EVALUATION OF THE IMPACTS OF ITS USING TRAFFIC SIMULATION

Dr Hussein Dia
ANZ ITS Technical Leader
AECOM
540 Wickham Street, Fortitude Valley, QLD Australia 4006
Email: Hussein.Dia@aecom.com
T +61 7 3553 3682
M +61 414 877 039

EVALUATION OF THE IMPACTS OF ITS USING TRAFFIC SIMULATION

ABSTRACT

The task of quantifying the impacts of Intelligent Transport Systems (ITS) projects is an important and necessary undertaking in order to justify the expenditure of public funds on ITS. For example, roadway incidents impose a substantial cost to society when delays, congestion, secondary accidents, and environmental emissions are taken into consideration. Incident impacts can be substantially reduced through implementation of incident management programs. In recent times, there has been a growing interest among researchers and practitioners in developing evaluation frameworks for assessing the benefits of ITS. However, comprehensive research tools for evaluating the benefits of these systems have not been fully developed. For example, the impacts of incident management programs will depend on the extent of existing congestion on the road network, and will also vary according to the severity of the incident, its duration, and the time of day during which it occurs. The use of computer modelling, and microscopic traffic simulation in particular, offers a cost-effective approach in which input conditions can be varied (e.g. to reflect incidents during peak and non-peak conditions) and the impacts of incidents on network performance can be evaluated. This paper presents results from a study which aimed to quantify the impacts ITS and provide road authorities with the necessary input information for developing the business case for implementation of ITS projects. The evaluation was based on the development of a large-scale micro-simulation model covering an area approximately 122 square kilometres, including 43 kilometres of motorway and about 85 kilometres of arterial roads on the Gold Coast, Australia. The study examined the effectiveness of selected ITS strategies including ramp metering, VMS information dissemination combined with route diversions, and variable speed limit systems. The results reported in this paper demonstrate the feasibility of using traffic simulation to assess the impacts of ITS, and the potential of ITS to provide substantial economic benefits in terms of reduction in travel times, and improvements in safety conditions.

INTRODUCTION

Roadway incidents impose a substantial cost to society when delays, congestion, secondary accidents, and environmental emissions are taken into consideration (Gillen and Levinson, 2004; US DoT 2008). The use of computer modelling, and microscopic traffic simulation in particular, offers a cost-effective approach in which input conditions can be varied (e.g. to reflect incidents during peak and non-peak conditions) and the impacts of incidents on network performance can be evaluated (Dia and Cottman, 2002; Ben-Akiva *et al*, 2003). The work reported in this paper is part of a study which aimed to quantify the impacts of incidents and the benefits of incident management strategies. The test-bed selected for this study comprised a traffic simulation model of the Pacific Motorway (also called the M1 Motorway) between Brisbane and the Gold Coast in Australia. The primary objective of this work was to demonstrate the feasibility of using microscopic traffic simulation to evaluate the impacts of incidents using field data and other related information from the Nerang Traffic Management Centre.

METHODOLOGY AND MODEL DEVELOPMENT

This work involved the development of a large scale simulation model covering an area approximately 122 square kilometres, including 43 kilometres of the Motorway and about 85 kilometres the arterial roads on the surrounding network. The Motorway also includes 15 interchanges which link the Motorway to an extensive service road network and to major roads in each locality. The development of the simulation model was characterised by a high degree of geometric detail and specification of route choice and driver behaviour parameters. The model was extensively calibrated and validated for the AM and PM Peak periods with approximately 90,000 vehicles modelled inside the network during a 2-hour period. Time-sliced traffic demand data was provided in 15-minute intervals for both the AM (07:00-09:00) and PM Peak (16:00-18:00) periods. The calibration process involved a detailed examination of the global and local parameters to ensure that the selected parameters produced results for modelled traffic counts and travel times which were in close agreement with field data. The validation process involved testing the calibrated model using a traffic data set which was not used in model calibration. A detailed discussion of the model development tasks is beyond the scope of this paper, and have been reported extensively in previous publications. The reader is referred to Stirzaker and Dia (2007) and Dia and Panwai (2007) for further details. A brief description of some of the details relevant to this paper are provided next.

Calibration and validation results

The Motorway (M1) and arterials model was calibrated using traffic counts from loop detector sites on the Motorway and mid-block counts on a number of roads on the arterial network. The calibration results for the motorway showed traffic count errors of around 14 and 6 percent during the AM and PM peak periods, respectively. For the arterials, the calibration errors were around 10 and 13 percent for the AM and PM peak periods, respectively. The calibrated M1 model was validated using average speeds collected from loop detector sites on the Motorway. The validation results showed overall validation errors of around 8.5 percent, which is an acceptable result given the large scale of the model. These results provided a good degree of confidence in the model's ability to replicate field conditions and its suitability for use as a valid tool for modelling traffic management and ITS applications on the M1 and surrounding arterial network on the Gold Coast.

