Development and Comparison of Planning-Level and Data-Based Evaluation Tools of Intelligent Transportation Systems

By

Yan Xiao, Ph.D.
Research Associate
Department of Civil and Environmental Engineering
Florida International University
10555 W. Flagler Street, EC 3730
Miami, FL 33174
Phone: (305) 348-1393
E-mail: yxiao001@fiu.edu

Mohammed Hadi, Ph.D., P.E.
Associate Professor
Department of Civil and Environmental Engineering
Florida International University
10555 W. Flagler Street, EC 3605
Miami, FL 33174
Phone: (305) 348-0092
E-mail: hadim@fiu.edu

Halit Ozen, Ph.D.
Research Associate
Department of Civil and Environmental Engineering
Florida International University
10555 W. Flagler Street, EC 3730
Miami, FL 33174
Phone: (305) 348-1393
E-mail: ozenh@fiu.edu

A Paper Submitted for Presentation and Publication at the 92nd Annual Meeting of the Transportation Board, Washington, DC

Word Count = 4,530 words + 6 figures + 1 table = 6,280 words

November 15, 2012

ABSTRACT

Increasingly, transportation agencies are identifying performance measurement and benefits-cost analyses of their Intelligent Transportation Systems (ITS) programs as high priority tasks. There is a recognition that evaluating the benefits and costs of ITS implementations is necessary for both planning and operation purposes. The evaluation of ITS as part of the transportation system planning process has been mainly performed using sketch planning tools. However, the assessment of ITS at the planning for operations and operation levels requires more detailed analysis and can be based on data from different sources and/or using more detailed modeling techniques such as macroscopic and microscopic simulation models.

This paper compares the abilities of a planning level ITS evaluation tool and a real-world data-based evaluation tool, both developed by the authors, to assess the impacts of incidents and incident management strategies. The results presented in this paper confirm the importance of utilizing good estimates of incident rates and durations in the benefit analysis of incident management. In addition, the results indicate the importance of using accurate estimates of traffic demands in the evaluation tools. The results also confirm the ability of the deterministic queuing analyses, when using accurate traffic and incident input parameters, to produce results that are close to real-world measurements of delays, at least for the case study used in this paper.

Key Words: Intelligent Transportation Systems, Benefit-Cost Analysis, Evaluation Tools

INTRODUCTION

Increasingly, transportation agencies are identifying performance measurement and benefits-cost analyses of their Intelligent Transportation Systems (ITS) programs as high priority tasks. There is a recognition that evaluating the benefits and costs of ITS implementations are necessary for both planning and operation purposes. However, the details required for such evaluations are different for different purposes.

The evaluation of ITS as part of the transportation system planning process has been mainly performed using sketch planning tools such the ITS Deployment Analysis System (IDAS), developed for the Federal Highway Administration (*1*). The authors of this paper developed a tool, referred to as the Florida ITS evaluation tool (FITSEVAL) for use to evaluate ITS deployments in Florida at the planning level (*2-4*). FITSEVAL can evaluate the benefits and costs of thirteen different ITS deployment alternatives and is suitable for assessing ITS as part of short-term and long-term transportation plans. The tool assesses the mobility, safety, environmental, and monetary benefits and produces estimates of the present-worth and benefit-cost ratios of ITS. FITSEVAL has been incorporated as part of the demand forecasting modeling environment in Florida. Xiao et al. (*4*) demonstrated the use of the tool to assess the benefits and costs of incident management strategies and found that the tool is able to demonstrate that the incident management can be an effective solution from a benefit-cost point of view.

The assessment of ITS at the planning for operation and operation levels requires more detailed analysis. This analysis can be based on data from different sources and/or more detailed modeling techniques such as macroscopic and microscopic simulation models. Examples of data-based evaluation of incident management include the work by Hadi et al. (*5*) who used measured and assumed input parameters as inputs to queuing analysis to evaluate the benefits of individual incident management components. Guin et al. (*6*) used a similar methodology to assess the benefits of incident management program and demonstrated the importance of ITS operation data to the evaluation results. Traffic simulation analysis has also been applied to estimate the benefits of traffic and incident management (*7*).

With the availability of rich ITS data and wide implementations of ITS, it becomes more feasible to evaluate the impacts of ITS based on real-world data for operation and planning for operation purposes. Furthermore, ITS impact factors and other input analysis parameters can also be derived based on ITS data and used in the analysis of other tools such as sketch planning tools and simulation models. Recently, the authors of this paper developed a tool referred to as *ITS Data Capture and Performance Management (ITSDCAP).* This tool has been developed to capture and fuse data from multiple sources, estimate various performance measures, perform data mining techniques, support simulation development and calibration, and allow the visualization of data and analysis outputs.

