OPTIMIZING INCIDENT MANAGEMENT STRATEGIES USING SIMULATION

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The Supervisory Committee certifies that this ***disquisition*** complies with North Dakota State University's regulations and meets the accepted standards for the degree of

MASTER OF SCIENCE

ABSTRACT

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Incidents, pre-programmed or random, are major sources of congestion on urban freeways. With many of urban freeways in the US operating close to capacity, the need to reduce the impact of incident-related congestion has become critical. Incident Management Strategies (IMS), when properly developed and deployed, have the potential to reduce such congestion on urban freeways.

The purpose of this paper is to develop an analytic framework for the calibration and application of a -simulation model for testing the impact of alternate IMS on an urban transportation network. Initially a framework is presented in a conceptual form, and demonstrates the calibration and application of the model on a real life network in the Detroit metropolitan region. While the initial results are positive, full-scale validation and testing with larger networks are recommended to justify the use of -simulation techniques for assessing the impact of different IMS.

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1. INTRODUCTION

Incidents continue to be major sources of congestion on urban freeways and arterials. Law enforcement and transportation agencies, along with emergency service providers in the United States are working together to develop viable incident management strategies (IMS) to alleviate freeway congestion problems. A traffic incident is defined as "any occurrence on a roadway that impedes normal traffic flow" [*1*]. Typically, these are non-recurring events that cause temporary reduction in roadway capacity. Similar definitions are also provided in other sources [*2-3*]. Incidents can be pre-programmed, such as pre-announced work zone activities, or random, such as traffic crashes disabled vehicles, spilled cargo, etc. Figure 1 show that events as defined above, contribute significantly to traffic congestion on US highways.

With many of the US roadways operating close to capacity under the best of conditions, the need to reduce the impact of incident-related congestion has become critical. One way to achieve this is to improve the management of traffic after an incident has occurred, including the use of traffic diversion strategies. Thus, key components of successful IMS are early detection, efficient recovery, and effective diversion of traffic to the surrounding links in the network, using variable message signs (VMS), and emerging technologies such as vehicle-vehicle communication, vehicle infrastructure integration (VII), etc. A crucial component of any IMS is the recovery stage, particularly the utilization of traffic diversion strategies. Prolonged recovery stages are associated with increased delay and longer queues.

1.1. Problem Statement

With the current emphasis on IMS, standardized techniques are not available to assess the impact of these strategies. The problem addressed in this paper deals with the question of dynamically finding alternate paths in a given network for travel between zone pairs, when a section of the network is temporarily incapacitated because of incidents, either pre-programmed or random. Instant knowledge of such alternate paths with surplus capacities may enable Traffic Management Centers (TMC) to efficiently divert traffic from the affected portion of the network, thereby helping alleviate congestion. In this paper, an analytical framework is presented that can be used for:

1. The calibration of a simulation model on a portion of a transportation network of a major metropolitan region.
2. The application of the (calibrated) model on the network to assess the impact of incidents on a section of a given freeway, and the effect of the deployment of different IMS on the same network.

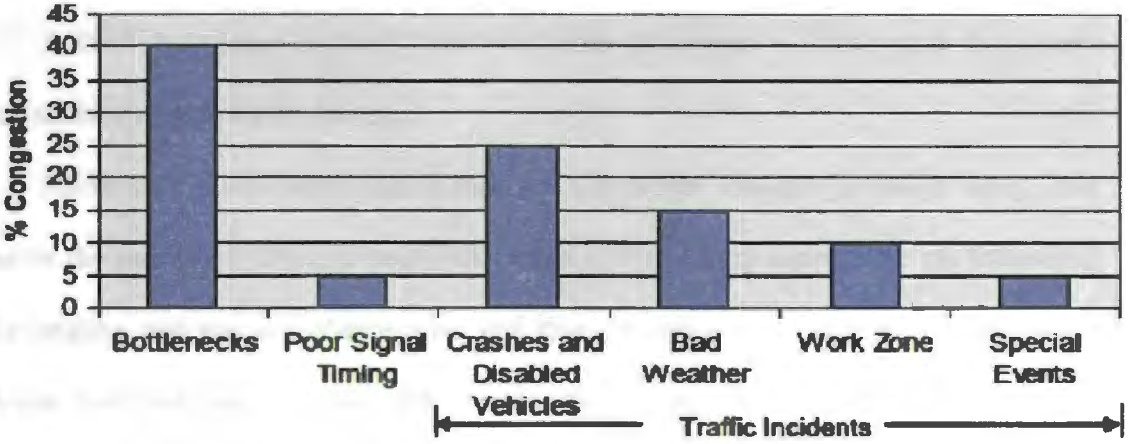

Figure 1. The sources of congestion

1.2. Simulation as a Tool

Simulation techniques have been used over the last fifty years to describe traffic flow over a transportation network. It is a process used to replicate a real-life phenomenon, such as traffic flow, through a set of models or mathematical formulations. Those are interlinked to describe the behavior of all the entities involved (the driver, the vehicle, the roadway, and the traffic control devices in the case of traffic flow) along with their interactions. The primary advantage of simulation is that it enables the analyst to assess the impact of various operational strategies on the performance of the system without physical experiments that typically require significant resources, and cause severe traffic disruptions.

The study of the network can be done by different types of simulation models. The three main models that are used these days are:

1. Micro-simulation Models.
2. Macro-simulation Models.
3. Meso-simulation Models.

A brief description of these three models is given below. However in this paper, Micro-simulation techniques are used.

Micro-simulation models have received significant research attention lately, that focus on the movement of each individual vehicle by applying appropriate car-following, lane changing, and gap acceptance rules, and thus provide a more accurate representation of driver behavior and network performance. Micro-simulation models are being used increasingly to study new systems, and to determine system requirements to optimize network performance.

Macro-simulation models, by contrast, are used to study "group behavior" i.e. traffic flow for a group of vehicles that are essentially expected to obey the same set of rules. Macro-models have also received extensive application in traffic studies.

A third category, Meso-simulation models are also receiving increased attention for studying dynamic traffic behavior. Meso-models attempt to combine the best features of micro and macro models, by retaining some of the individual vehicular characteristics and yet using some of the aggregate flow-density-speed relationships.

Many simulation software packages have been used over the years for dynamic traffic assignment, a complete discussion of which is beyond the scope of this paper. Examples include: CONTRAM [*5*], INTEGRATION [*6*] and DYNASMART [*7*], DYNAMIT/MITSIM [*8-9*], AIMSUN [*10*], CORSIM [*11*], PARAMICS [*12*], VISSIM [*13*]. Each model has its own special characteristics, and was developed with a specific focus.

CONTRAM, INTEGRATION and DYNASMART are 'macro-particle' traffic simulation models where individual vehicles are tracked as they move through the network, but their velocities are determined by macroscopic speed/flow/density relationships. By contrast, DYNAMIT/MITSIM, CORSIM, PARAMICS, and VISSIM are simulation models, where each vehicle is modeled as an individual entity through the entire simulation process. AIMSUN is unique in it that all the three features, (i.e. macro, micro and meso) are embedded in the model. Some models also allow representation of alternative route choice behaviors, including allowances for dynamic response to real-time information. Examples of simulation-based research under congested conditions include Breheret et al. [*14*], Ha et al. [*15*], Hounsell et al. [*16*], Smith and Ghali [*17*] and Smith and Russam [*18*]

2. LITERATURE REVIEW

As a part of the project that served the basis of the paper, a thorough review of the pertinent literature was conducted in four specific areas:

1. IMS and alternate route diversion on freeways and arterials.
2. Various types of path and route choice models applied in IMS,
3. Measures of effectiveness (MOE's) used to evaluate IMS.
4. Application of simulation models to analyze IMS.

Koutsopoulos et al. proposed a stochastic traffic assignment approach for assessing the effectiveness of motorist information systems in reducing recurrent traffic congestion [*19*]. The model was used for examining interactions among important parameters of the problem such as level and amount of information provided, users' access to information and congestion levels. Abdel-Aty et al. reviewed a number of studies to understand driver behavior, and in particular, behavior when influenced by an Advanced Traveler Information System (ATIS) [*20*]. He concluded that there is a need to understand how drivers choose or change routes in the absence of information in order to gain an understanding of route choice behavior in the presence of information. The study concluded that ATIS is helpful in driver decision making.

Khattak et al. developed a methodology for incident duration prediction, by using a series of truncated regression models [*21*]. The model accounts for the fact that incident information at a Traffic Operations Center is acquired over the life of the incident. Cragg and Demetsky examined the merits and demerits of using simulation model as a decision aid for deploying traffic diversion strategies [*22*]. A methodology for using such a model was demonstrated to determine the effects of various incident types on freeway traffic flow and the diversion of freeway traffic on the arterial network. The study concluded that simulation is an effective tool for IMS.

Madanat and Feroze predicted incident clearance time for Borman Expressway, Indiana [*23*]. A parametric least-generalized cost path algorithm is presented to determine a complete set of extreme efficient time-dependent paths that simultaneously consider travel time and cost criteria. FHWA developed a framework for evaluating a multiagency traffic incident management program involving many agencies [*24*].

Balke et al. conducted a survey of traffic, law enforcement, and emergency service personnel to identify incident management performance measures in Texas [*25*]. The basic objective of the survey was to collect driver behavior information and preferred route selection during incidents on road networks. Hidas investigated the effectiveness of variable message signs (VMSs) for incident management [*26*]. A survey was conducted in the Sydney Metropolitan Region to collect information on driver response to a range of VMS messages. He proposed a route-choice model to predict diversion rates resulting from various VMS.

FHWA developed an alternate route information guide during various types of incidents [*27*]. Five aspects are broadly discussed in the study (a) alternate route planning (b) alternate route selection (c) alternate route plan development (d) traffic management planning, and (e) implementation. FHWA also developed an Incident Command System (ICS), a tool for systematic command, control, and coordination for emergency response [*28*]. ICS allows agencies to work together using a common terminology and a standardized operating procedure for controlling personnel, facilities, equipment, and communications at an incident scene.

Bellman 1960 [*43*], Dreyfus 1969 [*39*], Fox 1973 [*43*], Eppstein 1994 [40], 1999 [*41*] gave a considerable attention to the problem of enumerating, in order of increasing length, the k shortest paths. The different algorithms to solve this problem Eppstein 1994, Eppstein 1999, Jimenez et al. 1999 [*46*], Martins 1984 [*44*], Martins et al. 1996 [*45*], are based in, after computing the shortest path from every node in the graph, the algorithm builds a graph representing all possible deviations from the shortest path.

Wirtz et al. tested a dynamic traffic assignment model for managing major freeway incidents [*29*]. Incidents of various scales and durations were modeled for a highway network in the northern Chicago area, and the impact of incidents and response actions were measured. It was found that the best response action to a given incident scenario was not necessarily intuitive and that implementing the wrong response could often worsen congestion.

The detailed literature review conducted as part of the projectclearly indicated that:

1. Traffic incidents are major causes of delays on US highways. IMS, if properly deployed, may have a significant impact on reducing traffic delay.
2. Micro-simulation models are being increasingly used to analyze procedures to alleviate congestion problems
3. Various MOE's have been used to evaluate different operational strategies, including: travel time, delay, queue length, and volume to capacity ratio.
4. Information, when properly communicated to motorists relative to time, space and sequence can be utilized effectively by motorists to find alternate paths in the network.