Simulation of incidents

The incident databases at the Nerang Traffic Management Centre were examined to retrieve information about the location of incidents, their duration and severity (in terms of the number of blocked lanes) for incidents dating back to 2004. The information also included the time the incident occurred, the time when it was cleared, classification of incident and the time stamped loop detector data from both the immediate upstream and downstream stations where the incident occurred. Analysis of this data showed a number of locations that were over-represented in terms of their incident frequency. A large number of incidents were simulated at these locations with durations of 1.0 to 1.5 hours where incidents were modelled to block either one or two lanes. A total of 54 incidents were simulated for the morning AM Peak and 66 incidents for the PM peak (total of 120 incident cases). A number of localised and network-wide key performance indicators including average speeds, travel times, delays, number of stops together with fuel consumption, operating costs and emissions (Akcelik and Besley, 2003; Biggs and Akcelik, 1986; Post et al, 1985; and Sturm et al, 2000) were collected. The results showed that the incidents resulted in average increases of 2.2 percent in travel times; 5.7 percent in delays; and 11.1 percent in number of stops. The incidents also resulted in an average increase of 1.5 percent in CO emissions and fuel consumption, and 5.0 percent increase in operating costs. On average, each AM-peak incident was found to result in an increase of $21,000 in operating costs over the duration of the incident. These results, when extrapolated to a set of 117 real incidents that occurred between January 2004 and September 2006 on the same facility, translate into a cost of around $2M in additional operating costs. A detailed discussion of the incident impacts can be found in (Dia and Gondwe, 2008).

EVALUATION OF THE EFFECTIVENESS OF SELECTED INCIDENT MANAGEMENT STRATEGIES

This study examined the effectiveness of the following incident management strategies: ramp metering, VMS information dissemination and route diversions, and variable speed limit systems. The task of evaluating the impacts of these strategies required coding each of these traffic management strategies into the M1 simulation model. This task also verified the operation of the strategy and identified issues that may limit its application. Once the traffic management strategies were coded and verified, they were then applied to the M1 model and the incident scenarios identified previously. The effectiveness of each of the strategies in reducing the negative impacts of incident-induced congestion was identified and documented.

Ramp metering

In this study, ramp meters were implemented using the Flow Metering Algorithm (TSS, 2008), which specifies the number of vehicles per hour to be released. Ramp meters were simulated for a particular field incident which severely disrupted traffic conditions (**Figure 1**). The ramp meter was modelled to allow a ramp flow of 500 vehicles per hour (with 450 vehicles per hour and 750 vehicles per hour for minimum and maximum values) and was simulated from 7:00 to 9:00 AM. The incident was simulated from 8:40 to 9:00 AM reflecting field conditions of the same incident. During the simulation, statistics covering the impact area were gathered. The statistics included delay, flow, speed, number of stops, and travel time which were averaged at 15 minute-interval. The ramp meter was tested under four levels of variation in traffic demand. Two cases of traffic demand were used: a base scenario reflecting current traffic conditions and a future scenarios reflecting 25 percent increase in the traffic demand compared to current conditions.

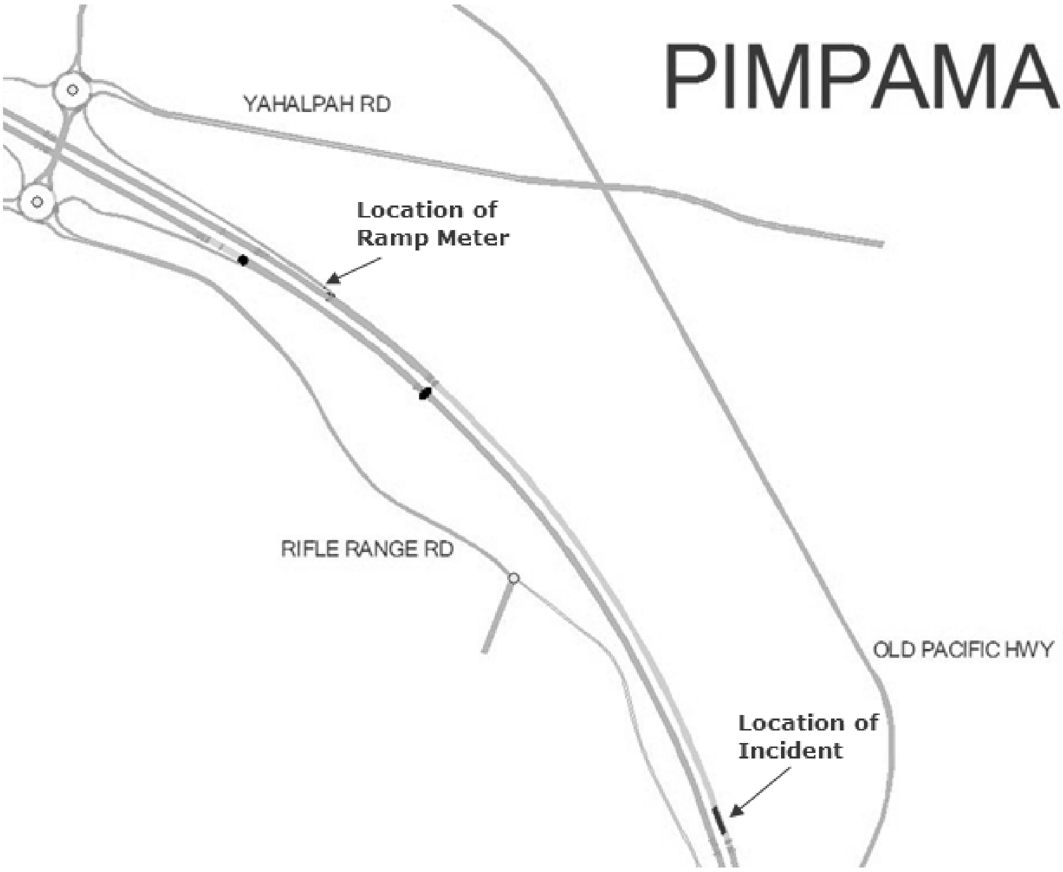

Fig. 1. Schematic of Location of the Incident and Ramp Meter Experiment

A number of performance measures were gathered during simulation execution. The results are presented in **Tables 1 and 2**. The results in **Table 1** indicate that ramp metering under current conditions does not produce any benefits on the mainline. This is probably due to the fact that existing ramp volumes are not too heavy (unnecessary delays will be introduced if ramp meters are implemented). However, ramp metering starts to provide substantial benefits when traffic demand increases (as shown in **Table 2**). For example, when the demand is increased by 25 percent, the delays on the mainline are reduced by 10.5 percent; travel times are reduced by 2.8 percent, and number of stops decrease by 23 percent as a result of implementing ramp metering.