One of the important functions of ITSDCAP is ITS evaluations based on ITS data. At the current stage of development, four types of freeway-related ITS implementations can be evaluated including, incident management, ramp metering, smart work zone, and road weather information system. ITSDCAP supports the ITS benefits and costs analyses of these implementations in three ways, as follows. First, it allows before and after analyses of the benefits of ITS deployments based on ITS data. Second, in cases when before and after evaluations are not possible, ITSDCAP utilizes analysis methods similar to those used in FITSEVAL to estimate the benefits but based on input information derived from ITS data instead of those estimated for sketch planning analysis. Third, ITSDCAP analysis of ITS data allows the derivation of benefit and other analysis parameters to be used as inputs to other tools like sketch planning tools and simulation to better account for the analyzed conditions when assessing the benefits.

This paper compares the methods used in ITSDCAP and FITSEVAL to assess the impacts of incidents and incident management, as an example of the ITS assessment methods used in these two tools. Incident Management aims at reducing incident durations and minimizing the negative impacts of incidents by facilitating efficient incident detection, response, and clearance. First, the paper presents a discussion of the required input parameters to the two different evaluation methods, followed by descriptions of the methods used by the two tools. Finally, case studies are presented to assess the calculations of incident impacts using different options in both tools.

CAPTURED DATA

Figure 1 presents a high level design of ITSDCAP. As shown in this figure, ITSDCAP allows capturing and grouping data from multiple sources, including traffic detector data, incident data, construction data, private sector data (INRIX) data, 511 call data, dynamic pricing of managed lanes, crash analysis data, weather data, and Florida Department of Transportation (FDOT) planning office volume data. The important databases to the discussion of this paper are traffic detector data and incident data, described below.

