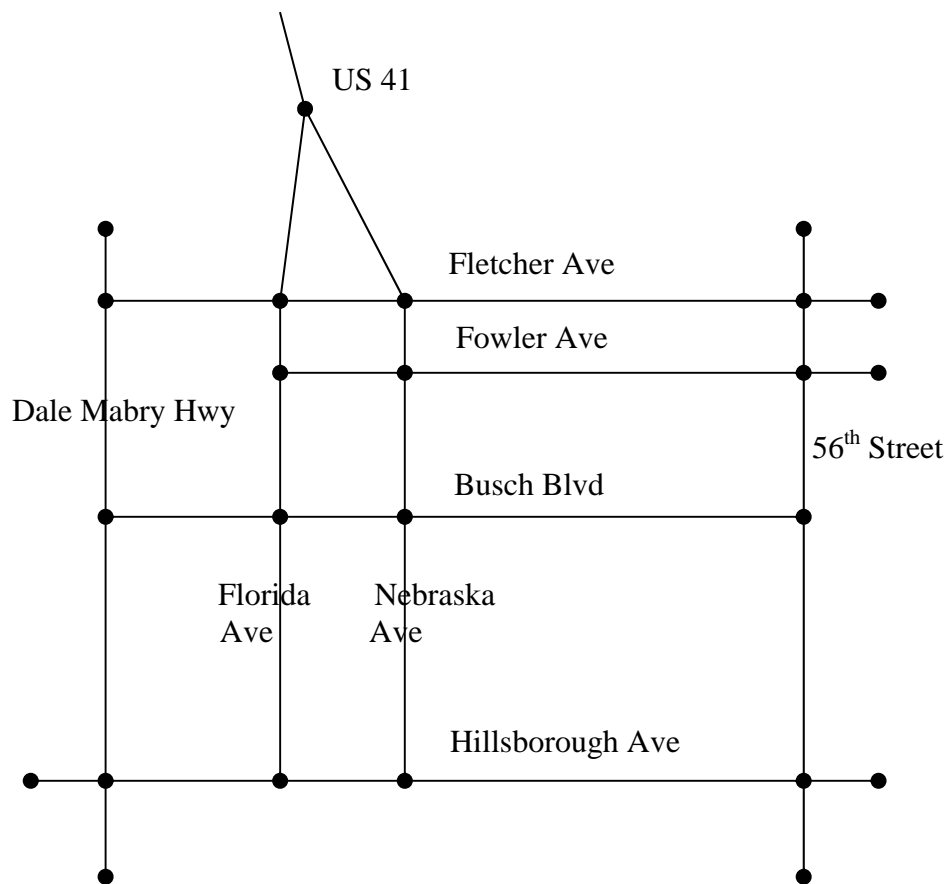


Figure 4.1 Network Corridor in Tampa Area

4.3 Factors Affecting the Network

Three important factors are identified that affect the performance of the network on the basis of MOEs specified by the Highway Capacity Manual. These factors are driver behavior, incident type and traffic flow. These factors are described in detail below.

4.3.1 Driver Behavior

Drivers are classified as aggressive or non-aggressive on the basis of three characteristics, driver type factor (F_{DA}), urgency threshold, and free flow speed multipliers according to driver type. It is necessary to understand certain concepts based on which these characteristics are used in simulation. They are explained as shown:

- *Driver type code.* One of the measures for driver aggressiveness is assigning a driver type code from 1 to 10, in increasing order of aggressiveness. The driver type code is then used in different equations to define the three characteristics mentioned above.
- *Driver intolerable speed (V_i).* This is the speed of the leading vehicle at which the driver will attempt to change lanes and pass the vehicle. It is computed as follows:

$$V_i = 0.7 * (V_f * DAF) \quad \dots\dots\dots (4.1)$$

where,

V_f = free flow speed

DAF (Driver aggressiveness factor) = $1.0 + (\text{Driver type code} - 5.5) / F_{DA}$

F_{DA} = Driver type factor

- *Driver type factor (F_{DA}).* It is evident from the equation for DAF that as the driver type factor (F_{DA}) is decreased, it will widen the gap between aggressive and timid drivers. Aggressive drivers would have lower intolerable speeds and would tend to change lanes more often. The exact opposite effect would be observed with more timid drivers, or those with lower driver type codes (1-5). While simulating in CORSIM, we use the driver type factor as a control for determining aggression.
- *Urgency threshold U_i .* The urgency (U) in ft/sec^2 of a driver is calculated as shown:

$$U = DAF * V_f^2 * NLC / (20 (X - X_o)) \quad \dots\dots\dots (4.2)$$

where,

NLC = number of lane changes. For discretionary lane change, NLC =1.

X = current position of vehicle (ft)

Xo = position of vehicle at which lane change is made (ft)

The urgency of a driver remains level from 0 up to a certain threshold value, wherein the acceptable deceleration of a vehicle is equal to the minimum deceleration specified. Beyond this point, the driver tends to show more urgency and changes lanes for lower deceleration values, hence increasing his/her risk. This threshold value is called urgency threshold, and can be set while simulating.

- *Free Flow Speed Percentages by Driver Type Code.* As each vehicle enters a link, they are assigned a free flow speed which a percent multiplier of the free flow speed of the link according to driver type code 1 to 10 using a decile distribution. The sum of the percent multipliers of free flow speed must equal 1000 for the simulation model. The mix of drivers in the network starting from code 1 to code 10 can be controlled by assigning 0 values for lower driver type code multipliers and higher values for the more aggressive set of drivers and vice versa. This way, we can control the driver behavior patterns within the network to observe performance with aggressive drivers or timid drivers in the same conditions in separate runs of simulation. A simple example is shown below that reflects a more aggressive set of driver type in the network.

Table 4.1 Percentage Multipliers of Free Flow Speed

Driver type code	1	2	3	4	5	6	7	8	9	10
Multiplier of free flow speed	0	0	65	90	125	130	140	145	150	155

From Table 4.1 it can be seen that adjusting the free flow speed percentage multipliers, we have eliminated driver types 1 and 2, creating a more aggressive set of drivers in the network.

4.3.2 Traffic Flow or Volume

The network performance greatly depends on the volume of traffic in terms of vehicles/hour entering the system. This is a function of the time of day. In general, there are three major times of a day considered for traffic study, AM peak, PM peak and off-peak hours. In this research we study the effects of incidents during PM peak hours only, as these are the most significant times when good incident management action is required. As the name suggests, PM peak occurs during the evening as drivers return from the business districts to residential areas. PM peak values for volume are obtained from actual observations collected as part of a traffic study conducted in 2002 by Hillsborough Traffic Services Division.

4.4 Model Assumptions

The assumptions made for the network and simulation model are given below. For the network, assumptions for links, nodes and road conditions are made. Furthermore, driver behavioral assumptions are also mentioned as shown in Section 4.4.1 through Section 4.4.4.

4.4.1 Links in the Network

All links in the model represent roads that are either divided highways or four lane bi-directional segments. For a link (a,b) direction a-b is called downstream and b-a is called upstream. In the simulation model, link (a,b) and (b,a) are treated separately in order to reflect directional properties and the outputs for each direction would be different. All streets on the network have at least two lanes in one direction with appropriate turning pockets provided at intersections as per real world conditions. There are several pseudo links provided in the network, these serve to connect pseudo nodes used for entering entry and exit volumes based on the Average Annual Daily Traffic (AADT) and formula mentioned in the previous section. Analysis for pseudo links is not conducted, as they are not a part of the real network under this study.

