Uso de datos ITS para calibrar modelos de simulación microscópica para condiciones incidentes

Use of ITS data to calibrate microscopic simulation models for incident conditions

Álvarez P.1 y Hadi M.2

[1]Departamento de Ingeniería Civil y Ambiental, Universidad del Bío-Bío, Chile.
[2]Department of Civil and Environmental Engineering, College of Engineering and Computing, Florida International University, United States.
palvarez@ubiobio.cl, Phone: 56-41-3111645, 56-41-3111646

INFORMACIÓN DEL ARTICULO

Historial del artículo:

Recibido 11-07-2013
Aceptado 22-11-2013
Publicado 18-12-2013

Palabras Claves:
Simulación de tráfico
Calibración
Incidentes
Datos de Sistemas Inteligentes de Transporte

Resumen

Varios estudios han investigado la calibración de modelos de simulación de tráfico para condiciones de congestión recurrentes. Sin embargo, existen limitadas referencias respecto de la validación y calibración de modelos de simulación para condiciones no recurrentes de tráfico (incidentes). Dado que la información generada por dispositivos de monitoreo en Sistemas Inteligentes de Transporte (ITS) es cada vez más accesible, la utilización de dichos datos para el desarrollo y calibración de modelos de simulación de tráfico, tanto en presencia de incidentes y en condiciones normales de operación, en una opción natural. Este estudio investiga la utilización de archivos de datos ITS para apoyar el desarrollo y calibración de modelos de simulación de tráfico en condiciones no recurrentes de operación.

Los resultados de este estudio indican que los parámetros del modelo de simulación deben ser ajustados para reproducir los descensos esperados en la capacidad y consecuentemente reproducir además los impactos de los incidentes de tránsito en el desempeño del sistema. Los datos ITS proporcionan información valiosa para apoyar este proceso, incluidos entre otros, las características de los incidentes, el manejo o gestión de los incidentes, medidas de desempeño del sistema y otros insumos necesarios para el proceso de modelación. La simple especificación de bloqueos en las pistas del sistema simulado sin la calibración adecuada de los parámetros del modelo de simulación no es suficiente para reproducir los efectos esperados de los incidentes en la simulación.

Article history:

Received 11-07-2013
Accepted 22-11-2013
Available 18-12-2013

Keywords:
Traffic Simulation
Calibration
Incidents
Intelligent Transportation

Abstract

A large number of studies have investigated the calibration of traffic simulation models for recurrent congestion conditions. However, very limited research has been done to support the validation and calibration of simulation models for incident conditions. As the data archives of Intelligent Transportation Systems (ITS) become more widely available, the utilization of such archives for the development and calibration of simulation models, for both incident and no-incident conditions, will become a logical option. This study investigates the utilization of ITS data archives to support the use of simulation to model incident conditions. The results from this study indicate that simulation model parameters should be fine-tuned to produce the expected or measured drops in capacity and incident impacts on system performance.

ITS data can provide valuable information to support this process including incident attributes, associated incident management activities, traffic performance measures, and other inputs required to the modeling process. Simply specifying lane blockages in the simulation without the proper fine-tuning of simulation model parameters is not sufficient to reproduce the expected impacts of incidents in the simulation.

1. Introduction

Traffic incidents have significant impacts on the performance of transportation systems. These incidents can reduce roadway capacity and result in excessive queues and delays. Advanced Transportation Management Systems (ATMS) have been applied successfully to minimize the negative impacts of incidents on traffic operations. However, to improve the effectiveness of ATMS, there is a need to assess how different types of incidents affect traffic operations and the impacts of various incident management strategies and technologies on system performance. Many of the existing studies used for such assessments have utilized analytical methods such as queuing and shock wave analyses. Hadi et al. [1] have also utilized the freeway facility analysis procedures in the Highway Capacity Manual (HCM) [2] for this purpose.

This procedure uses shock wave analysis combined with other HCM procedures to assess the impacts of queuing, such as for cases in which the capacity drops due to incidents.

Microscopic traffic simulation modeling has been proposed as a more detailed, flexible, and potentially more accurate, approach for assessing the impacts of incidents and management strategies. A microscopic simulation tool can model individual vehicles on a roadway network, typically on a second-by-second, or a fraction of a second, basis. Microscopic simulation models have the benefit of being able to model complex roadway geometries, traffic control devices, integrated multi-facility operations, variations in vehicle characteristics, and variations in driver behaviors. These simulation model's capabilities are beyond those of the existing analytical methods. However, modeling microscopic driver behaviors is difficult under normal traffic conditions and even more difficult under incident conditions. Limited research has been done to understand how incidents impact microscopic driver behaviors, such as lane changing and vehicle following, which are critical to the accuracy of microscopic traffic simulation modeling. These microscopic behaviors directly impact the macroscopic traffic performance measures, such as throughput, density, speed, and queue length, as assessed by the simulation models.

A large number of studies have investigated methods to calibrate simulation models for recurrent conditions. For example, Volume 3 of the Traffic Analysis Toolbox series produced by the Federal Highway Administration (FHWA) [3] includes guidelines for calibrating traffic micro-simulation modeling tools. Volume 4 of that series [4] presents guidelines that are specific to the calibration of the CORSIM microscopic simulation tools. However, very limited research has been done to identify those methods with which to validate and calibrate simulation models for incident conditions.

