AN INTEGRATED KNOWLEDGE-BASE/SIMULATION SYSTEM FOR REAL-TIME INCIDENT MANAGEMENT

Nan Zou, Pei-Wei Lin[1], Gang-Len Chang[2], Saed Rahwanji[3]

ABSTRACT

This paper presents a real-time incident management system that integrates the knowledge base with a microscopic traffic simulation model. The system consists of five modules: input module, knowledge-based module, prediction module, simulation module, and output module. The knowledge base is used to inventory the operational experience and traffic impact information associated with all recorded incidents. The prediction module is developed to predict the information of maximum queue length and incident duration predictions. The simulation module, developed with design plans for construction, contains traffic volumes and all detailed geometric features for both mainline segments and interchanges.

The proposed system will enable traffic control operators during the incident management period to perform two critical functions: (1) having an immediate estimate of the traffic impacts such as the queue length, average speed due to the detected incident; and (2) performing a subsequent detailed real-time analysis of network traffic conditions under various candidate incident management and/or control strategies with the simulation module. The simulation results also offer the information between departure time and estimated travel time during the period of incident management. Furthermore, the system can also connects to the on-line detectors so that the real-time information can be used in the prediction and update of the simulation module.

To minimize both the learning and executing efforts of our target users, the integrated simulator is given a GIS-type of map features, allowing the operators to perform the input and output tasks through a user-friendly graphical interface.

Keywords: Incident Management, Incident Impact Prediction, and Knowledge-Base Simulation System.

INTRODUCTION

Efficient response to a detected incident so as to minimize the impact of non-recurrent congestion has long been recognized by highway traffic agencies, and a variety of corporative traffic management programs have also been implemented over the past decades (1-5), especially since the emerge of Intelligence Transportation System (ITS). One of the essential aspects which has yet to be better addressed in the incident management is to have a system that can reliably project the incident impacts on the traffic network within a time period sufficiently short for real-time operations, such as display of variable message signs (VMS) at proper locations, implementation of detour plans at critical ramps, and report of traffic conditions through highway advisory radios. With such information, traffic control operators can employ available ATIS or ATMS strategies to prevent the formation of traffic queue or to mitigate the congestion level if traffic shockwaves due to the incident have been propagated. To provide a reliable estimate of traffic impacts during the period of incident management, however, is a quite challenging task, as the traffic condition (such as queue length, average delay, or speed) over those segments plagued by the incurred incident may vary with a

[1] Ph. D. student, Department of Civil and Environmental Engineering, University of Maryland at College Park, 20740, MD, USA, Phone: (301)-405-8736, Fax: (301) 405-2585
[2] Professor, Department of Civil and Environmental Engineering, University of Maryland at College Park
[3] Maryland State Highway Administration, SRahwanji@sha.state.md.us

variety of factors which are all time-varying in nature. Examples of such factors include the progress of incident clearance efforts, the speed and volume of the approaching traffic from upstream segments, compliance rate of a detour operation, effectiveness of VMS, and ramp metering control.

In response to this need, transportation professionals over the past several decades have devoted considerable efforts on development of various methods for projection of traffic conditions (6-9). Most of these state-of-the-art studies reported in the literature, either based on statistical methods (7-8), knowledge-base approaches (1-5, 10), or simulation techniques are quite promising in nature, but inadequate for use in real-time incident management where both efficiency and accuracy are essential for every step of its operations. Hence, from the perspective of traffic control operations, it would be very desirable if there exists an effective system that can provide the vital functions for incident response and management.

Currently, a system with all such desirable functions should be sufficient user-friendly to minimize both the learning time and execution efforts of control center operations (11). The knowledge-base/simulation system, named I-270 simulator, to be presented in the ensuing sections is designed with the above functions in mind. Our proposed system features its capability to offer an immediate estimate of traffic conditions based on similar previous incident scenarios stored in the knowledge base. The effectiveness of previous employed congestion management strategies is also available from the knowledge base for incident operations. The preliminary estimated results also allow the microscopic simulation module, embedded in the I-270 simulator, to select the target sub-network and execute its detailed operational analysis under the instruction from the control center operators. To ensure that the potential users under stressed condition (e.g. during incident operations) can execute our proposed system correctly and efficiently, we have employed the GIS type of graphical interface for both the input and output modules.

This paper is organized as follows: the operational structure and key features of the proposed I-270 simulator is presented in the next section. This is followed by an illustrative example of executing the proposed system under an incident scenario in Section 3. Conclusions and further research needs are reported in the last section.