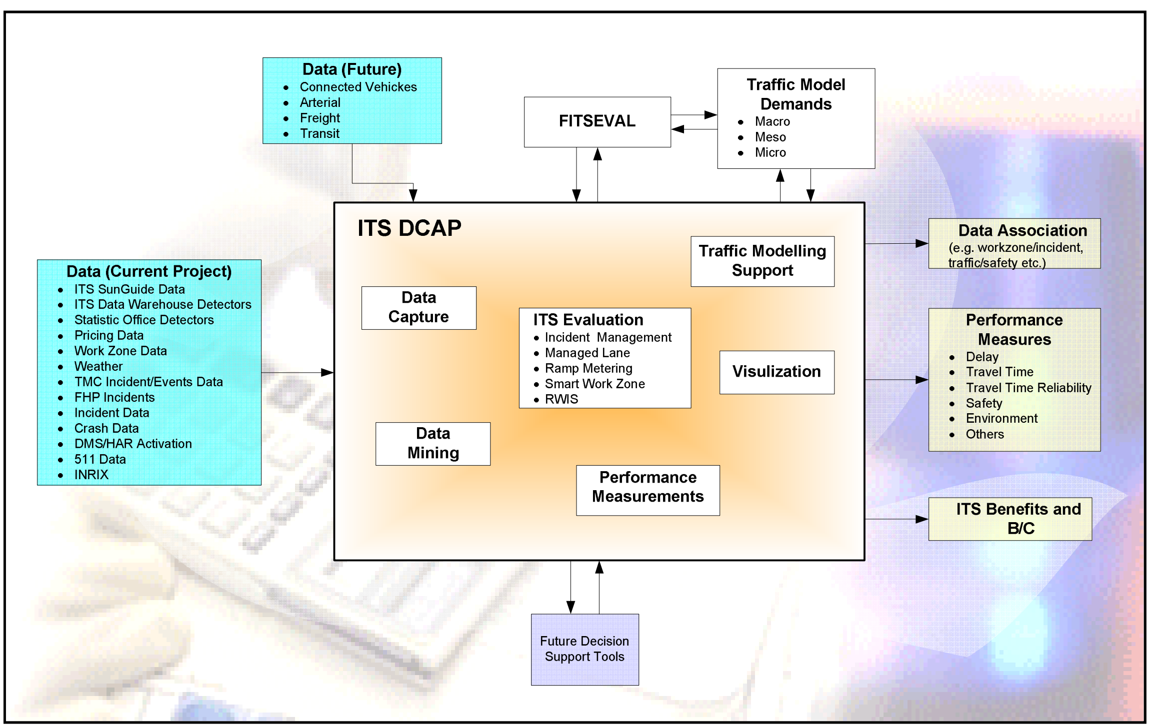

Figure 1 High level design of ITSDCAP

Traffic Detector data were obtained from the Statewide Transportation Engineering Warehouse for Archived Regional Data (STEWARD). STEWARD was developed as a proof of concept prototype for the collection and use of ITS data in Florida (*8*). The current effort has concentrated on archiving point traffic detector data and travel time estimates. The STEWARD database contains summaries of traffic volumes, speeds, and occupancies collected from point traffic detectors.

Incident data was also used as an important input to the analysis. The traffic management centers in Florida maintain incident management archives in Oracle database files. 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.

INPUT PARAMETERS

The incident management methodology based on queuing theory in FITSEVAL requires a number of input variables listed as followings:

- Traffic demands during incident conditions
- Capacity drops due to incidents by blockage type
- Incident statistics including average incident durations and frequencies by blockage type

For the evaluation methodology in ITSDCAP, speed and volume data from traffic detectors and data from incident database are needed as input. The parameters listed above for FITSEVAL can be estimated from input data as described below.

Traffic Demands

As stated earlier, FITSEVAL is incorporated within the regional demand models in Florida and the traffic demands used in the analysis are obtained for each peak and off-peak period of the day based on the output of the travel demand forecasting models. The demand forecasting models usually go through extensive calibration and validation efforts for the base year of the model.

In ITSDCAP, the travel demands are estimated based on the ITS detector data archives. The traffic demand for a normal day traffic pattern is obtained by first eliminating the days with incidents, construction, or special events, and the days that are holidays/weekends and then clustering out other unusual days using the k-means clustering algorithm (*9*).

Incident Duration and Frequency

Incident frequency (or incident rate in incident per million vehicle miles travel) and average incident durations by blockage types are essential parameters for calculating incident impacts. FITSEVAL has default values of these parameters. These default values were originally calculated based on a detailed incident management database maintained by the FDOT District 4 ITS program and can be changed by the user based on local conditions.

In ITSDCAP, the incident frequency and average incident duration parameters are calculated based on the incident data captured by the tool. These parameters are summarized by time, location, and blockage type, and can be visualized giving users a picture of the temporal and spatial distribution of incidents. The calculated parameters can be used in the benefit-cost evaluation in ITSDCAP or used as inputs to FITSEVAL to better customize the analysis of this tool to local conditions.

Reductions in Capacity

FITSEVAL analysis requires the drop in capacity due to incidents. The 2010 Highway Capacity Analysis (HCM 2010) (*10*) 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 and are used in FITSEVAL analysis.

In ITSDCAP, when mobility benefits are directly estimated from speed and volume measurements, the capacity drop due to incidents is implicitly considered and thus does not need to be estimated. If the queuing analysis is applied in ITSDCAP, the reductions in capacity during incidents are required and can be estimated based on traffic detector volumes downstream of the incident location. However, these reductions can also be estimated based on the HCM values or values reported in other studies.

EVALUATION METHODOLOGIES

When conducting benefit/cost analyses of incident management, five types of performance measures are assessed: incident mobility impacts, secondary accidents, fuel consumption, emissions, and monetary benefits. The above mentioned performance measures are converted to dollars by considering the values of time, safety, fuel costs and emission costs. The resulting benefits in dollar values are then used in combination with the initial and recurrent costs of implementing incident management systems to produce the benefit/cost ratios and present–worth values of the systems. This section describes the methodologies used in FITSEVAL and ITSDCAP to calculate various measures.

Mobility Measures

FITSEVAL uses deterministic queuing analysis to calculate queue length and incident delays (*11*). The parameters required for the analysis include incident duration, traffic demands, and capacity with and without incidents. The analysis can use default values of these parameters or input values based on available information from local conditions.

In ITSDCAP, two analysis methods can be used to estimate mobility impacts. The first is deterministic queuing analysis and the second is direct measurements based on captured data. In cases where mobility measures cannot be assessed directly based on the captured data, a deterministic queuing analysis similar to that used in FITSEVAL can be used to estimate these measures. However, measured values of demands, capacity drops, and incident durations are used in the ITSDCAP queuing analysis based on the data captured by the tool. This option is expected to produce better results when the captured data do not allow accounting for the full lengths of queues due to incidents. However, if sufficient data are available to account for the full queues, mobility measures can be directly measured based on the captured data by comparing incident day's vehicle-hour traveled with normal day's vehicle-hour traveled for the timestamps with incident conditions, including the incident recovery time period, as described next. Readers are referred to the references (*4*, *9*) for more detailed information.