4.4.2 Nodes in the Network

All nodes, except pseudo nodes represent intersections and are either controlled by traffic signals or stop sign controls. Pseudo nodes are placed outside the study network to provide for incoming and outgoing traffic volume information

4.4.3 Driver Assumptions

The assumptions about drivers are made and listed below.

1. Fifty percent of drivers in the network co-operate with lane changers. This means 50% of drivers will either decelerate or make a safe maneuver in order to allow the lane changer to pass.
2. In order to reflect urban and arterial conditions, we assume that all drivers are familiar with routes. We assume that 20% of drivers know one turn movement in advance and 80% of the drivers are aware of streets at least two turn movements in advance and will take appropriate action like changing lanes in order to make the turn.
3. Time to react to sudden deceleration by the lead driver is kept constant at 1 second.
4. All drivers are set at a safety factor of 0.8 in the simulation model. This means if a follower vehicle can react to the lead vehicle decelerating at 10 ft/sec^2 then the driver in front assumes that the follower can only react up to $0.8 * 10 = 8 \text{ ft/sec}^2$. Note that this does not make a driver less aggressive, as aggression depends on tolerable speeds and deceleration and not perception of the driver of other drivers' abilities.

4.4.4 Road and Driving Conditions

1. It is assumed that all roads are level grade with no damages, and that the driving conditions are conducive to all drivers.
2. The lighting is adequate, weather conditions do not affect drivers and road surfaces are flat with no potholes or hindrances.
3. All roads are 12 feet wide with clear street markings.

4.5 Network Enhancement Strategies

Once the real life conditions for the corridors selected are simulated, the network is tested for enhancements with the intention of improving MOEs. These enhancements are variable speed limits and actuated signal controls.

4.5.1 Fixed and Variable Speed Limits

Many studies conducted on freeways, including research conducted by Jha, Ben-Akiva and Cuneo (2002) suggests that varying speeds limits during incidents may be appropriate for enhancing the network performance. When speeds are regulated during incidents, the shockwave effect downstream is reduced, thus decreasing the effects of congestion. In our research, we compare the effects of fixed speed and variable speed limit strategy on surface streets to observe the performance of selected control variables or MOEs. The links associated with incidents on the test corridors are tested for lower free flow speeds after the incident occurs. In the model, speed is reduced in two steps. In the first step, it is reduced by five mph one mile away from the incident, and by another five mph in the second step. The length of each reduced speed zone is half a mile. Variable speed limits are explained in detail in Section 3.6.2.

4.5.2 Semi-Actuated Signal Times

For this enhancement, we test the networks by using semi-actuated signals and pre-timed signals during incident scenarios. The effects of using actuated signals on network performance are compared with existing signal timings for the corridors. Since actuated signals work using detectors that react according to traffic volume at the intersections, it is likely that actuated signals might improve network performance during incidents. Concepts, advantages and recent work are covered in section 3.6.1 in detail.

4.5.3 Network Type

The network types selected exist within the test geographical area shown in figure 4.1. For this research, three corridors were selected based on the varying traffic volumes within the area and were classified as high volume, medium volume and low volume corridors. The network geometry, volumes and signalization are explained in detail in Chapter 5.

4.6 Measures of Effectiveness (MOEs)

The control variables selected for monitoring network performance are average speed, average travel times and total delay. The Highway Capacity Manual recommends all control variables selected as measures of network performance for surface streets with signalized intersections.

4.6.1 Average Speed (Miles per Hour)

Average speed is simply the total miles traveled divided by the total moving travel time by all the vehicles in the test corridor. This provides us with information of how fast vehicles can travel compared to the free flow speed during an incident. High average speed values are desirable for better network performance.

4.6.2 Average Travel Time (Seconds)

This is the ratio of total travel time and number of vehicles during the simulation run over the test corridor. This measure gives us a sense of quality of ride drivers experience in the test network under incident conditions. Low travel time values are desirable.

4.6.3 Total Delay (Vehicle Minutes)

The difference between the total travel time and the total moving time for all vehicles during the run represents the time that vehicles are delayed if they cannot travel at the free flow speed. This measure collectively provides a sense of total network delay experienced in vehicle minutes, including intersection delay and incident stop and go delay. For network performance to be good, total delay must be low.

4.7 Expected Results

The purpose of this research is to find workable strategies for alleviating the effects of congestion during an incident on surface streets. Our objective is also to test whether variable speed limits, which have successfully been tested for freeway corridors, are a viable strategy for surface streets on three inherently different types of existing networks. The expected results are listed below.

1. It is expected that semi-actuated signals will work more efficiently than pre-timed signals in incident scenarios for high volume and the saturated medium volume networks. This because since actuated signals assign a minimum green time to the main line, no matter where an incident occurs, traffic from the main line will keep on flowing. Also, in case the side street is not being used much, more traffic from the main line can be passed.
2. Variable speed limits will show lower total delay values than fixed speed limits over all three networks. The average speed of travel will remain the same or be lower using variable speed limits. From research conducted on freeways, as traffic backs up behind the scene of incident, by slowing the approaching traffic down a more continuous flow can be maintained. This helps to reduce queue build-ups.
3. The difference in output values for each strategy for all the three control variables will be highest for the high volume corridor. For example, the variation between average speeds for signal strategy will be most for the high volume corridor. As high volume corridors are most adversely affected during incidents, if a beneficial strategy is to be found, we expect it to work best on this network.
4. The signal strategy for all three networks will be most significant.

The objective of this research is to recommend appropriate strategies for managing incidents and improving network performance in different types of surface street corridors. It is expected that the strategy best suited for a high volume corridor may not be suitable for lower volume corridors. The results from simulation and the experimental design will also suggest which strategy has the maximum impact on these networks, providing an insight into the best course of action for local traffic management authorities to take in case limited resources are available to implement all recommendations. For example, to use variable speed limits, ITS technologies like dynamic message signs are required on all affected links. Since message signs may not be available on smaller surface street networks, only an appropriate signal strategy may be used. Furthermore, as variable speed limits are implemented more widely on freeways, it is important to study their viability on surface street networks also. This research aims at testing the viability of this strategy.

In this chapter, the research problem was established along with the network details, model assumptions, enhancement strategies and the measures of effectiveness of the strategies. The next chapter explains the model development for each network, the experimental design and expected results from the model.

5. MODEL DEVELOPMENT

In the preceding chapter, the problem was established and the significant parameters of the simulation model were discussed. In this chapter we explain the geometry of each network, the different scenarios tested, the experimental design set-up and the results of simulation and the factorial design.

5.1 High Volume Corridor

The corridor selected for analysis was a segment of Dale Mabry Highway between the intersections of Stall Road and Bearss Avenue. This corridor consists of three intersections with Dale Mabry Highway, namely Stall Road, Fletcher Avenue and Fire Station Road. Typically, during PM peak hours on weekdays there is very heavy traffic as Dale Mabry connects the business district in Tampa downtown to major residential areas. The observed peak hour volumes between 5:30 PM to 6:30 PM in every direction are given below in Table 5.1.

