MICHIGAN OHIO UNIVERSITY TRANSPORTATION CENTER
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MANAGEMENT AND ANALYSIS OF MICHIGAN INTELLIGENT TRANSPORTATION SYSTEMS CENTER DATA WITH APPLICATION TO THE DETROIT AREA I-75 CORRIDOR

FINAL REPORT

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FINAL REPORT

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DISCLAIMERS

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TS21 Projects 1 and 2

ABSTRACT

An understanding of traffic flow in time and space is fundamental to the development of strategies for the efficient use of the existing transportation infrastructure in large metropolitan areas. Thus, this project involved developing the methods necessary to systematically describe, explain, and predict the flow of traffic with respect to time and space. The utility of this knowledge was demonstrated in routing voluminous traffic. Achieving these objectives required the collection, management, and analysis of traffic data concerning volume, speed, and traffic sensor occupancy. Management of this data required the design and implementation of a database management system as well as assuring data quality. Descriptive, explanatory, and predictive statistical models were developed to help gain the desired understanding of traffic flow. Application efforts focused on the Detroit metropolitan area. Traffic data was regularly obtained from the Michigan Intelligent Transportation System Center. Statistical models of traffic flow in the Detroit area I-75 corridor were constructed. A previously developed routing model was extended and adapted to the I-75 corridor and the newly developed statistical models incorporated to help compute traffic flow metrics. Both a software solver and a hardware solver for the model were implemented. A framework for traffic simulation was constructed and used to develop and calibrate a micro-simulation model of the same subset of the I-75 corridor. This model was used to demonstrate the benefits of guidance in re-routing traffic as a result of a traffic incident. A web site describing project activities and supporting downloading of traffic data was developed.

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1. Executive Summary

As investment in construction and expansion decreases, making better use of urban traffic infrastructure is essential. One important aspect of doing so is developing an understanding of the movement of traffic in time and space, including how to re-route large volumes of traffic in case of an incident. Meeting this need requires developing traffic data analysis methods, dynamic re-routing models, and simulation-based incident management system assessment tools. Thus, the development of such tools was the focus of this project. In addition, validation of the tools was performed through their application to I-75 corridor in Detroit. The project team consisted of faculty and students from Grand Valley State University and Wayne State University supported by staff of the Michigan Department of Transportation and the Southeast Michigan Council of Governments. The project was divided into three components each of which will be discussed in turn.

Statistical analysis of intelligent transportation systems data, in particular the data from the Michigan Intelligent Transportation Systems Center, was one project component. Data from one 12 month period was graphed. By examination of the graphs, it was determined that non-holiday weekday data was homogeneous and of the most interest. A multi-level regression model was employed to predict traffic speed update to 30 minutes in the future using only the current speed and the speed one minute in the past. The coefficients of the regression were themselves equations whose parameters were estimated by regression as a function of prediction interval. Predicted speeds were compared to actual speeds with the largest median error being 5.4% over the 30 minutes time horizon. For validation, model parameters were re-estimated using data from the following 12 month period. No significant differences in the models were observed. The model for the first 12 months was used to predict traffic speeds for the second 12 months. The largest median error was 10.13% for the 30 minute time horizon.

A dynamic re-routing model for large volumes of traffic around one or more freeway incidents was developed and applied. The model was implemented in software using MATLAB. Results showed the proper change in routes as more traffic was re-routed. A prototype hardware solver for the model, an analog computer, was developed as well. This addressed the issue of computational speed of the re-routing algorithm in order to produce routes repeated in near-real time.

A five-step framework for constructing, calibrating, and applying a micro-simulation model to assess incident management strategies has been developed. Calibration was successfully performed in light of no traffic incidents and selected traffic incidents using both graphs and standard metrics of performance. Application of the modeled showed that incident management strategies improved traffic flow in terms of both volume and speed.

Documentation of the project is available at utc.egr.gvsu.edu/mdot. In addition, traffic data may be downloaded from this same site.

2. Action Plan for Research

The action plan was designed to help the research team meet its fundamental goals of understanding traffic flow in time and space as well as to apply this understanding in routing voluminous traffic. The research team sought to transform the speed, volume, and occupancy data collected by the Michigan Intelligent Transportation Systems Center (MITSC) concerning the interstate system in the Detroit metropolitan area into a highly usable public resource. Meeting this objective involved the following.

1. Systematically acquire the MITSC data, which has been accomplished and is ongoing via FTP twice a month.
2. Design and implement a database management system for this voluminous data, about 50 gigabytes per year within a MySQL database as well as demonstrate this capability for a small, less than 10%, subset of the data concerning the Detroit area I-75 corridor.
3. Evaluate the quality of the data. This included determining missing data values and evaluating the effectiveness of the traffic sensors in consistently collecting data.
4. Develop and implement procedures for descriptive, explanatory, and predictive statistical model building to represent the movement of traffic in time and space as well as building models and validating them as appropriate.
5. Apply these results to voluminous traffic re-routing in the Detroit area I-75 corridor, thus demonstrating their utility.
    a. Continue refining routing models that take into account time and space.
    b. Continue refining both hardware and software based solvers for these models.
    c. Develop a procedure to assist an intelligent transportation system (ITS) in finding alternate routes in an efficient manner in response to traffic incidents.
6. Develop a procedure for developing, calibrating, and applying micro-simulation to traffic incident management scenario (IMS) assessment. Apply this procedure to the Detroit area I-75 corridor.

3. Introduction

A team of university-based transportation system experts, simulation experts, optimization experts, and applied statisticians has been assembled to develop, implement, and validate an approach to reducing congestion in integrated transportation corridors. This team has been working together since November, 2006 with funding provided by the Michigan-Ohio University Transportation Center (MIOH-UTC) through the U.S. Department of Transportation (USDOT) with matching funds supplied by the Michigan Department of Transportation (M-DOT), Grand Valley State University (GVSU), and Wayne State University (WSU). This report covers the period: September 2008 through December 2010.

The team has been working in three areas:

1. Statistical analysis of intelligent transportation systems data, in particular the data from MITSC.
2. Optimal re-routing of traffic due to traffic inc idents on a freeway.
3. Micro-simulation to assess the ability of incident management strategies to effectively re-route traffic around an incident.

As a proof of concept of the procedures and methods we have developed, the above have been applied to a selected portion of the I-75 corridor in Detroit.

The effort has been lead by faculty in the GVSU School of Engineering (SOE) and Department of Statistics as well as the WSU Department of Civil and Environmental Engineering (CEE). Students from these units as well as the School of Computing and Information Systems (SCIS) at GVSU and the Department of Electrical and Computer Engineering (ECE) at GVSU have ably assisted. Support for our work has been provided by the Southeastern Michigan Council of Governments (SEMCOG) as well as MDOT, particularly the staff of MITSC. The organization of the project is shown in Figure 1.