In ITSDCAP, it is possible to estimate queue lengths based on detector measurements utilizing one of three methods that examine the congestion levels at each detection station. These methods are a speed threshold-based method, occupancy threshold-based method, and clustering analysis-based method. The speed-threshold method identifies the station to be within the queue, if the measured speed at the detector station is less than a pre-defined speed threshold. The second method uses occupancy threshold instead of speed-threshold for this determination. The third method is based on cluster centroids identified based on *k*-mean clustering analyses (*12*). In this method, the fundamental diagram of traffic flow is subdivided into four clusters representing different congestion levels. Cluster I corresponds to nearly free-flow conditions with the average speed almost constant at free flow speed regardless of the demand. Traffic Cluster II is still uncongested but with a reduced speed. Cluster III is a more congested region, where the speed drops but to a lesser degree than in Cluster IV. Cluster IV corresponds to extremely congested conditions, with low speed and low constrained flows. Depending on the Euclidean distances from each cluster centroid, the traffic measures at each detection station are associated with one of these clusters (or congestion levels). Once the congestion level is identified for each detector station, the spatial distribution of congestion levels is used to determine the queue length. The queue lengths associated with each incident is calculated for each incident and used in the calculation of average values.

Two sources of data can be used in ITSDCAP for use to estimate travel time for incident and no incident conditions. The first is point detector data from the ITS detector data archive and the second is data from a private sector data supplier (INRIX). INRIX collects data from multiple mobile sources, fuses the data, and provides travel time estimates based on the data. Various methods are also incorporated to estimate travel times based on point detector data including the mid-point method and minimum speed method (*12*).

Probability of Secondary Incidents

Another important impact of incidents is the potential for secondary crashes. Both ITSDCAP and FITSEVAL utilize a logistic regression model developed by the author in a previous study to assess the potential for secondary incidents (*13*). This model was developed based on the FDOT District 4 incident database. The factors that were determined to be statistically significant in predicting the secondary crash likelihood in the model are lane blockage duration, queue length, time of day, and type of incident (accident or not). Equation 1 shows the derived expression for the secondary crash likelihood.

$$
\begin{aligned}
\Pr ob(SecondaryCrash) = \exp(&-6.100 + 0.462 \times \ln(\text{LaneBlockage}) + 0.170 \times \text{QueueLength} \\
&+ 0.702 \times \text{PM} + 0.959 \times \text{Midday} \\
&+ 1.397 \times \text{AM} + 0.451 \times \text{Accident})
\end{aligned} \tag{1}
$$

where LaneBlockage represents the total length of lane blockage in minutes and QueueLength denotes the maximum queue length in miles caused by the incident. All the other variables in Equation 1 are binary variables with a value of 0 or 1. The variables of AM, Midday, and PM have values of 1 if the incident occurred during the weekday AM peak period, midday period, or PM peak period, respectively. If the incident type is crash, the variable of Accident has a value of 1.

Fuel Consumption and Emission

In both ITSDCAP and FITSEVAL, the fuel consumption and emission impacts of incidents are calculated based on the method used by Skabardonis and Mauch (*14*) and Lin et al. (*15*). The equation for fuel consumption and pollutant emission calculation is as follows:

$$F_i = D \times e_{si} \tag{2}$$

where the variable F_i represents either the fuel consumption or CO, HC, NOx emissions. The symbol D is the incident-induced delays and e_{si} is the fuel consumption rate or emission rate at speed s. The advantage of this method is that it can better capture the fuel consumption and emissions under the stop-and-go conditions caused by incidents.

Monetary Benefits

One of the significant benefits of the incident management program in Florida is the monetary benefits of the provided assistance by the service patrol program to stranded motorists. Service patrol trucks provide many free services to the Florida Highway Patrol (FHP) and motorists. Examples of these services are tire changes, gas and water provision, assisting FHP in maintenance of traffic (MOT) during incidents, minor repairs, and jump-starts. If motorists or the FHP decide to call a private towing/automobile service company, they will be responsible for any incurred charges. In ITSDCAP and FITSEVAL implementations, the costs per service for service patrol assistance are estimated based on costs charged by private automobile service/towing companies and included in the overall benefits assessment (*5*).

