MODELLING OF THE SOUTHERN EXPRESSWAY USING PARAMICS MICROSIMULATION SOFTWARE

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Abstract: A Paramics microsimulation model of an Adelaide radial road corridor has been constructed. This corridor includes a novel one-way reversible direction expressway equipped with an ATMS. Under the prevailing tidal nature flow regime, the expressway operates northbound in the morning and southbound in the evening. The modelled area includes two alternative radial routes: an arterial road and the expressway. The model can compare the two routes in terms of congestion parameters (e.g. congestion index, acceleration noise and proportion stopped time) and emissions. Real world data has been collected on both routes using an instrumented vehicle which records vehicle engine, positional and emissions data in real time. The paper describes the utility of microsimulation modelling and some of the benefits that Paramics can offer to ITS modelling. Paramics output data are compared with those from the real world probe vehicle and the emission impacts of ATIS and IMS are described.

Key Words: Intelligent Transport Systems, instrumented vehicle, microsimulation model, Paramics, air quality emissions, greenhouse gas emissions

1. INTRODUCTION

A model of the Southern Expressway corridor (SEC) in Adelaide has been constructed using the *Paramics* microsimulation software. The software was developed in the UK and has been used throughout the world for modelling ITS impacts on road networks. Many of these users have found the model to be robust and well suited to ITS applications. In addition, Paramics also possesses a powerful visualisation engine making the task of network validation and calibration much more thorough. However, the learning curve for Paramics is steep and as with all microsimulaiton models, the construction of such networks is labour intensive and data hungry. The complete verification and calibration of such networks can take condsiderable time (months to years) to achieve properly.

The SEC includes a novel one way reversible direction expressway which is operated using an Advanced Traffic Management System (ATMS). The ATMS uses detector loops and panning video cameras to detect incidents and monitor the changeover in direction of flow on the expressway. The expressway uses a combination of Changeable Message Signs (CMS), variable pavement marking (via lights in the road pavement) and a series of boom gates to manage traffic. Due to the tidal nature of flows in the corridor, the expressway operates northbound in the morning and southbound in the afternoon. The expressway effectively relieves peak flow traffic on an alternative arterial route (Main South Road) by providing three extra lanes capacity to tidal traffic.

Microsimulation modelling has been used to compare the two routes in terms of congestion measures (for example: congestion index, acceleration noise and proportion stopped time) and air pollutant emissions. Real world data has been collected on the two alternate routes using an instrumented vehicle which records speed-time profile, vehicle engine performance, positional and emissions data second by second. Measures of fuel consumption and emissions are available for the two routes and a comparison of the routes in terms of delay and congestion parameters has been made. The microsimulation model is able to generate virtual probe vehicles, whose journeys through the network can be monitored and speed-time profiles recorded. This paper includes a comparison of the real world speed profiles and emissions data with the equivalent simulated data.

2. PROBE VEHICLE STUDIES IN THE CORRIDOR

Taylor *et al* (2000ab) reported on an extensive study of the corridor, before and after the opening of the expressway, using an instrumented vehicle as a probe. This vehicle is instrumented so that it can log data continuously directly from its engine management system in synchronisation with GPS receivers. Differentially corrected GPS position data is recorded in real time using differential corrections broadcast via an FM radio network. The engine management system module directly provides data such as time, distance, speed, fuel consumption, engine revolutions (RPM), throttle position, engine temperature, engine gear, use of air conditioning and economy/power mode (see Table 1). The combined data is used to derive traffic parameters including percentage stopped time and other congestion indices. Air pollutant emissions are determined using engine maps for the vehicle – see Section 4.

Table 1. Vehicle parameters logged in real time by the TSC probe vehicle

Variable	Measurement Units	Variable	Measurement Units
Time	Sec	Air Conditioning	on/off
Distance	M	Power / Economy mode	on/off
Speed	km/h	Engine Gear	gear (1 to 4)
Fuel Consumption	L	Hydrocarbons (HC)	g/s
Engine Revolutions	Rpm	Nitrogen oxides (NOX)	g/s
Manifold Pressure	Pa	Carbon monoxide (CO)	g/s
Throttle Position	Ratio	Carbon Dioxide (CO2)	g/s
Engine Temperature	°C	Oxygen (O2)	g/s
GPS position	Latitude + Longitude		

The vehicle and GPS data are stored and then displayed in GIS software running on a notebook PC in the vehicle. Street centre line data are included as a layer in the GIS so that the exact route, speed profile and time data can be determined on a link by link basis. In addition, other map layers such as aerial photography, electronic street directory maps, topographical features and land marks can be included. Figure 1 provides a sample plot of probe vehicle locations over time along a route, superimposed on the street centre line data. Vehicle location at each point in time is represented by a small coloured circle. The circles are colour-coded to indicate values of a specified data item, such as speed or fuel consumption rate. In the case of Figure 1, the display shows instantaneous travel speeds of the TSC vehicle when driven along each route.