3. METHODOLOGY

The purpose of this paper is to present a framework for using -simulation techniques in assessing the effect of IMS. The calibration and application of the framework is also presented on an actual transportation network, comprising freeways and arterials in the northern part of the Detroit metropolitan area, USA. The Michigan Department of Transportation (MDOT) [*47*], in collaboration with US Department of Transportation (USDOT) [*48*] has established a Traffic Management Center (TMC) in Detroit, designed to monitor the performance of the regional freeway network, instrumented with state-of-the-art ITS equipment including sensors, detectors, cameras, and close-circuit televisions. Much of the data used in the calibration and application of the model was extracted from archived records of the MDOT/TMC commonly referred to as the Michigan Intelligent Transportation Systems Center (MITSC) [*49*].

3.1. Framework

The proposed framework is presented in Figure 2. The five-step methodology encompassing policy and operational strategies associated with IMS can be summarized as follows:

1. Network creation and assembling different databases.
2. Identification of policies and development of an algorithm that comprises the IMS.
3. Calibration of simulation model.
4. Conducting simulation-based experiments by creating incidents on the network.
5. Analysis of results.

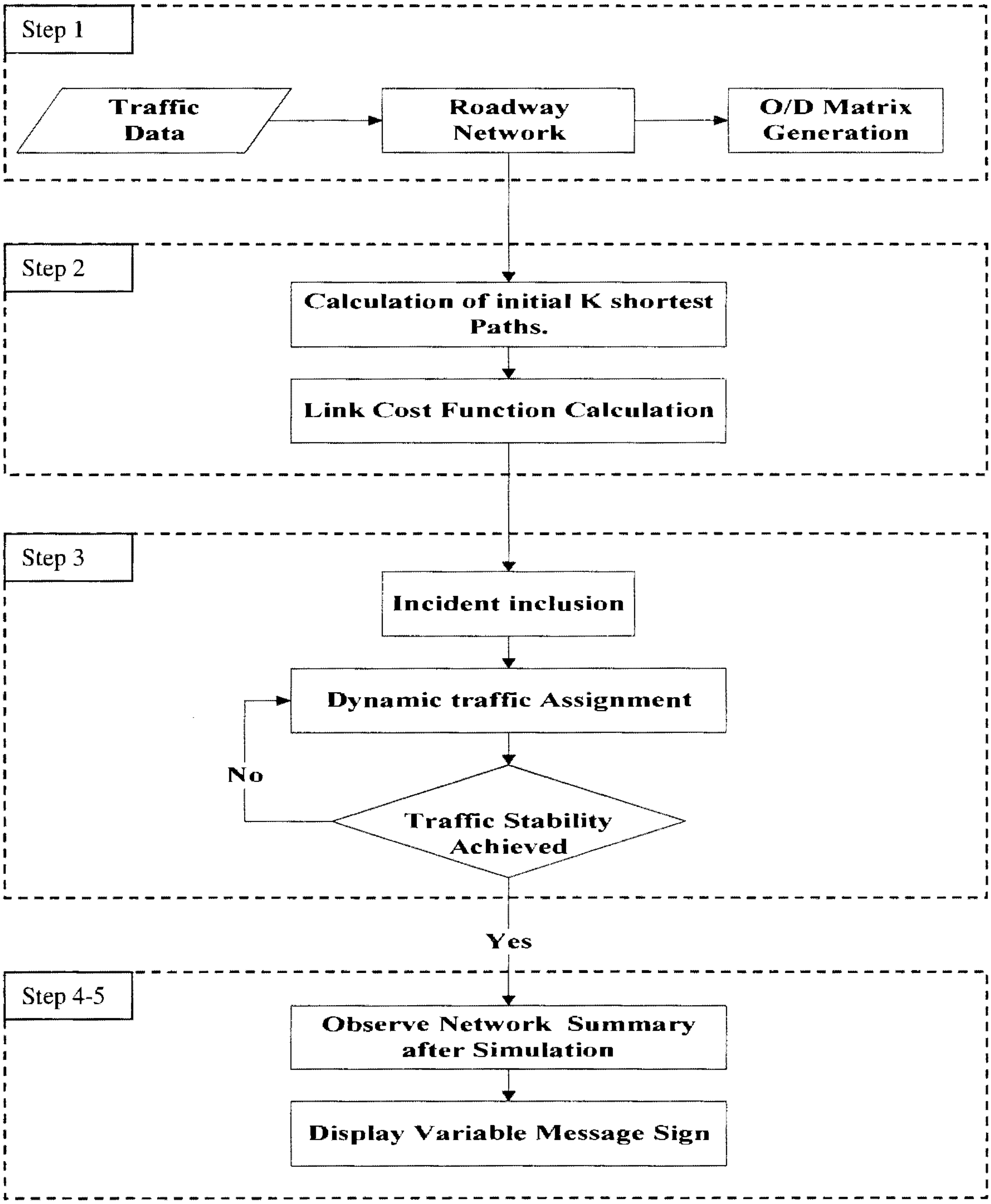

Figure 2. Framework for testing Incident Management Strategies

3.2. Use Case Diagram

The use case diagram is presented in Figure 3.

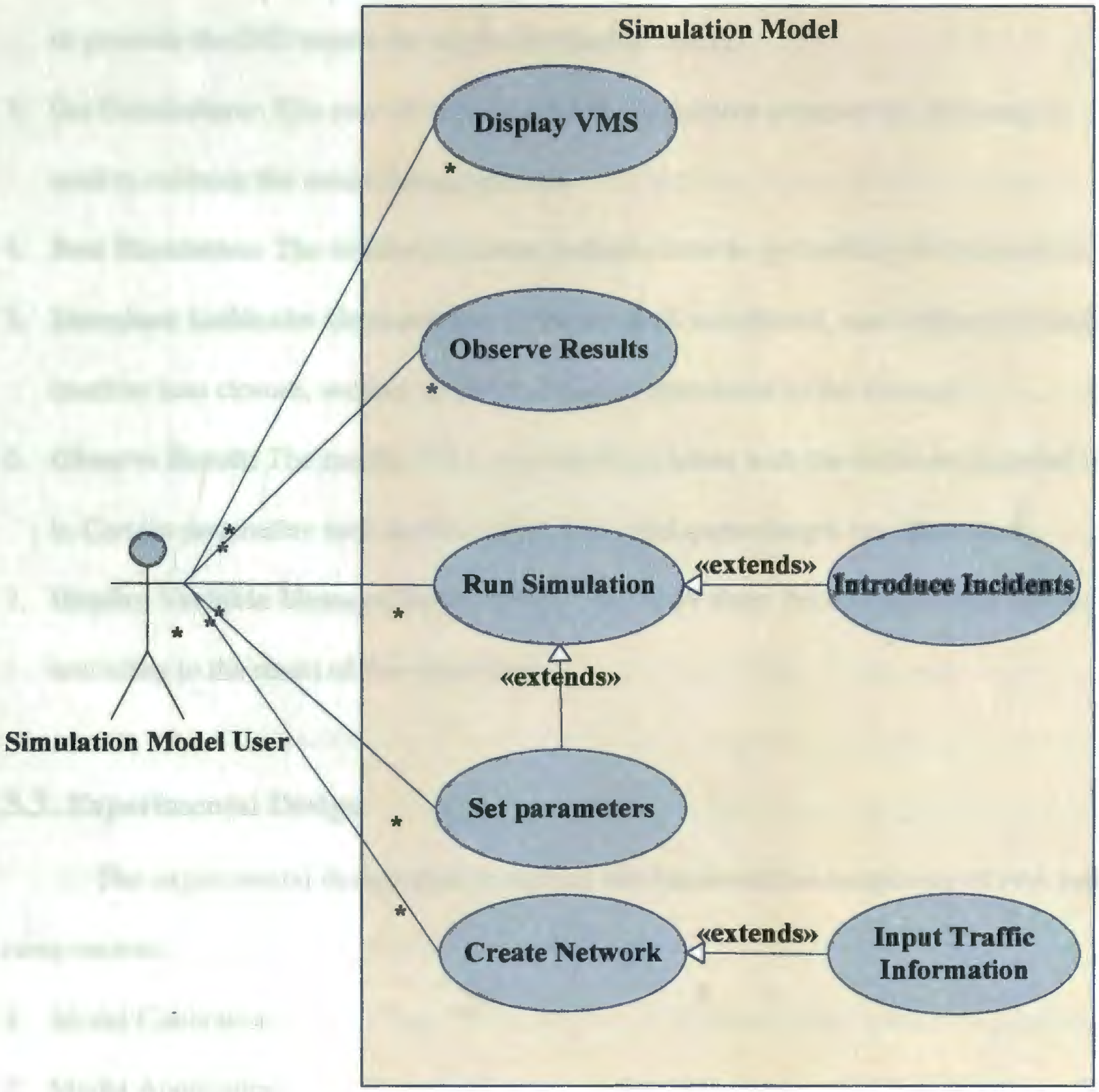

Figure 3. Use case diagram for traffic simulation model

1. **Create Network:** The user creates the network with different types of roads, intersections, turns and lanes. These components are represented as links and nodes in the network.
2. **Input Traffic:** The traffic information for the links included in the network is supplied to generate the O/D matrix (or origin-destination matrix).
3. **Set Parameters:** The user chooses to alter the simulation parameters. This step is used to calibrate the model for acceptance.
4. **Run Simulation:** The simulation is run multiple times to get stability in the network.
5. **Introduce Incidents:** Once stability in the network is achieved, user-defined incidents (such as lane closure, section incidents, etc.) are introduced to the network.
6. **Observe Result:** The results of the simulation are taken with the incidents included in it. Certain parameters such as travel time delay and queue length are calculated.
7. **Display Variable Message Signs (VMS):** The VMS show the corresponding messages according to the result of the simulation.

3.3. Experimental Design

The experimental design used in testing the framework encompasses of two major components:

1. Model Calibration
2. Model Application

3.3.1. Model Calibration

The purpose of model calibration is to ensure that the model output is a reasonable replication of traffic-flow characteristics observed in the field. The parameters that explain the field data are then used in testing the effectiveness of different strategies. In this case, the experimental design consists of several steps:

1. **Selecting an appropriate real life network:** The best results can be achieved if we can gather a real time data so for this paper some real statistics were used. The delay time in natural or no incident condition was collected manually. Also some of the archived data, such as the number of vehicles per hour on a particular link is also readily available. All this information is required to calculate some parameters which are further used for measuring "Goodness-of-fit" statistics as well as Dynamic Traffic Assignment. These terms are described later in the paper.
2. **Developing network characteristics for computer simulation:** This section contains the various characteristics that will be used in the network for the study. Some of the things included in this section are route description, traffic flow information, calculation of K shortest paths, and calculation of dynamic cost functions, etc.
3. **Collecting information about current traffic, including traffic volume, turning counts, signal operation, etc:** Again this section includes the manual collection of information. To obtain this information data was collected for 3 hours on a section of network. This information was used to calculate the simulated traffic information, with a little change in the parameters.
4. **Using the traffic volume data as an input to the simulation model to generate a synthetic trip table (O/D matrix), appropriate for the network developed in step 2:** In this section, an O/D matrix was generated which had the information that was collected manually using *dynamic cost function.* This new matrix is further used for testing the network.

5. **Assigning the trip table to the network:** Once the O/D matrix is created with the help of the collected data, it is applied to the created network for testing the system. Because the O/D matrix was applied to a real life network, the result obtained was supposed to be elemental in creating a real time application in future for traffic management.
6. **Comparing the assigned volume with independently collected volume data for goodness-of-fit statistics:** Once we had the simulated traffic information, the second set of data was collected for the same network so that the actual and the simulated traffic data could be compared.
7. **Reiterating steps 4, 5, and 6:** Change model parameters until a desired goodness-of-fit is achieved.
8. **Designating a set of parameters:** These parameters provide the desired goodness-of-fit as a part of the calibrated model.