CASE STUDY

A case study is presented in this section to compare the use of different evaluations methods and parameters in ITSDCAP and FITSEVAL. Several differences in the evaluation methodologies of these two tools are expected to affect the analysis results, as listed below:

- In ITSDCAP, the demand level is based on normal day traffic volumes estimated using detector measurements. FITSEVAL utilizes volume estimates from demand forecasting models. Although the demand forecasting models are generally well calibrated, the accuracy of the volume estimates varies depending on the used regional model and the corridor under investigation.

- Incident rates and durations are obtained from the local incident database in ITSDCAP. FITSEVAL utilizes default values for these parameters obtained based on data from corridors managed by FDOT District 4 in Broward County, FL but allows the users to change the defaults based on local conditions. In this study, FITSEVAL estimation of incident delays is conducted first with the default values and then with incident rates and durations estimated for the corridor under investigation using ITSDCAP.
- Queuing analysis is the only method used to assess the mobility impacts of incidents in FITSEVAL. On the other hand, incident mobility benefits can be calculated in ITSDCAP based on queuing analyses or based on travel time measurements using captured data, as described earlier. The assessment in this paper includes comparison of the mobility impacts calculated in ITSDCAP based two methods.
- Emission and fuel consumption are calculated using the same methods in ITSDCAP and FITSEVAL, as described earlier. However, the speed within the queue is calculated based on detector data in ITSDCAP but using a traffic model in FITSEVAL.
- The probability of secondary incidents is a function of the queue length, as indicated in Equation 1. The queue length is calculated based on queuing theory in FITSEVAL but can be based on either the queue theory or detector measurements in ITSDCAP.

In this case study, SR 826 EB in Miami-Dade County, FL is selected as the study corridor to determine the mobility impacts of one-lane incidents during the time period from November 1, 2011 to March 31, 2012. Figure 2 illustrates the location of the study corridor.

FIGURE 2 Study corridor utilized in assessing incident mobility impacts

Figures 3 to 5 present the estimated incident duration, incident rate and traffic demand from the ITSDCAP compared to the default values used in the FITSEVAL, respectively. As shown in Figures 3, the actual incident rate obtained from ITSDCAP is more than twice the default values used in FITSEVAL for the Mid-Day period and more than three times these values for the AM peak period. However, Figure 4 shows that the average incident durations, particularly for the AM peak period is close to the default value used in FITSEVAL.

As an example for the comparison of demands, the traffic demands for the first link of SR 826 EB obtained from both the ITSDCAP and FITSEVAL are presented in Figure 5. Figure 5 shows that the traffic demand estimated based on the real-world detector data in ITSDCAP is significantly higher than the volumes estimated based on the time-of day travel demand forecasting model that are used in FITSEVAL, particularly for the off-peak period.