Table 1
Performance Measures- Current Traffic Demand Conditions

Performance Measure		Without Ramp Metering (current conditions)	With Ramp Metering	% Difference
Speed (kph)				
	On-ramp	57.8	52.6	-9.1
	Mainline	88.2	87.7	-0.6
Number of stops per vehicle				
	On-ramp	0.0	0.2	200.0
	Mainline	0.3	0.3	0.0
Travel Time (second/vehicle)				
	On-ramp	36.2	40.3	11.2
	Mainline	171.5	173.0	0.9
Delay (seconds/vehicle)				
	On-ramp	2.9	6.8	131.2
	Mainline	29.7	31.2	4.9

Table 2
Performance Measures- 25 Percent Increase in Traffic Demand

Performance Measure		Without Ramp Metering (current conditions)	With Ramp Metering	% Difference
Speed (kph)				
	On-ramp	57.6	52.0	-9.7
	Mainline	83.2	83.8	0.6
Number of Stops				
	On-ramp	0.0	0.2	200.0
	Mainline	1.4	1.1	-23.0
Travel Time (seconds/vehicle)				
	On-ramp	36.3	40.6	11.8
	Mainline	192.1	186.8	-2.8
Delay (seconds/vehicle)				
	On-ramp	2.7	7.1	156.5
	Mainline	50.5	45.2	-10.5

VMS information and route diversion

This study also evaluated the benefits of incident response in terms of provision of Variable Message Sign (VMS) information on the M1 and implementation of dynamic signal plans on diversion routes. An incident was simulated on an arterial road (Smith Street) and VMS information was provided on the Motorway advising motorists of incident conditions (**Figure 2**).

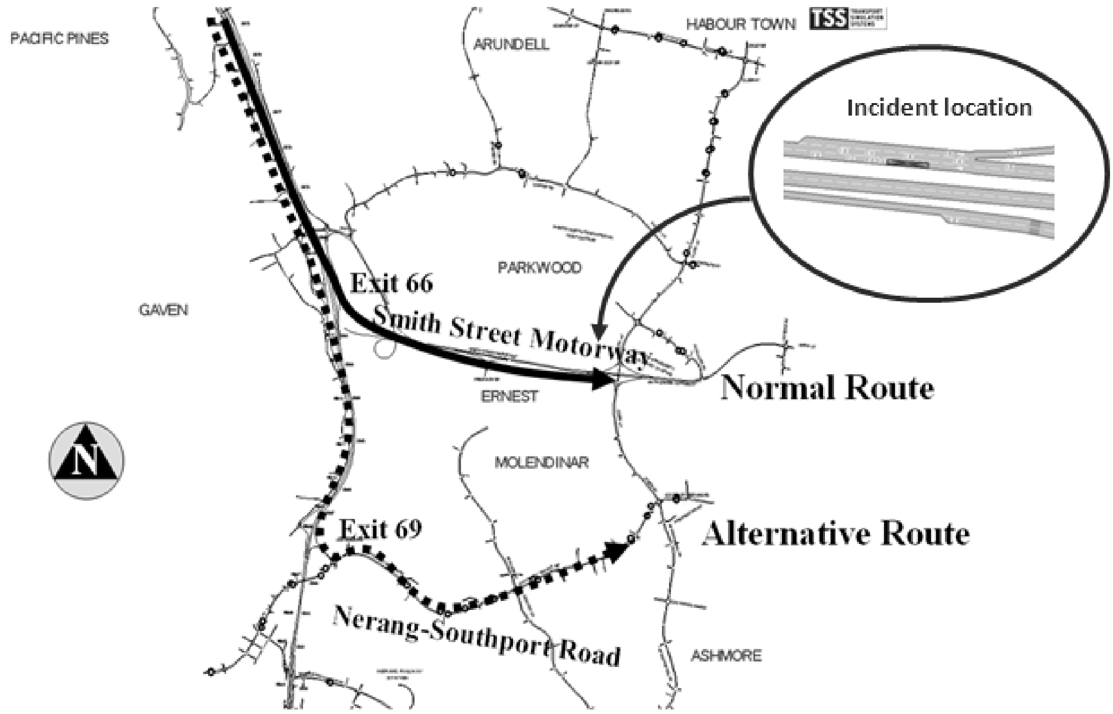

Fig. 2. Schematic Showing Normal and Diversion Routes

This task included simulating the incident for the particular duration, both with and without the route diversions, and extracting the traffic performance outputs. In the incident scenarios, the incident was replicated and traffic was diverted at different percentages ranging from 30 to 80 percent. The signal timing plans that were implemented in the Traffic Management System (called STREAMS) before and after the incident were also obtained and simulated on Nerang-Southport road. This provided a measure to determine the benefits of the dynamic signal plan response. The following simulation scenarios (**Table 3**) were investigated.