OPERATIONAL STRUCTURE OF THE I-270 SIMULATOR

In practice, upon receiving an incident report, the control center operator will immediately dispatch emergency response units (ERU) to the incident site, and then estimate the potential traffic impacts such as the evolution of traffic queues, vehicle delays, and speeds during the incident management period. Such traffic impact information will offer the basis for operators in the control center to determine where and how to inform the approaching motorists, and evaluate the necessity as well as effectiveness of implementing any traffic control strategies. The I-270 simulator reported in this study is designed to assist traffic operators in performing these critical prediction and evaluation tasks in real-time incident management. As illustrated in Figure 1, our developed I-270 simulator consists of the following principal modules:

- Interface module for information input and for receiving real-time data;
- Simulation module for real-time analysis and projection of network traffic conditions due to detected incidents;
- Knowledge-base/prediction module for both inventorying previous incident scenarios and performing the preliminary estimate of the traffic impacts.
- Output module for monitoring and assessing the time-varying traffic conditions on target roadway segments after the onset of an incident

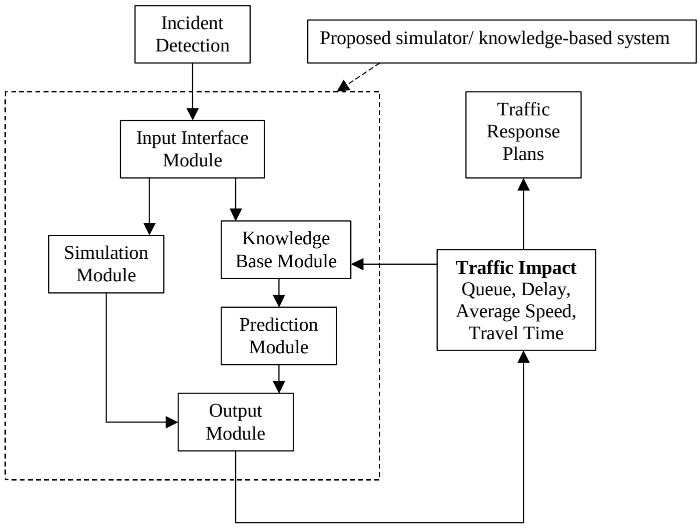

Figure 1. Principal modules and their interrelations in the simulation/knowledge-based system for real-time incident management

Note that the preliminary estimate of traffic conditions with the knowledge-base/prediction module can be done in less than one minute, but the real-time simulation of the I-270 network will take, for instance, about 5 minutes for the impact period of 50 minutes. The purpose of executing the knowledge base/prediction function is thus to offer the traffic operator an immediate and best estimate of traffic conditions during the incident period while the simulation module remains interacting with real-time data and executing the microscopic analysis of traffic conditions over the projected incident clearance period.

After completing the initial simulation, the I-270 simulator will automatically replace the traffic conditions estimated from the knowledge-base/prediction module with the simulated results, which will then serve as the basis for control center operators to update or revise their incident management plan. Depending on the available on-line detector data, the microscopic traffic simulator can continuously update the projected traffic condition and evaluate the effectiveness of various candidate control strategies to be implemented during the incident management period. The output nodule of the I-270 simulator offers a full flexibility for traffic control operators to monitor the traffic condition of any segment over the selected time horizon under either the current operating plan or various “what-if” scenarios. A detailed illustration of the above operational procedures and interrelations between all principal modules of the I-270 simulator is presented in Figure 2. The key design features of each principal system module are briefly discussed below:

Input Interface Module: This module employs the GIS design concept that enables the users to first directly identify the approximate location of the target freeway segment from the map, and then input the related information (if available) through subsequent interactive questions, as the geometry data contained in the I-270 microscopic simulation module are directly imported from the highway design plans which contain more detailed geometric features than those in the GIS.

Knowledge-Base Module: This module is designed to take advantage of information and operational experience accumulated from previous incident management experiences. For instance, Maryland State Highway Administration (MSHA) has kept a detailed response time, incident duration, lane-blockage conditions, and the approximate traffic impacts on the network for each responded incident. All such incident impact information and management experiences from the year 1997 to 2002 are available for constructing the knowledge base. Such a knowledge base will offer the traffic control operators a reliable reference for estimating the potential impact due to a detected incident (e.g., from previous incidents incurred around the same location and over similar time periods).