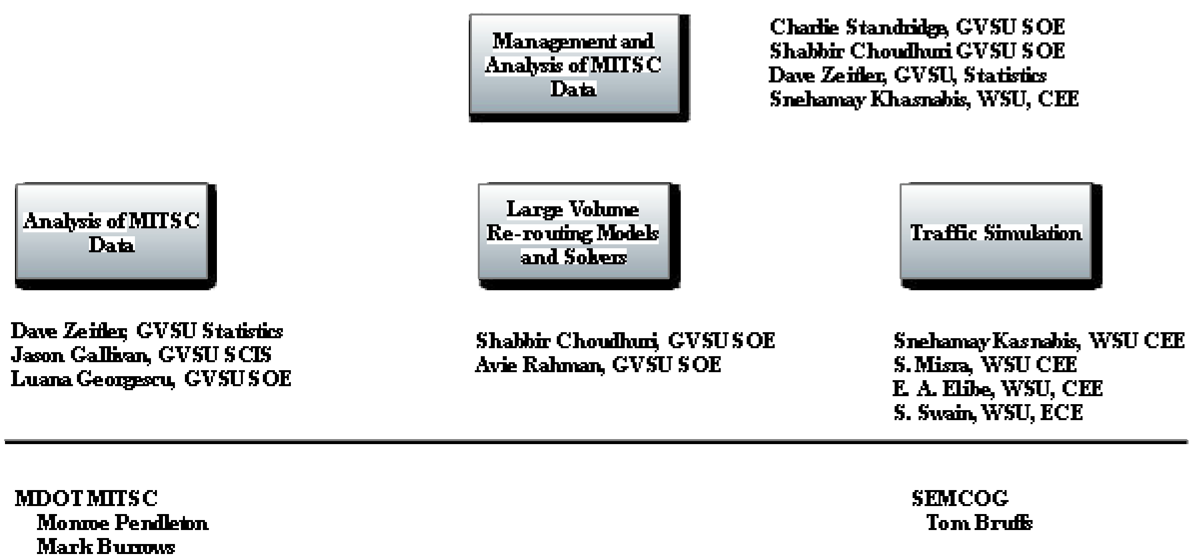

Figure 1. Project Organization

Project activities have been supported by graduate assistants and undergraduate students. All students who have participated in the project since its inception are listed in Table 1.

Table 1. Student Participation

Student	Faculty Mentor	Department	Degree Program	Status on Project	When on Project
Vishnu Yada	Shabbir Choudhuri	GVSU, Computer Information Systems	Master of Science	20 hours weekly, Graduate Assistant	January – December 2007
Ashfaq Rahman	Shabbir Chouduri	GVSU, School of Engineering	Master of Science	20 hours weekly, Graduate Assistant	August 2007 – August 2009
Andrew Even	Shabbir Chouduri	GVSU, School of Engineering	Master of Science in Engineering	Capstone project, unpaid	January – December 2007
Luana Georgescu	Dave Zeitler	GVSU, School of Engineering	Master of Science	20 hours weekly, Graduate Assistant	August 2007 – August 2009
S. Mishra	Snehamay Khasnabis	WSU, Civil & Environmental Engineering	Ph.D.	Hourly, Graduate Assistant	January 2007 – August 2009
A. Manori	Snehamay Khasnabis	WSU, Electrical & Computer Engineering	Master of Science	Hourly, Graduate Assistant	September 2007-December 2007
S. Swain	Snehamay Khasnabis	WSU, Electrical & Computer Engineering	Master of Science	Hourly, Graduate Assistant	February 2008-August 2010
E. Elibe	Snehamay Khasnabis	WSU, Civil & Environmental Engineering	Master of Science	Hourly, Graduate Assistant	September 2008 – August 2010
S. Vuyyuru	Snehamay Khasnabis	WSU, Civil & Environmental Engineering	Master of Science	Hourly, Graduate Assistant	September 2008 – December 2009
Jason Gallivan	Charlie Standridge	GVSU, Computer Information Systems	Master of Science	20 hours weekly, Graduate Assistant	January 2007 – present
Andrew Van Garderen	Dave Zeitler	GVSU, Statistics Department	Bachelor of Science	Semester stipend	August 2007 – May 2008
Allison Wehr	Dave Zeitler	GVSU, Statistics Department	Bachelor of Science	Semester stipend	January – May 2008
Ryan Masselink	Dave Zeitler	GVSU, School of Engineering	Bachelor of Science in Engineering	Semester stipend	May 2009 – April 2010
Alex Roemer	Charlie Standridge	GVSU, School of Engineering	Bachelor of Science in Engineering	Hourly Undergraduate Assistant	September – December 2010

4. Objective

The team has established that its primary research objectives are:

- *To describe, explain, and predict the flow of traffic in a corridor with respect to time and space.*
- *To apply these results in the routing of voluminous traffic.*

The team has addressed the former through the statistical analysis of traffic data obtained from MITSC. Achieving the latter has to do with developing re-routing models for voluminous traffic in response to traffic incidents, particularly on freeways, as well as assessing IMS using micro-simulation.

5. Scope

In pursuit of its objectives, the team has developed methods in the statistical analysis of traffic data, optimization modeling of voluminous traffic re-routing, and micro-simulation analysis of traffic IMS. Proof of concept for these methods has been accomplished by applying them to the I-75 traffic corridor in Detroit, specifically southbound I-75 between 8 Mile Road on the north and Clay on the south for statistical analysis as shown in Table 2 as well as Baldwin Avenue on the north and 8 Mile Road on the south as shown in Figure 2 for optimization modeling and micro-simulation.

Table 2. Location of the Sensors for Statistical Analysis

Location	Sensor ID	Latitude	Longitude
SB I-75 S of 8 Mile Road	68865	42.44226000000	-83.09524000000
SB I-75 S of 8 Mile Road	68612	42.43976105390	-83.09518743310
SB I-75 S of 7 Mile Road	68353	42.43219393	-83.09489812000
SB I-75 S of Mc Nichols (6 Mile) Road	67841	42.41632659650	-83.08648851500
SB I-75 S of Davison	67333	42.40634558200	-83.07608999730
SB I-75 S of Holbrook	66561	42.38444669210	-83.06696384570
SB I-75 S of Clay	66305	42.37999518890	-83.06403518030

Traffic data of interest was from the period November 2006 through August 2009. Sub-periods were selected in which to demonstrate each of the methods.