Table 3
Traffic Simulation Scenarios Tested

Case Number	Description	Traffic Signal Timing Plan on diversion route	Driver Compliance Rate With VMS Information or Diversion Rate (Percent)
Case 1	Normal conditions	Normal plan 140 seconds	Not applicable
Case 2	Incident conditions	Normal plan 140 seconds	Not considered
Case 3	Incident conditions	Incident plan 160 seconds	Not considered
Case 4	Incident conditions	Incident plan 160 seconds	30
Case 5	Incident conditions	Incident plan 160 seconds	40
Case 6	Incident conditions	Incident plan 160 seconds	50
Case 7	Incident conditions	Incident plan 160 seconds	80

Case 1 represents the base case scenario reflecting normal traffic conditions without incidents. In this case, normal traffic signal timings operate on the diversion route and consist of a cycle time of 140 seconds. **Case 2** represents incident conditions with a normal traffic signal plan the diversion route. Similarly, **Case 3** represents incident conditions but with an incident timing plan (cycle time of 160 seconds) and no route diversion. **Cases 4-7** represent incident conditions using an incident traffic signal timing plan with varying degrees of driver compliance with the provided VMS information. For example, in **Case 4**, it is assumed that 30 percent of drivers who pass the VMS

will accept the VMS advice and act on it by taking alternative route (**Exit 69 in Figure 3**). Similarly, it will be assumed that 80 percent of drivers will comply with the VMS information in **Case 5**. This approach is needed because it is unknown how drivers would respond to the VMS and hence a sensitivity analysis can provide an indication of the impacts under varying compliance rates. As was mentioned above, this study will also simulate the impacts of the dynamic signal plans. **Figure 3** shows the signalised intersections on the diversion route which will be simulated with dynamic signal timing.

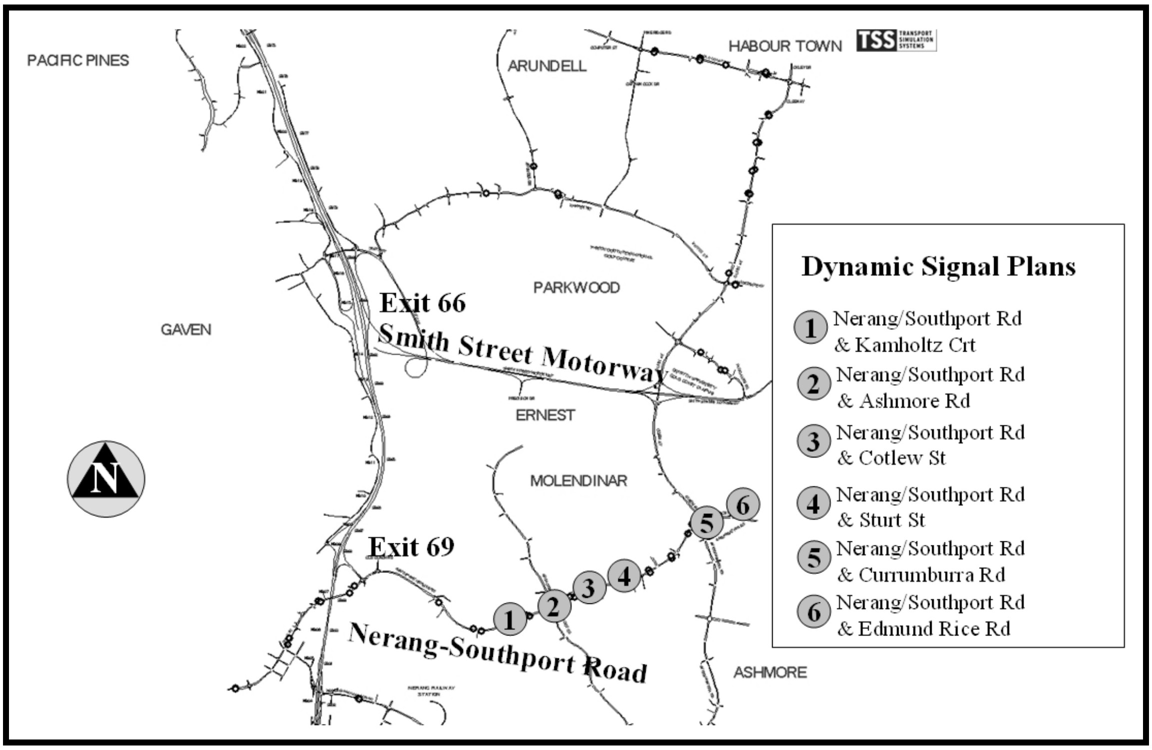

Fig. 3. Schematic of Signalised Intersections with Dynamic Signal Plans

The signal timing plans on these intersections will switch between Plan 5 (140 seconds) and Plan 2 (160 seconds) after the occurrence of the incident to increase throughput on the diversion route (Nerang-Southport Road). **Table 4** shows the traffic volume variations in 15-minute intervals for Exits 66 (normal route) and Exit 69 (alternative route). Given that the incident occurred at 8:30 AM, then clearly traffic conditions are the same for all scenarios for the period 7:00 to 08:30 AM. However, the distribution of traffic along the two routes becomes substantially different during the incident period between 8:30 and 9:00 AM. It should be noted that the traffic flow results for **Cases 2** and **3** were the same as for **Case 1** because no traffic diversions were implemented. Therefore, only the results for **Cases 1** and **4-7** are reported below.