While the procedure described above has been used in a number of studies in the past, a special characteristic of this study is the utilization of archived data collected from sensors in the freeway network available through MDOT/MITSC [*47*].

3.3.2. Model Application

The model thus calibrated, along with the appropriate parameters, was used to test the effectiveness of alternate IMS on the same network. The various IMS tested are: lane closure, incidents and forced turning.

1. Lane closure is basically when any lane in a section is closed due to construction or some other reason. It can lead to partial or full closure of the section depending on the number of lanes that are closed.

2. Section incident corresponds to full blockage of a road section due to an accident or some other damage. In this type of closure, vehicles are completely rerouted to an alternative route until the incident has cleared.
3. Forced turning is a special case of section incident when only a part of the vehicle flow is forcefully turned to a new route.

All the above incidents lead to the congestion in the network and, hence, create a delay in the normal vehicle travel time.

4. SHORTEST PATH AND LINK COST FUNCTION

When we compute the shortest path in the network using link node representation, we assign a cost to each link available in the network. In this study, we are calculating two different types of cost functions which will be used in calculating the shortest path. The shortest path calculation depends on whether we have simulated data available. Depending on the above condition, the two different types of cost functions are, *initial cost function* and *dynamic cost function*. In both cases, we assume a default cost function, which is used to represent the link travel time in seconds. (This function includes the summation for link travel time and turning movement travel time, if it exists).

A brief description of the different cost functions that are used in our study is given below:

1. **Initial Cost Function:** is used in the starting phase of the network calibration. Basically, this function is used because we do not have any prior information about the traffic flow. In this scenario, the cost of each link in the network is calculated as a function of the travel time in free flow, or no incident condition, and the capacity of the link. Generally, there are two types of cost function which are used to calculate the initial cost. The first function does not specify the type of vehicle, so there is a uniform cost for all vehicles. The second function considers different types of vehicles which imply that there is a distinct cost for each type of vehicle. For this study, we are considering the first function. However, there are some simulation tools that also use the vehicle-type function.
2. **Dynamic Cost Function:** is the most important cost function in our study. It is adaptive in nature. It is applied when we already have simulated data and the travel

time for those data is available, that is, when the simulated data have already been collected for the previous iterations (by using the initial cost function). The default current cost for each section is calculated as the mean of the travel time for all vehicles that were present in the network in the previous run when the data were collected similar to the initial cost function. There are two types of default cost function. The first function takes all vehicle types as a single entity so the dynamic cost function is same for all vehicles. The other function takes different types of vehicles into account, which implies that there are different cost functions associated with each vehicle type. Again, we are using the first cost function which assumes all the vehicles are one type.

3. **User Defined Cost Functions:** There are several different types of attributes required to calculate the cost function of a link. These attributes are probability of a link to be chosen, road capacity, capacity/volume ratio(C/V ratio) and many other numerical attributes such as length of the link, number of vehicles per hour on that link, maximum capacity, etc. The cost functions explained above simply calculate the travel time for each link; they do not take other attributes into account. We can customize the user-defined function in any way we want; basically, we can use the available attributes and perform certain mathematical functions (summation, subtraction, log, exponential, etc.)-to compute the cost function. We can use fixed values or the values that are variable and dependent on the simulation.

The dynamic assignment of the traffic is explained below:

1. Compute the first iteration of the shortest path for each O-D pair with the help of the user-defined initial cost function.

    1.1. Initialize:

1.1.1. Compute the cost function for each link available in the network (say j) for each $j \in 1 \ldots L : Cost_j = InCo_j$

1.2. Use the shortest path iteration:

1.2.1. For all the nodes in the network (say d) compute and trace the tree SPT_d with $Cost_j j \in 1 \ldots L$

1.3. Figure out the shortest path in the tree:

1.3.1. For all the pairs in the network (say i) add path(s) SP_{con} to K_i

2. Now, synchronize the interval, and apply it to the available shortest path for each O-D pair for that particular interval. This process will generate the number of vehicles in each O-D pair for that interval and, will select the shortest path K_i for that time interval.

3. This time, we need to calculate the shortest path, but we use the values of travel time that are calculated from previous iterations.

3.1. Refresh the dynamic-link cost functions:

3.1.1. Compute the dynamic cost function for each link available in the network (Say j): for each $j \in 1 \ldots L : Cost_j = DynamicCost_j$

3.2. Step 3.2: Use the shortest path iteration:

3.3. For all the nodes in the network (Say d): Compute and trace tree SPT_d with $Cost_j$ $j \in 1 \ldots L$

3.4. Figure out the shortest path in the tree:

For all the pairs in the network (Say i): Add Path(s) SP_{con} to K_i

4. If the vehicles in the network are guided-or if they can get the route information for the VMS for alternate routes, the information calculated in step 3 should be used to dynamically allow the vehicles to go to the suggested route.
5. Stop when all the traffic and route information has been assigned.

5. PROCESS FLOW

There are four steps in this process; the steps are stated below. A detailed description of these processes is given later on in the paper.

1. First of all, a set of traffic data is assigned to the network that is created. The information about the network and data is given in Table 1. This information is used to make an O/D matrix which has route information about all possible routes in the network. This O/D Matrix is instrumental for further calculations.
2. In this step, the initial K shortest paths are calculated, along with the link cost function. The link cost function is used to dynamically assign the traffic. A detailed discussion about how dynamic traffic assignment is done is given in Appendix A.
3. In this step the actual calculation takes place, which includes dynamic traffic assignment and the results.
4. In this step the results are observed and based on those results, the traffic is routed to the best available alternate route with the help of variable message signs.

6. TESTING THE FRAMEWORK

A basic simulator model has been used to test the methodology that is proposed in this paper. Although it is a basic simulation model, some key attributes are calculated, such as the various types of incidents in a network. The input for this simulation is a set of scenarios (network description, traffic control plan, and traffic demand data) and parameters (simulation time, statistical intervals, reaction time, etc.) which define the experiment [*10*]. The input data have been collected manually by physically noting the number of vehicles and timings of the intersection lights, and the general behavior of the traffic. There are some attributes that are collected from the MDOT website such as the maximum number of vehicles on a link, the length of a section, and some of the incidents that are supposed to be happening in reality (i.e. In some places, there were lane closures scheduled for reconstruction of the roads, including one lane, two lanes, and all lanes closed.). The Measures of Effectiveness (MOE) used in assessing the performance of the model are: travel time, delay, and queue length.

6.1. Network Description

The methodology is applied to test a heavily traveled portion of urban network in the Detroit metropolitan area. The network consists of 2 freeways, and 11 arterials (Figure 4). The freeways, Interstate 75 (I-75) and Interstate 696 (I-696) provide major mobility needs for the region in the north-south (N-S) and east-west (E-W) directions, respectively. The arterials serve a combination of mobility and access functions in the region. A summary of the network features - is presented in Table 1.

The object of analysis is to assess the possible impact of incidents on I-75 in the northern part of the region. MDOT is planning to embark upon a major reconstruction program for I-75. Hence, the proposed framework is tested on I-75 as part of the project that serves as the basis of this paper. All the E-W routes with an interchange on I-75 and-, all the N-S facilities connecting to the major E-W arterials are included in the network, so that any traffic diverted from I-75 because of incidents could find alternate routes on E-W and N-S arterials.

The network analyzed consists of 47 nodes and 108 links as shown in Figure 4. There are 3152 sections in the network, where a section is defined as a group of contiguous lanes where vehicles move in the same direction. The partition of the traffic network into sections is usually governed by the physical boundaries of the area and the existence of turning movements. There are 26 centroids representing 26 zones that comprise 676 origin destination (O-D) pairs. VMS can be placed before freeway exits to inform drivers about regulations that are applicable only during certain periods of the day or under certain traffic conditions [*30*]. Freeway ramps, merging points, and exit points are coded according to their lengths and curvatures. Traffic-volume, and signal-timing data were collected from the Southeast Michigan Council of Governments (SEMCOG); Macomb County Road Commission (MCRC); and Traffic.com, a private agency that works closely with MDOT.

The calculation of the simulation model needs some attributes. Table 1 gives some of the attributes of the freeways and arterials that are used in this network-(i.e. name of the highway, highway class, and whether it is a freeway or an arterial.). This attribute is really important because it sets an idenfier in each section of the network about whether we can deploy a VMS. The number of lanes is also a key feature because it is a fundamental attribute in calculating the impact of the incidents in specifying, how many lanes are closed.This situation will be shown in the result section.

Figure 4. Study area network

In the last attribute in table 1, approximate length of each section is used in the network, which will be used in calculating the delay time in the queue and the queue length. There are some more attributes that are not listed in this table but are also instrumental in calculating the final result,such as maximum capacity of traffic on each link (C), and average volume of traffic (V). These two factors, in a ratio are used to calculate a very important feature called the V/C ratio which is always less than 1.We also need to signal timings which are calculated manually by observing a fixed time interval.

Table 1. Network summary

Highway Name	Highway Class	# of Lanes per Direction	Posted Speed Limit (Miles per Hour)	Approximate Length (Miles)
I-75	Freeway	3*	70	18.97
I-696	Freeway	3*	70	14.48
Telegraph	Major Arterial	3	40	15.16
Woodward	Major Arterial	4	40	16.05
Ryan	Major Arterial	2	30	12.38
Van Dyke	Major Arterial	3	40	12.58
M59	Arterial	3	40	15.88
8 Mile	Arterial	4	45	13.57
12 Mile	Arterial	2	40	13.32
14 Mile	Arterial	2	40	13.27
Big Beaver	Arterial	3	40	7.9

Note*: Some sections of freeway (I-75 and I-696) consist of 4 lanes per direction

6.2. Model Calibration

Basic steps included in the calibration of the model are as follows:

1. The collected set of volume data was saved in a database for the creation of the - O/D matrix.

2. With the help of the route information from the archived data, initial shortest paths were calculated and saved in another database table.
3. Each link in the section has a maximum capacity, and I already had the volume of the traffic, so these two parameters were used to -calculate the C/V ratio which is desired to be less than 1.C/V ratio is the key parameter in dynamically assigning the traffic.
4. The cost function of each link was calculated dynamically. Some of the assumptions in this calculation were as follows:-
    4.1. The traffic was supposed to be free-flow, meaning that traffic was supposed to be running in the maximum allowable speed in each section (available in table 1).
    4.2. There was no specification about the vehicle type, so all vehicles were considered to be single-type vehicles.
    4.3. The flow of the traffic was assumed to be uniform in the network (-A detailed explanation of this process is given in Appendix A.).
5. Now, the incidents were introduced, which caused -partial or full closure of the section, further increasing the delay and queue length and changed the dynamic cost of each link.
6. The traffic was assigned to the best available link (the link with the shortest path and lowest cost) from a list of links arranged in order of increasing cost.
7. As soon as the C/V ratio of any assigned link reached 1 or any desired value set by the user (closer to 1) that link is removed from the list of links.
8. The assignment of traffic was used to trigger the VMS sign placed on each highway exit in the network. At any point of time, when a section became unusable, the VMS was triggered to route the traffic to available alternate routes.

The model calibration process was accomplished following the steps described earlier. Key features of calibration are as follows:

1. First, a set of volume data was collected from sensors on I-75 and I-696 on Tuesday, 10th June 2008 for three hours between 7AM and 10AM. Turning movements and traffic signal data collected for the same period were also given as input to the network. This collection of data gave a detailed overview about the average traffic flow in that section of freeway. Plus, it also gave the delay caused by traffic signals. All values recorded at that time were instrumental in calculating the "queue length" in no incident time.
2. These manually collected volume data were used to create an O/D matrix for the exact time period between 7 AM and 10 AM. The O/D matrix is a simple two dimensional matrix used to calculate all possible paths in a network.
3. This trip table, when assigned to the network, produced a set of volume data on the freeway and arterials in 5-minute intervals, for a total of 36 intervals for the 3-hour period.
4. For assessing the goodness-of-fit of the assigned volume data, a second set of traffic volume data on the freeways was collected on Tuesday, 17th June 2008, between 7 AM and 10 AM from archived records.
5. A set of preliminary visual tests was conducted between the assigned volume (model output) and a second set of volume data (observed data) in an iterative manner, and the parameters were adjusted in every iteration until there was a reasonable match between the two sets of data.