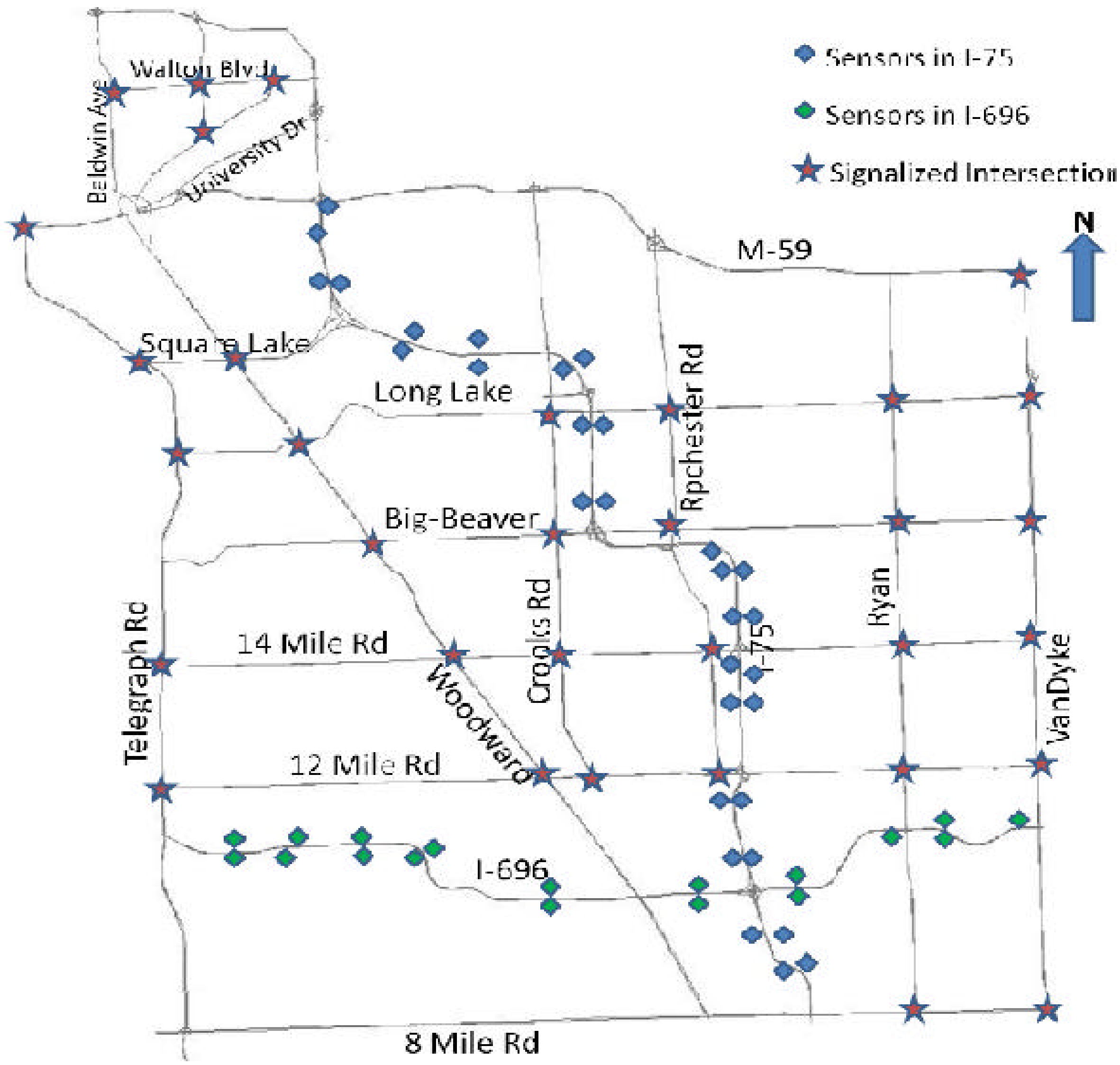

Figure 2. Northern Portion of I-75 Corridor in Detroit

6. Methodology

6.1. Statistical Analysis

The statistical analysis of the MITSC data was done in two stages. In the first stage, the data was examined and graphed. Upon examination of the data, it became apparent that some of the sensors transmit erroneous data that is not useful. Only about seven of them, those listed in Table 2 above, transmitted data that could be used in statistical analysis.

The traffic data was graphed for each day of the year for each sensor. Data from November 2006 through October 2007 was employed. It was clear from these graphs, that weekday traffic patterns were different from weekend patterns and holidays. No differences were noted among the days of the week or the months of the year. Thus, the second stage statistical analysis used all non-holiday weekdays.

For each minute, the average across days was computed and subtracted from each day's observed value. The statistical analysis of these residuals proceeded as follows. An explanatory / predictive multi-level model (MLM) for traffic speed was developed using regression. The variance in the residuals can be explained based on the current speed and the speed at one time unit previous, in other words by the current speed and the acceleration. The intercept, b_{0n}, is the average of the residuals which must be 0.

$$S_{t+n} = \underbrace{\bar{S}_{t+n}}_{\text{1st level of MLM}} + \underbrace{b_{0n} + b_{1n} * r_{s_t} + b_{2n} * r_{s_{t-1}}}_{\text{2nd level of MLM}}$$

n is prediction horizon

S_{t+n} is the future speed at time t+n

$\bar{S}_{t+n}$ are the means for every minute calculated at t+n

r_{s_t} are the residuals of the speed calculated at the current time t

$r_{s_{t-1}}$ are the residuals of the speed calculated at the past time t-1

b_{0n} is the constant term or the intercept

b_{1n}, and b_{2n} are regression coefficients

The coefficients b_{1n} and b_{2n} are themselves estimated by regression equations, thus the MLM. The prediction horizon n ranged from 1 to 30 minutes with intervals 1, 2,.., 10, 15, and 30 minutes used to estimate the parameters of the regression equations of the coefficients in the above equation.

For validation, the parameters were estimated a second time using data from November 2007 through October 2008 for the same sensors.

6.2. Re-Routing Models

The re-routing model previously developed was extended and tailored to the traffic corridor shown in Figure 2. This previous model is shown in Figure 3.

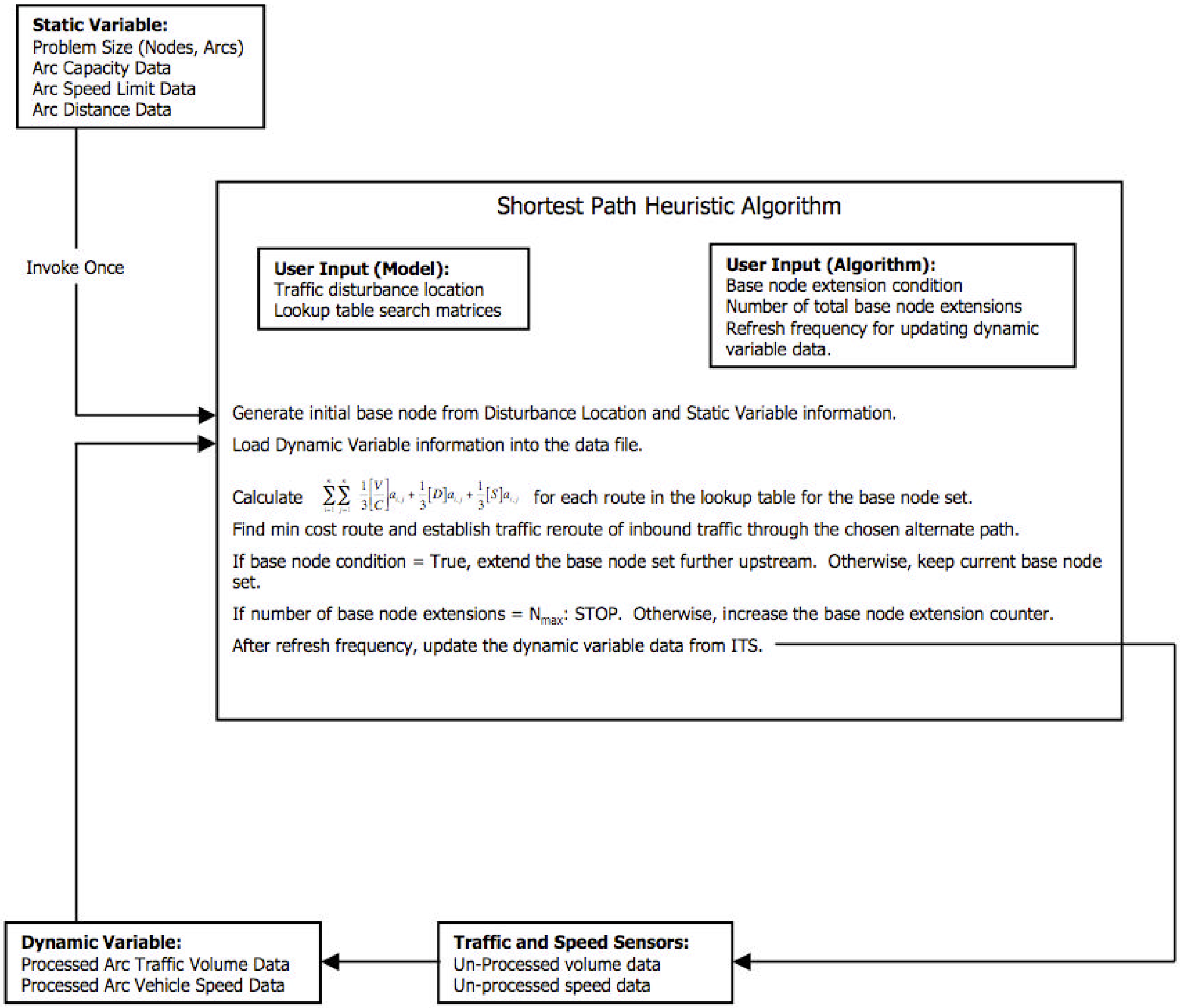

Figure 3. Previous Re-routing Model

The revised model is called DETSIM and has the following features:

- Graphical Road Network Editor
- Graphical output
- Interactive selection of one or more incidence locations
- Partial closure of a freeway segment
- Usage of standard data interchange format
- A simple simulator of traffic flow
- An improved solver written in MATLAB

The size of the traffic network in Figure 2 raised the issue of whether a software model solver could always compute re-routing information in near real time. Thus, a hardware implementation was proposed. An electrical network has stark similarities with a traffic network. If the traffic flow of arc can be modeled as a resistor in the electrical network then the electrical system itself becomes an analog of the traffic system. The re-routing solution can be obtained as quickly as electricity will flow through the network.

6.3. Micro-Simulation for Incident Management Assessment Strategies

A framework for the assessment of incident management strategies using micro-simulation has been developed. The five-step methodology encompassing policy and operational strategies associated with IMS can be summarized as follows:

1. Network creation and assembling various databases.
2. Identification of the policies and development of algorithm that comprise the IMS.
3. Calibration of the micro-simulation model.
4. Conducting micro-simulation-based experiments, by creating incidents on the network, and by using the databases, algorithm and policies identified in the earlier steps.
5. Analysis of the results.

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

Model Calibration (Step 3) and Model Application (Step 4). Table 3 gives the measures of calibration.

Table 3. Measures of Calibration

GOODNESS-OF-FIT MEASURES	DESIRABLE
RMSE (Measures Overall % Error)	Close to 0
Correlation Coefficient: *r*	Close to 1
Theil's Inequality Coefficient: *Ui* (Disproportionate Weight of Large Errors)	Close to 0
Theil's Component: *Us* (Measure of Variance Proportion)	Close to 0
Theil's Component: *Uc* (Measure of Covariance Proportion)	Close to 1
Theil's Component: *Um* (Measure of Bias Proportion)	Close to 0

Calibration is done with respect to both traffic volume and traffic speed, both with no traffic incidents and in the presence of traffic incidents.

To test the framework, a model of the traffic network shown in Figure 2 was developed using AIMSUN. Data sources included Traffic.com, MITSC, SEMCOG, and the Detroit area Freeway Courtesy Patrol.

7. Discussion of Results

7.1. Statistical Analysis

The graphs in Figure 4 show speed and occupancy for one weekday for sensor 68855. Occupancy is increasing between about 6-10am with a minimal speed decrease. Speed is low (about 30 mph) at a congestion point between about 3:30-6:00pm.

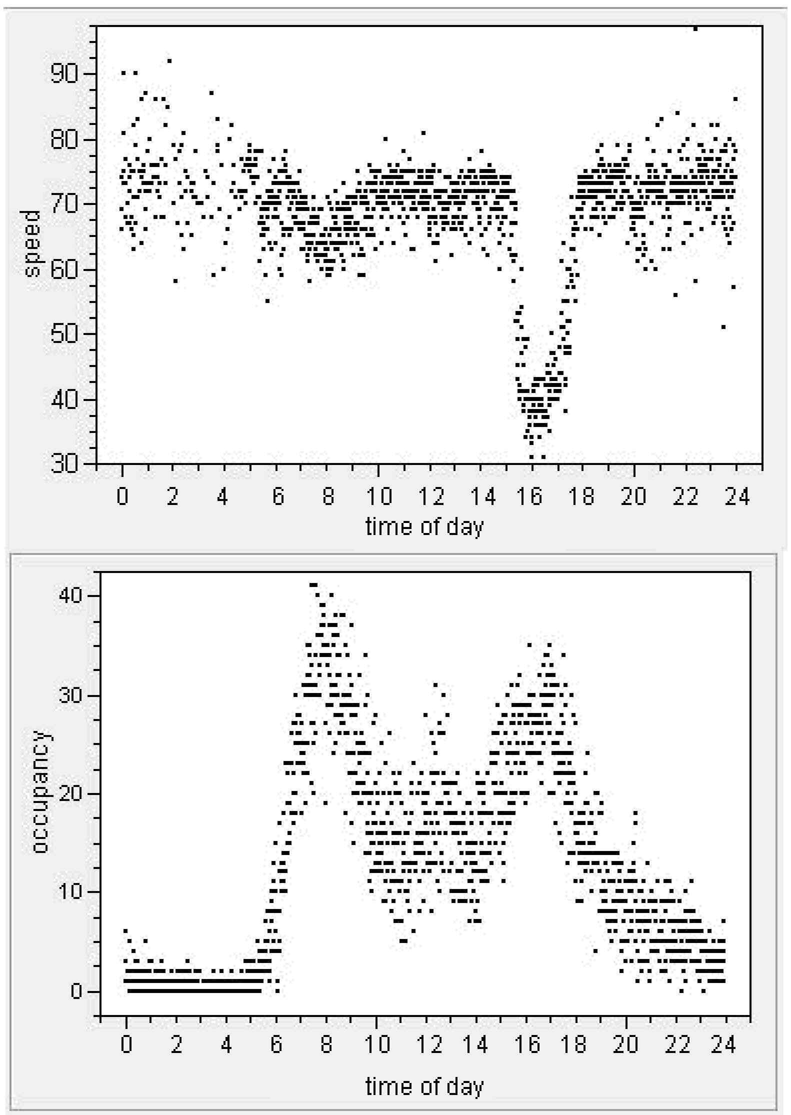

Figure 4. Speed and Occupancy for One Day for the Sensor 68865

Figure 5 show the results of estimating the regression coefficients b_{1n} and b_{2n} in the MLM.