Table 4
Traffic Flow Variations across All Scenarios Tested

Time Interval	**Case 1** Normal Conditions		**Case 4** Incident 30% Diversion		**Case 5** Incident 40% Diversion		**Case 6** Incident 50% Diversion		**Case 7** Incident 80% Diversion	
	Exit 66	**Exit 69**	**Exit 66**	**Exit 69**	**Exit 66**	**Exit 69**	**Exit 66**	**Exit 69**	**Exit 66**	**Exit 69**
07:00-07:15	1,712	668	1,712	668	1,712	668	1,712	668	1,712	668
07:15-07:30	1,884	1012	1,884	1012	1,884	1012	1,884	1012	1,884	1012
07:30-07:45	2,120	872	2,120	872	2,120	872	2,120	872	2,120	872
07:45-08:00	1,984	904	1,984	904	1,984	904	1,984	904	1,984	904
08:00-08:15	2,056	840	2,056	840	2,056	840	2,056	840	2,056	840
08:15-08:30	2,012	852	2,012	852	2,012	852	2,012	852	2,012	852
08:30-08:45	2,064	716	1,508	1052	1,304	1156	1,120	1224	576	1224
08:45-09:00	1,920	816	1,208	1248	1,124	1240	880	1200	400	1272

Analysis of the results in **Table 4** reveals that the traffic volume on both the normal route (Exit 66) and alternative route (Exit 69) becomes almost identical (1208 and 1248 vph, respectively) at the end of simulation when the diversion rate is 30 percent. This is compared to traffic volumes of (1920 and 816 vph) for the base case scenario. The results also show that when the percentage of drivers diverting to Exit 69 increases above 30 percent, then (as expected) traffic volumes on the alternative route increase and start to exceed the traffic volume on the normal route. For example, when the diversion rate is 80 percent, the traffic volumes on the normal and alternative routes are (400 and 1272 vph, respectively). These results suggest that the optimal diversion rate should not exceed 30 percent, as this diversion percentage creates a balanced distribution of traffic on both the normal and alternative routes.

Traffic performance impacts

Table 5 presents the impacts for the scenarios described before, aggregated for all traffic classes (cars and heavy vehicles). **Figures 4** and **5** show the road sections used to measure the traffic impacts on the two routes. The delay results show that the incident, which blocked one lane for the duration of one hour, resulted in considerable delays on the normal route (Exit 66)). For example, if no action was taken to ameliorate the impacts of the incident (Case 2), then the delay per vehicle on Smith Street would increase by 10 percent (from 145 seconds to 159 seconds under incident conditions). The results also show that if the traffic signal plan on the alternative route (Exit 69) was increased to 160 seconds due to the incident (Case 3), then that response alone (without diversions) does not produce much benefit. The benefits are only realised when the two incident management responses (VMS route diversion and incident cycle plan 160 seconds) are implemented at the same time. As was mentioned before, the 30 percent diversion option offered the best outcome because it resulted in a balanced distribution of traffic volumes on both the normal and alternative routes. Therefore, the best benefits are realised for Case 4 and result in the reduction of delays by 8.8 percent (from 159 to 145 seconds per vehicle); increase in speeds by 4.5 percent (from 44 to 46 kph); decrease in number of stops by 22 percent (from 9 to 7); and decrease in travel time by 3.3 percent (from 451 to 436 seconds).

Table 5
Traffic Impact Results

Scenario	Route	Delay (seconds per vehicle)	Speed (kph)	Number of Stops (per vehicle)	Travel Time per Vehicle (seconds)
Case 1 (Normal Conditions-140s cycle)	Exit 66	145	46	7	437
	Exit 69	157	21	4	410
Case 2 (Incident -0% Diversion-140s cycle)	Exit 66	159	44	9	451
	Exit 69	157	21	4	410
Case 3 (Incident -0% Diversion-160s cycle)	Exit 66	160	44	9	451
	Exit 69	157	21	4	410
Case 4 (Incident- 30% Diversion-160s cycle)	Exit 66	145	46	7	436
	Exit 69	292	30	9	656
Case 5 (Incident- 40% Diversion-160s cycle)	Exit 66	145	46	7	436
	Exit 69	287	30	9	658
Case 6 (Incident- 50% Diversion-160s cycle)	Exit 66	145	46	7	435
	Exit 69	304	29	10	668
Case 7 (Incident- 80% Diversion-160s cycle)	Exit 66	146	46	7	436
	Exit 69	322	29	11	689