Intelligent Transportation Systems (ITS) agencies have used traffic detectors to collect measurements of traffic flow parameters for operational purposes. In recent years, these agencies have started archiving the data collected by these devices [5]. As ITS data archives become more widely available, the utilization of such archives for the development and calibration of simulation models for both incident and no-incident conditions will become a logical option. This utilization allows a significantly lower cost and a more effective development and calibration as compared to the utilization of data collected using traditional methods. The additional details provided by the ITS data will allow for better representations of real-world environments in simulation applications. This study investigates the utilization of ITS data archives to support the use of simulation to model incident conditions. The ITS data archives utilized include detailed incident management and point traffic detector data.

2. Previous studies on incident impacts

Traffic incidents can introduce two types of changes that can impact traffic operations; changes in the roadway environment and changes in driver behaviors. Examples of changes in the roadway environment include capacity reductions due to lane and/or shoulder closures and changes to traffic control strategies such as ramp metering, incident site control, and dynamic message sign activations. On the other hand, changes in driver behaviors include changes in the microscopic (tactical and operational) driving behaviors, such as lane changing, car following, speed, gap acceptance, and accelerating behaviors. In addition, incidents can modify strategic driving behaviors such as changes to trip route, mode, and time choices.

There are a limited number of studies that have investigated the impacts of traffic incidents. These studies mostly focused on the impacts on macroscopic traffic measures such as the reduction in capacity, rather than on microscopic traffic parameters such as lane changing and car following parameters. The reason is that the impacts on macroscopic measures can be more easily assessed by utilizing current data collection technologies. This section includes a review of the studies available on the subject.

2.1 Incident impacts on roadway environment

The studies of incident impacts on the roadway environment have mostly focused on the reductions in capacity due to incidents. These capacity reductions were studied by Goolsby [6] in 1970. He concluded that an incident, blocking one lane out of three lanes, reduces capacity by about 50%. He also concluded that an incident, blocking two lanes out of three lanes, reduces the capacity by about 79%. HCM 2000 [2] provides estimates of the remaining capacity during incident conditions as a function of the number of the blocked lanes (or shoulder) and the number of lanes of the highway section under consideration. The HCM estimates have been widely used in studies that investigated the effects of incident management strategies on system performance.

A study by Qi and Smith [7] found, based on data collected in the Hampton Roads in Virginia, that the capacity reduction with one lane blocked out of three lanes can be modeled as a Beta distribution with an average of 63% and a standard deviation of 14%. The study also found that the capacity reduction due to two blocked lanes out of three lanes can be modeled as a Beta distribution with an average of 77% and a standard deviation of 12%.

Knopp et al. [8] found that in the case of a blocked driving lane, the queue discharge rate for each available lane is reduced by 50%. They also found that the queue discharge rate is reduced by 30% when the driving lanes are open but there is an incident on the shoulder or on the opposite direction of travel.

Hadi et al. [9] adjusted the parameters of three widely used microscopic simulation tools to determine their abilities to replicate the reported reductions in capacities due to traffic incidents. They concluded that it was possible to fine tune the parameters of the three simulation tools to simulate the drops in capacities due to incident lane blockages.

2.2 Incident impacts on microscopic driver behavior

One existing study investigated the impacts of incidents on the microscopic behaviors of drivers. The study collected empirical trajectory data using a digital camera mounted under a helicopter (10). The analysis showed considerably different behaviors between driving under normal conditions and driving at the incident sites. It was found that at incident sites, drivers choose a longer headway, have higher reaction time, and reduce speed. These behavioral changes lead to queue discharge rates during incident conditions that are between 60% to 75% of the normal queue discharge rate per lane, according to the study.

2.3 Incident impacts on strategic driver behavior

The study of incident impacts on driver behaviors have focused on changes at the strategic behavior level, particularly changes in the route choice behavior. Several researchers have used the stated preference approach to determine the percentage of travelers changing trip decisions in response to information disseminated by advanced Traffic Information Systems (ATIS). The studies concluded that, based on these types of surveys, the disseminated information can result in up to 60% to 70% of the freeway traffic exiting the freeway ahead of an incident location [11-14]. However, limited information is available about the actual diversion due to traveler information as reflected by revealed preference or field measurements. Several European field studies have found that dynamic message signs (DMS) compliance rates range between 27% to 44% [15]. Knopp et al. [16] found that for major incidents, up to 50% of travelers take another route.

Luk and Yang [17] developed a simulation modeling framework to assess the performance of ATIS under different conditions. They assumed the average diversion rate to be 15% and the highest diversion rate to be 30%. Cragg and Demetsky [18] used the CORSIM microscopic simulation tool to analyze route diversion strategies from freeways to arterial roads. The study concluded that there was often an optimal diversion percentage beyond which the system delays increased. This diversion percentage is expected to be different for different systems depending on traffic and incident conditions on the original and alternative routes.

3. Utilized its data

As stated earlier, the objective of this paper is to investigate the use of archived ITS data to support the simulation of incidents and incident management activities. The Florida Department of Transportation (FDOT) districts have installed traffic detectors to collect traffic parameters for operational purposes. The detector data have been stored in what can be referred to as operational databases that include volume, speed, and occupancy measurements by lane at short time intervals (20 to 30 seconds). The FDOT has also investigated storing the data in a data warehouses for long-term use. As part of this investigation, the Statewide Transportation Engineering Warehouse for Archived Regional Data (STEWARD) has been developed as a proof of concept prototype for the collection and use of ITS data in Florida [19]. The current effort has concentrated on archiving point traffic detector data and travel time estimates. The STEWARD data warehouse includes data checking, filtering, cleaning, and imputation processes to ensure the quality of the traffic detector stored data. The data can be aggregated at the 5, 15, and 60-minute aggregation levels.