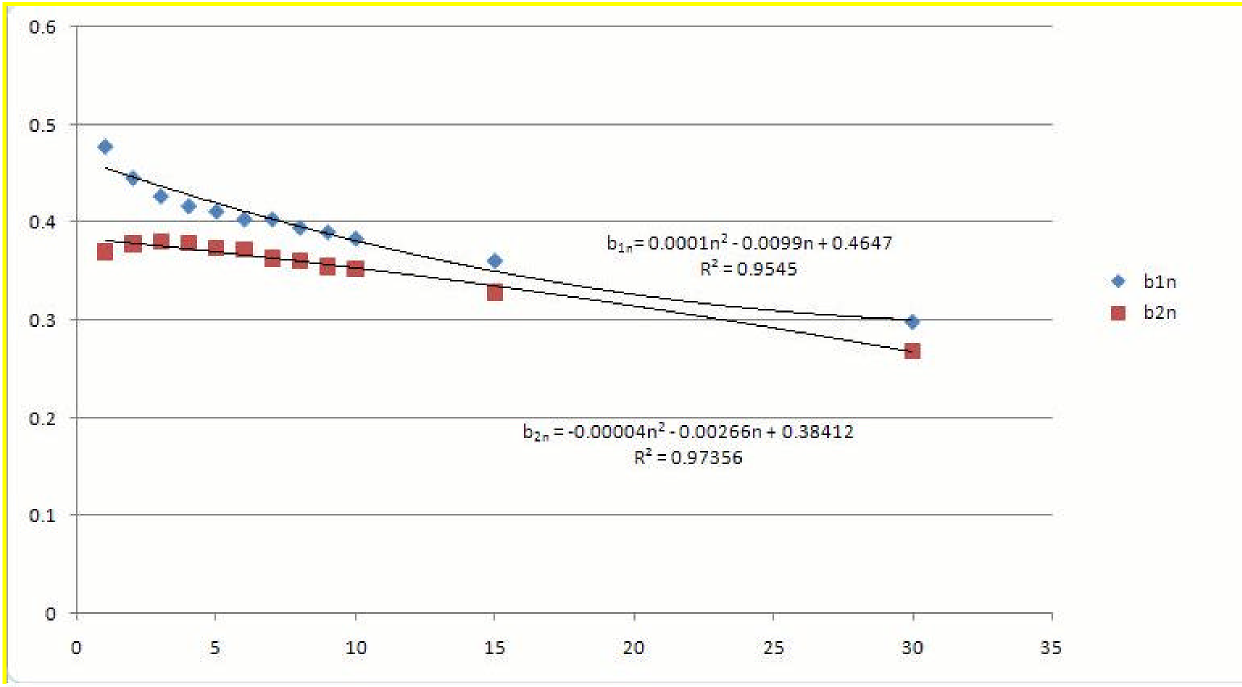

Figure 5. Regression Equations for Coefficients

To evaluate the model, predicted speeds were compared with observed speeds. The median error (ME) for the five prediction horizons ranged from 2.6% to 5.4%, with smaller percentages associated with smaller prediction horizons. Figures 6 and 7 show the prediction errors for time intervals of 1 minute and 30 minutes.

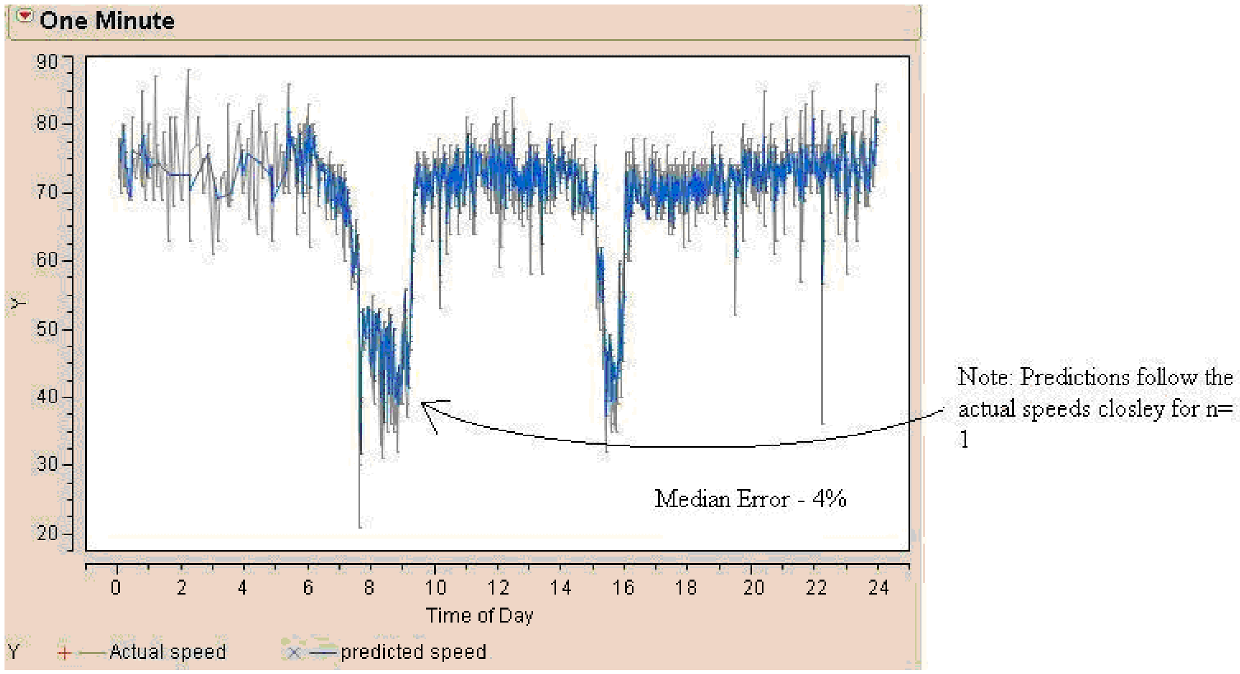

Figure 6. Prediction Error for One Minute Time Interval

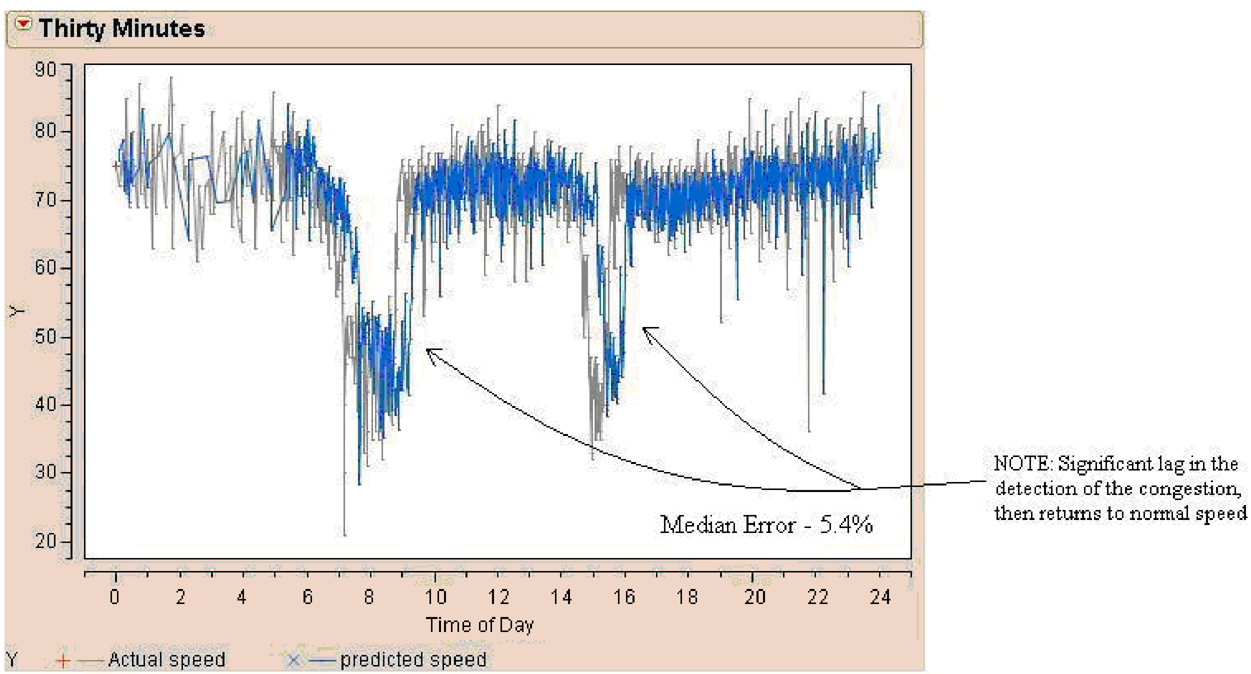

Figure 7. Prediction Error for 30 Minute Time Interval

Data from November 2007 through October 2008 were used to obtain a second estimate of model parameter values. These values varied little from the estimates for the previous 12 months shown above. For further verification, the original model was used with the November 2007 through October 2008 to predicted speed in this time period.