6. In Figures 5-8, the best match for two sensor locations on each freeway is represented. Each of the data pairs represents a 5-minute volume, the model output, and the observed data. There are 36 five-minute intervals during the simulation period of three hours, and many data pairs are shown in the Figures (5, 6, 7, and 8). (Note: The four locations can be identified as the circle marked sensors in Figure 4).
7. These figures indicate that, even though there is not a perfect match, a reasonable correspondence was attained between the two sets of data. Similar comparisons were conducted for a number of sensor locations-, but, for brevity, not reported.
8. Table 2 lists a set of tests that were conducted to further validate the model. There are different constants that are generally used to test whether the parameters we want to use in our test are acceptable, depending on the result of these constants. To make sure that results will be acceptable, the values are tested in six different constants called "Goodness-of-fit Measures". There are certain desirable values of these constants, so if the result comes close to those values, our system is acceptable; otherwise, it is not. All the details about these constants are explained in Table 2.We will measure the deviation of the values in real and simulated traffic.
9. Results of this test are presented in Table 3, which shows that, for all the tests conducted, the Goodness-of-fit measures are acceptable, either by error or by degree of correlation.
10. A composite Root Mean Square Error (RMSE) test was also conducted for the Goodness-of- fit between the two sets of volume data in the network for I-75. The simulated volume and actual volume are plotted in Figure 9 showing 612 data points being the result of multiplying 17 locations with 36 five minute counts at each location.

6.3. Goodness-of-fit Measure Calculations

There are several parameters that can be used to test the model for Goodness-of-fit. After referring to various research papers regarding transportation, I saw that some of the most commonly used parameter for testing Goodness-of-fit Measures are RMSE, Poisson Regression Model, correlation coefficient, etc. I have tried to use different parameters to test the measure of my system. All the parameters were eventually testing the same thing; the purpose of using so many different parameters was to test the model in a more rigorous manner so that it could be accepted by all the different parameters. The justification for using these parameters is given below.

1. **Root Mean Square Error (RMSE)**: This technique is a common method to measure the difference between the values that are supposed to come as an output of a model and the actually observed values. RMSE is used for testing the precision of the model. If the value of RMSE is coming close to 0, it means our system is strong. In my study, I had the values of the simulated traffic flow as well as the actual traffic flow, so testing the precision of the model RMSE proved to be a good parameter.
2. **Correlation Coefficient (r)**: Again, a correlation coefficient is a measure of the relationship (linear) between two variables. In my study, the two variable values are actual traffic and simulated traffic. The value closer to 1 determines a strong system.
3. **Theil's Proportion (U)**: Theil's U is also used to get the degree to which one series differs from another. Here, we have two different series for simulated traffic and actual traffic, so Theil's inequality proportion is used to determine the deviation from the normal values. Again, if the value of U is closer to 0, the system is considered strong or, acceptable.

Table 2. Goodness-of-fit measures for calibration.

Goodness-of-fit Measures	Desirable	Formula
Root Mean Square Error (RMSE) %	Close to 0	$\sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(\frac{x_i-y_i}{y_i}\right)^2}$
Correlation Coefficient (r)	Close to 1	$\frac{1}{n-1}\sum_{i=1}^{n}\frac{\left(x_i-\bar{x}\right)\left(y_i-\bar{y}\right)}{\sigma_x\sigma_y}$
Theil's Weight of Large errors (Ui)	Close to 0	$\frac{\sqrt{\frac{1}{n}\sum_{i=1}^{n}(x_i-y_i)^2}}{\sqrt{\frac{1}{n}\sum_{i=1}^{n}y_i^2}+\sqrt{\frac{1}{n}\sum_{i=1}^{n}x_i^2}}$
Theil's Variance Proportion (Us)	Close to 0	$\frac{n\left(\sigma_y-\sigma_x\right)^2}{\sum_{i=1}^{n}(y_i-x_i)^2}$
Thiel's covariance proportion (Uc)	Close to 1	$\frac{2(1-r)n\sigma_y\sigma_x}{\sum_{i=1}^{n}(y_i-x_i)^2}$
Theil's Bias Proportion (Um)	Close to 0	$\frac{n\left(\bar{y}-\bar{x}\right)^2}{\sum_{i=1}^{n}(y_i-x_i)^2}$

Notations used in the goodness-of-fit measures are:

xi : Simulated traffic measurement value at time i

yi : Actual traffic measurement value at time i

x : Mean of simulated traffic measurement values

y : Mean of actual traffic measurement values

σx: Standard deviation of simulated traffic measurement values

σy : Standard deviation of actual traffic measurement values

Table 3. Summary of Goodness-of-fit measures

Location	Root Mean Square Error (RMSE) %	Correlation Coefficient (r)	Theil's Weight of Large errors (Ui)	Theil's Variance Proportion (Us)	Thiel's covariance proportion (Uc)	Theil's Bias Proportion (Um)
I-75 at I-696	0.036	0.988	0.015	0.053	0.928	0.045
I-75 at 14 Mile	0.054	0.988	0.018	0.002	0.873	0.014
I-696 at Telegraph	0.053	0.975	0.024	0.046	0.922	0.058
I-696 at Telegraph	0.044	0.97	0.02	0.089	0.915	0.013
I-75 at Corridor	0.001	0.995	0.013	0	0.987	0.014