Prediction Module: This is a set of statistical models designed to perform a supplemental analysis for the knowledge-based module, as a detected incident may not exist in the current database. Hence, the prediction module will execute its embedded statistical models, based on the Ordered Probit Model and the candidate set of similar incidents identified by the knowledge base, to provide a quick prediction of the incident duration during the period of incident management. Two Ordered Probit Models presented in this paper are estimated by the Year 2001 incident data provided by the highway incident management program of the Maryland State Highway Administration, named CHART. The Scaled R^2s for the two models are 0.69 and 0.38, respectively. After adopting the 2002 incident data to the precision test, the accuracy of the two models are 51.80% and 35.17%, respectively. The incident duration is categorized into 30 intervals. The incident with an incident duration less than 150 minutes is categorized as an interval for every 5 minutes. The incident with an incident duration larger than or equal to 150 minutes is categorized as interval 30.

Model 1:

$$
\begin{aligned}
Y^* &= 1.198 + 0.054 \times \text{RespTime} - 0.222 \times \text{ShldrBlck} - 0.921 \times \text{Chart} + 0.477 \times \text{Weekend} \\
&+ 0.547 \times (\text{ShldrBlck} + \text{LaneBlck}) / \text{NumLane} + 0.273 \times \text{Truck} + 0.317 \times \text{TractorTrailer} \\
&+ 0.594 \times \text{VehicleFire} + 0.806 \times \text{Collision-PersonalInjury} + 1.851 \times \text{Collision-Fatal}
\end{aligned}
$$

Thresholds: -∞, 0, 0.5498, 1.0642, 1.4758, 1.8569, 2.2360, 2.5503, 2.7742, 3.0085, 3.2204, 3.4463, 3.5783, 3.8457, 4.0097, 4.1452, 4.3825, 4.5063, 4.6179, 4.7719, 4.8640, 4.9534, 4.9945, 5.0910, 5.1467, 5.1865, 5.2079, 5.3156, 5.3825, 5.4048, ∞

Model 2:

$$
\begin{aligned}
Y^* &= 0.882 - 0.182 \times \text{ShldrBlock} + 0.247 \times \text{LaneBlock} - 0.312 \times \text{Chart} \\
&+ 0.433 \times \text{Truck} + 0.400 \times \text{TractorTrailer} + 0.090 \times \text{VehicleNum} - 0.144 \times \text{Peak} \\
&+ 0.577 \times \text{VehicleFire} + 0.985 \times \text{Collision-PersonalInjury} + 3.152 \times \text{Collision-Fatal}
\end{aligned}
$$

Thresholds: -∞, 0, 0.4622, 0.8791, 1.2002, 1.4865, 1.7571, 1.9719, 2.1210, 2.2696, 2.3966, 2.5280, 2.6030, 2.7437, 2.8219, 2.8853, 2.9951, 3.0480, 3.0946, 3.1636, 3.2060, 3.2510, 3.2754, 3.3364, 3.3757, 3.4031, 3.4174, 3.4940, 3.5435, 3.5602, ∞

Simulation Module: It is the core of the I-270 traffic simulator, featuring its ability to simulate the actual traffic condition over the period of incident operations, or to assess the effectiveness of various candidate incident management strategies. Since the entire simulation needs to be executed at a sufficiently fast speed for real-time operations (e.g. 5 minutes for 1 hour simulation), the simulation module is capable of simulating only the sub-network that is likely to be impacted by the detected incident, rather than the entire I-270. The current simulator is build with CORSIM – the corridor simulation program by FHWA.

Output Module: While executing the I-270 simulator, this module will first yield the projected traffic conditions from the knowledge-base/prediction module in response to the urgent need of the traffic operators. All such results will then be automatically replaced with those from real-time simulation and updated continuously as more real-time data become available.

Overall, the proposed I-270 simulator has taken advantage of strengths from simulation, knowledge base, and GIS, and integrated all information such as roadway geometry, volume and control strategies as an effective system for incident management. Traffic operators with such a system can first reference previous incident scenarios to provide immediate incident impact assessment, and then evaluate various operational plans with a real-time simulation analysis. They can also continuously monitor traffic conditions in either the entire network or on target segments with the proposed output module, and take necessary actions in advance to minimize the formation of congestion.