The predicted speed one minute in the future versus actual speed is shown in Figure 8. The value of the median relative error for actual speed at sensor 66305 versus predicted speed for 1,5,10,15, and 30 minute prediction intervals are 5.9, 6.95, 7.7, 8.34, 10.13 percent respectively.

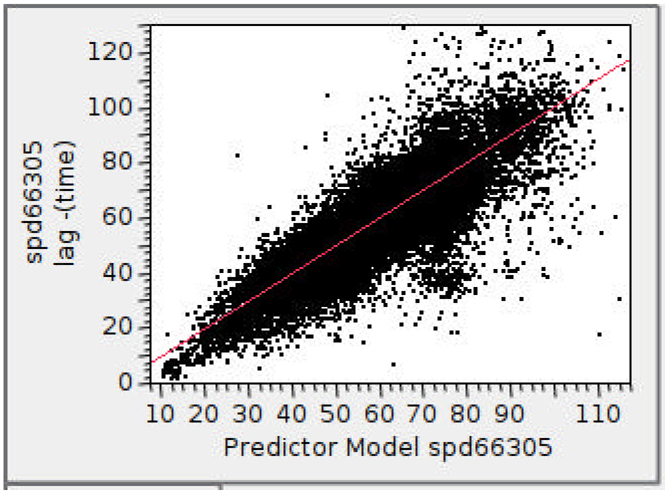

Figure 8. Actual Speed versus Predicted Speed at Sensor 66305

7.2. Re-Routing Models

With respect to the improved software solver, results showed that the best detour path, with respect to avoiding congestion, changes frequently. This was expected as the traffic flow metric on each arc in the traffic network is constantly recomputed, which allows the re-routing to adapt to changes in volume and speed due to previous traffic re-routing.

With respect to the hardware solver, the traffic corridor shown in Figure 2 was implemented as an electric circuit whose schematic is shown in Figure 9. By locating the highest current paths, the best routes with respect to traffic flow can be determined. To measure current, the voltage drop across a fixed value resistor was amplified by an instrumental amplifier, and then sensed by a micro-controller's Analog-to-Digital Converter (ADC). The ADC values were then compared for each segment to find the optimal path.

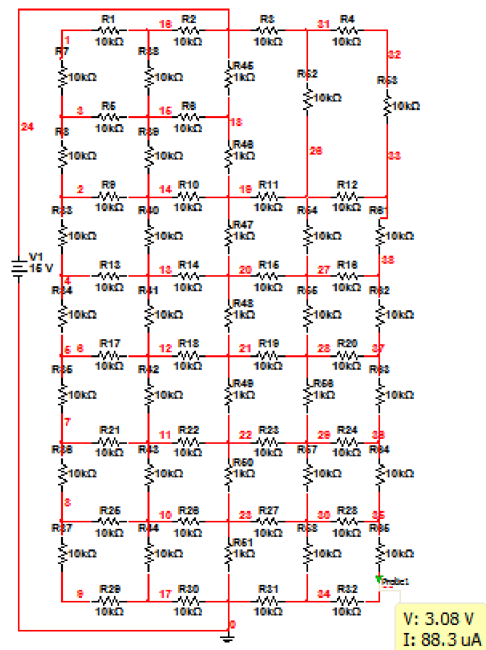

Figure 9. Electrical Schematic Representation of the Traffic Corridor Figure 2

7.3. Micro-Simulation for Incident Management Assessment Strategies

The model was first calibrated with no incidents considered. Traffic volume data was collected from Traffic.com in the form of sensor data for three hours on 7/12/2008, from 3:00 to 6:00 P.M. This volume data, when input to AIMSUN was instrumental in creating a 185 X 185 origin-destination (O-D) matrix for this three-hour duration. A sub-area O-D matrix (185 X 185) is generated for the network under consideration from SEMCOG'S large regional matrix for the year 2015. The two 185 X 185 O-D matrices developed using two different tools from two different sources are input back to AIMSUN and are subjected to dynamic traffic assignment (DTA), while adjusting the DTA parameters.

Sensors present in the model are used to record traffic volumes at five-minute intervals. These traffic volumes are compared to achieve a reasonable correspondence. DTA parameters are adjusted until a desired degree of correspondence is achieved between the two data sources.

Figures 10, 11, 12 and 13 show typical graphs used to determine calibration. Tables 4 and 5 show the statistical results. These graphs and tables show a close enough correspondence between simulation results and collected data to verify calibration.

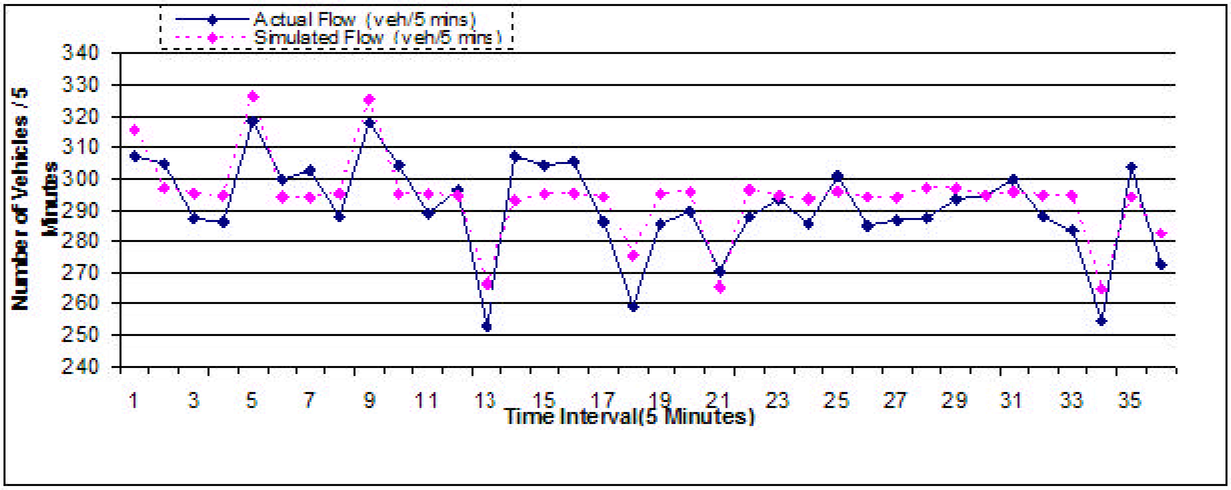

Figure 10. No Incident Scenario
Sensor: MI075200N (I-75 S of 12 Mile Rd.), Date: 7/12/2008, Time: 3:00 - 6:00 P.M.