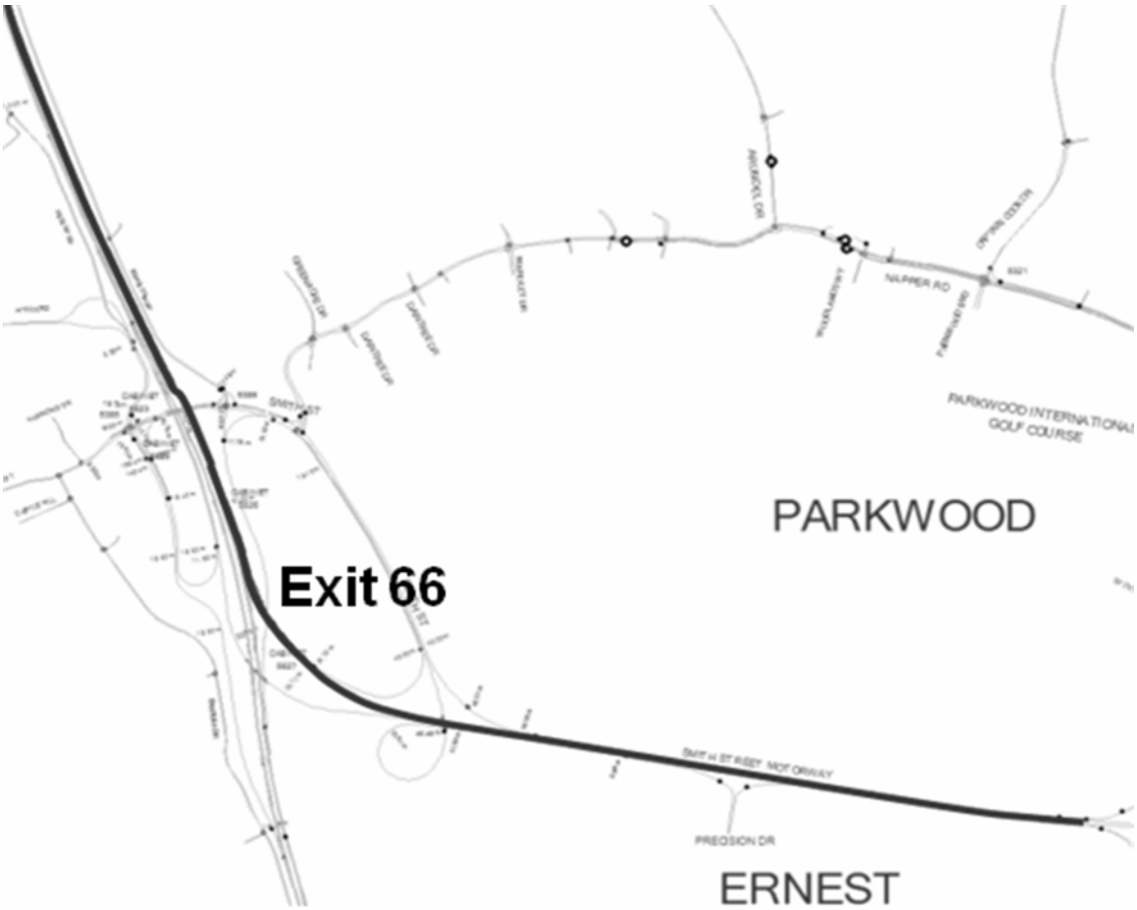

Fig. 4. Section Used for Measurement of Impacts- Normal Route

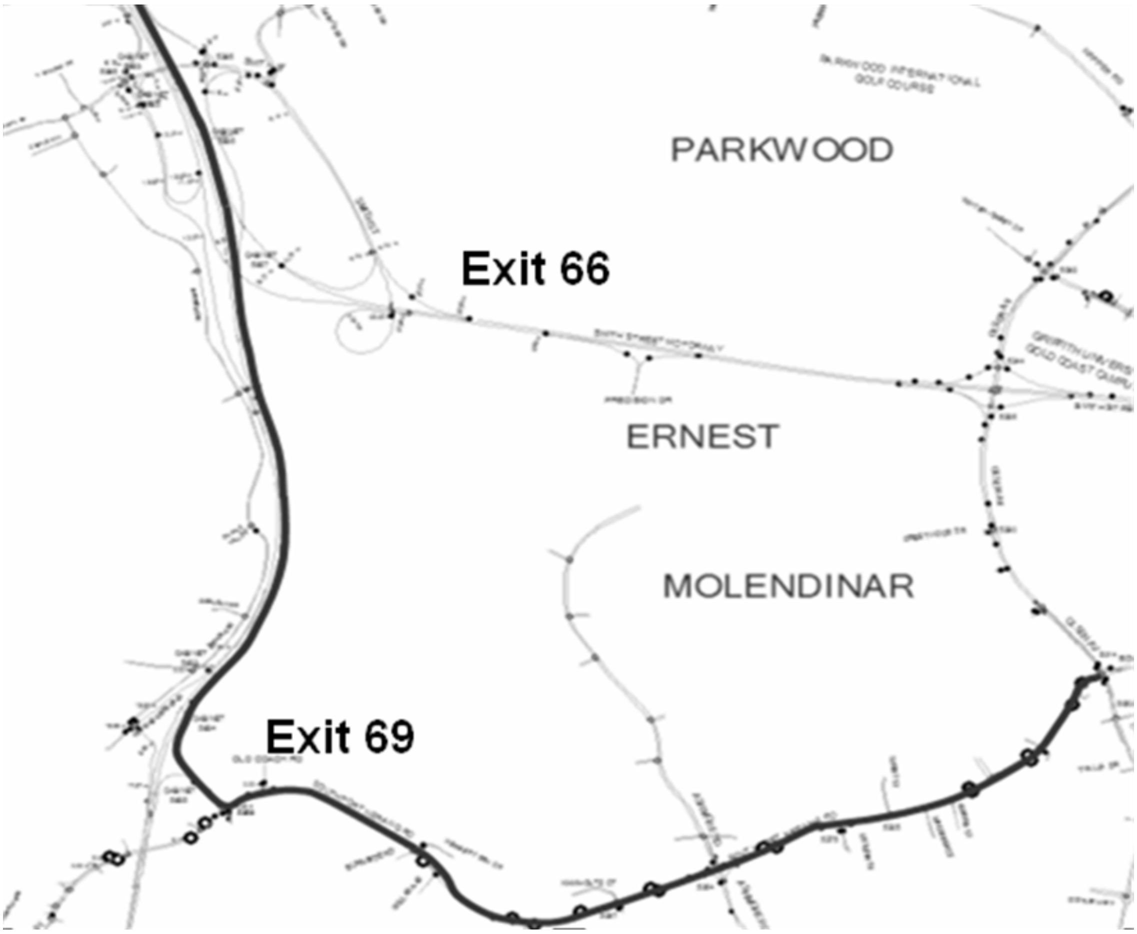

Fig. 5. Section Used for Measurement of Impacts- Diversion Route

It is interesting to note, from comparison of the results for Cases 1 and 4, that implementation of VMS route diversion and incident traffic signal cycle timing plans (Case 4) almost resulted in restoring traffic conditions to pre-incident conditions (Case 1), which shows that the incident's negative impacts can be reduced or eliminated through these two responses. It is also important to note the impacts of these responses on the alternative route. As would be expected, the results in **Table 5** show that the traffic performance on the alternative route is not impacted if route diversions are not implemented (Case 2 and 3). However, once the VMS route diversions are implemented, then traffic performance on the alternative route starts to deteriorate when compared with normal conditions (even with the implementation of the 160 second cycle incident plan). The delays on the diversion route increased by 85 percent (from 157 second under normal conditions to 292 seconds under incident conditions with 30 percent diversion). As would be expected, the delays on the alternative routes increased as the diversion rate increased. When the diversion rate reached 80 percent, the delays on the diversion route reached 322 seconds which is an increase of 105 percent compared to normal conditions. It is also noteworthy that diversion rates above 30 percent did not reduce the delays on the normal route, which corroborates previous results that the optimal diversion rate to alternative routes in the event of an incident on Smith Street should not exceed 30 percent. **Table 6** summarises the benefits obtained using VMS diversion and dynamic signal timing.

Table 6
Impacts of VMS Route Diversion and Dynamic Signal Timing

Scenario	Route	Delay (seconds)	Speed (kph)	Number of Stops (per vehicle)	Travel Time per Vehicle (seconds)
Case 2 Incident occurs on normal route but no response is initiated (no diversions or dynamic signal plans)	Exit 66	159	44	9	451
Case 4 Incident occurs on normal route, 30% of traffic is diverted to alternative route, where traffic signal timing is increased to 160s cycle	Exit 66	145	46	7	436
Benefits (%) (Case 4 over Case 2)		8.8%	4.5%	22.2%	3.3%

Variable speed limit systems