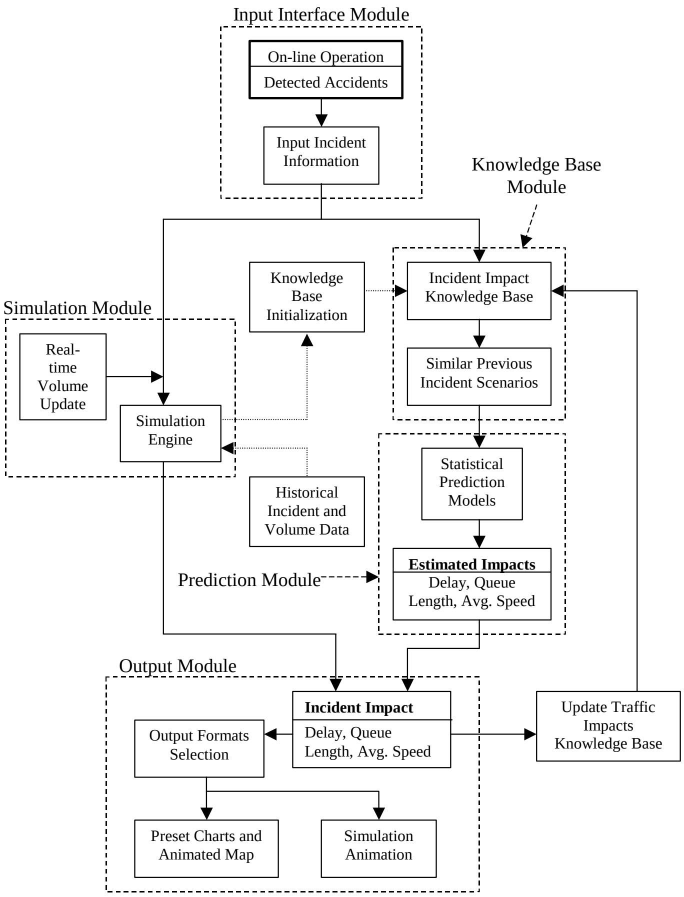

Figure 2. Flowchart of principal modules in the simulation/knowledge-based system

AN EXAMPLE OPERATION OF THE I-270 SIMULATOR

To facilitate the illustration, the incident scenario is used to present the operating process of the developed I-270 simulator: At 8:20AM, one incident occurred on the south bound of I-270 between exit 5 and exit 6. The second right lane has been blocked. The location of the incident is about 1500 feet from exit 6. The estimated time for recovering the traffic is about 40 minutes.

With the above information input by the operator, the I-270 simulator will automatically provide the estimated time-varying impacts of the detected incident on the I-270 with its knowledge-base/prediction module, while executing its simulation module. In this assumed incident scenario, the knowledge-base module has yielded 4 similar previous incidents for further execution of the prediction task (see Table 1). From these previous incidents, the prediction module, which contains statistical models, will first identify the sub-network of I-270 which would be impacted by the detected incident (see Table 2), and then perform the preliminary estimation of its traffic conditions based on procedures shown in Figure 3.

Table 1. 4 similar incident cases that are generated from the knowledge base and are used for preliminary prediction of traffic conditions due to the detected incident

	Time	Duration	Lane Blockage	Location
Current Incident	8:20AM	40 min	2nd Right Lane	1500 ft from upstream Ex 6
Similar Case 1	8:00AM	60 min	Most Right Lane	800 ft from upstream Ex 6
Similar Case 2	8:00AM	60 min	Most Right Lane	2876 ft from upstream Ex 6
Similar Case 3	8:30AM	60 min	Most Right Lane	800 ft from upstream Ex 6
Similar Case 4	8:30AM	60 min	Most Right Lane	2876 ft from upstream Ex 6

Table 2. Estimated impact segment for detected incident from the information of first 40 minutes of similar incident cases

	Impact Segment	Time Period
Similar Case 1	From Exit 9 to Exit 5	8:00-8:40
Similar Case 2	From Exit 9 to Exit 5	8:00-8:40
Similar Case 3	From Exit 9 to Exit 5	8:30-9:10
Similar Case 4	From Exit 9 to Exit 5	8:00-9:10
	Estimated Impact Segment	
Current Incident	From Exit 9 to Exit 5	8:20-9:00