In addition, the traffic management centers in Florida maintain detailed incident management archives. The incident archives include incident timestamps (detection, notification, responses, arrivals, and departures), incident ID, responding agencies, event details, chronicle of the event, and environmental information for all incidents in the region. This study uses the data stored in the STEWARD data warehouse and incident management archives in Florida. Although this study uses Florida ITS data archives in the analyses, the results are applicable to the use of ITS data archives in other regions.

4. Methodology

The availability of detailed incident and traffic detector data from ITS data archives allows the identification of important parameters required to model incidents in simulation models. These parameters include traffic demands during incident conditions, diversion rates, capacity reductions due to incidents, and the resulting impacts on various performance measures. This section describes the estimation and use of these parameters for simulating incident conditions. The CORSIM microscopic simulation tool is used to illustrate this use. However, similar procedures can be used for other simulation tools.

Simulating incident impacts on traffic requires the following steps:

a) Estimation of traffic demands during no-incident and incident days;
b) Estimation of capacity during incident and no-incident conditions;
c) Fine-tuning of simulation model parameters with the objective of producing, in the simulation, the capacities estimated for incident and no-incident conditions; and
d) Fine-tuning of simulation model parameters to produce observed performance measures based on traffic detector data.

These steps are discussed in the next section.

4.1 Estimation of traffic demand

The first challenge in setting a simulation model for incident conditions is to estimate the traffic demands during these conditions. In a previous study [20], the authors of this paper developed procedures to estimate the demands in a system based on archived ITS detector data. However, during incident conditions, the measured volumes by the ITS system are severely constrained by the remaining capacity at the incident location and in many cases the queues extend well beyond the simulated system boundary, preventing the direct estimation of the true demands for each interval based on detector measurements. Thus, a procedure was developed in this study to estimate the traffic demands based on other day volume measurements combined with the incident day volume measurements.

First, the k-means clustering algorithm, discussed in a previous study by the authors [20], was used to identify "typical" days that are expected to have similar traffic demand patterns to the incident day when there is no incident in the system. The algorithm utilizes the time-variant detector measurements at each detection station to classify the days into groups with similar traffic patterns. By examining these patterns, the analyst can clearly identify the typical day pattern.

The average demands for the typical days were then calculated and used as initial estimates of the demands during the incident day. These average demands were then adjusted to account for the expected difference between the average demands of the typical days and the demands during the incident day. The demands during the incident day are expected to be different from the average demands due to two reasons: the stochastic variations in demands between days and traffic diversions due to incident conditions. As stated above, because of the constrained traffic conditions, the true demands during incident conditions are difficult to estimate for short time intervals based on traffic detector measurements. However, it is possible to calculate the differences in the cumulative traffic volumes between the average day and the incident day. These differences in volumes can be used to estimate the differences in demands between the average and the incident day, as long as the compared accumulations of volumes include all the demands before the queue formation, during the queue, and after the queue discharge, as shown in Figure 1. The accumulated difference in demand can be distributed uniformly among the time intervals impacted by the incident.

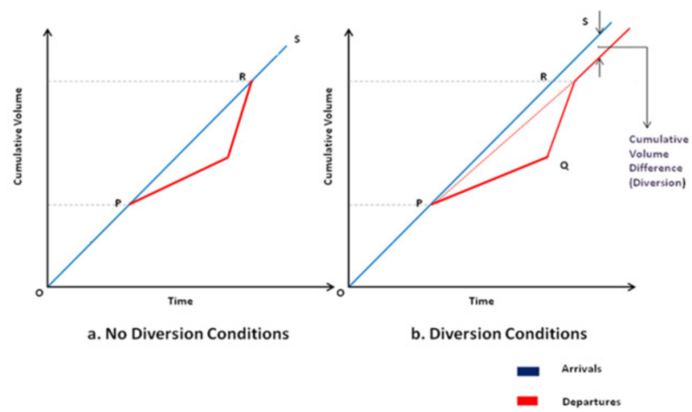

Figure 1 Estimation of the difference between the demands during average and incident day

The above analysis should be repeated at all detector locations since the diversion rates at each location are expected to be different depending on the locations of the diversion points for the particular incident under consideration. This will allow the determination of the mainline, on-ramp and off-ramp demands for the incident day at different corridor locations based on the calculated differences from the average demands of the typical days.

4.2 Estimation of capacity

The next step is to estimate the capacity during incident and no-incident conditions for each highway segment. For no-incident conditions, this could be achieved at bottleneck locations by plotting the fundamental diagrams at various detector stations based on ITS data and determining the maximum traffic flow from the diagrams. However, if the simulated segments do not exhibit recurrent congestion, the measurements on the congested side of the fundamental diagram will be insufficient to allow for the plotting of the full diagram. In these cases, the capacity for no-incident conditions can be estimated using the HCM procedures [2].

The drop in capacity due to the incident can be estimated using values reported in the Highway Capacity Manual [2] or in the literature [6-8]. As stated earlier, the HCM estimates the remaining capacity during incident conditions as a function of the number of blocked lanes (or shoulder) and the number of lanes of the highway segment under consideration. However, if detector measurements are available, the remaining capacity during incident conditions can also be estimated based on volume measurements at a detection station downstream of the incident location. This will be discussed in more detail later in this paper.