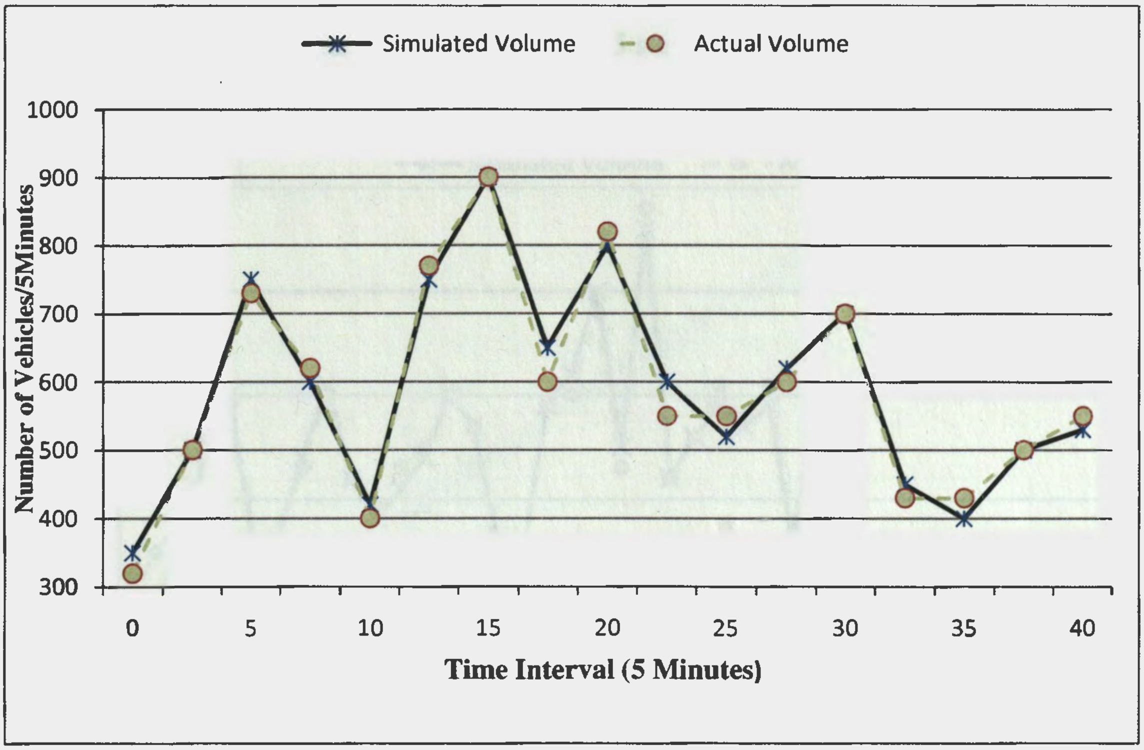

Figure 5. Actual and simulated volume on I-75 south and I-696

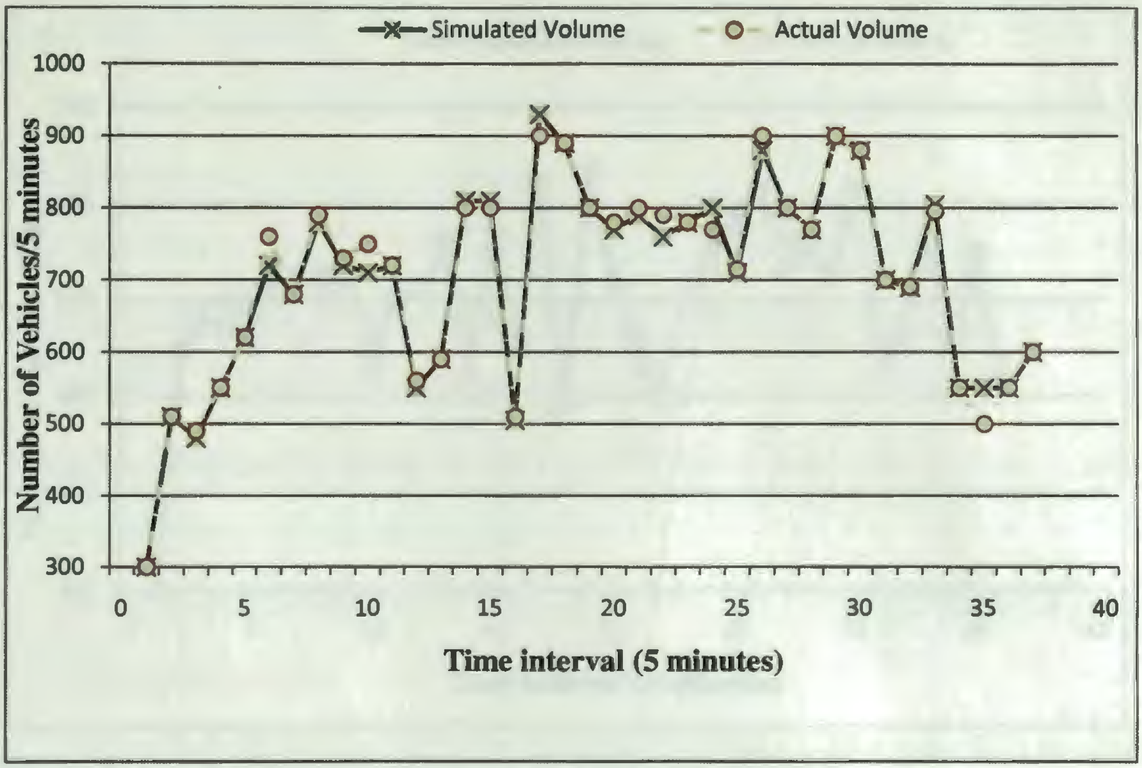

Figure 6. Actual and simulated volume on I-75 south and I-696

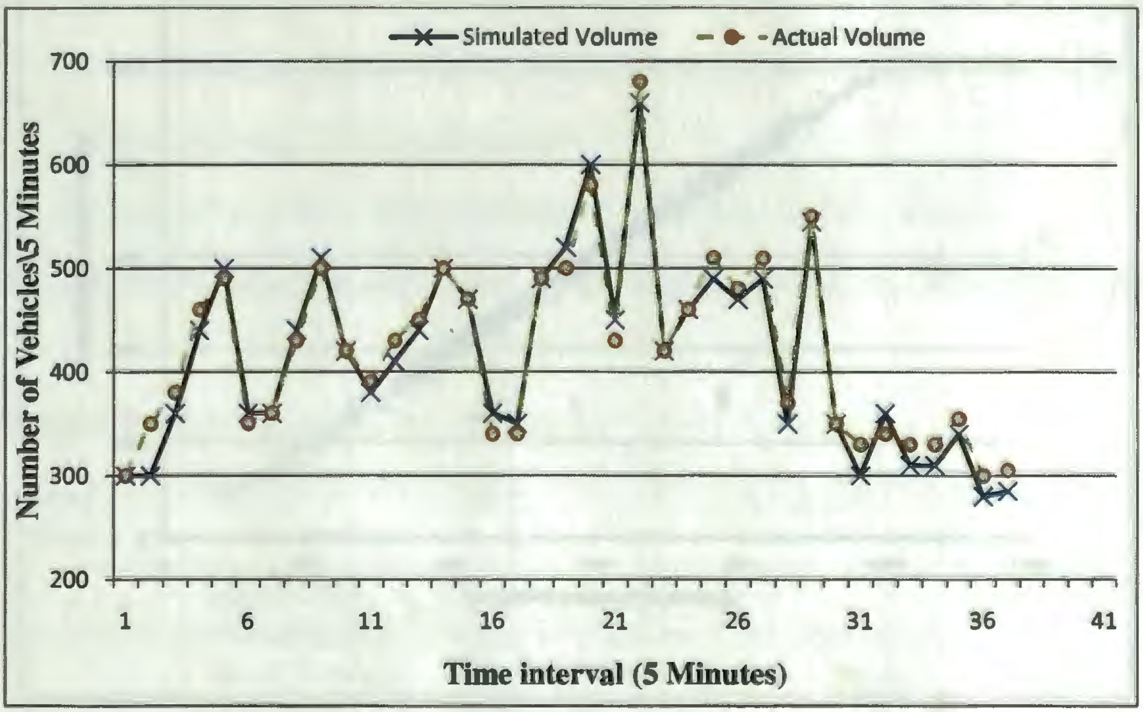

Figure 7. Actual and simulated volume on I-696 at east and north I-75

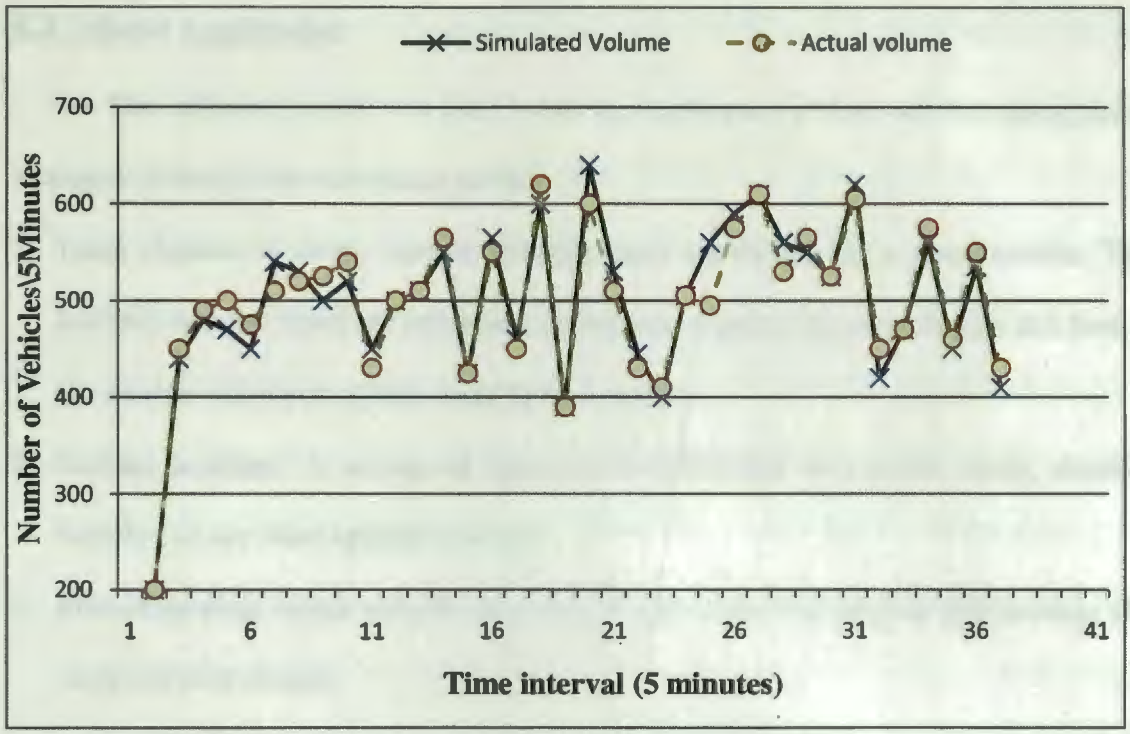

Figure 8. Actual and simulated volume on I-696 near telegraph

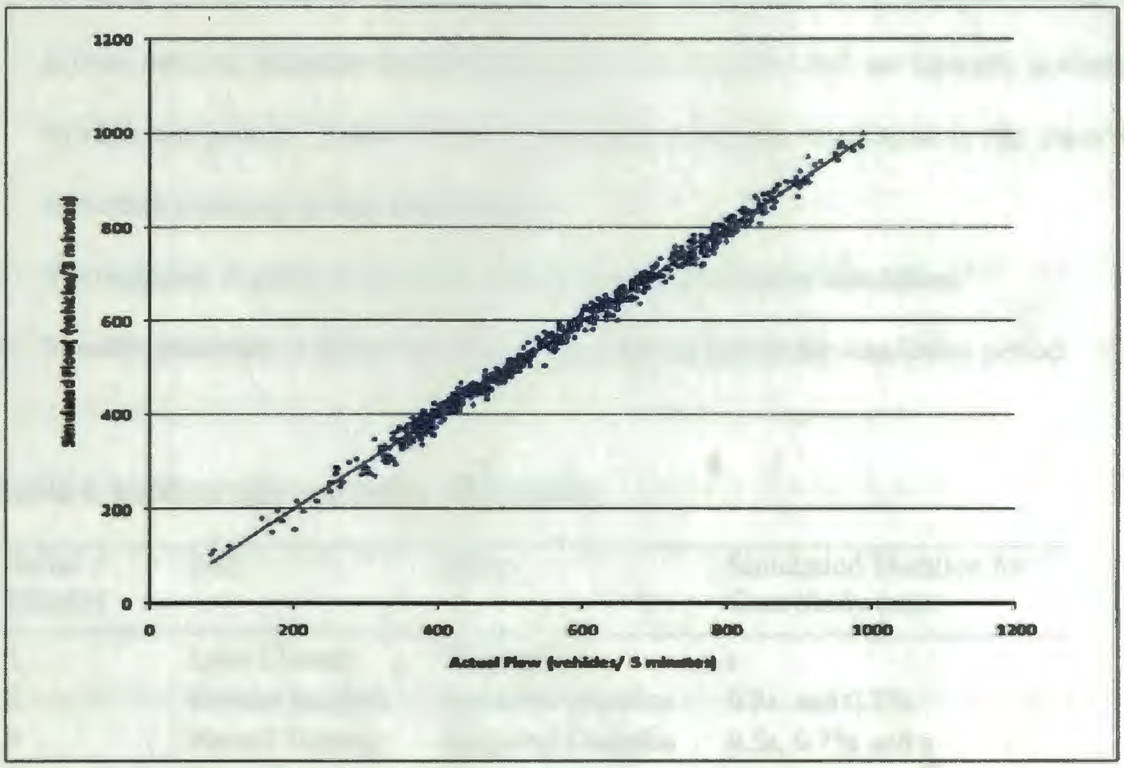

Figure 9. Actual and simulated flow on I-75 (7AM -10AM)

6.4. Model Application

The calibrated model was used to test the implication of four incident-management strategies defined in the simulation model.

1. **Lane closure**: A single lane or multiple lanes are closed for a given section. This incident does not block the entire section but only a part of it, so traffic can still flow in the section; some part of lane needs to be rerouted.
2. **Section incident**: A section of lane(s) is blocked due to a traffic crash, disabled vehicles, or any other specific reasons.
3. **Forced turning**: where vehicles are forced to turn from their original path because of a complete road closure.
4. **Congestion**: The volume-to-capacity ratio is more than 0.9 in at least one link of the network. For the purpose of this paper, strategies are defined as pre-planned courses of actions taken to minimize the advanced impact of incidents. IMS are typically governed by different policies. Table 4 shows two types of policies considered in this paper to constitute a strategy-policy combination.
5. **Throughout**: A policy is activated during the entire period of simulation.
6. **Specific duration**: A policy is activated only during part of the simulation period.

Table 4. Incident type and policy explanation

Serial Number	IMS	Policy	Simulation Duration for Case Study (min)
1	Lane Closure	Throughout	s
2	Section Incident	Specified Duration	0.5s, and 0.75s
3	Forced Turning	Specified Duration	0.5s, 0.75s and s
4	Congestion	Throughout	s

Note: s = simulation period in minutes

Results of the incident-management strategies tested in this paper are presented in three scenarios as explained below:

1. **No Incident**: Represents the base condition depicting normal traffic flow. Traffic conditions in this case are not affected by incidents or any IMS, because there are no incidents in the first place.
2. **Unguided**: Represents situations where incidents have occurred but no IMS has been deployed. Thus, the situation represents conditions where drivers essentially use their knowledge of the network, or use their intuition, in selecting the shortest path. The simulation model that we are using here applies a "static" assignment process, and route selection is based upon the shortest path, given an incident (e.g. lane closure, speed change, etc.) has occurred. Ideally, MOE data for such "unguided" conditions should be derived from archived data, if available from the Traffic Management Center (TMC). For the purpose of testing the framework, simulation data generated by the model, based on static assignment as discussed above, are used, because no archived data on delay, travel time, and queue length were readily available.
3. **Guided**: Represents a situation where an appropriate IMS has been deployed during/after the incident, and vehicles are "guided" through the network following a dynamic assignment procedure. Under these conditions, vehicles are "guided" through VMS to the shortest path that is dynamically updated at a pre-specified route choice cycle. Note, only a fraction of the trips, that are "captured" during the route choice cycle are assigned to the then shortest route, and the route may change from cycle to cycle. Remainder fractions are dynamically assigned to the respective shortest routes

during successive route- choice cycles, until all trips are exhausted for the specified time duration.

Results for each strategy tested are presented below. The procedure used in testing these strategies consisted of:

1. Searching the archived database in identifying the incidents stated above.
2. Obtaining the freeway volume data during the incidents from archived (sensor) data
3. Using the volume data to generate a trip table and to produce network performance data under the "no-incident" condition.
4. Regenerating the network performance data from the specific incident resulted in two pieces of information, "unguided" and "guided" condition, as explained above.

An IMS tested for a multiple number of days and at different locations is presented in Table 5. Four types of IMS are presented in the first column of Table 5 (i.e. lane closure, section incident, forced turning and congestion). Days and time of these IMS tests are presented in the second and third columns of Table 5. The last two columns of the table show the notation used in designating an IMS, and the location of incidents.