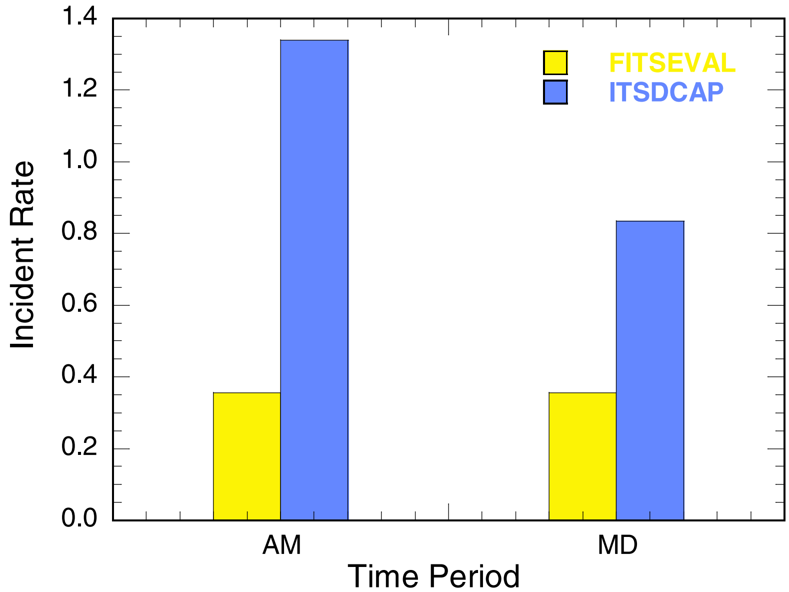

FIGURE 3 Comparisons of incident rates from ITSDCAP with FITSEVAL defaults

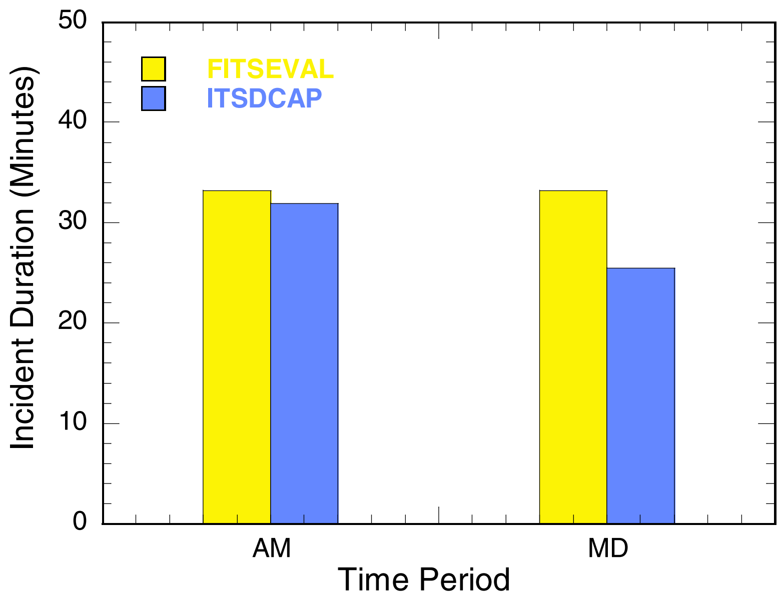

FIGURE 4 Comparisons of incident durations from ITSDCAP with FITSEVAL defaults

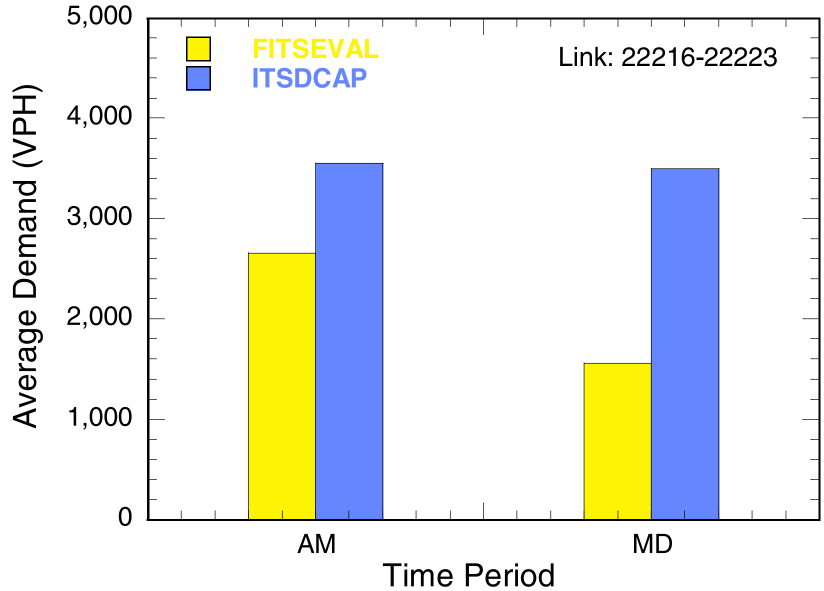

FIGURE 5 Example of the comparison of traffic demands from ITSDCAP and those used by FITSEVAL

Table 1 summarizes the comparison results of four mobility impact assessment methods. The methods are listed below.

- FITSEVAL-Default: this is the queuing theory evaluation in FITSEVAL based on the default incident duration and rates and the demands from the demand forecasting models.
- FITSEVAL-Modified: this is FITSEVAL evaluation with the inputs modified to account for incident duration and incident rate estimated for the corridor based on the data captured by ITSDCAP.
- ITSDCAP-Queuing: this is the queuing theory evaluation in ITSDCAP based on the incident duration, incident rate and demands estimated by the tool.
- ITSDCAP-Measured: this is ITSDCAP estimation of delays using real-world travel time data by calculating the difference in the vehicle-hour traveled in incident days versus normal days as estimated based on detector data.

Obviously, the ITSDCAP-Measured method is the most direct method to calculate delays and when sufficient detectors are available, as is the case in this case study, this method results can be assumed to better represent real-world measurements and can be used as the base method in the evaluation to assess other methods' accuracies.