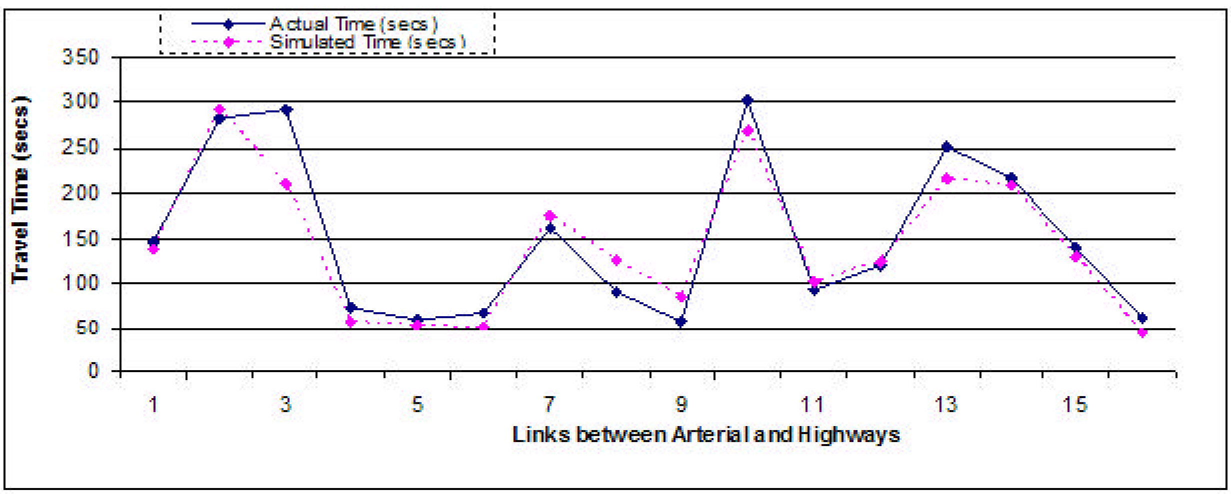

Figure 11. No Incident Scenario
Date: 7/12/2008, Time: 3:00 - 4:00 P.M.

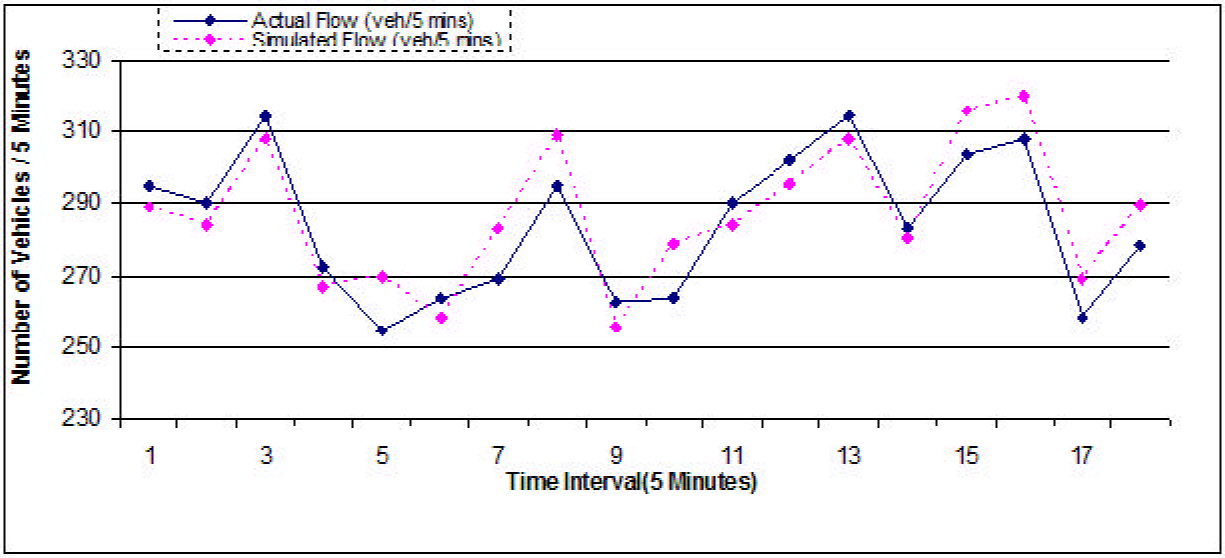

Figure 12. Incident Scenario: Abandoned Vehicle
Right Lane Closure: SB I-75 @ 12 Mile Rd.
Sensor: MI075180S (I-75 S of 14 Mile Rd.), Date: 1/19/2009, Time: 8:35 - 10:00 A.M.

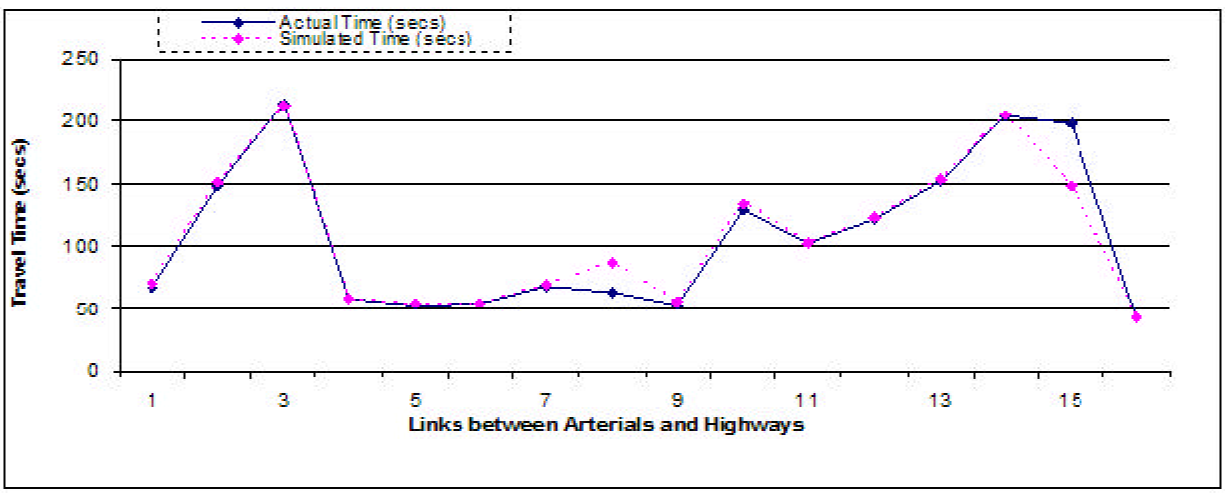

Figure 13. Incident Scenario: Abandoned Vehicle
Right Lane Closure: SB I-75 @ 12 Mile Rd.