Table 5.1 Traffic Volume for High Volume Corridor

Street Name	Direction	Volume (vehicles/hour)
Dale Mabry Highway	Northbound	3548
Dale Mabry Highway	Southbound	2487
Fletcher Avenue	Westbound	2000
Fletcher Avenue	Eastbound	1220
Stall Road	Westbound	493
Stall Road	Eastbound	112

the road is cleared (Florida Highway Patrol Incident Database). All the results gathered were for the second time period only, as we are interested in performance of the network only during the incident.

3. All the pre-timed and semi-actuated signal timings were generated using Synchro software. Synchro uses the Highway Capacity Manual methodology for signal time allocation and is the same methodology adopted throughout Hillsborough County.
4. Twenty replications were made for each case. For every corridor, there were four cases. These were pre-timed with fixed and variable speed limit strategy and semi-actuated with fixed and variable speed limit strategy. Results were obtained for each link affected by the incident for every control variable.
5. The output variables were average speed in miles per hour, average travel time in seconds and total delay in vehicle-minutes.

5.2 Medium Volume Complex Corridor

This corridor is unique because it experiences medium to high volumes from several contributing arteries, very similar to downtown surface street traffic in cities. This corridor is located on two major connecting roads, namely Fletcher Avenue and Bruce B. Downs Boulevard. The area surrounding this intersection is the University of South Florida and a medical park, both of which add traffic to the two roads during PM peak hours. Commuter traffic is present in every direction making this corridor more complex for traffic management. The traffic volumes for this network are given below in Table 5.2.

The details of the simulation model are given below.

1. The network for the medium volume corridor selected is shown in Figure 5.2 below. The traffic during peak hours is almost in every direction. Bruce B. Downs (NS) intersects Fletcher Avenue (EW) at node 147 as shown in figure 5.2. As Fletcher Avenue receives traffic both east and west bound directions and connects to major interstates I-75 and I-275 in the east and west directions respectively, a hypothetical incident is created on the right-most lane of the two-lane surface street on link (759,758). The lane was closed for 30 minutes and results were collected for this time only.

2. All other parameters for the simulation model were similar to the high volume network except network geometry. This includes time periods, durations, peak hour times, number of replications, signal strategy, speed strategy, and driver behavior attributes.

Table 5.2 Traffic Volume for Medium Volume Complex Corridor

Street Name	Direction	Volume (vehicles/hour)
Bruce B. Downs Blvd	Northbound	1959
Bruce B. Downs Blvd	Southbound	2464
Fletcher Avenue	Westbound	2219
Fletcher Avenue	Eastbound	2176
Bearrs Avenue	Eastbound	493
Magnolia Drive (USF)	Northbound	904
Holly Drive	Westbound	947
131 st Avenue	Eastbound	353
Livingston Avenue	Northbound	294
138 th Avenue	Westbound	577

5.3 Low Volume Corridor

Casey Road, South Village and Lowell Road form a triangular corridor that experiences relatively low volumes during the PM peak hour between 5:30 PM to 6:30 PM. A large proportion of the traffic is west bound on South Village Road and north bound on Casey Road. Traffic volumes for this corridor are given below in Table 5.3.

The details of the simulation model are given below.

1. The network for the low volume corridor selected is shown in figure 5.3 below. The traffic during peak hours is almost entirely westbound. South Village Road (EW) intersects Casey Road (NS) at node 228. As south Village receives most traffic, a hypothetical incident is created on the right-most lane of the two-lane surface street on link (222,223). The lane was closed for 30 minutes and results were collected for this time only.

2. All other parameters for the simulation model were similar to the high volume network except network geometry. This includes time periods, durations, peak hour times, number of replications, signal strategy, speed strategy, and driver behavior attributes.

Table 5.3 Traffic Volume for Low Volume Corridor

Street Name	Direction	Volume (vehicles/hour)
Casey Road	Northbound	818
South Village	Westbound	1160
South Village	Eastbound	593
Lowell Road	Eastbound	352