This study also conducted a preliminary investigation of Variable Speed Limits (VSL) as a means to reduce the negative impacts of incidents. The literature on this topic shows that although it is generally recognised that VSL improves safety and efficiency, few field studies have quantified the impacts of these systems in a rigorous manner (Lee *et al*, 2006). In most cases, the data was of poor quality and insufficient quantity to provide statistically reliable evidence. The use of traffic simulation overcomes some of these limitations and provide a test-bed for evaluating their performance under different regimes and network topologies. Simulation also allows for determining the parameters and conditions that are conducive to the implementation of these systems. The M1 traffic simulation model was used to test an 8 kilometre section of the Motorway **(Figure 6)** to ascertain whether VSL had a positive impact on the safety and efficiency of the motorway.

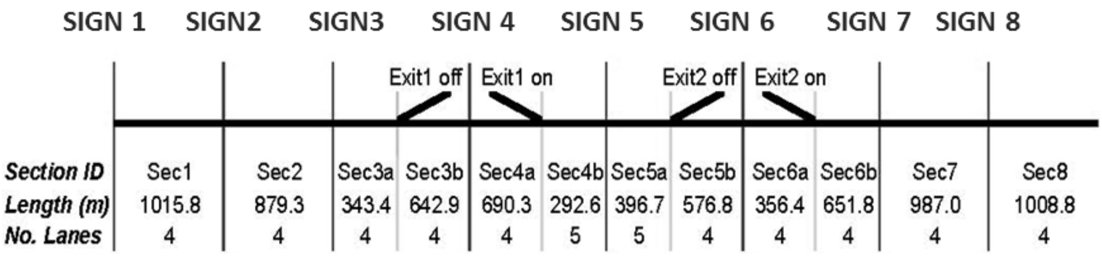

Fig. 6 Schematic of VSL Test Section

This was explored through examination of flow homogenisation (reduction in the variation of the speeds between vehicles, both within a lane and adjacent lanes) and reduction in decelerations at the back of queued vehicles.

A number of experiments were conducted to prove this hypothesis, with each experiment having different traffic demands (heavy congestion and queuing in the middle section of the motorway and moderate congestion throughout the motorway). The distance between VSL signs is an important constraint that impacts on the performance of the whole VSL system. This also has a bearing on the safety of the system, as VSL signs that display speed limits that vary too much in time and space could confuse drivers. A distance of approximately one kilometre between VSL signs was adopted for this analysis. This effectively broke the 8km stretch of motorway into 8 groups of 1km segments, where each segment started with a VSL sign and could take on a different speed limit **(Figure 6)**. The triggers that prompt a change of speed limit in VSL and the operating logic that coordinate its operation also have a significant bearing on its performance. Existing VSL systems around the world have triggers that range from the basic time of day algorithms, through implementations using variables such as occupancy or flow, to complex algorithms that calculate the likelihood of a crash occurring in real time (Abdel-Aty *et al.* 2006). As this project is primarily looking at the impacts of a well-functioning VSL system, it was chosen to implement VSL using simple time-based triggers. Key indicators of the safety and efficiency of a network were examined as outputs from each experiment. Given that micro-simulation car following models are based on maintaining a safe gap between vehicles (and hence crashes cannot be simulated), surrogate measures were introduced for evaluation of safety. These included measurement of headways and decelerations. Other indicators for evaluating efficiency included travel time, stop time, average speed, and number of stops, which were collected and analysed for each experiment.