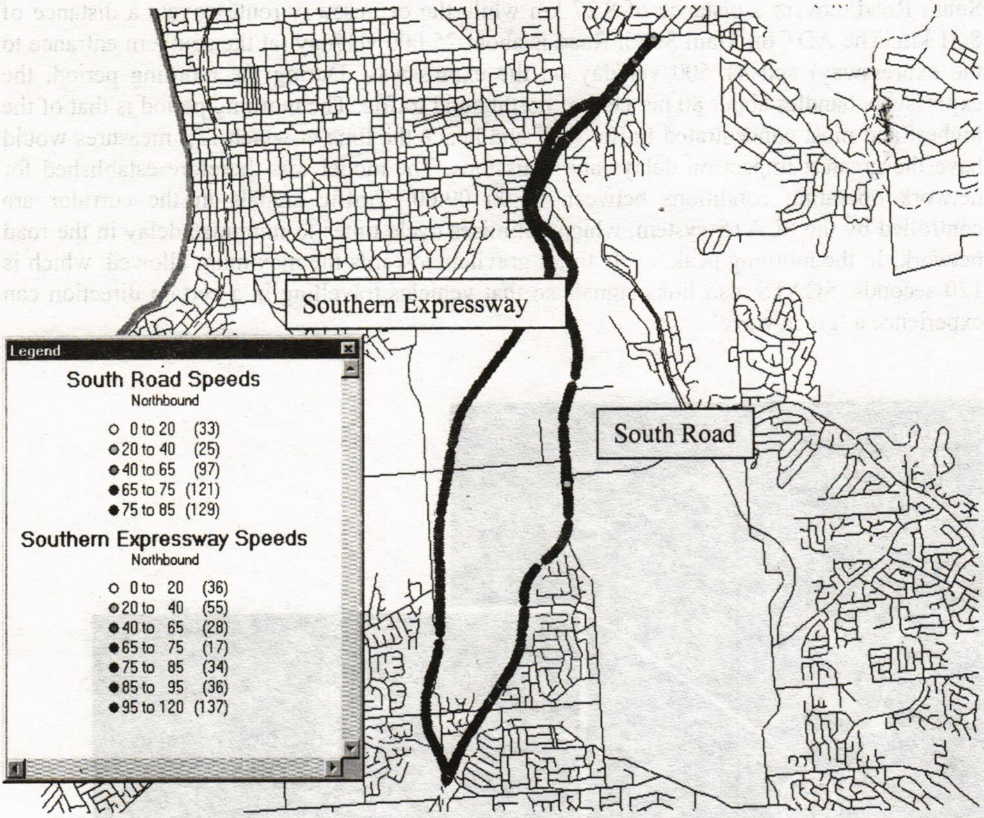

Figure 1. Instantaneous speeds of the TSC probe vehicle driven along the two routes

3. *PARAMICS* MODELLING IN THE CORRIDOR

The *Paramics* microsimulation package (Quadstone, 2000) is able to model the network at the level of the individual vehicle and can monitor the progress of 'virtual' probe vehicles. The distribution of operating modes (acceleration, deceleration, cruise and idle phases) in which vehicles operate is critical when considering emissions from vehicles within a small system. *Paramics* can provide data that reflects this for emissions calculations, using the same techniques as applied to the real world probe vehicle. It uses 'car-following' and 'lane-changing' models interacting with driver aggression and awareness parameters to mimic the behaviour of individual vehicles in the network. It also has extensive network modelling options making it ideal for investigating the impacts of ITS schemes (Paterson *et al*, 2001).

Traced *Paramics* probe vehicles provide data on headway, instantaneous speed, acceleration and position every half-second. This data is then available for processing into driving phases (acceleration, cruise, deceleration and idle) for emissions calculations.