As shown in Table 1, when using the default parameters in FITSEVAL, the resulting performance measures are quite different from those obtained from the ITSDCAP-Measured method. When the incident duration and incident rates are updated to reflect real-world measurements; the delay, fuel consumption and emissions estimates based on queuing analysis in FITSEVAL became closer to those based on ITSDCAP-Measured values. This indicates the importance of using locally derived incident rates and durations in the analysis. It may also indicates the need to update FITSEVAL default values, if future analyses show that these defaults are not the best representative values for Florida incidents.

Table 1 shows that there are still significant differences between the estimates from the FITSEVAL-Modified and the values of ITDCAP-Measured, mainly due to the high differences between the forecasted traffic demands in FITSEVAL and those measured based on detectors in ITSDCAP. It should be pointed out again here that the ITSDCAP-Queuing method uses the same procedure and parameters as those used in the FITSEVAL-Modified method, except it uses the measured demands by ITSDCAP rather than the forecasted demands. The difference between the estimates from the ITSDCAP-Queuing method and the real-world measurements estimated by ITSDCAP-Measured is relatively small and significantly lower than the difference between the FITSEVAL-Modified and ITSDCAP-Measured methods. This clearly indicates the importance of using accurate demand estimates in conjunction with FITSEVAL.

Figure 6 presents the estimates of the delays when they are converted to monetary values in dollars. This conversion was done assuming 13.45 dollar per vehicle-hour of delay for autos and 71.05 dollar for trucks based on the 2005 Urban Mobility Report (*16*). Again, this plot also indicates that the updates of the assessment parameters based on real-world conditions in FITSEVAL can bring the evaluation results closer to real-world measurements of the mobility impacts.

TABLE 1 Comparison of Incident Impact Evaluation Results between FITSEVAL and ITSDCAP

		FITSEVAL-Default	FITSEVAL-Modified	ITSDCAP-Queuing	ITSDCAP-Measured
Incident Delay (VHT)	AM	224.32	781.43	3,486.67	3,672.30
	MD*	0.00	0.00	1,305.62	1,558.06
	Total	224.32	781.43	4,792.29	5,230.36
Fuel Consumption (Gallons)	AM	324.41	1,130.12	4,772.05	5,427.36
	MD*	0.00	0.00	1,798.38	2,885.13
	Total	324.41	1,130.12	6,570.43	8,312.49
CO Emission (Tons)	AM	0.07	0.23	0.66	1.36
	MD*	0.00	0.00	0.35	0.67
	Total	0.07	0.23	1.01	2.03

Note: The FITSEVAL-Default and FITSEVAL-Modified methods produced zero delays due to low demands, as indicated in the table

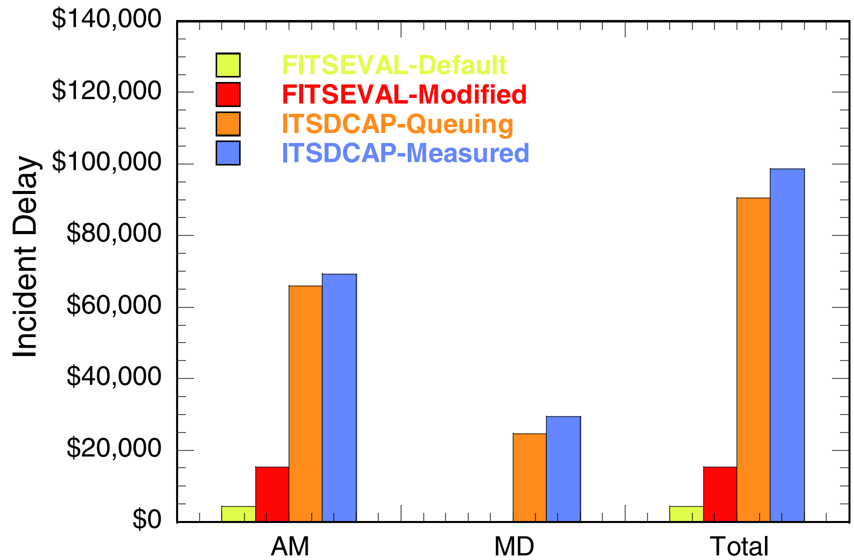

FIGURE 6 Comparisons of incident delays in dollar values between the four assessed methods

CONCLUSIONS

The developments of a planning level ITS evaluation tool as well as a real-world data-based evaluation tool were presented in this paper. The abilities of these two tools to assess the impacts of incidents and incident management are further compared. The results presented in this paper confirm the importance of utilizing good estimates of incident rates and durations in the benefit analysis of incident management, as indicated when comparing the results from the FITSEVAL-Default and FITSEVAL-Modified methods. In addition, the comparison between the results from the FITSEVAL-Modified and ITSDCAP-Queuing methods indicates the importance of using accurate estimates of demands in the analysis. The comparison between the results from ITSDCAP-Queuing and ITSDCAP-Measured methods confirms the ability of the deterministic queuing analysis to produce results that are close to real-world measurements of delays, as reflected by the ITSDCAP-Measured method results, at least for the investigated case studies.