4.3 Adjusting simulation parameters for capacity assessment

The next step is to fine-tune a number of calibration parameters in the selected simulation tool to achieve the measured or expected capacities during incident and no-incident conditions. Based on past experiences with simulation studies, Volume 4 of the FHWA Traffic Analysis Toolbox [5] identified a few CORSIM input parameters for adjustment when calibrating freeway capacity for no-incident conditions. These parameters include the car following sensitivity factor and multiplier, lag acceleration and deceleration time, and Pitt car following constant.

CORSIM has a set of incident-specific parameters that can be used for modeling incidents. However, unlike the capacity for no-incident conditions, there is limited work to guide the analyst when selecting appropriate values for these parameters. The incident-specific parameters in CORSIM include lane blockage details (number, location, and duration), rubberneck factor, incident length, and incident warning sign location. To model the capacity drops during incidents, CORSIM allows the analyst to specify what lane(s) are blocked in addition to a rubberneck factor for each adjacent lane. Incidents in CORSIM can be specified at any longitudinal position on a freeway link, can extend over a user-specified length of the roadway, and have a start and end times.

CORSIM uses the rubberneck factor (in a percentage) to increase the time headway between vehicles, reflecting driver distraction while observing the incident. This in turn will result in a reduction in the capacity of the lanes that are adjacent to the blocked lanes or shoulder. The default value for the rubberneck factor is zero. CORSIM also allows the specification of the incident length, which is the length of the roadway affected by the incident. The CORSIM User Manual recommends estimating the incident length as the number of vehicles involved in the incident plus one vehicle length. For example, in a two-vehicle collision with an assumed vehicle length of 20 feet, the manual recommends coding a 60-foot incident length [21]. As discussed below, it was found that coding this length is not adequate to produce the expected drops in capacity due to incidents.

The impacts of varying the rubberneck factor and incident length parameters on the drop in capacity due to incidents was investigated by modeling a simple hypothetical system consisting of a single lane link. The incident length was varied from 60 ft to 2,500 ft and the rubberneck factor was varied between 35% and 90%. Figure 2 shows that the effect of the rubberneck factor depends on the coded length of the incident. For short lengths, the effect of the rubberneck factor on reducing capacity is very small.

In fact, for the 60-ft incident length recommended by the CORSIM user manual as discussed above, the resulting drop in capacity is zero for all rubberneck factors investigated. As stated earlier, CORSIM uses the specified rubberneck factor to increase the time headways between vehicles. If the specified incident length in the simulation is too short, this change cannot be fully achieved and thus the capacity will not drop to the expected levels. As can be seen in Figure 2, the full impact of the rubberneck factor on capacity drop is achieved at an incident length of 1,000 ft. The recommendation of the user manual that leads short incident length to be specified in the inputs should be revised based on the above results.

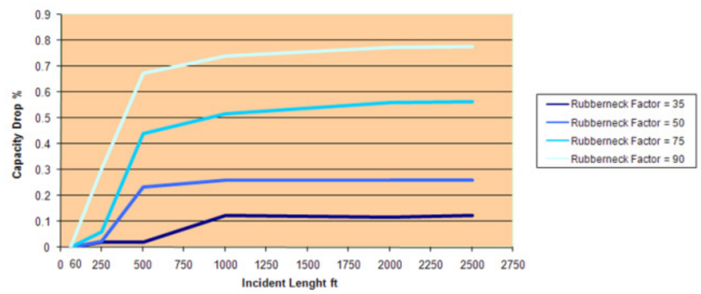

Figure 2 Effects of incident length and Rubberneck Factor on capacity drop.

Another incident parameter in CORSIM is the warning sign upstream of the incident. This warning sign represents a location at which vehicles start changing lanes in response to the specified lane blockage. The default value for the warning sign location is 1,500 ft ahead of the incident. In the investigation undertaken by this study, varying the warning sign location did not have a significant effect on the capacity drop. However, as discussed in the next section, the sign location was found to have significant effects on the other performance measures assessed when simulating incidents.

4.4 Parameter adjustment based on other measures

In addition to the drops in capacity calibrated as described above, simulation models should be able to replicate the changes in performance measures such as throughputs, speed, occupancies, and queue measures at different locations of the system due to incidents. These measures can be estimated based on data collected by detection stations. Based on a detailed investigation conducted in this study of a variety of input parameters to CORSIM, it was found that the parameters that affect the performance measures during incident conditions are the deceleration for non-emergency conditions parameter and the location of the incident warning sign parameter.

5. Case study

A case study is presented in this section to explore the use of the processes discussed in the previous section to support the simulation of incident conditions based on ITS data. The case study includes the simulation of three incidents located on the eastbound section of the SR 826 limited access highway in Miami, FL. The simulated corridor includes six interchanges and begins west of the NW 67th Avenue interchange and ends east of the NW 12th Avenue interchange with a total length of 6.5 miles. The simulation was conducted using the CORSIM microscopic simulation tool for weekday traffic conditions between 4:00 AM and 11:00 AM. Each scenario was run ten times using ten different random seed numbers and the reported results in this study are based on the averages from these runs.

First, the corridor was simulated for an average no-incident weekday. Then, the simulation was conducted for three different incident days. All selected incidents were one-lane blockage incidents located on the SR 826 eastbound (EB) at locations that are in close proximity to each other. The three incidents occurred in the morning peak period and were detected by the traffic management center (TMC) between 7:39 AM and 7:50 AM. Figure 3 depicts the incident locations and nearby microwave detections stations in SR826.