Table 4. Summary of Calibration Test Results – Traffic Volume

WITH/WITHOUT INCIDENT	TYPES OF INCIDENTS	DATE, TIME OF THE INCIDENT	LOCATION OF THE INCIDENT	LOCATION OF THE SENSOR	FIGURE	ROOT MEAN SQUARE ERROR (RMSE) % ERROR	CORRELATION COEFFICIENT (R)	THEIL'S WEIGHT OF LARGE ERRORS (U)	THEIL'S VARIANCE PROPORTION (US)	THEIL'S COVARIANCE PROPORTION (UC)	THEIL'S BIAS PROPORTION (UM)
No Incident	No incidents	7/12/2008, 3PM-6PM	No Incident	S of 12 Mile at I-75	1A	0.03	0.95	0.01	0.12	0.89	0.12
				S of 14 Mile at I-75	1B	0.07	0.95	0.03	0.05	0.90	0.10
				S of 12 Mile at I-75	1C	0.03	0.86	0.02	0.29	0.84	0.02
		9/22/2008, 3PM-6PM	No Incident	S of 12 Mile at I-75	2A	0.02	0.95	0.01	0.03	0.98	0.12
				S of 14 Mile at I-75	2B	0.02	0.96	0.01	0.23	0.87	0.04
				S of 14 Mile at I-75	2C	0.03	0.86	0.01	0.26	0.86	0.02
With incident	Abandoned Vehicles	1/19/2009, 9:25AM-10:00AM	SB I-75 @ 12 Mile (Right Lane)	North of I-696 at I-75	4A	0.03	0.92	0.02	0.01	0.97	0.14
				S of 14 Mile at I-75	4B	0.04	0.88	0.02	0.00	0.98	0.07
	Flat Tire	1/19/2009, 5:40PM-7:05PM	SB I-75 @ 12 Mile (Right Lane)	S of 12 Mile at I-75	4C	0.03	0.97	0.02	0.12	0.80	0.13
				S of 14 Mile at I-75	4D	0.03	0.90	0.02	0.06	0.91	0.10
	No Gas	1/24/2009, 3:15PM-4:40PM	NB I-75 @ 13 Mile (Right Lane)	S of 14 Mile at I-75	4E	0.03	0.90	0.01	0.14	0.90	0.04
				S of 12 Mile at I-75	4F	0.02	0.92	0.01	0.20	0.86	0.01
	Mechanical Problems	1/26/2009, 2:25PM-3:50PM	SB I-75 @ 12 Mile (Right Lane)	S of 12 Mile at I-75	4G	0.03	0.95	0.01	0.11	0.89	0.09
				S of 14 Mile at I-75	4H	0.03	0.87	0.01	0.16	0.89	0.10
	Debris on Road	2/6/2009, 4:25PM-5:50PM	SB I-75 @ 14 Mile (Right Lane)	S of 14 Mile at I-75	4I	0.02	0.91	0.01	0.02	0.98	0.11
				S of 15 Mile at I-75	4J	0.02	0.96	0.01	0.10	0.95	0.01
	Accident	1/13/2009, 8:10AM-9:35AM	SB I-75 @ 13 Mile (Right Lane)	S of 12 Mile at I-75	4K	0.03	0.93	0.01	0.02	0.96	0.34
				S of 14 Mile at I-75	4L	0.03	0.96	0.01	0.02	0.90	0.26

Table 5. Summary of Calibration Test Results – Travel Time

WITH/WITHOUT INCIDENT	TYPES OF INCIDENTS	DATE, TIME OF THE INCIDENT	LOCATION OF THE INCIDENT	FIGURE	ROOT MEAN SQUARE ERROR (RMSE) % ERROR	CORRELATION COEFFICIENT (R)	THEIL'S WEIGHT OF LARGE ERRORS (U)	THEIL'S VARIANCE PROPORTION (US)	THEIL'S COVARIANCE PROPORTION (UC)	THEIL'S BIAS PROPORTION (UM)
No Incident	No incidents	7/12/2008, 3PM-4PM	No Incident	3A	0.21	0.96	0.08	0.16	0.82	0.06
		9/22/2008, 3PM-4PM	No Incident	3B	0.15	0.97	0.07	0.10	0.80	0.15
With Incident	Abandoned Vehicles	1/19/2009, 9:35AM-10:00AM	SB I-75 @ 12 Mile (Right Lane)	5A	0.12	0.97	0.06	0.13	0.94	0.00
	Flat Tire	1/19/2009, 5:40PM-7:05PM	SB-I-75 @ 12 Mile (Right Lane)	5B	0.06	0.99	0.04	0.19	0.85	0.06
	No Gas	1/24/2009, 3:15PM-4:40PM	NB I-75 @ 13 Mile (Right Lane)	5C	0.11	0.98	0.04	0.05	0.89	0.14
	Mechanical Problems	1/26/2009, 2:25PM-3:50PM	SB-I-75 @ 12 Mile (Right Lane)	5D	0.07	0.98	0.05	0.04	0.94	0.07
	Debris on Road	2/6/2009, 4:25PM-5:50PM	SB I-75 @ 14 Mile (Right Lane)	5E	0.10	0.96	0.07	0.01	0.97	0.17
	Accident	1/13/2009, 8:10AM-9:35AM	SB I-75 @ 13 Mile (Right Lane)	5F	0.06	0.99	0.02	0.00	0.90	0.00

The calibrated model, along with the appropriate parameters, was used to test the effectiveness of alternative IMS on the same network. The two types of IMS were adapted from AIMSUN, then tested: lane closure, and forced turning (FT).

Lane closure refers to a scenario where single or multiple lanes are closed for a given freeway section. FT refers to scenarios where vehicles are forced to divert from their original intended path, due to the occurrence of a road closure. For each IMS tested, two types of performance data are gathered: unit travel time and unit delay, both measured in seconds per kilometer per vehicle. In all the cases recorded, both travel time and delay measures are reduced under guided conditions signifying a positive impact of the IMS in alleviating congestion.

8. Conclusions

8.1. Statistical Analysis

MLM can be use to predict traffic speed up to 30 minutes in the future. Only two speed values are required to make such predictions, making computations fast and data storage requirements minimal. The parameters of statistical models used to make such predictions may need to be recomputed frequently (monthly) to minimize prediction errors.

8.2. Re-Routing Models

Dynamic re-routing models can be used with an ITS to route traffic around incidents in near-real time, including changing alternative routes in response to traffic flow. A hardware-based model solver may be needed to perform needed computations in near-real time.

8.3. Micro-Simulation for Incident Management Assessment Strategies

Micro simulation analysis shows that managed routing of traffic improves traffic volume and travel time in dealing with a traffic incident.

9. Recommendations for Future Research

9.1. Statistical Analysis

The MITSC data can be used to indicate the potential benefits of avoiding turbulent conditions such as those caused by non-metered entry during rush hour.

9.2. Re-Routing Models

For the re-routing model of the I-75 corridor, a formal comparison of the computational speed of the hardware and software solvers would be helpful.

A test of the re-routing model with respect to re-routing traffic around a freeway incident at MITSC is a necessary next step. This would involve obtaining the data needed by the model in near-real time and transmitting re-routing information via message signs or other electronic means to vehicles. Performance metrics would need to be developed.

9.3. Micro-Simulation for Incident Management Assessment Strategies

The role of traffic simulation in regional modeling should be explored.

10. Recommendations for Implementation

10.1. Statistical Analysis

MLM models can be straightforwardly developed from traffic data on speed. Speed prediction from MLM models can be used in software to compute the freeway travel time from one location to another. Such times are often displayed on message signs.

10.2. Re-Routing Models

Implementation would depend on the results of the test of the model at the MITSC described in the preceding section.

10.3. Micro-Simulation for Incident Management Assessment Strategies

Traffic routing policies should be assessed using micro-simulation before implementation.

11. List of Acronyms, Abbreviations, and Symbols

ADC	Analog-to-Digital Converter
CEE	Civil and Environmental Engineering
DTA	Dynamic Traffic Assignment
ECE	Electrical and Computer Engineering
FT	Forced Turning
GVSU	Grand Valley State University
IMS	Incident Management Scenario
ITS	Intelligent Transportation System
MDOT	Michigan Department of Transportation
ME	Median Error
MIOH-UTC	Michigan Ohio University Transportation Center
MITSC	Michigan Intelligent Transportation Systems Center
MLM	Multi-Level Model
O-D	Origin Destination Matrix
SCIS	School of Computing and Information Systems
SEMCOG	Southeastern Michigan Council of Governments
SOE	School of Engineering
USDOT	United States Department of Transportation
WSU	Wayne State University

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