Results of the network performance summaries for the different IMS tested are presented in Table 6 through 9. A one hour simulation period is considered in all the analyzed strategies. As mentioned earlier, in the absence of archived data, a comparison of MOEs can only be made between "guided" and "unguided" conditions, assuming that "unguided" conditions represent actual actions of drivers. For each IMS tested, two types of performance data are presented; unit travel time and unit delay, both measured in seconds/mile/vehicle

Table 5. Location and timing of incidents in the network

Type	Date	Time	Notation	Location in the Network
Lane Closure	2/20/2006	9:00 AM- 10:00 AM	L1	On I 75 North at 14 Mile Rd
	3/24/2006	7:00 AM - 8:00 AM	L2	On I 75 North at 12 Mile Rd
	6/2/2006	7:00 AM - 8:00 AM	L3	On I 75 North at 14 Mile Rd
	6/9/2006	9:00 AM- 10:00 AM	L4	On I 75 North between 12 Mile Rd and I 696
	6/4/2007	1:00 Pm - 2:00 PM	L5	On I 75 North between 14 Mile Rd and 12 Mile Rd
Section Incident and Forced Turning	6/21/2006	10:00 AM - 11:00 AM	S1	On I 75 North at Big Beaver Rd
	8/27/2006	12:00PM - 1:00 PM	S2	On I 75 North between 14 Mile Rd and 12 Mile Rd
	5/2/2007	7:00 AM - 8:00 AM	S3	On I 75 North at 14 Mile Rd
	6/22/2007	10:00 AM - 11:00 AM	S4	On I 75 North between 14 Mile Rd and 12 Mile Rd
	10/11/2007	7:00 AM - 8:00 AM	S5	On I 75 North approaching 12 Mile Rd
Congestion	6/2/2006	4:00 PM- 5:00 PM	C1	On I 75 South to the west of 12 Mile Rd
	6/21/2006	5:00 PM - 6:00 PM	C2	On I 75 North to the west of I 696
	5/2/2007	4:00 PM- 5:00 PM	C3	On I 75 South to the west of I 697
	6/22/2007	2:00 PM - 3:00 PM	C4	On I 75 South to the west of 14 Mile Rd
	6/10/2008	5:00 PM - 6:00 PM	C5	On I 75 North to the west of I 697

6.4.1. Lane Closure

Table 6 shows unit travel time and unit delay fewer than three lane-closure conditions:

1. One lane closed,
2. Two lanes closed
3. All lanes closed.

A hypothetical "no-incident" scenario is also presented. Lane closure is a special scenario where we do not consider a full stoppage of traffic in the section where the incident has occurred, but it still causes a delay in the traffic and adds to the queue length. The traffic needs to be rerouted in this case, but it does not incorporate the full traffic diversion, so each lane in the section needs to be calculated separately. In all cases analyzed, there were reductions (improvements) in unit travel time. The percentage of reduction ranged from a low of 20 to a high of 43. In all "unguided" conditions, the unit travel time was higher than the "no-incident" condition, as expected. The "guided" conditions produced a reduced unit travel time compared to the "no-incident" and "unguided" conditions. The "one lane closed" strategy produced better results than its "two lanes closed" counterpart, because the reduction in capacity is much more for a two lane closure condition. The "all lanes closed" strategy produced the least unit travel time. This finding is reasonable, because all vehicles completely avoid the "all lanes close" section, being "guided" to alternate routes. Similarly, for the delay data shown in Table 6, there were improvements in all cases analyzed. The percentage improvement ranged from a low of 24 to a high of 50. The highest percentage increase generally occurred under the "all lanes closed" condition.

Table 6. Travel time and delay data for lane closure (sec/mi/vehicle)

Measure	Notation		1 Lane Closed			2 Lanes Closed			All Lanes Closed		
		No Incident	Unguided	Guided	% Improvement	Unguided	Guided	% Improvement	Unguided	Guided	% Improvement
Travel Time	L1	70.65	77.26	58.23	24.64	80.92	63.46	21.57	85.66	50.02	41.6
	L2	72.84	76.64	59.34	22.57	80.48	64.65	19.67	87.08	49.61	43.03
	L3	77.33	81.05	61.19	24.5	86.68	68.17	21.35	92.24	54.34	41.1
	L4	77.44	82.83	62.93	24.03	88.35	69.07	21.82	93.76	56.2	40.05
	L5	78.05	80.63	62.3	22.73	86.85	69.14	20.4	92.31	53.34	42.22
Delay	L1	14.83	17.97	13.16	26.77	20.61	15.7	23.81	23.73	11.84	50.1
	L2	15.98	19.89	14.42	27.51	22.43	16.99	24.25	25.74	13.05	49.31
	L3	16.23	21.8	14.93	31.51	24.65	17.49	29.05	27.58	14.24	48.37
	L4	16.43	21.37	15.27	28.54	24.26	17.75	26.86	27.92	13.95	50.03
	L5	17.28	23.78	16.41	30.99	25.87	18.78	27.43	29.78	15.41	48.24

6.4.2. Section Incidents

Table 7 shows the impact of section incidents the last over 30 and 45 minutes. In all 15 cases analyzed, the "guided" condition resulted in better performance that reflects in lower unit travel time compared to the "unguided" condition. The percentage improvement ranged from 17 to 25, with the higher improvements generally being attained under the "one lane closed" condition. The performance measure did not appear to vary significantly between 30 and 45 minutes of duration. The unit delay data shown in Table 7 essentially show similar trends. In all the cases analyzed, the "guided" condition resulted in smaller delays with the greater improvement occurring for the "two lanes closed" condition. Further, the incident duration of 30 minutes generally produced higher improvement compared to 45 minute duration.

Table 7. Travel time and delay data for section incident (sec/mi/vehicle)

Measure	Notation		30 Minutes						45 Minutes					
			1 Lane Closed			2 Lanes Closed			1 Lane Closed			2 Lanes Closed		
		No Incident	Unguided	Guided	% Improvement	Unguided	Guided	% Improvement	Unguided	Guided	% Improvement	Unguided	Guided	% Improvement
Travel Time	S1	75.75	79.42	62.8	20.93	81.43	65.6	19.42	80.48	64.57	19.77	82.56	67.4	18.36
	S2	75.48	80.4	60.03	25.34	81.98	62.3	24	80.71	61.01	24.4	83.3	64.7	22.33
	S3	77.26	80.5	60.37	25	82.49	63.0	23.6	81.62	61.72	24.38	83.52	64.94	22.25
	S4	69.96	74.03	59.66	19.41	76.14	62.4	18.05	75.48	61.54	18.46	77.22	64.31	16.71
	S5	77.62	83.56	63.91	23.51	85.53	66.5	22.22	84.46	65.16	22.84	86.92	68.48	21.21
Delay	S1	17.2	19.28	15.16	21.37	21.16	16.85	20.38	20.51	15.96	22.2	22.22	17.78	19.99
	S2	16.67	19	15.3	19.48	20.85	16.93	18.83	20.16	16.14	19.95	21.85	18.09	17.23
	S3	18.84	20.71	16.62	19.74	22.38	18.28	18.33	21.77	17.68	18.77	23.43	19.6	16.35
	S4	14.11	16.78	13.31	20.71	18.41	14.95	18.79	17.73	14.34	19.15	19.36	16.04	17.12
	S5	20.88	22.64	18.09	20.11	24.33	19.84	18.45	23.67	19.23	18.76	25.34	20.93	17.4

6.4.3. Forced Turning

When all the lanes are closed during a section incident, motorists are forced to turn from the original path, resulting in a strategy termed as “forced turning”. Thus, the “forced turning” strategy is a special case of the “section incident” strategy. The effects of “forced turning” are reflected in Table 8 for three cases: 30 minutes, 45 minutes and 60 minutes. Table 8 shows that the improvement in unit travel time is significant in all 15 cases analyzed; the percentage improvement ranged from 26 to 46. Generally, the largest percentage improvement occurred at the highest level of “forced turning”, i.e. 60 minutes. No major difference is observed between the 30 and 45 minute durations. Table 8 shows that reductions in unit delay were attained in all 15 cases analyzed for the “guided” condition compared to the “unguided” counterpart, with the percentage of improvement ranging from 38 to 58. Generally, the highest level of improvement was obtained for the 60 minute duration.

As explained above, “forced turning” is a special case of the section incident; in this case, the variable message sign (VMS) forcefully reroutes the vehicle in the available alternate routes. The VMS is actuated in such a way that, as soon as the incident clears, the vehicles are routed in the same way they were supposed to go if there were no incident. Forced turning can also be applied in almost all the incidents because the result of the incidents is a rerouting, which is nothing but the forced turning; apart from the above scenarios, forced turning can also be activated with other factors, and that is why it is considered a totally different incident. There are different IMS that apply to the forced turning scenario. A longer period of this strategy can cause a better improvement in traffic time.

Table 8. Travel time and delay data for forced turning (sec/mi/vehicle)

Measure	Notation		30 Minutes			45 Minutes			60 Minutes		
			All Lanes Closed			All Lanes Closed			All Lanes Closed		
		No Incident	Unguided	Guided	% Improvement	Unguided	Guided	% Improvement	Unguided	Guided	% Improvement
Travel Time	S1	76.78	83.17	61.17	26.45	86.39	59.39	31.25	89.67	52.39	41.58
	S2	76.96	83.62	57.78	30.9	86.85	55.86	35.68	90.09	49.81	44.7
	S3	78.74	84.38	58.13	31.1	87.98	55.53	36.89	91.25	49.06	46.24
	S4	71.86	78.44	56.93	27.43	81.99	55.29	32.57	85.23	48.62	42.95
	S5	79.31	87.19	62.22	28.64	90.72	60.35	33.47	94.06	53.39	43.24
Delay	S1	18.13	23.56	13.52	42.62	26.79	14.77	44.86	29.75	13.23	55.54
	S2	18.91	25.25	13.63	46.02	28.59	15.12	47.1	31.79	13.37	57.95
	S3	20.76	24.59	14.98	39.07	27.82	16.35	41.24	30.68	14.71	52.07
	S4	15.46	20.1	11.68	41.87	21.75	13.1	39.79	24.76	11.44	53.8
	S5	21.61	26.53	16.43	38.08	29.59	17.84	39.7	32.55	15.96	50.96

6.4.4. Congestion

The "congestion" case is designated to reflect a higher volume-to-capacity ratio on one or more links in the network (Table 9). Five days of data are considered, and two cases, "unguided" and "guided" are presented for unit travel time and unit delay. Congestion can be caused by any of the above scenarios, or it can be caused by incorrect calculation for the attributes of shortest path and the link cost function. Ideally, we always want our volume-to-capacity ratio to be less than one. In my study, if the volume to capacity is getting close to one or if it is exceeding one, we immediately direct the traffic to other routes using the VMS signs. This VMS sign is actuated by the ratio of volume to capacity.

Table 9. Travel time and delay data for congestion (sec/mi/vehicle)

Measure	Notation	Unguided	Guided	% improvement
Travel Time	C1	98.81	65.62	33.59
	C2	96.11	63.04	34.4
	C3	96.44	63.62	34.03
	C4	92.69	60.55	34.68
	C5	85.92	57.12	33.52
Delay	C1	35.61	17.96	49.57
	C2	36.86	19.84	46.18
	C3	36.57	19.42	46.9
	C4	29.17	15.04	48.43
	C5	21.22	11.31	46.7

6.4.5. Queue Length

A series of queue length comparisons for the "unguided" and "guided" conditions on various sections is presented in Figures 10 through 13. The graphs represent average queue lengths for a one-hour simulation for "all lane closure", on 2nd June 2006, from7:00 AM to 8:00 AM (notation "L3" in Table 5) for four locations in the network. Each "guided" and "unguided" case consists of 12 data points for a 5-minute interval in 1 hour of a simulation period. The four locations used to test the Goodness-of-fit in calibration are also used for the queue-length demonstration. In all cases, the "guided" condition provided a shorter queue length than the "unguided" counterpart. The queue Lengths presented in Figure 10 are for lane closure strategy. Similar results can be produced for all other strategies.