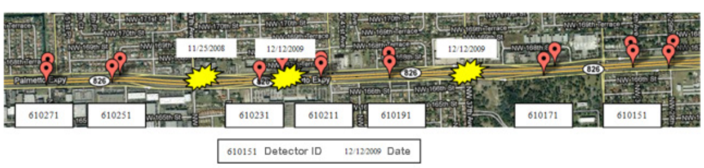

Figure 3 Locations of the selected incidents and detector stations.

5.1 Estimation of traffic demand

As described in the Methodology section, the demands for the incident days were estimated based on the difference between the cumulative volumes during the incident days and the average demands of the no-incident days. It was found that the differences between the incident days and the average no-incident days at the incident locations were 4%, 22%, and 4% for Incidents 1, 2, and 3, respectively. The lane blockage duration of Incident 2 was very long compared to Incidents 1 and 3. Thus, the estimated demands for the incident days show the expected trend of higher diversion rates with longer incident durations. The difference between incident and typical day demands was obtained for each detection station to allow the calculation of the mainline and ramp demands.

5.2 Estimation of no-incident capacity

During no-incident conditions, SR 826 EB does not have mainline bottlenecks that result in recurrent congested operations. Thus, it was not possible to estimate the segment capacity based on detector measurements. This study estimated the no-incident highway capacities of the corridor segments using the HCM procedures [2]. The capacity for the three-lane segment on which the three incidents occurred was estimated to be about 2,200 vphpl (vehicle per hour per lane).

5.3 Estimation of capacity drop

Figure 4 shows the time series for throughput and speed measurements at the three incident locations based on data extracted from the STEWARD data warehouse. Region I in these figures is the region of lane blockage while region II is the congested period after lane clearance (the queue discharge period).

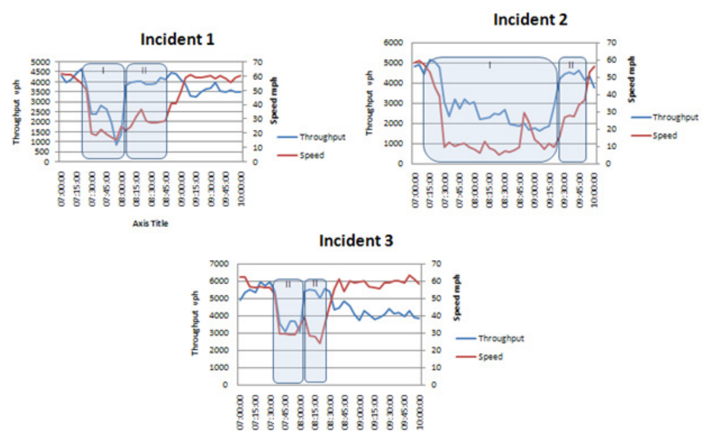

Figure 4. Throughput and Speed measurements for the three investigated incidents.

It is interesting to note the following for the three investigated incidents based on Figure 4:

Just after the incidents occurred, the capacity dropped to between 2,600 and 3,000 vph, depending on the incident considered. This constituted a 54% to 60% drop in capacity, assuming a 6,600 vph no-incident capacity. The drop in capacity due to one-lane blockage incidents on three-lane segments is 51% according to HCM [2]. Qi and Smith [7] estimated the average drop in capacity to be 63%, as described earlier.

During the lane blockage period for incidents 1 and 2, additional significant drops in capacity occurred (down to 1,000 vph in the case of incident 1 and 1,800 vph for incident 2). Further examination of the incident management database indicated that these additional drops are due to the arrivals of fire trucks that blocked additional lanes during incident management activities.

The magnitudes of the drops are expected to be functions of incident attributes and the intensity of incident management activities at the incident sites. This dynamic nature of lane blockages during the incident management process may need to be modeled when simulating incident conditions.

After lane clearance, the queue starts dissipating. However, the queue does not dissipate at 6,600 vph, which is the estimated capacity of the section but at lower rates. The queue discharge rates were 4,000, 4,500, and 5,400 vph, for Incidents 1, 2, and 3, respectively. These rates correspond to 39%, 32%, and 19% reductions in segment capacity. There are two reasons for not achieving the estimated capacity of the section during queue discharge. First, when the incident is moved to the shoulder, the presence of the involved vehicles and emergency vehicles on the shoulders still result in drops in capacity due to rubberneck effects. The HCM [2] estimated that crashes with emergency vehicles on the shoulder drop capacity by 17% on three lane freeways. Knopp et al. [8] found that the queue discharge rate is reduced by 30% due to shoulder incidents. Another factor that affects the maximum throughput during the queue discharge period is that the rate at which a queue is discharged is expected to be lower than the capacity as defined by the HCM. The results of this study show that the queue discharge rate vary between 4,000 and 5,400 vph, indicating that this rate is a function of the intensity of emergency vehicle operations and the nature of the incident scene on the shoulder.

5.4 Adjusting simulation parameters for assessment of capacity

The next step is to adjust the simulation model parameters to ensure that the simulation model is able to produce the capacity during incident and no-incident conditions. For no-incident conditions, the lane capacity was reproduced in the simulation by adjusting the values of two parameters: the car following sensitivity factors and the lag acceleration and deceleration times. As stated earlier, these parameters have been used in previous studies to adjust the assessed capacity in CORSIM applications [4].