The results showed that VSL has the potential to provide an 11 percent improvement in efficiency of congested sections during peak hours. The benefits in efficiency are likely to be due to the smoother flow attributed to VSL. Restricting the speed limit allowed the variance in the speeds of vehicles leaving the queue to be reduced. This meant that it was easier for vehicles to find gaps and merge due to the more homogonous nature of the flow. It was also found that VSL allowed for greater speed within queued sections and allowed queues to be cleared faster. VSL was also found to provide safety and efficiency benefits by homogenising the flow in higher speed regimes. The number of stops per vehicle on the motorway reduced by 64 percent following the speed limit being reduced from 110 kph to 70 kph as a result of the incident.

SUMMARY AND CONCLUSIONS

This study demonstrated the feasibility of using a traffic simulation approach to quantify the impacts of selected incident management strategies. The study also evaluated the benefits of incident response in terms of provision of VMS information on the M1 and implementation of dynamic signal plans on diversion routes. The results revealed that traffic adjustments due to the diversions and dynamic signal plans resulted in equilibrium conditions on both the normal route (Smith Street) and alternative diversion route (Nerang-Southport Road) when the diversion rate did not exceed 30 percent. The results also showed that the benefits were only realised when the two incident management responses (VMS route diversion and implementation of incident cycle plan 160 seconds) are implemented at the same time. The best benefits were realised for diversion rates of 30% and resulted in the reduction of delays by 8.8 percent (from 159 to 145 seconds per vehicle); increase in speeds by 4.5 percent (from 44 to 46 kph); decrease in number of stops by 22 percent (from 9 to 7); and decrease in travel time by 3.3 percent (from 451 to 436 seconds). Finally, the study also conducted a preliminary investigation of variable speed limits as a means to reduce the negative impacts of incidents. The results showed that VSL has the potential to provide an 11 percent improvement in efficiency and showed that VSL can be used as a measure to increase the efficiency of congested sections on motorways. VSL was also found to provide safety and efficiency benefits by homogenising the flow in higher speed regimes. The number of stops per vehicle on the motorway reduced by 64 percent following the speed limit being reduced from 110 kph to 70 kph as a result of the incident. Although these results show that the impacts of incident management strategies are network-dependent, they also suggest that these strategies, especially when combined, have the potential to provide substantial economic benefits in terms of reduction in travel times and improvements in safety conditions.

ACKNOWLEDGEMENTS

The work reported in this paper was undertaken by the author as part of a research program when he was with the ITS Research Laboratory at the University of Queensland. The contributions of a number of postgraduate students, including Dr Sakda Panwai and Mr William Gondwe, are gratefully acknowledged. This paper is a substantially revised version of an earlier presentation delivered by the author at the Australian Transport Research Forum.

REFERENCES

Abdel-Aty M, Dilmore J and Dhindsa A (2006). Evaluation of variable speed limits for real-time freeway safety improvement. Accident Analysis & Prevention, Volume 38, Issue 2, Pages 335-345.

Akcelik, R. and Besley, M. (2003) Operating cost, fuel consumption, and emission models in aaSIDRA and aaMOTION, *25th Conference of Australian Institutes of Transport Research (CAITR 2003),* University of South Australia, Adelaide, Australia, 3-5 December 2003.

Ben-Akiva M, Cuneo D, Hasan M, Jha M, and Yang, Q (2003) Evaluation of freeway control using a microscopic simulation laboratory. *Transportation Research Part C, 11, 29-50.*

Biggs, D. C. and Akcelik, R. (1986) An energy-related model of instantaneous fuel consumption, *Traffic Engineering & Control,* **27,** 320-325.

Dia, H. and Gondwe, W. (2008). Evaluation of Incident Impacts on Integrated Motorway and Arterial Networks using Traffic Simulation. Submitted to the 29th Australasian Transport Research Forum, to be held on the Gold Coast, August 2008.

Dia, H. (2003) Unpublished report to the Queensland Department of Main Roads, North Coast Hinterland.

Dia, H. and Panwai, S. (2007). Modelling drivers' compliance and route choice behaviour in response to travel information. Special issue on Modelling and Control of Intelligent Transportation Systems, Journal of Nonlinear Dynamics, Volume 49, Number 4, pp 493-509, September, 2007 (Springer).

Dia, H. and Cottman, N. (2002). Evaluation of Incident Management Benefits using Traffic Simulation. Proceedings of the 13th Mini-EURO Conference and the 9th Meeting of the EURO Working Group on Transportation, Politechnic University of Bari, June 10-13, Bari, Italy.

Gillen D and Levinson D (2004). Assessing the Benefits and Costs of ITS. *Making the Business Case for ITS Investments*. Springer, USA.

Lee, C., Hellinga, B. Saccomanno, F. Evaluation of variable speed limits to improve traffic safety, Transport Research Part C 14, 2006, 213-228.

Post, K., Kent, J. H., Tomlin, J. and Carruthers, N. (1985) Fuel consumption and emission modelling by power demand and a comparison with other models, *Transportation Research Part A,* **18,** 191-213.

Stirzaker, C. and Dia, H. (2007). Evaluation of Transportation Infrastructure Management Strategies Using Microscopic Traffic Simulation. Journal of Infrastructure Systems, Vol 13, No 2, pp. 168-174 (June 2007), American Society of Civil Engineers.

Sturm, P. J., Hausberger, S., Keller, M. and de Haan, P. (2000) Estimating real world emissions from passenger cars - use and limitations of instantaneous emissions data, *International Journal of Vehicle Design,* **24,** 19-33.

TSS (2008). AIMSUN NG 5.1 Microsimulator User Manual. Version 5.1.10, Transport Simulation Systems, Barcelona, Spain.

U.S. Department of Transportation (2008). Intelligent Transport Systems Benefits, Costs and Lessons Learned. http://www.benefitcost.its.dot.gov, Accessed 12-June-2008.