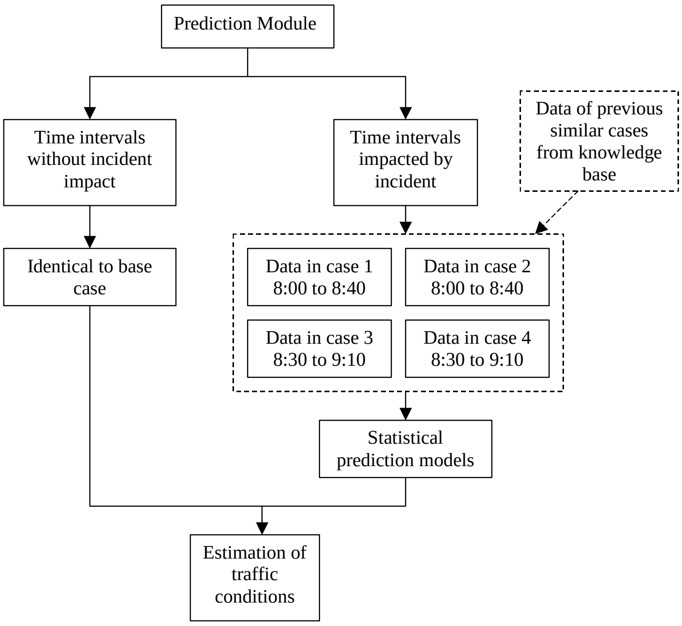

Figure 7. The procedures of preliminary estimation performed with the prediction module

While the I-270 simulator is generating the preliminary incident impact information with its knowledge base and prediction modules, its simulator module will be simulating the network traffic conditions with real-time information. The geometry features of the I-270 network embedded in the simulation are as detailed and accurate as those available from highway design plans, which include: Freeway segments (both horizontal and vertical alignments), Local roads, Ramps, HOV lanes, Signal controls at ramps and surface streets, and Traffic signs. The simulation module covers the entire I-270 and part of the I-495 network. An example interchange included in the simulator is shown in Figure 4.

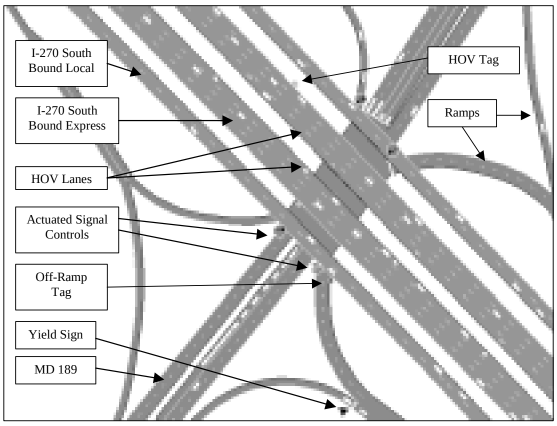

Figure 4. An example interchange of Great Falls Rd. (MD189) at I-270

Note that to minimize the execution time the simulator, based on the preliminary estimate from the knowledge-base module, will simulate only the sub-network to be impacted by the incident, rather than the entire network.
As soon as executing the I-270 simulator, the operators can choose to directly view the animation of the entire system during the incident operations, or to review traffic conditions with the preset output formats. For instance, the operator may monitor the traffic impacts due to the incident by first selecting the display of delay charts and average speed distributions, and then targeting the roadway segment between exit 9 and exit 5, from 8:30 to 9:50 (see Figure 5a). The output module of the I-270 simulator offers the functions as shown in Figure 5,6, and 7.