The next step was to fine-tune other parameters in the simulation model to allow the simulation to replicate the drops in capacity due to incident lane blockages, as observed in the real-world. To achieve these drops in the CORSIM simulation model, a search was performed to find the values of the rubberneck factor, incident length, and lane blockage that produce the capacity drop levels during the incident period.

Figure 5 shows the drop in throughputs in the real-world and the simulation model with the fine-tuned incident calibration parameters for the three incidents. It was found that CORSIM was able to reproduce the capacity reduction fairly accurately with a moderate level of effort. As stated earlier, there were three different throughput levels during Incidents 1 and 2, and two different throughput levels during Incident 3. It was possible to replicate these levels in the simulation as shown in Figure 5 by coding time varying rubberneck factors and an incident length of 1,000 ft. The values of the rubberneck factor that produced the observed drops in capacity due to one-lane blockage (54% to 60% drop in capacity, as discussed in the previous section) ranged from 70% to 80% for the lanes that are adjacent to the blocked lanes. For the queue discharge phase, the required rubberneck factors were 70%, 65%, and 50% to produce the observed drops in capacity for Incidents 1, 2, and 3, respectively.

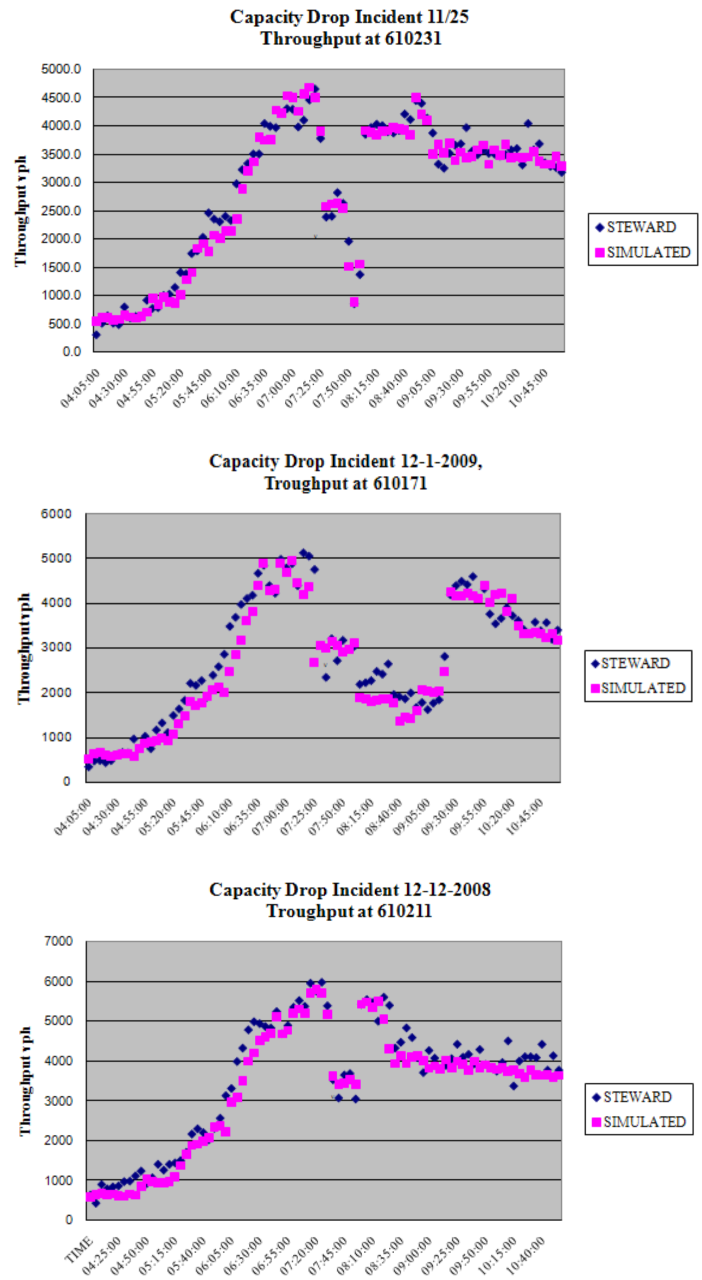

Figure 5 Comparison of capacity drop based on detector measurements and simulation.

5.5 Parameter adjustment based on other measures

In addition to the drops in capacity calibrated as described above, it is important that the simulation models are able to replicate the changes in performance measures, such as throughputs, speeds, and occupancies. In order to compare the simulation results with traffic detector field measurements, the traffic detector readings in the simulation model were extracted at 20-second intervals and aggregated at 5-minute and 15-minute intervals for comparison purposes.

As stated in the methodology section of this paper, two parameters were found to impact the performance measures when fixing the assessed segment capacity in CORSIM: the deceleration for non-emergency conditions parameter and the location of incident warning sign parameter. These parameters were varied to obtain the best goodness of fit between the observed and simulated measurements. Three measures were used to evaluate the goodness of fit of the throughput and speed measurements under incident and normal conditions. These measures were the absolute mean percent error (AMPE), the normalized root mean square error (RMSN), and the root mean square percent error (RMSPE). Table 1 shows the aggregated values of these measures for all detection stations during the period of analysis. Table 1 indicates that, for all simulated conditions (i.e., the no-incident and three incident conditions), the deviations of the simulated throughputs from the measured throughputs as measured by the RMSN and RMSPE were between 12% and 15%. The AMPE for the throughput ranged from 1% to 10%. It thus appears that the goodness of fit of throughput measurement for incident conditions was as good as those for no-incident conditions. However, Table 1 shows that the RMSN, RMSPE, and AMPE for speed measurements were higher for incident conditions (7% to 14%) compared to normal conditions (1% to 5%). This is to be expected, since unlike incident conditions, the normal conditions are free-flow conditions that are easier to simulate

Goodness of Fitness Measure	Non-incident conditions	Incident 1	Incident 2	Incident 3
Throughput Goodness of Fit				
RMSN	0.12	0.13	0.15	0.12
RMSPE	0.13	0.13	0.15	0.13
AMPE	0.06	0.01	0.06	0.10
Speed Goodness of Fit				
RMSN	0.05	0.14	0.13	0.10
RMSPE	0.05	0.11	0.08	0.11
AMPE	0.01	0.11	0.13	0.07

Table 1 Goodness of fit of throughput and speed.