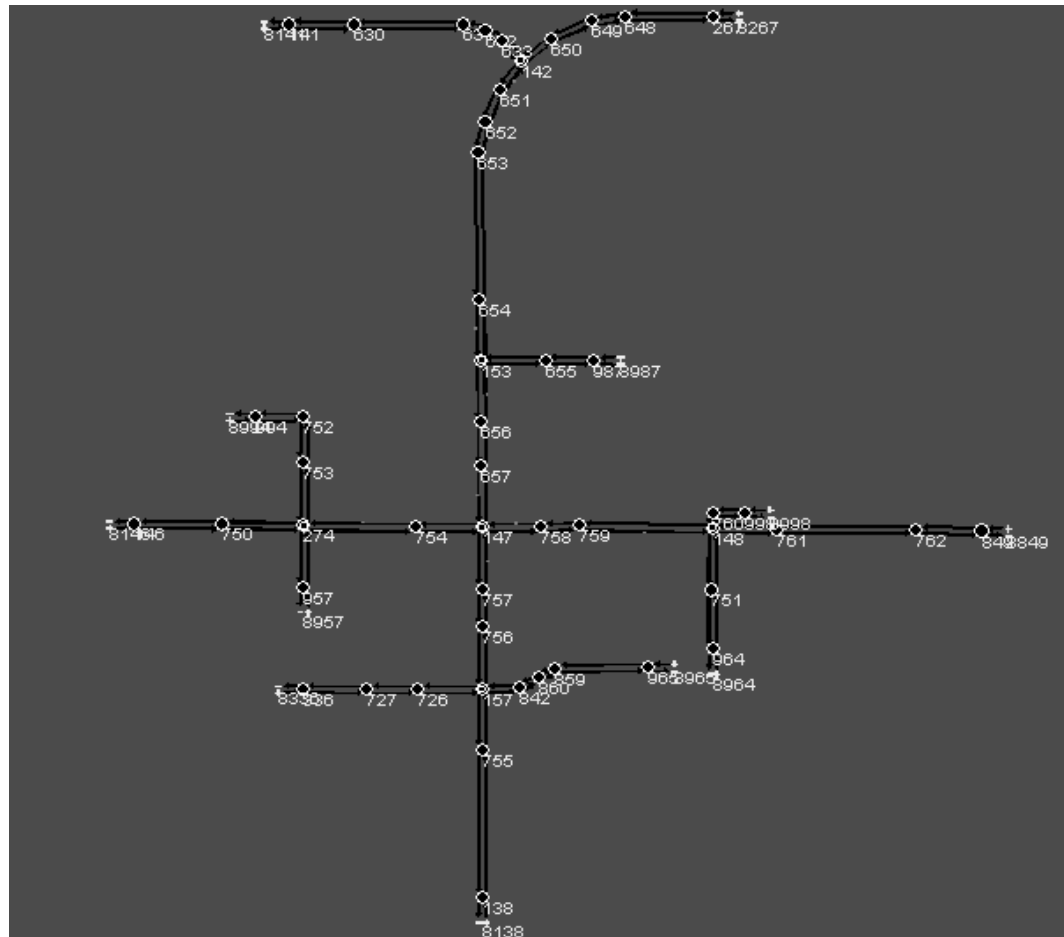


Figure 5.2 Medium Volume Corridor

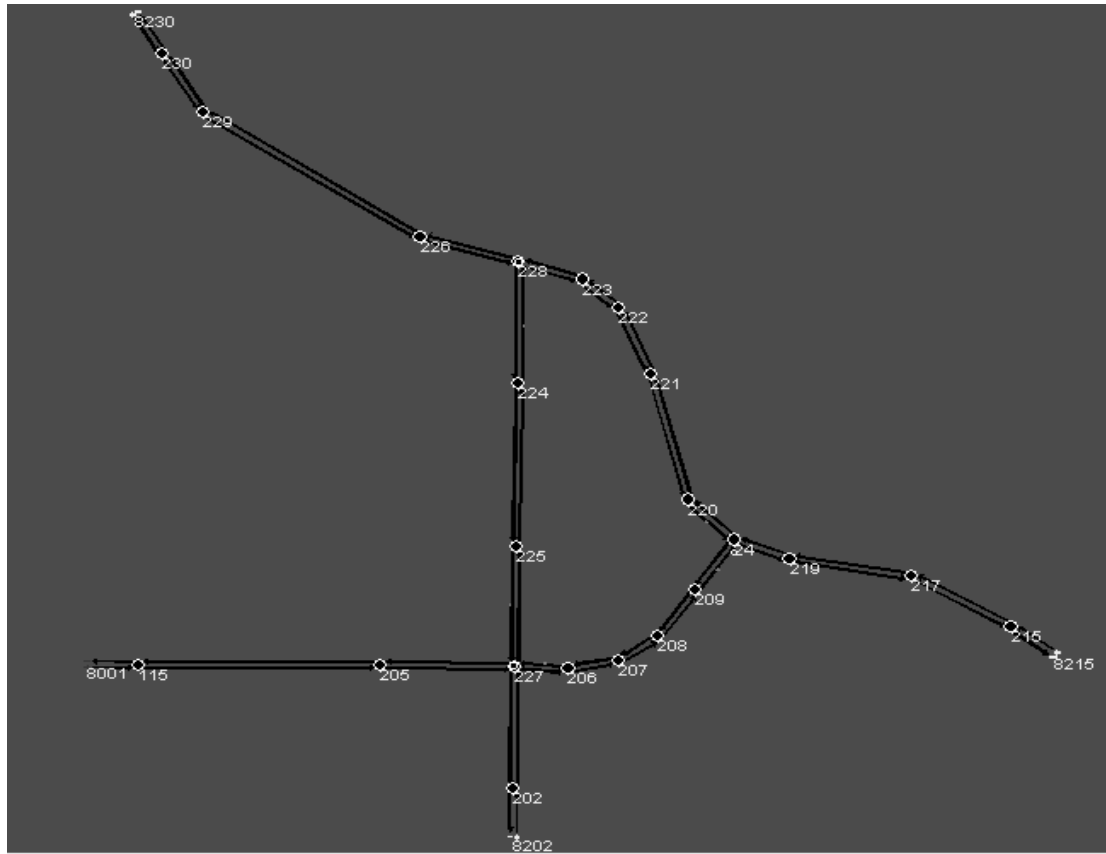


Figure 5.3 Low Volume Corridor

The values for defining driver behavior for all of the models are given in Table 5.4. The driver behavior was discussed in Section 4.3.1.

Table 5.4 Driver Behavior Configurations

Characteristic	Value	Units
Driver types 1-10		
Acceptable deceleration	21,18,15,12,9,7,6,5,4,4	ft /sec ²
Free flow speed compliance	75,81,91,94,97,100,107,111,117,127	%
Driver familiarity	10	%
Duration of lane change	3	sec
Urgency threshold	0.2	sec ² / ft
Safety factor	0.8	

In this chapter the approach to modeling the selected corridors was discussed, along with the parameters for the simulation model. We also described the geometry of each corridor in detail and their inherent differences. Finally, we discussed the expected results from simulation and the factorial analysis. The last chapter then will summarize the work done and draw the conclusions based on the simulation results. The scope for future research on this topic will also be discussed.

6. RESULTS AND ANALYSIS

In this chapter the results from simulation and design of experiment are shown. The explanation of the experiment design and the interpretation of the results are given.

6.1 Simulation Results

In the preceding chapter, we explained how the simulation model was set-up, the details for each corridor and the parameters used in CORSIM. The simulation results by MOEs are shown in Tables 6.1, 6.2 and 6.3 respectively. A glance at the results shows some consistency with expected results, especially semi-actuated signal strategy. The results show that semi-actuated signals provide better network performance under incidents than pre-timed signals. Also, the total delay for medium volume corridor is significantly lesser for variable speed limits than fixed speed strategy.

A factorial design was set up for analyzing the simulation results and interpreting them. This is further explained in Section 6.2.

6.2 Design of Experiment

In this research, we used two types of signal strategies, two types of speed strategies and tested them on three types of surface street corridors to observe how the network performs based on three control variables, namely average speed, average travel time and total delay. Looking at this it becomes obvious that the factorial design selected was of the type 3 X 2 X 2. Here the three represents the network types, and the twos represent the speed and signaling strategies as shown below. Minitab software was used for design of experiment and analysis of variance with $\alpha = 0.05$.

Table 6.1 Simulation Results for Average Speed

	High volume corridor				Medium volume corridor				Low volume corridor			
Runs	Pre-timed		Semi-actuated		Pre-timed		Semi-actuated		Pre-timed		Semi-actuated	
	Fixed	Variable	Fixed	Variable	Fixed	Variable	Fixed	Variable	Fixed	Variable	Fixed	Variable
1	13.0	13.0	24.9	25.0	18.8	18.2	32.4	30.1	34.1	29.7	35.9	32.7
2	13.5	13.4	25.0	25.0	18.7	17.9	32.5	31.4	33.3	28.8	35.3	32.4
3	12.9	13.0	24.7	24.9	19.4	17.6	32.5	31.4	33.8	29.2	35.5	32.3
4	13.3	13.0	25.0	25.1	19.4	18.1	31.3	31.3	33.4	29.1	35.7	32.8
5	13.3	13.3	24.9	25.1	18.8	17.5	32.2	31.2	33.2	28.8	35.6	32.7
6	13.4	13.2	25.1	24.6	18.2	17.8	32.0	31.3	32.9	28.8	34.9	31.9
7	12.8	13.2	24.5	24.6	19.5	17.5	31.2	31.0	33.1	28.7	35.6	32.5
8	13.1	13.3	24.7	25.0	19.8	17.1	31.9	31.3	33.1	28.8	35.6	32.4
9	12.9	13.1	24.9	24.9	18.6	17.1	32.1	31.2	33.1	28.9	35.1	32.3
10	13.3	13.1	24.9	25.0	19.0	17.9	32.5	31.4	33.6	28.9	35.4	32.3
11	13.1	13.0	24.9	25.0	18.9	18.4	32.0	31.4	33.1	28.8	35.5	32.5
12	13.6	13.4	24.9	24.9	19.1	17.4	32.5	31.0	33.0	28.4	35.3	32.3
13	13.5	13.4	24.6	24.2	18.6	17.3	32.0	30.8	32.9	28.7	35.3	32.2
14	13.5	13.5	25.2	25.2	19.0	18.7	31.8	30.8	32.9	28.8	35.7	32.6
15	13.5	13.3	25.2	25.1	19.7	17.5	31.9	30.2	33.2	28.8	35.2	32.3
16	13.1	13.0	25.3	25.3	19.8	17.5	32.5	31.5	32.8	28.7	34.9	32.1
17	13.1	13.2	25.2	25.2	19.8	17.5	32.9	31.4	33.4	28.9	35.2	32.1
18	13.7	13.4	25.4	25.2	17.8	17.3	32.2	31.4	33.2	28.9	35.8	32.8
19	13.4	13.3	25.1	24.8	19.4	17.4	31.4	31.0	33.5	28.9	35.4	32.5
20	13.1	13.3	24.3	24.8	18.7	18.4	32.4	31.4	33.5	28.8	35.1	32.2