Figure 2 shows the *Paramics* network for the SEC. Individual vehicles, lane geometry and traffic signals can be seen on the network representation. The model has been coded in three dimensions to model the effect of gradients on route performance. The arterial road, Main South Road, covers a distance of 8.27 km while the expressway route covers a distance of 8.31 km. The ADT on Main South Road is about 25 000 veh/day (at the southern entrance to the expressway) and 41 500 veh/day on the expressway. During the morning period, the expressway handles about 80 per cent of northbound traffic. The morning period is that of the highest and most concentrated traffic flow and hence the time at which ITS measures would have the greatest impact on delays and emissions. The model was therefore established for network operating conditions between 07:00 09:00. Traffic signals in the corridor are controlled by the SCATS system, which optimises cycle times to minimise delay in the road network. In the morning peak, cycle times gravitate towards the maximum allowed, which is 120 seconds. SCATS also links signals so that vehicles travelling in a certain direction can experience a ‘green wave’.

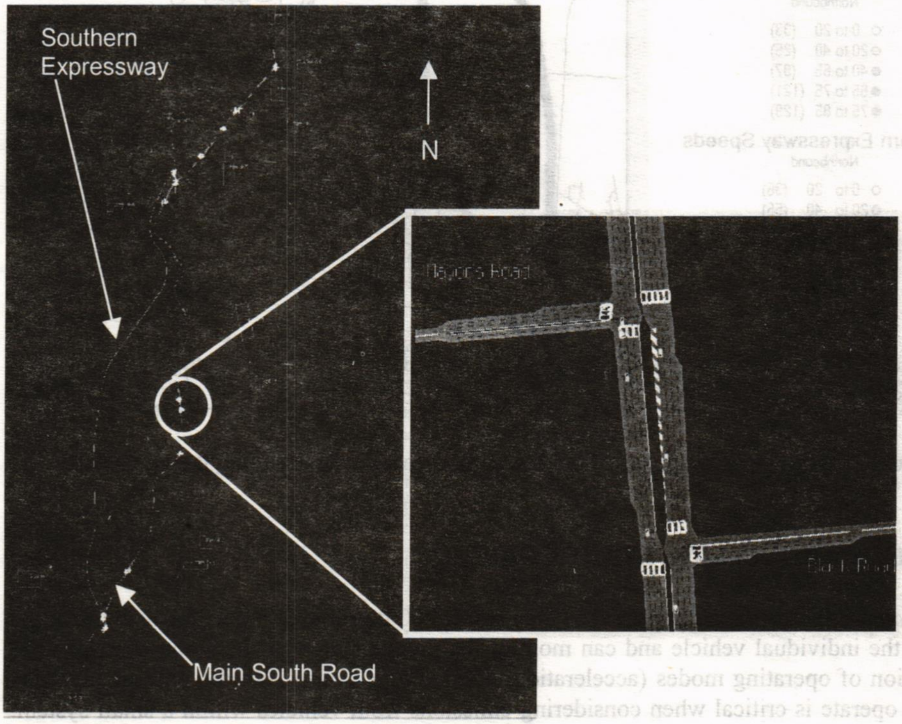

Figure 2. Extent of network and level of detail provided by the *Paramics* model

In the *Paramics* model of the SEC, optimal cycle and phasing times were adopted based on data provided from SCATS along with linking plans adopted for the morning peak. An 18×18origin-destination (OD) matrix was estimated from SCTAS link volumes to simulate trip-making behaviour for the corridor. The build-up of traffic over time for the morning period indicated that the peak demand occurs between 07:45 and 09:00.

3.1 Existing situation

The ten simulation runs shown in Figure 3 show the natural variation in traffic conditions built into *Paramics* to mimic the variation which exists in the real-world traffic conditions. Simulation run 003 was taken as representing the average of the ten runs and all subsequent modelling was performed using this run as a base case. Comparisons of the simulated runs with the observed probe vehicle data (Taylor *et al*, 2000b) provided support for this decision.