Figure 6 shows the simulated throughput and speed measurements as compared to real-world detector measurements (from the STEWARD data warehouse) for selected detector locations during Incident 1. As shown in this figure, the calibrated CORSIM model was able to reproduce reasonably well the spatial and temporal variations of the observed volume and speed measurements.

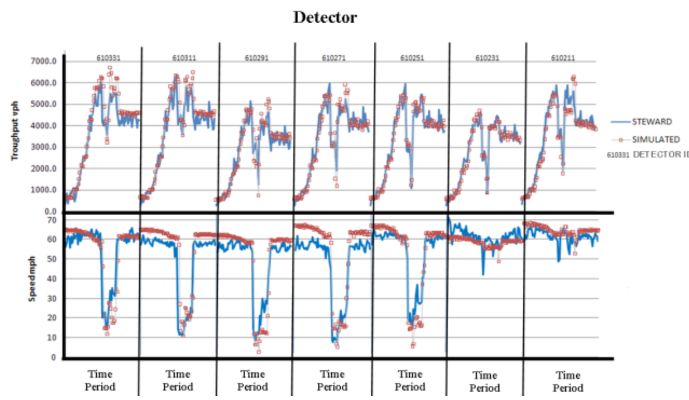

Figure 6 Simulation and Real-World Speed and throughput measurements for Incident 1.

5.6 Investigation of the significance of the modeling efforts

This section includes a discussion of the simulation model performance when different approaches were used to simulate the incident. These approaches varied in the level of effort required to collect and use ITS data, and to fine-tune the model parameters. The comparison was made based on the simulation of incident 1, as introduced earlier in this paper. The following approaches were investigated and are sorted below based on the increasing level of effort required:

Case IC1: In this case, a one-lane blockage was coded with no rubberneck factor. This is the least effort required to code a one-lane blockage incident. This case used only the lane blockage duration in the incident database.

Case IC2: This case involves the use of the rubberneck factor (RF) in addition to lane blockage specifications to produce the capacity reductions as suggested by the HCM [2]. This case does not require ITS data but requires the fine-tuning of the incident simulation parameters to achieve the predetermined capacity drops due to incidents.

Case IC3: This case is similar to case IC2 but is based on the capacity reductions during lane and shoulder blockage incidents reported by Knopp et al. (8) rather than those suggested by the HCM [2].

Case IC4: In this case, the rubberneck factors were adjusted to produce the observed capacity reductions based on ITS detector data. As discussed earlier, there were three different capacity levels during the period impacted by incident 1. In Case IC4, all three levels of capacity drops were replicated.

Case IC5: This case is the same as Case IC4 but with the adjustment of the incident sign location in an attempt to reproduce the observed detector measurements.

Case IC6: This case is the same as Case IC5 but with the adjustment of the non-emergency deceleration in an attempt to reproduce the observed detector measurements.

The results for Input Case 1 (IC1) in Table 2 show that the capacity drop due to specifying one-lane blockage in the simulation was not sufficient to create a queue. In Input Case 2 (IC2), the input parameters were fine-tuned to produce the capacity drops in the HCM [2]. The results indicate that a queue was generated in the simulation, but that it was significantly shorter than what is estimated from the real-world data. Increasing the drops in capacity during lane and shoulder blockages to the values suggested by Knopp et al. [8], as in input Case 3, resulted in longer

hange to Input Parameters	Time to dissipate the Queue (min)	Average Time in Queue (min)	Average Queue Length (miles)	Maximum Queue Length (miles)
Observed Values	125.0	89.5	3.6	4.9
IC1[2]: Code one-lane blockage only	0.0	0.0	0.0	0.0
IC2[2]: Adjust RF[1] to produce capacity reductions based on HCM	50.0	41.8	0.7	0.8
IC3[2]: Adjust RF[1] as recommended by Knopp et al.(*8*)	95.0	74.3	1.7	2.0
IC4[2]: Adjust RF[1] to produce observed capacity reductions	105.0	79.8	2.3	2.7
IC5[2]: Adjust RF[1] and Sign Location	110.0	81.2	2.2	2.7
IC6[2]: Adjust RF[1], Sign Location, and non-emergency deceleration	120.0	94.3	2.9	4.1

Table 2. Queue measures based on simulation outputs and Real-World measurements.

6. Conclusion

It can be concluded from the results presented in this study that, when simulating incident conditions, the analyst should fine-tune simulation model parameters to produce the expected or measured drops in capacity during incidents and the expected impacts of incidents on various performance measures. Simply specifying lane blockages is not sufficient to produce the expected impacts of incidents in the simulation.