Table 6.2 Simulation Results for Average Travel Time

Runs	High volume corridor				Medium volume corridor				Low volume corridor			
	Pre-timed		Semi-actuated		Pre-timed		Semi-actuated		Pre-timed		Semi-actuated	
	Fixed	Variable	Fixed	Variable	Fixed	Variable	Fixed	Variable	Fixed	Variable	Fixed	Variable
1	57	54	34	35	54	52	16	18	12	8	7	8
2	47	50	34	35	55	57	15	16	12	8	7	8
3	54	53	35	35	51	59	15	16	12	8	7	8
4	50	56	34	34	52	54	17	16	12	8	7	7
5	53	49	35	35	55	59	16	17	12	8	7	7
6	50	51	33	34	58	55	16	16	12	8	7	8
7	53	50	35	33	52	59	17	16	12	8	7	8
8	56	55	35	34	50	60	16	16	12	8	7	8
9	55	51	34	35	54	61	16	16	12	8	7	8
10	49	51	34	34	53	57	15	16	12	8	7	8
11	50	50	34	35	55	53	16	16	12	8	7	8
12	54	54	33	34	54	59	15	16	12	8	7	8
13	51	50	35	35	55	60	16	17	12	8	7	8
14	55	53	34	34	54	53	16	17	12	8	7	7
15	50	50	33	35	50	60	16	17	12	8	7	8
16	52	54	33	34	49	57	15	16	12	8	7	8
17	52	53	34	32	50	57	15	16	12	8	7	8
18	54	55	34	33	61	61	16	16	12	8	7	7
19	50	53	34	33	52	62	16	17	12	8	7	8
20	49	48	36	34	54	53	16	16	12	8	7	8

Table 6.3 Simulation Results for Total Delay

Runs	High volume corridor				Medium volume corridor				Low volume corridor			
	Pre-timed		Semi-actuated		Pre-timed		Semi-actuated		Pre-timed		Semi-actuated	
	Fixed	Variable	Fixed	Variable	Fixed	Variable	Fixed	Variable	Fixed	Variable	Fixed	Variable
1	2057	2087	1110	1099	1368	1984	255	209	15	30	24	25
2	1802	1971	1097	1090	1394	2150	245	160	17	31	24	23
3	2004	2047	1126	1093	1302	2193	239	164	17	32	23	24
4	1858	2104	1059	1083	1300	2035	300	155	17	31	24	22
5	1978	1966	1105	1105	1357	2190	248	178	18	33	22	22
6	1915	1992	1078	1077	1436	2075	260	170	15	32	25	23
7	1945	1960	1096	1077	1313	2200	310	165	17	34	22	24
8	2015	2068	1115	1092	1266	2202	263	170	16	32	23	24
9	2025	2010	1072	1081	1381	2254	252	167	17	34	24	23
10	1869	2014	1070	1090	1351	2110	237	162	17	31	24	24
11	1885	1967	1105	1097	1361	1989	261	165	17	30	25	24
12	1987	2069	1083	1078	1385	2176	243	164	18	34	23	22
13	1872	1953	1092	1137	1383	2200	249	177	16	34	22	24
14	1986	2038	1124	1088	1360	1964	255	183	15	34	23	21
15	1873	1974	1055	1084	1270	2211	259	207	16	31	24	23
16	1930	2063	1096	1093	1225	2150	246	163	16	30	26	23
17	1937	2094	1076	1052	1254	2117	230	153	18	32	23	23
18	1965	2084	1086	1049	1529	2248	258	160	16	31	24	21
19	1868	2010	1087	1059	1297	2288	269	179	17	33	23	22
20	1845	1917	1123	1110	1389	2012	253	154	17	34	24	23

Table 6.4 Factorial Design

Factor	Type	Levels	Values
Network Type	Fixed	3	High volume, Medium volume, Low volume
Signal strategy	Fixed	2	Pre-timed, Semi-actuated
Speed strategy	Fixed	2	Fixed, Variable

Analysis was run for all the three control variables and their interactions. The ANOVA tables are shown below by each control variable or MOEs. The results shown include the effects of interaction between selected strategies and individual strategies. Plots for individual and interaction of strategies are also provided to obtain an easier understanding of the results.

6.2.1 Results and Analysis for Average Speed

The analysis of variance, plots of main effects and interaction of strategies for average speed and their interpretation are shown in Table 6.5.

Table 6.5 Analysis of Variance for Average Speed

Source	DoF	Seq SS	Adjusted SS	Adjusted MS	F value	P value
Network Type	2	7210.8	7210.8	3605.4	31311.31	0.000
Signal strategy	1	5138.7	5138.7	5138.7	44626.98	0.000
Speed strategy	1	158.9	158.9	158.9	1380.38	0.000
Network Type*Signal strategy	2	1259.7	1259.7	629.9	5469.97	0.000
Network Type*Speed strategy	2	141.6	141.6	70.8	614.77	0.000
Signal strategy*Speed strategy	1	5.4	5.4	5.4	47.09	0.000
Network Type*Signal strategy*Speed strategy	2	5.0	5.0	2.5	21.66	0.000
Error	228	26.3	26.3	0.1		
Total	239	13946.4				

The results obtained from simulation and factorial design are analyzed and interpreted for average speed below.

1. From the ANOVA table it is apparent that all the main effects and interactions are significant. This is because $\alpha > P$, and we reject the null hypothesis, which is speed strategy is not significant.
2. Semi-actuated signals definitely provide major improvement to the network by increasing average speeds as is seen from the main effects plot for network type.
3. Speed strategy is significant and the main effects plot (Figure 6.1) indicates that fixed speed strategy yields slightly better performance than variable speed. The interaction plot between speed and network shows that speed strategy has almost no impact on complex medium volume and high volume corridors, but reduces the average speed for low volume network by about 12%.
4. In general speeds for high volume networks are lowest, followed by medium volume and then low volume networks, which is consistent with the perception of high, medium, and low volume networks.
5. The interaction (Figure 6.2) between speed and signal strategy shows once again that fixed speed limits with semi-actuated signals yield higher average speeds than variable speed limits.