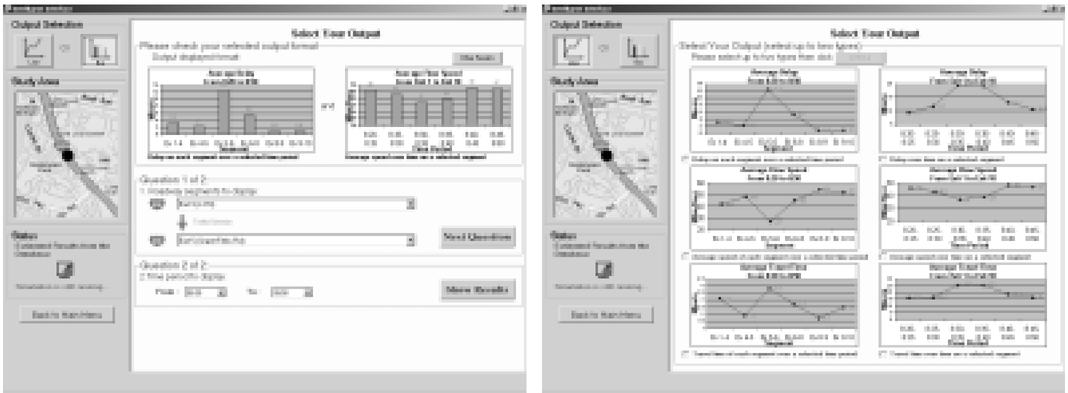

Figure 5. A screenshot of the display format selection from the output module

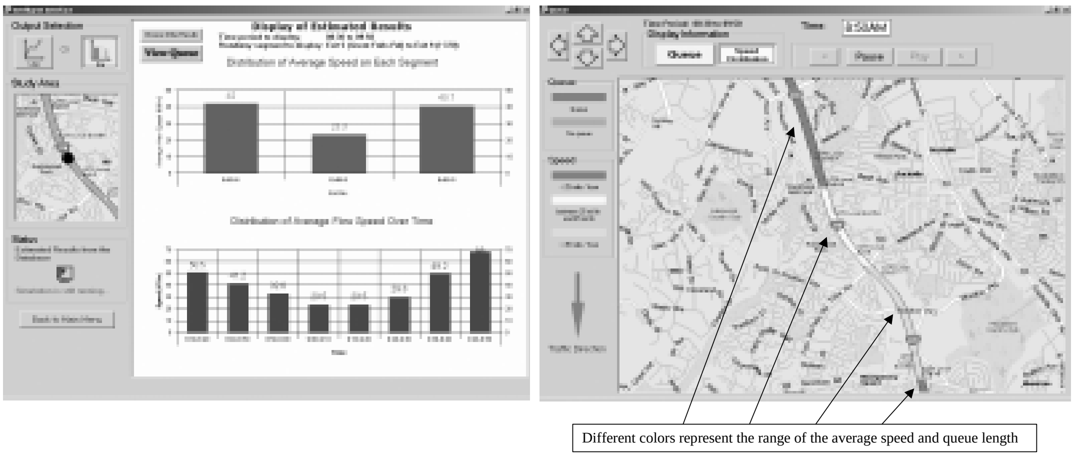

Figure 6. A screenshot of chart output for the case study and the animated map output

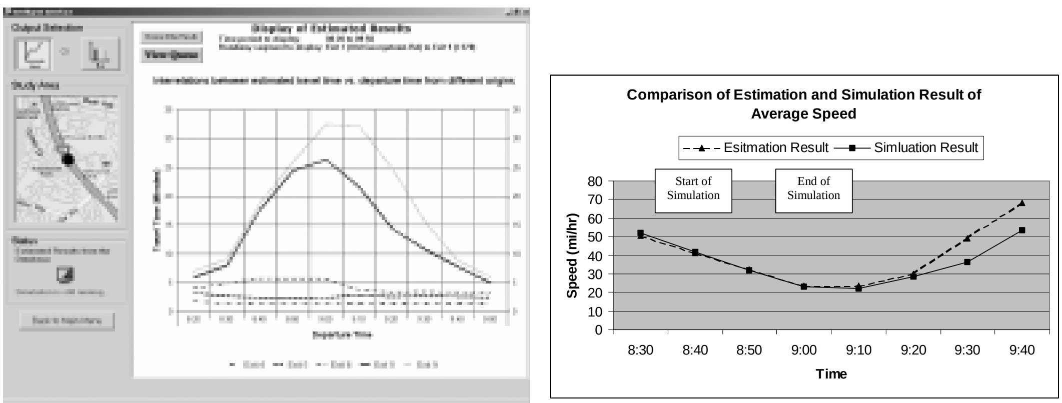

Figure 7 Interrelations between estimated travel time vs. departure time from different origins and Interrelations between the preliminary estimation and simulation result

CONCLUSION

The study has presented a knowledge-base/simulation system to assist traffic operations in real-time incident management. Our proposed system has taken advantage of strengths from microscopic simulation, knowledge base, and GIS, offering the flexibility for control center operations to perform the immediate preliminary estimate of incident impacts and subsequent detailed real-time operational analysis. With the proposed system, traffic control center can learn from previous incident management experience, and also use state-of-the-art simulation for efficient real-time analysis. Since the simulation module, based on the preliminary estimated results, can automatically decompose the network and simulate only the sub-network to be impacted by the incident, its computational speed is far faster than real-time. This distinguished feature allows traffic control center to effectively evaluate all candidate incident response plans and management strategies prior to their implementation.

Our on-going research is to integrate the proposed system with an optimization module that can assist traffic control operators in selecting the most effective plans such as ramp metering, integrated freeway/surface street control, in contending with non-recurrent congestion.

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