To improve the planning-level analysis such that of the FITSEVAL and IDAS tools, it is recommended that data-based tools like ITDCAP are used to estimate the incident rates and durations to be used as inputs to the sketch planning tools. In addition, the demand forecasting models used in conjunction with these tools should be well calibrated to produce accurate estimates of demands for the corridors under investigation.

REFERENCES

1. Cambridge Systematics Inc. *ITS-Deployment Analysis (IDAS) User's Manual*. Prepared for the Federal Highway Administration, Oakland, CA, November 2001.

2. Hadi, M., Y. Xiao, H. Ozen, and P. Alvarez. Evaluation Tools to Support ITS Planning Process: Development of a Sketch Planning Tool in FSUTMS/Cube Environment. Final Report, BD015-9, Florida International University, October 2008.
3. Xiao, Y. and M. Hadi. Integrated Intelligent Transportation System Evaluation and Demand Forecasting Environment. Presented at 87th Annual Meeting of the Transportation Research Board, Washington, D.C., 2007.
4. Xiao, Y., M. Hadi, H. Ozen, and V. Mysore. An ITS Evaluation Tool in the FSUTMS Regional Demand Modeling Environment. *Transportation Research Record: Journal of the Transportation Research Board*, No. 2176, 2010, pp. 76-83.
5. Hadi, M., L. Shen, C. Zhan, Y. Xiao, S. Corbin, and D. Chen. Operation Data for Evaluating Benefits and Costs of Advanced Traffic Management Components. *Transportation Research Record: Journal of the Transportation Research Board*, No. 2086, 2008, pp. 48-55.
6. Guin, A. and Porter, C. Bayne Smith and Carla Holmes. Benefits Analysis for an Incident Management Program Integrated with Intelligent Transportation Systems Operation: A Case Study. Presented at 86th Annual Meeting of the Transportation Research Board, Washington, D.C., 2007
7. Birst, B. and A. Smadi. An Application of ITS for Incident Management in Second-Tier Cities: A Fargo, ND Case Study. Proceeding of Mid-Continent Transportation Symposium, Iowa, 2000, pp. 30-34.
8. Courage, K.G., and S. Lee. *Development of a Central Data Warehouse for Statewide ITS and Transportation Data in Florida: Phase II Proof of Concept*. Florida Department of Transportation, 2008.
9. Hadi, M., Y. Xiao, C. Zhan, and P. Alvarez. *Integrated Environment for Performance Measurements and Assessment of Intelligent Transportation Systems Operations*. Final Report. BDK80 977-11, Florida International University, July 2012.
10. Highway Capacity Manual (HCM 2010), transportation Research Board, 2010.
11. May, A. D. *Traffic Flow Fundamentals*. Prentice Hall Inc., Englewood Cliffs, New Jersey, 1990.
12. Xiao, Y. Hybrid Approaches to Estimate Freeway Travel Times Using Point Traffic Detector Data. Ph.D. Dissertation, Florida International University, Miami, FL, 2011.
13. Zhan, C., A. Gan, and M. Hadi. Identify Secondary Crashes and Their Contributing Factors. In *Transportation Research Record: Journal of the Transportation Research Board*, No. 2102, 2009, pp. 68-75.
14. Skabardonis A. and M. Mauch. *FSP Beat Evaluation and Predictor Models: Users Manual,* Research Report, No. UCB-ITS-RR-2005-XX, Institute of Transportation Studies, University of California-Berkeley, California, 2005.
15. Lin, P., A. Fabregas, H. Chen, H. Zhou, Q. and Wang. *Review and Update of Road Ranger Cost Benefit Analysis*. Final Report, Center for Urban Transportation Research, University of South Florida, January 2012.
16. Schrank, D. and T. Lomax. *The 2005 Urban Mobility Report*. Texas Transportation Institute, Texas A&M University System, College Station, TX, May 2005.