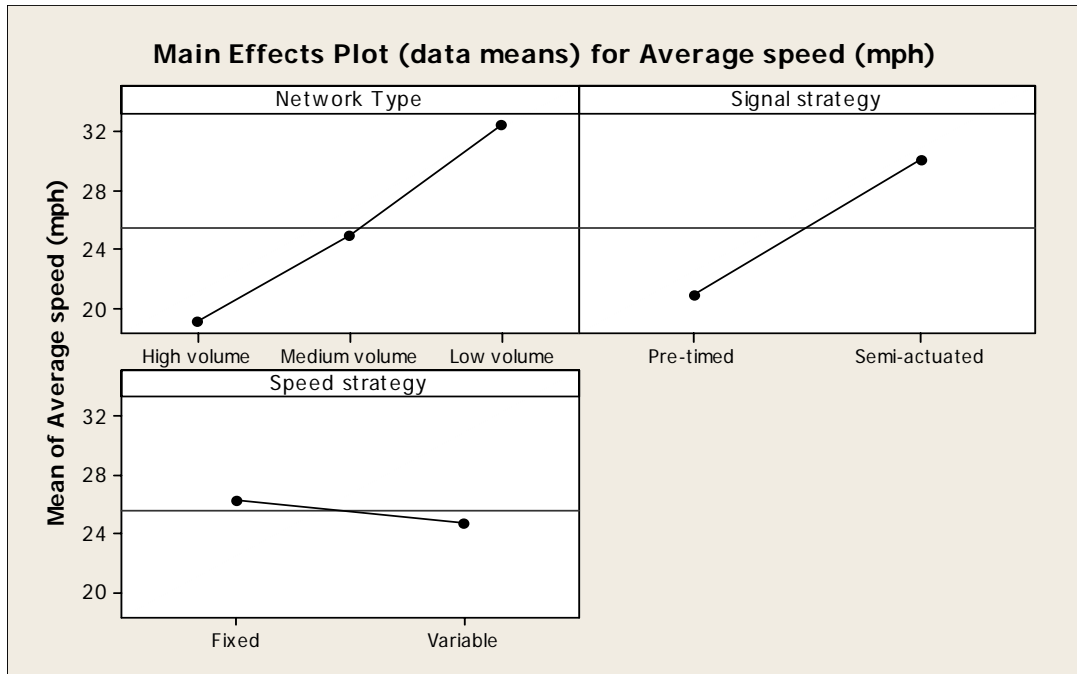


Figure 6.1 Main Effects Plot for Average Speed

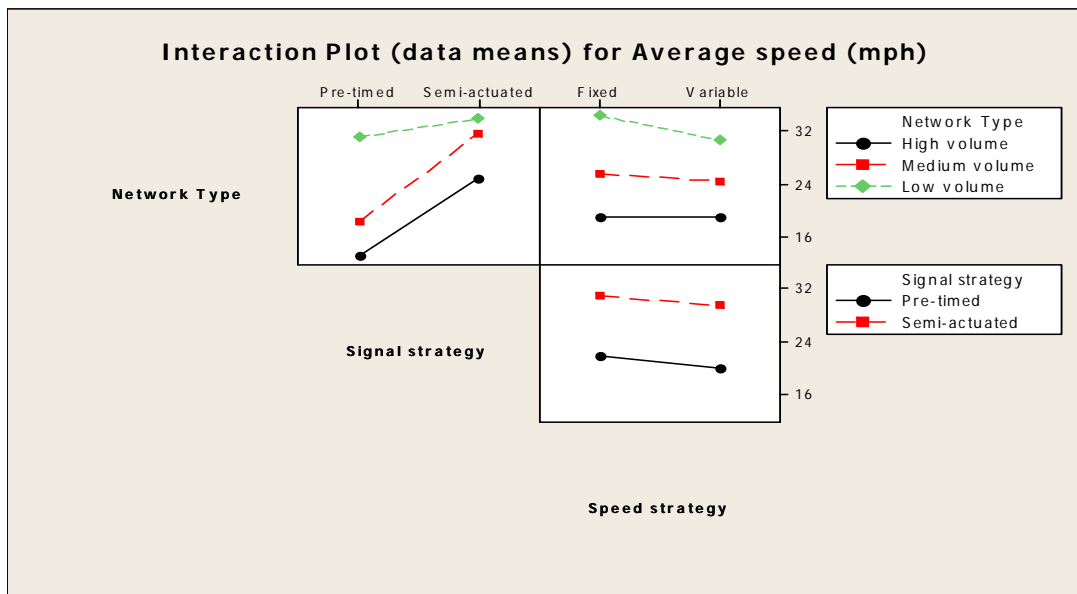


Figure 6.2 Interaction Plot for Average Speed

6.2.2 Results and Analysis for Average Travel time

The analysis of variance, plots of main effects and interaction (Figures 6.3 and 6.4) of strategies and interpretation for average travel time are shown in Table 6.6.

Table 6.6 Analysis of Variance for Average Travel Time

Source	DoF	Seq SS	Adjusted SS	Adjusted MS	F value	p value
Network Type	2	52657.1	52657.1	26328.6	9995.16	0.000
Signal strategy	1	23984.2	23984.2	23984.2	44626.98	0.000
Speed strategy	1	7.5	7.5	7.5	2.86	0.092
Network Type*Signal strategy	2	13601.9	13601.9	6800.9	2581.85	0.000
Network Type*Speed strategy	2	152.8	152.8	76.4	29.01	0.000
Signal strategy*Speed strategy	1	0.3	0.3	0.3	0.12	0.731
Network Type*Signal strategy*Speed strategy	2	133	133	66.5	25.25	0.00
Error	228	600.6	600.6	2.6		
Total	239	91137.5				

The results obtained from simulation and factorial design are analyzed and interpreted for average travel time below.

1. The ANOVA table shows speed strategy and the interaction between speed and signal strategies are not significant. This is because $\alpha < P$ for these strategies, and we cannot reject the null hypothesis, which is speed strategy and speed and signal interaction is not significant.
2. All other strategies are significant by the same logic.
3. Semi-actuated signals reduce travel times by approximately half, making them very desirable, as can be seen from the main effects plot for signal strategy. The interaction plot between network type and signal strategy shows that for pre-timed signals, travel times for high volume and medium volume networks are almost equal, while with semi-actuated signals travel times reduce by almost 300% for medium volume networks.
4. The changes in travel time for network type are more likely due to inherent differences in volumes as seen in the main effects plot. We can say this

because while travel times between high volume and low volume networks differ by as much as 500%, high volume network travel times being higher.

5. From the interaction charts variable speed limit shows lower travel times for the low volume network, almost no change for the high volume network and higher travel times for the medium volume network. So depending on the network type, speed strategy results are mixed without a large variation in travel times.
6. The interaction between network type and signal strategy shows significant advantage for using semi-actuated signals for medium and high volume networks.