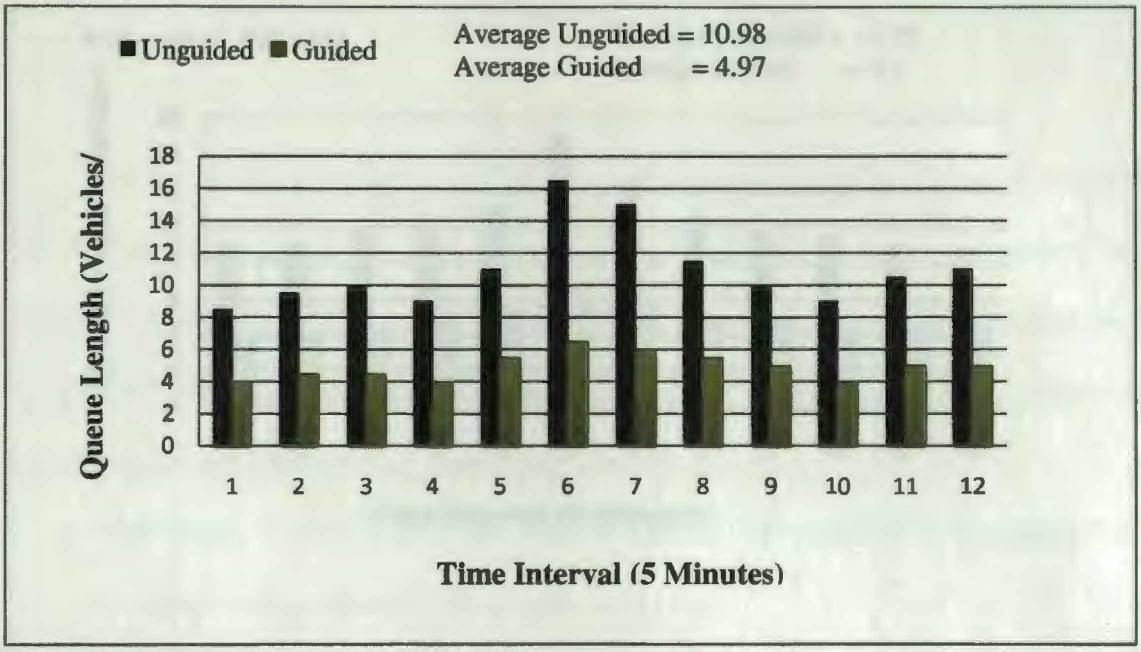

Figure 10. Queue length for unguided and guided scenarios on I-75 south and I-696

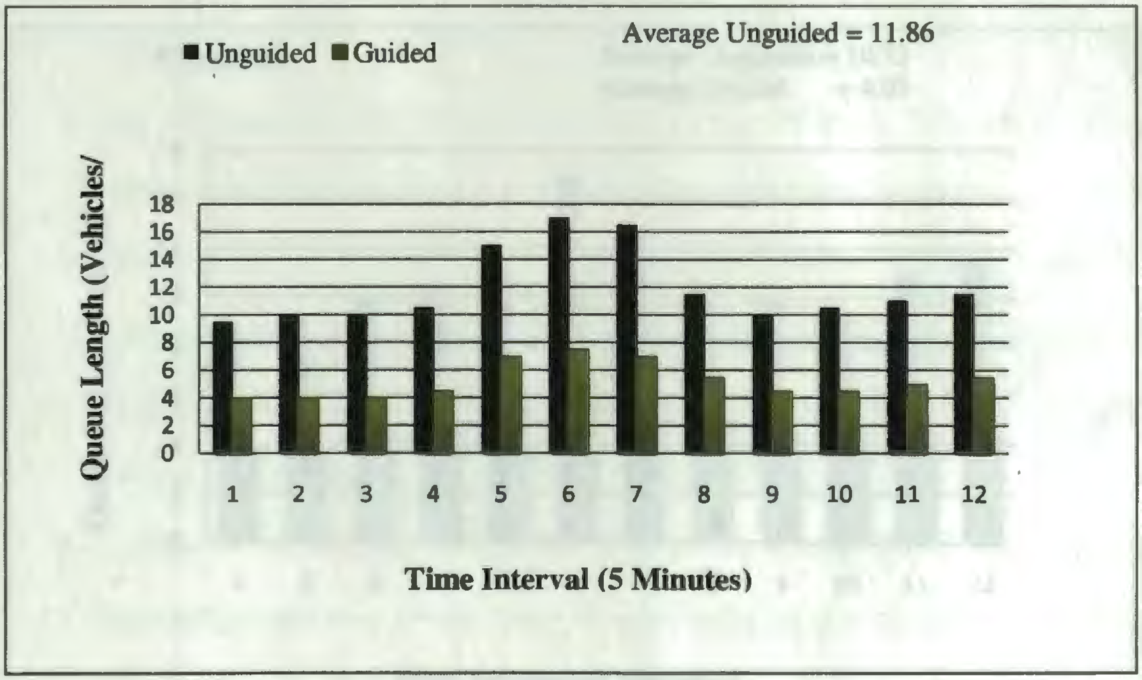

Figure 11. Queue length for unguided and guided scenarios on I-75 north and I-696

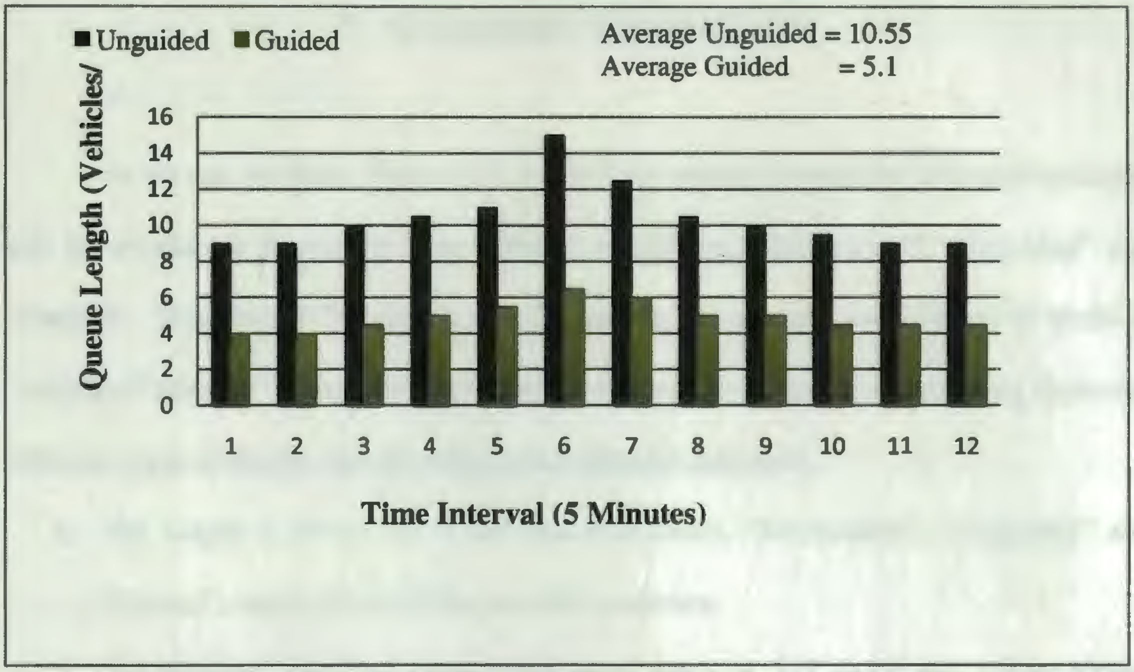

Figure 12. Queue length for unguided and guided scenarios on I-696 and north I-75

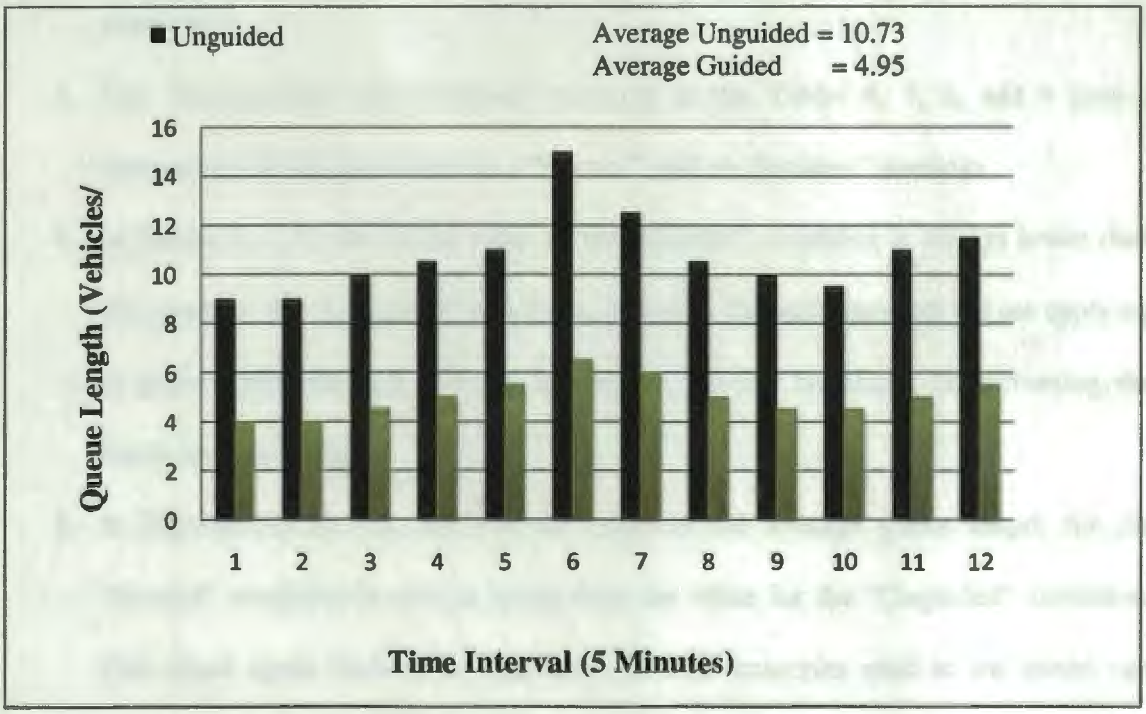

Figure 13. Queue length for unguided and guided scenarios on I-696 near Telegraph

7. SUMMARY OF RESULTS

As we can see from Tables 6, 7, 8, and 9 the model is tested for different incidents, and the results are shown for three different conditions; "No-incident", "Unguided" and "Guided". Similarly, in Figures 10, 11, 12, and 13, the average queue length in terms of "vehicles/5 minutes" is shown for "Guided" and "Unguided" vehicles. Analyzing these two different types of results, the following interpretations can made.

1. The output is shown for 3 different conditions, "No-incident", "Unguided" and "Guided", which cover all the possible outcomes.
2. The "Guided" and "Unguided" columns in Tables 6, 7, 8, and 9 give a clear picture about the travel time with and without the application of incident-management strategies.
3. The "No-incident" and "Guided" columns in the Tables 6, 7, 8, and 9 give a comparison of the travel time in a "normal" and an "incident" scenario.
4. In Tables 6, 7, 8, and 9, the value of the "Guided" condition is always lower than the value for the "Unguided" condition, meaning, the strategies that we are applying to guide traffic through alternate routes are actually beneficial in decreasing the travel time and delay.
5. In Figures 10, 11, 12, and 13, the value of the average queue length for the "Guided" condition is always lower than the value for the "Unguided" condition. This result again leads to a conclusion that the strategies used in the model can reduce the queue length considerably.