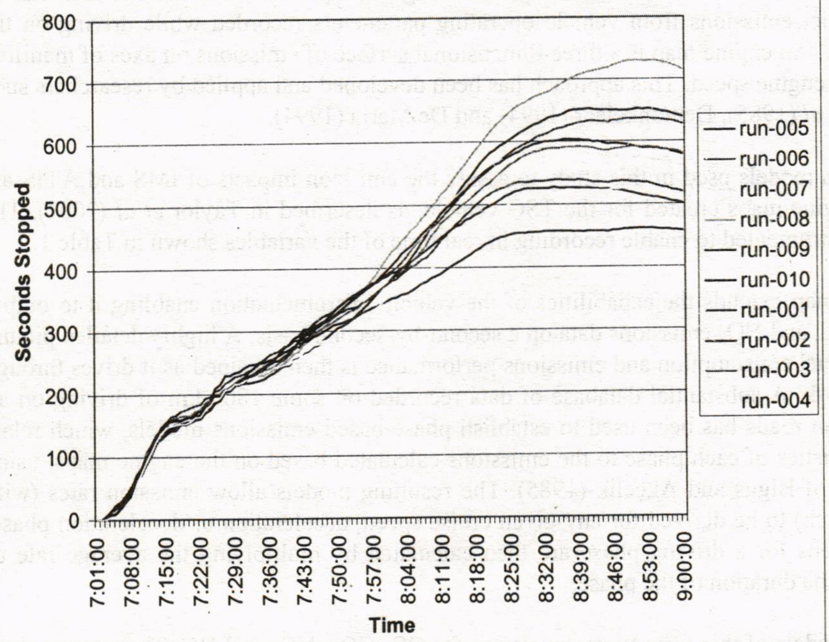

Figure 3. Variation in stoppage time for 10 simulation runs

The model was used to simulate incidents on the expressway and then to examine the effectiveness of ITS measures such as an incident management system (INMS) and an advanced traveller information system (ATIS) in minimising delay and emissions outcomes.

3.2 Incident Modelling

Paramics can trigger incidents at precise locations and times within the network. The type of incident adopted for the current project involved the blocking of two (of three) lanes on the

Southern Expressway about half way along its length. Vehicles therefore had to merge into the third lane to pass the blockage thus causing a shockwave effect and a build-up of traffic upstream of the incident. Passing vehicles in the remaining third lane were restricted to a speed of 40 km/h to simulate 'rubber necking' behaviour of drivers as they slowed down to look at the incident. The available traffic data suggested that the worst time an incident could occur is around 07:45. It was therefore decided to trigger incidents around this time to achieve a *worst case scenario*. Incidents were triggered for durations of 20, 40 and 60 minutes to provide a range from which INMS impacts could be inferred. The maximum duration was set at 60 minutes, the maximum incident duration from a starting time of 07:30 in which the network would recover to normal conditions before 09:00 (the end of the simulation period).

4. THE EMISSIONS MODELS

One method to determine the tail-pipe emissions of a vehicle in the road network is to use a chassis dynamometer in the laboratory to measure emissions at various levels of engine power and speed. This data can then be used to create 'engine maps' for the vehicle, which can be used to predict emissions from vehicle operating parameters recorded while driving on the road network. An engine map is a three-dimensional surface of emissions on axes of manifold pressure and engine speed. This approach has been developed and applied by researchers such as Watson *et al* (1985), Dentonkelaar (1994) and De Maria (1994).

The emission models used in this study to assess the emission impacts of IMS and ATIS are based on engine maps created for the TSC vehicle, as described in Taylor *et al* (2001). The vehicle is instrumented to enable recording in real time of the variables shown in Table 1.

The engine map extends the capabilities of the vehicle instrumentation enabling it to output CO, CO_2, HC, and NO_x emissions data on a second-by-second basis. A highly detailed picture of the car's fuel consumption and emissions performance is then obtained as it drives through a road network. A substantial database of data recorded on some 1800 km of driving on all types of urban roads has been used to establish phase-based emissions models, which relate the characteristics of each phase to the emissions calculated based on the engine maps, using the methods of Biggs and Akçelik (1985). The resulting models allow emission rates (with units of g/s/veh) to be derived for any given cruise speed, acceleration or deceleration phase. Total emissions for a driving phase are then calculated by multiplying the average rate of emission by the duration of the phase.

Emissions models of this form were developed for CO, CO_2, NO_x and HC. The advantage of this type of modelling is that predicted emissions explicitly account for the effect of traffic conditions on vehicle operating conditions. Any speed-time profile (as output by the *Paramics* model or recorded by an instrumented vehicle) can be split up into its component phases to derive emissions values for each phase. This enables calculation of emissions for a complete journey or for parts of a journey if required.

5. MODELLING THE EMISSIONS OUTCOMES OF INCIDENTS

The *Paramics* model of the SEC was coded to provide speed-time profiles of trace (virtual probe) vehicles as they travelled along the expressway. Three virtual probe vehicles were chosen for each ten minute time period from 07:30 to 08:50. Therefore there were nine time periods each with three virtual probe vehicles giving a total of 27 virtual probe vehicles. Four incident scenarios ranging in duration from 0 to 60 minutes were simulated in the *Paramics* model using the above strategy.