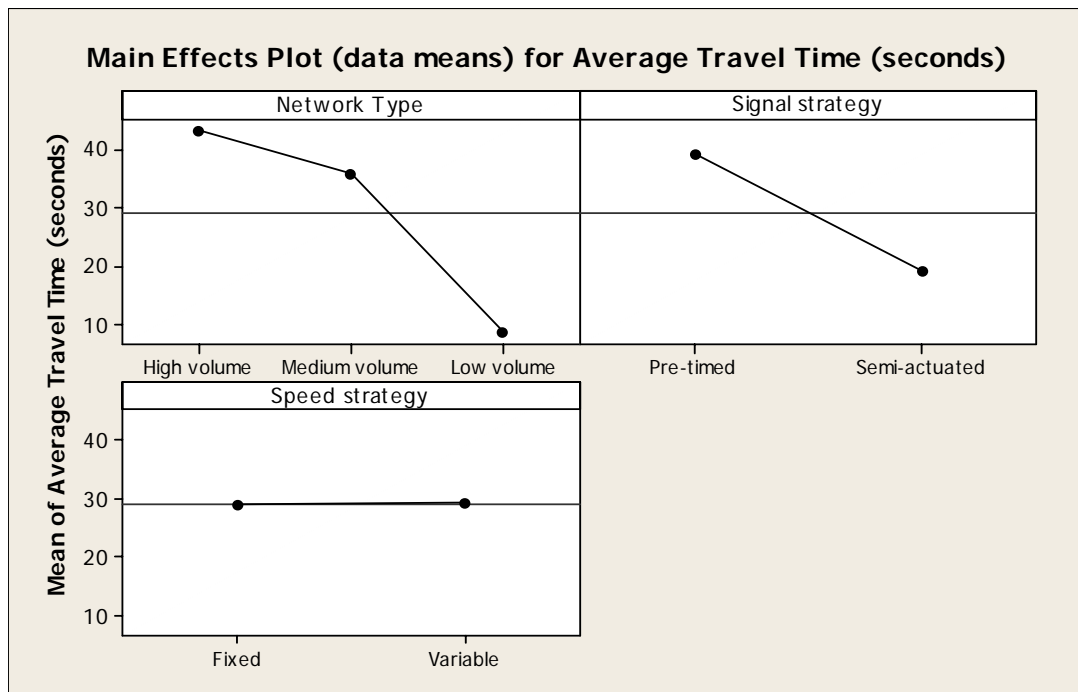


Figure 6.3 Main Effects Plot for Average Travel Time

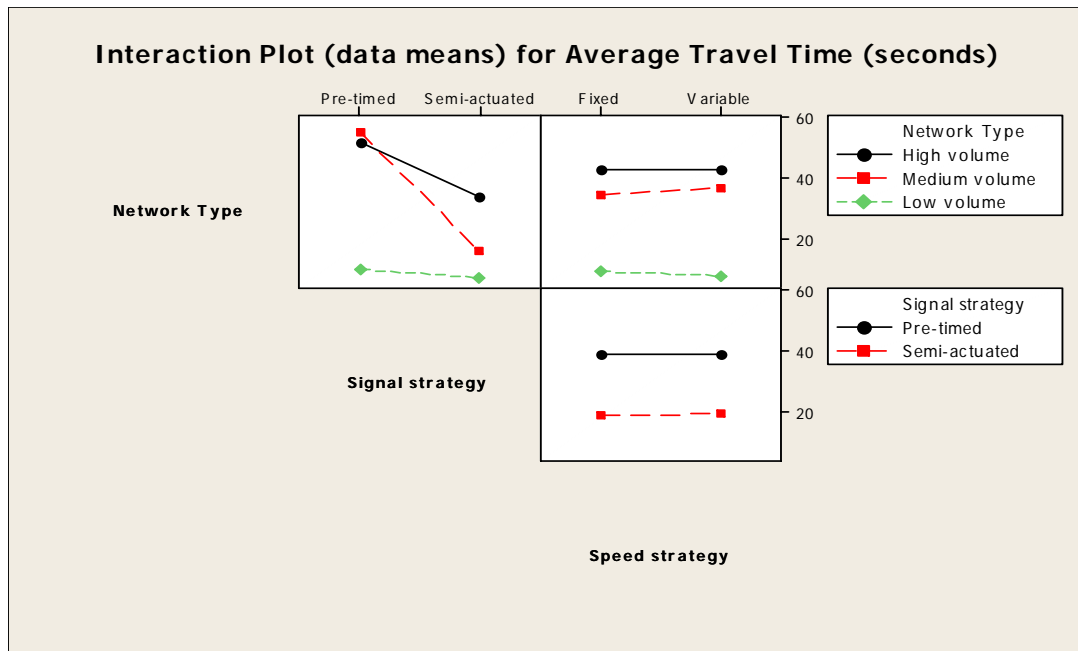


Figure 6.4 Interaction Plot for Average Travel Time

6.2.3 Results and Analysis for Total Delay

The analysis of variance and plots of main effects and interaction of strategies for total delay are shown in Table 6.7. The results obtained from simulation and factorial design are analyzed and interpreted for total delay below.

1. The ANOVA table shows that all strategies are significant (Figure 6.5). This is because $\alpha > P$, and we reject the null hypothesis, which is the strategy is not significant.
2. The main effects plots show a reduced delay with semi-actuated signals, and an increased delay with variable speed limits. The main effects plot for network type shows that total delay is proportionate to volume, which is consistent with perception.
3. Interaction plots (Figure 6.6) between signal and network type shows that medium volume networks show considerable delay reduction with semi-actuated signals and variable speed limits as compared to fixed speed. This is the only case where variable speed limits have proven significantly better, although for the same signal strategy and network. The improvement in delay is by a

reduction of almost 30%. As this result conflicts with findings in the previous result, we can conclude that this reduction is more due to signal strategy.

Table 6.7: Analysis of Variance for Total Delay

Source	DoF	Seq SS	Adjusted SS	Adjusted MS	F value	p value
Network Type	2	93141139	93141139	46570570	23432.39	0.000
Signal strategy	1	38884724	38884724	38884724	19565.19	0.000
Speed strategy	1	1072154	1072154	1072154	539.46	0.000
Network Type*Signal strategy	2	23517173	23517173	11758586	5916.44	0.00
Network Type*Speed strategy	2	1448208	1448208	724104	364.34	0.000
Signal strategy*Speed strategy	1	1629866	1629866	1629866	820.08	0.000
Network Type*Signal strategy* Speed strategy	2	2267779	2267779	11338890	570.53	0.00
Error	228	453137	453137	1987		
Total	239	162414181				