ITS data can provide valuable information to support the simulation of incidents. Data from existing ITS deployments allow the validation and calibration of simulation models based on macroscopic measures. However, IntelliDrive technologies will provide a significantly richer data source that will allow the validation and calibration of simulation models based on microscopic traffic parameters.

Traffic detector data combined with incident management data provide information that is critical to the successful use of simulation for the modeling of incidents. The analysis of ITS data indicates that there are different levels of capacities during the periods impacted by lane-blockage incidents. The first level is associated with the drop in capacity due to the initial blockage of lanes by the incident and the associated rubbernecking effects. The second drop in capacity can occur due to emergency vehicle operations that may block additional lanes. This drop in capacity is expected to be a function of the intensity of emergency vehicle operations and the nature of the scene of the incident. The lanes originally blocked may be opened gradually during the incident period. For example, a two-lane blockage incident may become a one-lane blockage incident, if one of the two blocked lanes is opened. Emergency vehicle operations on the shoulder after opening the blocked lanes may also impact the segment capacity due to the rubbernecking effects. Again, this is expected to be a function of the intensity of emergency vehicle operations and the nature of the scene of the incident. Thus, in this study, modeling the dynamic nature of capacity during the incident is found to produce better simulation results.

7. References

[1] Hadi M., Xiao Y. , Zhan C., Gan A. 2010. Use of the HCM Freeway Facility Procedures Combined with ITS Data Archives to Assess the Benefits of Incident Management Systems. Transportation Research Record, to be published. p 115 – 122.

[2] Transportation Research Board. 2000. Highway Capacity Manual 2000, Washington D.C., United States.

[3] Dowling R., Skabardonis A., Alexiadis V. 2004. Traffic Analysis Toolbox Volume III: Guidelines for Applying Traffic Micro-simulation Modeling Software. Washington D.C., United States: Federal Highway Administration. Contract report EL-93-2.

[4] Holme P., Tomich D., Slodoben J., Lowrance C. 2007. Traffic Analysis Toolbox Volume IV: Guidelines for Applying CORSIM Micro-simulation Modeling Software. Washington D.C., United States: Federal Highway Administration. Contract report EL-93-2.

[5] Author. 2005. Archived Data Management Systems - A Cross-Cutting Study. Washington D.C., United States: Federal Highway Administration. Contract report EL-93-2.

[6] Goolsby M. E. 1971. Influence of Incidents on Freeway Quality of Service. In: 1971 Proc. 50th TRB Annual Meeting; (Día, Mes); Washington, D.C. United States: Transportation Research Board.

[7] Qi L., Smith B. 2001.Characterization of Accident Capacity Reduction. Charlottesville (VA), United States: Center for Transportation Studies, University of Virginia. Contract report EL-93-2.

[8] Knoop V.L., Hoogendoorn S.P., Adams K. 2009. Capacity Reductions at Incidents Sites on Motorways. European Journal of Transport and Infrastructure Research 363-379.

[9] Hadi M., Sinha P., Wang A. 2007. Modeling Reductions in Freeway Capacity due to Incidents in Microscopic Simulation Models. Transportation Research Record 62-68.

[10] Knoop V. L., van Zuylen H. J., Hoogendoorn S. P. Year. Microscopic Traffic Behaviour near Accidents. In: Proc. 18th International Symposium of Transportation and Traffic Theory; (día, Mes); New York (NY).

[11] Barfield W., Conquest L., Spyridakis J., Haselkorn M. 1989. Information Requirements for Real-Time Motorist Information Systems. In: Proc. of the Vehicle Navigation and Information Systems Conference (VNIS); New York (NY), United States:. p 101-112.

[12] Benson B. G. 1996. Motorist Attitudes about Content of Variable-Message Signs. Washington D.C., United States: Transportation Research Record. Contract report EL-93-2.

[13] Madanat S., Yang C. Y., Yen Y. M. 1995. Analysis of Stated Route Diversion Intentions under Advanced Traveler Information Systems Using Latent Variable Modeling. Transportation Research Record. p 10-17.

[14] Chatterjee K., Hounsell N. B., Firmin P. E., Bonsall P. 2002. Driver Response to Variable Message Sign Information in London. Transportation Research Part C. p 149-169.

[15] Tarry S., Graham A. 1995. The Role of Evaluation in ATT Systems. Traffic Engineering and Control. London. p 688- 693.

[16] Knoop V. L., Hoogendoorn S. P., van Zuylen H. J. 2009. Route Choice Under Exceptional Traffic Conditions. In: Proc. International Conference on Evacuation Management; (dia, Mes); The Hague (South Holland). Netherlands: The Hague.

[17] Luk J., Yang C. 2003. Comparing Driver Information Systems in a Dynamic Modeling Framework. Journal of Transportation Engineering. p 42-50.

[18] Cragg C., Demetsky M. 1995. Simulation Analysis of Route Diversion Strategies for Freeway Incident Management. Charlottesville (VA), United States: Virginia Transportation Research Council.

[19] Courage K. G., Lee S. 2008. Development of a Central Data Warehouse for Statewide ITS and Transportation Data in Florida: Phase II Proof of Concept. Tallahassee (FL). United States: Florida Department of Transportation. Contract #BD545, RPWO #37, UF Project 051449.

[20] Alvarez P., Hadi M., Zhan C. 2010. Using Intelligent Transportation Systems Data Archives for Traffic Simulation Applications. Transportation Research Record. to be published.

[21] Federal Highway Administration. 2006. CORSIM User's Guide. Department of Transportation. United States.