6. From Tables 6-9 and Figures 10-13, it is evident that the results calculated for all the links are positive.

8. LIMITATIONS

Although we have seen that the results of the "model application" are positive, there are some limitations of the model which need to be addressed before applying it to the real world.

1. The traffic flow is assumed to be uniform here. There are no variations in the incoming traffic that are taken into account. The maximum number of vehicles that entered a network in an hour is counted, and then, the average value of that count is taken for the calculation.
2. The different link cost functions, that are calculated (initial link cost function, dynamic link cost function and user defined function) in this paper are considered for a single type of vehicle, meaning the function vehicle type (*vt*) is uniform for all traffic that is introduced in the network. In other words, there is no specifications for different vehicle types in the link cost functions
3. This study is done considering a real roadway network in the Detroit metropolitan area, and the O/D matrix generation and various other attributes calculated are confined to this network. This step is a future phase of the project to test this model on a larger network so that its robustness can be identified.
4. The model is only calibrated for the "no incident" condition. Because there was no information about the traffic for any incident, the model could not be calibrated for the "Guided" condition. There was not enough evidence to show that the output is generated in the case of an incident was valid.

9. CONCLUSION AND FUTURE WORK

The purpose of the paper is to present a framework for testing the impact of alternate incident-management strategies on an urban transportation network through the use of a simulation model. Results of testing the framework through calibration and application of the model are also presented. An analytic framework is initially presented in conceptual form; it incorporates various policy and operational considerations associated with the deployment of different IMS. For testing the framework, an actual network in the Detroit metropolitan area, where a reconstruction program for a freeway is soon to be undertaken, is used. Four types of strategies are simulated: lane closure, section incident, forced turning and congestion. Conclusions of the study are as follows:

1. The framework presented is conceptually sound and robust, and it incorporates five critical steps that lend themselves to testing various policy options, as well as operational changes reflecting different IMS.
2. The model calibration demonstrated with two sets of independent data sources collected from sensors in the freeway system appears to reflect a reasonable correspondence between the model output and observed data.
3. The model application to test three IMS shows that the model output is sensitive to the operational changes associated with the strategies tested and that the trends observed in the model output appear to be logical and reasonable.
4. In virtually all cases analyzed, the unit travel time for the "guided" condition is lower than that for the "unguided" condition. Similar results were obtained for the unit delay MOE.

5. Even though the testing of the framework shows positive results relative to calibration and application, there can still be some additional testing with a larger network, and with additional IMS if possible, before the simulation model can be used as a tool for assessing the impact of IMS.

As explained earlier, the next phase of this paper would be to test the simulation in a larger network with more freeways and arterials as well more traffic conditions, and if the test is still successful, it can be deployed as a real tool to assess the traffic situation and route traffic on alternate paths to minimize congestion; this tool saves a lot of time that is wasted in delays because of a wrong route choice by drivers, especially for commercial and emergency vehicles.

REFERENCES

1. *Highway Capacity Manual.* Transportation Research Board, National Research Council, Washington, D.C., 2000.

2. *Traffic Incident Management Handbook*, Federal Highway Administration, FHWA, pp. 1-46, 2000.

3. *Traffic Management Data Dictionary*, Institute of Transportation Engineers, Washington DC, USA, 2007.

4. *Traffic Congestion and Reliability: Trends and Advanced Strategies for Congestion Mitigation*. Prepared for Federal Highway Administration, FHWA, by Cambridge Systems Inc., and Texas Transportation Institute, USA, pp 1-20, 2004.

5. Taylor, N. B. CONTRAM 5: an enhanced traffic assignment model. *TRRL Research Report 249*, 1990.

6. Van Aerde, M. and Yagar, S. Dynamic integrated freeway/traffic signal networks: a routing-based modeling approach. *Transportation Research A,* 22 (A), 6, 1988, pp. 435-443.

7. Mahmassani, H. S., Hu, T. Y. and Jayakrishnan R. Dynamic traffic assignment and simulation for advanced network informatics (DYNASMART). *Proceedings of the 2nd International Capri Seminar on Urban Trajic Neworks,* Capri, Italy, 1992.

8. Ben-Akiva, M., Cortes, M., Davol, A., and Toledo, T. MITSIMLab: Enhancements and Applications for Urban Networks. Document Prepared for Presentation at Stockhalm, 2000.

9. Yang Q., Koutsopoulos H.N. and Ben-Akiva M. A simulation laboratory for evaluating dynamic traffic management systems. *Transportation Research Board, 79th Annual Meeting*, 2000.

10. *AIMSUN*: Advanced Interactive Microscopic Model for Urban and Non-urban Networks. Transportation Simulation Systems. Barcelona, Spain, 2007.

11. CORSIM. Product Information. Available from McTrans Website, http://mctrans.ce.ufl.edu/store/description.asp?itemID=450, Date Accessed 20th July 2008.

12. PARAMICS. Product Information Available from Paramics Website http://www.paramics-online.com/, Date Accessed 20th July 2008.

13. VISSIM. (2007) Product Information. Available from McTrans Website http://mctrans.ce.ufl.edu/store/description.asp?itemID=662, Date Accessed 20th July 2008.

14. Breheret, L., Hounsell, N. B. and McDonald, M. The simulation of route guidance and traffic incidents. *Presented at 22nd Annual Universities Transport Studies Group Conference, Hatfield, U.K*, 1990.

15. Ha, Dong-Ik, Jung J.-H. and Baik H. An application of the simulation model to evaluate dynamic route guidance systems. *Proceedings of the 1994 Korea-U.S.A. Symposium on IVHS and GIST, Seoul, Korea*, 1994.

16. Hounsell, N., McDonald, M. and Breheret, L. Models and strategies for dynamic route guidance. In *Advunced Telematics in Road Transport*, pp. 89-98, Elsevier, Brussels, 1991.

17. Smith, M. J. and Ghali, M. New dynamic model to evaluate the performance of urban traffic control systems and route guidance strategies. *Transportation Research Record*, 1306, 33-39, 1989.

18. Smith, I. C. and Russam, K. Some possible effects of autoguide on traffic in London, vehicle navigation and information systems (VNIS). Conference record, pp. 288-29, 1989.

19. Koutsopoulos, H. H., Polydoropoulou A. and Ben-Akiva, M. The use of driving simulators to investigate the response to traffic information. Center for Transportation Studies, Massachusetts Institute of Technology, 1993.

20. Abdel-Aty, M, Vaughn, K.M., Kitamura, R., and Jovanis, P.P. Impact Of ATIS On Drivers' Decisions And Route Choice: A Literature Review. *Research Report: Institute of Transportation Studies California Partners for Advanced Transit and Highways (PATH)*, 1993.

21. Khattak, A.J., Schofer, J.L., and Wang, M. A Simple Time Sequential Procedure For Predicting Freeway Incident Duration. *Research Report: Institute of Transportation Studies California Partners for Advanced Transit and Highways (PATH)*, 1994.

22. Cragg, C.A. and Demetsky, M.J. *Simulation Analysis of Route Diversion Strategies for Freeway Incident Management*, Final Report. Published by the Virginia Transportation Research Council. February 1995.

23. Madanat, S., and Feroze, A. Prediction Models for Incident Clearance Time for Borman Expressway. *Joint Transportation Research Program, Purdue University, Indiana*, 1996.

24. FHWA. Regional Traffic Incident Management Programs, *Federal Highway Administration, US Department of Transportation*, 2001.

25. Balke, K.N., Fenno, D.W., and Ullman, B. Incident Management Performance Measures. Texas Transportation Institute, Prepared for Federal Highway Administration U.S. Department of Transportation Contract Number: DTFH61-01-C- 000182, 2002.

26. Hidas, P., and Awadalla, E. Modelling driver response to variable message signs for incident management. *Road and Transport Research*, v 12, n 2, p 15-30, 2003.

27. FHWA. Alternate Route Handbook. Alternate Route Handbook. *Federal Highway Administration, US Department of Transportation*, 2006a.

28. FHWA. Simplified Guide to Incident Command System for Transportation Professionals. *Federal Highway Administration, US Department of Transportation*, 2006b.

29. Wirtz, J.J., Schofer, J.L., and Schulz, D.F. Using Simulation to Test Traffic Incident Management Strategies The Benefits of Preplanning. *Transportation Research Record*. 1923, 82-90, 2005.

30. R. Doughty, "Traffic signs and markings". In W. S. Homburger, , L. E. Keefer, and W. R. McGrath (Ed.). *Transportation and Traffic Engineering Handbook* (Second Edition). Englewood Cliffs, New Jersey: Prentice-Hall, Inc, 1982.

31. Hourdakis, J ; Michalopoulos, P G; Kottommannil, J. *Practical Procedure For Calibrating Microscopic Traffic Simulation Models*. Transportation Research Record, 1981, pp. 130-139, 2003.

32. Kleijnen, J.P.C. *Verification and validation of simulation models; Theory and methodology*. European Journal of Operational Research 82, pp. 145-162, 1995.

33. Hellinga, B.R. *Requirements for the calibration of traffic simulation models*, Proceedings of the Canadian Society for Civil Engineering, Vol IVB, pp. 211-222, 1998.

34. Rao, L., Owen, L. *Development and application of a validation framework for traffic simulation models*, Proceedings of the 1998 Winter Simulation Conference, 1079- 1086, 1998.

35. Rakha, H., Hellinga, B., Van Aerde, M., Perez, W. *Systematic verification, validation and calibration of traffic simulation models*, Paper presented at the 1996 Transportation Research Board Annual Meeting, 1996.

36. Jayakrishnan, R., Oh, J., Sahraoui, A. *Calibration and path dynamic issues in microscopic simulation for advanced traffic management and information systems*, Paper presented at the 80th Transportation Research Board Meeting, 2001.

37. MIOH. http://mioh-utc.udmercy.edu.

38. Douglas R. Shier. *A factoring approach for the stochastic shortest path problem.*39. Dreyfus S.E., An Appraisal of Some Shortest Path Algorithms. Op. Res. 17 395-412, 1969.

40. Eppstein D., Finding the k Shortest Paths. In: Proc. 35th IEEE Symp. FOCS, pp.154 – 165, 1994.

41. Eppstein D., Finding the k Shortest Paths. SIAM J. Computing 28(2) 652 – 673, 1999.

42. Fox B.L., Calculating kth Shortest Paths. INFOR - Canad. J. Op. Res. And Inform. Proces. vol 11 n° 1 pp. 66-70, 1973.

43. Bellman R., and R. Kalaba, On kth Best Policies. J. SIAM 8 582-588, 1960.

44. Martins E. Q. V., *An Algorithm for Ranking Paths that may Contain Cycles*, European J. Op. Res. 18 1984, 123-130.

45. Martins E.Q.V.and J.L.E.Santos, *A New Shortest Paths Ranking Algorithm.* Technical report, Univ. de Coimbra, http://www.mat.uc.pt/~eqvm 1996.

46. Jiménez V. M and A. Marzal, *Computing the K Shortest Paths: a New Algorithm and an Experimental Comparison*. Proc. of the 3rd Int. Workshop on Algorithm Engineering, WAE'99, London, July 1999.

47. Michigan Department of Transportation (MDOT): http://www.michigan.gov/mdot.

48. US Department of Transportation (USDOT) : http://www.dot.gov.

49. Traffic Management Center (TMC): http://www.semcog.org/tranplan/its/e/2.cfm.