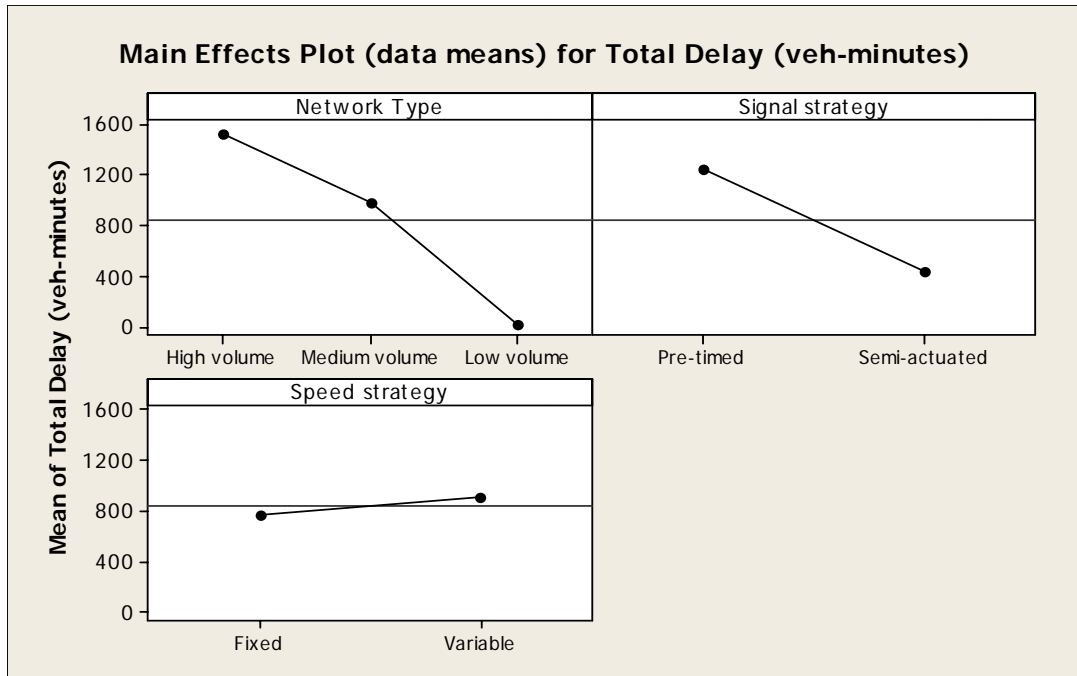


Figure 6.5 Main Effects Plot for Total Delay

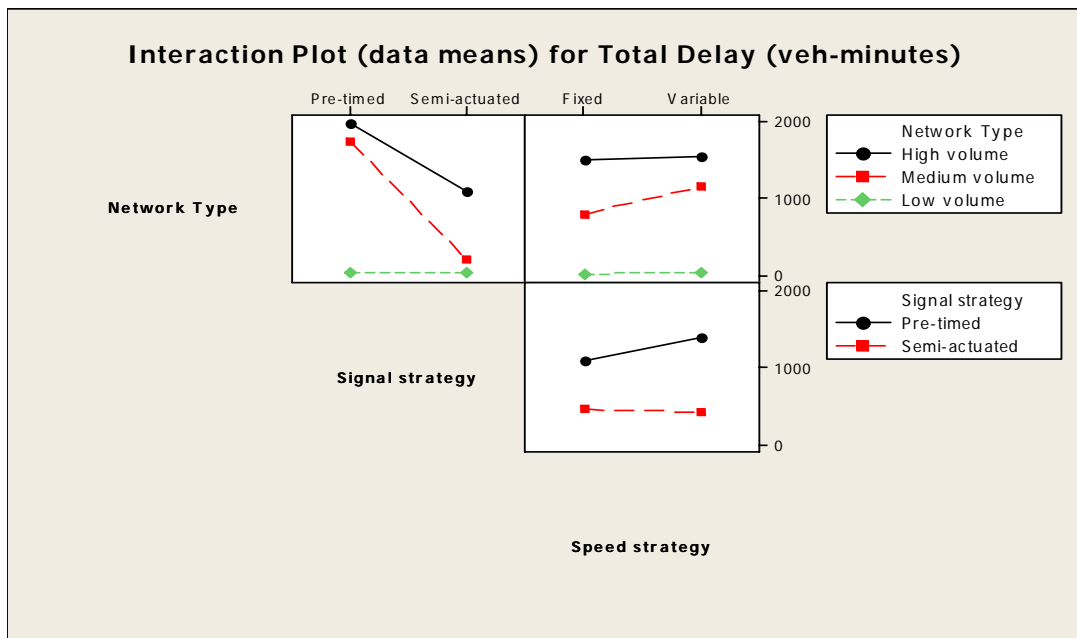


Figure 6.6 Interaction Plot for Total Delay

7. SUMMARY AND CONCLUSIONS

We summarize the research undertaken in this thesis and report the major findings as well the further avenues for research in the incident management field in this chapter.

7.1 Research Summary

The lack of attention to the impact of incidents while planning improvements or construction of roads in urban areas was identified as the research problem in this work. After a detailed study of possible methods to incorporate the impact of incidents it was found that microsimulation studies worked best. Microsimulation is non-intrusive and relatively accurate as compared to pure analytical modeling. This is mainly because with microsimulation, many elements of the traffic environment like car following logic, driver behavior, incident scenarios and varying network geometry can be re-created simultaneously. In order to decide the right Measures of Effectiveness (MOEs), previous incident management research was reviewed along with guidelines provided by the Highway Capacity Manual. Driver behavior and network assumptions were made to reflect real life traffic environment. This research provides a method to incorporate effects of incidents on surface street networks based on MOEs like average speed, travel time and total delay. Strategies were tested on each corridor to find out the best combination. The strategies tested were signal type and speed for three inherently different real networks subjected to incident scenarios. Another interesting aspect of this research was testing effectiveness of variable speed limits on surface streets. An experiment was designed for analyzing the results from the different simulation runs.

7.2 Conclusions

The goal of this research as stated earlier was to suggest effective strategies for enhancing network performance on surface streets during incident scenarios, keeping in

mind emerging technologies that ITS brings into traffic engineering. In order to meet the research objective, the effectiveness of variable speed limits on surface streets with signalized intersections under incident scenarios was tested. It should be mentioned that the variable speed limits have been successfully tested but not implemented widely in many freeway research studies. Based on the simulation model that was developed and run for three different corridors (varying in volume of traffic), the following conclusions can be made.

- Semi-actuated signals yield significantly better performance from a corridor under incident scenarios as compared to traditional pre-timed signals. The biggest impact was on medium volume corridor, followed by the high volume corridor. This is of particular interest to practitioners because most downtown traffic signals in medium and small size cities operate on pre-timed signals. This is because pre-timed signals are more effective when operated without incidents. With enhanced communication networks and ITS technologies, signal schemes can be changed through the TMCs remotely from pre-timed to semi-actuated operation as required during incidents. This explains why the best results from semi-actuated signals were seen in the complex medium-volume network that is similar to downtown traffic. Furthermore, although semi-actuated signals are more costly, the benefit obtained from them easily justifies the cost given that the cost of managing congestion is also very high. Incident management costs are explained in the introduction to this research.
- It can be concluded from the results that variable speed limits provide no advantage on surface streets. The effects of this speed strategy were minimally significant, if not detrimental to the corridors studied. Implementing variable speed limits is very expensive, as it requires dynamic message signs between intersections to regulate speed. A similar study for surface streets using variable speed limits was not found in literature before this research, therefore these findings help to narrow the scope for similar research.
- The benefits from the strategies adopted were not very significant for low volume networks, leading to the conclusion that it is not economically viable

to convert existing low volume corridor pre-timed signals into semi-actuated signals.

7.3 Scope for Further Research

Research conducted for incidence management on surface streets is still limited to reactive solutions. While planning for surface streets, only projected demands are considered. Instead, if incidence management were to be a part of surface street planning, it would prevent very high costs of congestion management as established earlier in this research. This research can also be carried forward in the following ways:

- Using a combination of signalization strategies along with route diversion. In this research, we use pre-timed and semi-actuated signals. Testing the similar scenarios with fully actuated signals or adaptive control signals can carry the research forward.
- This research assumes that the drivers are unaware of the incident until they arrive at the scene. In ITS scenario, using advanced communication networks, detailed traffic advisories can be transmitted to drivers making them aware of the incident as they approach the incident site. This research can be taken forward if the effect of information available in advance was observed to study route choice patterns.
- Developing viable strategies using ITS technologies to get real-time volumes and using route diversion strategies instead of signalization or speed strategies as used in this research.
- This research does not consider response units, their response times and incident information available to them. Under ITS environment, communication systems are enhanced making information flow fast. It would be interesting to study the effect of incident clearance times provided route and incident information is available to all critical stakeholders of incident management.
- Measuring network performance using alternate control variables that reflect ride quality. In this research we stick to MOEs recommended by the Highway Capacity Manual. Alternately, innovative MOEs that measure quality of ride, or driver satisfaction can be used for a similar study to understand the driver perspective and experience better.

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