The analysis firstly attempted to quantify the congestion for each incident duration scenario by using average travel times for the virtual probe vehicles. Then the average emission value for each of these incident durations could be calculated. The average congestion parameter value and the average emission parameter value were found by averaging the appropriate parameter for the three trace vehicles in each ten minute time period. Then the average congestion and emission parameter values were calculated over the nine time periods for each of the incident durations. This provides representative travel time and emissions values at different time intervals for a given incident duration. Average travel time steadily increased as the incident duration increased, as would be expected.

Figure 4 shows a disaggregated view of travel time on the expressway under the base case and different incident durations. Each point in Figure 4 shows the average travel time for the virtual probe vehicles for a particular start of journey time and for a particular incident duration. What is interesting to note about this figure is that the family of travel time curves is basically in sequential order. Figure 4 also indicates that the maximum travel time occurs at different start of journey times according to the duration of the incident. The longer the incident the more time is taken for its full effect to unfold. For the 60-minute incident the maximum travel time occurred at a journey start time of 08:20, for the 40-minute incident duration it occurred at 08:00, and for the 20-minute and no incident cases the maximum travel time occurred at the 07:50 start of journey time.

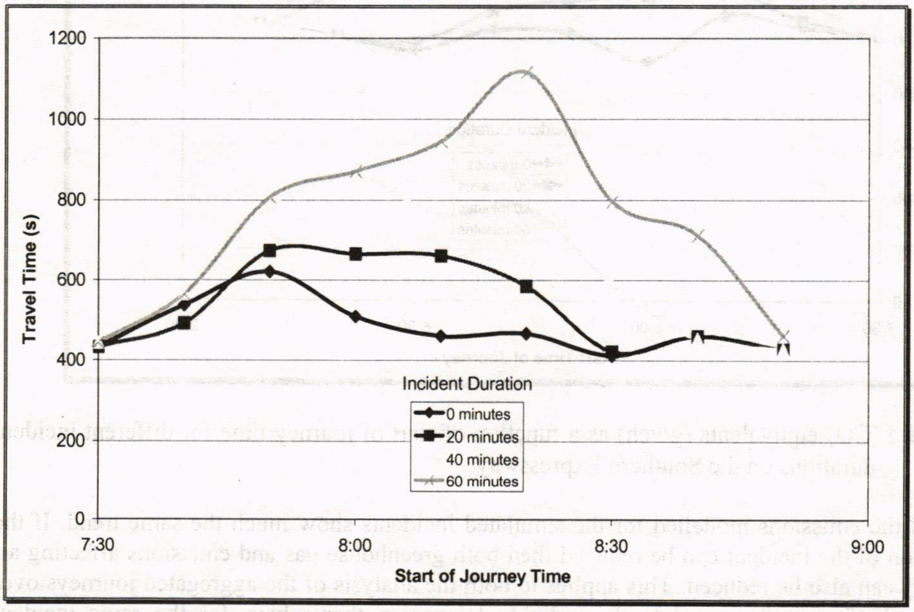

Figure 4. Mean travel time for different incident durations on the expressway

Figure 5 shows the greenhouse gas emissions in CO_2 equivalents for each of the incident durations and start of journey times. The CO_2 equivalents include emissions of NMVOC and CH_4 as well as CO_2, with the CO_2 contributing about 90 per cent of the CO_2 equivalents. Similar plots for other (air quality) emissions are given in Taylor *et al* (2001). The broad outcome for all the emission types [except CO and, to some extent, NO_x] is that the maximum emission occurs when the maximum travel time occurs, and that this outcome depends on both the time taken to complete the journey and the driving style.

This is an important finding. Typical emission rate models are often based on emissions per vehicle-km of travel (VKT) for average driving conditions, i.e. a constant emission over a set distance, no matter what the driving style or traffic conditions. These models cannot reflect the variation in emissions due to time-dependent variations in driving conditions, as occur in incident situations. Since all our probe vehicles in the simulation model have the same start and end points then their emissions outcomes would have been fixed regardless of incident duration or start of journey time had VKT-based rates been employed. Microsimulation modelling together with phase based emissions models provides a powerful method for detecting variations in emissions due to driving style and changes in traffic conditions.

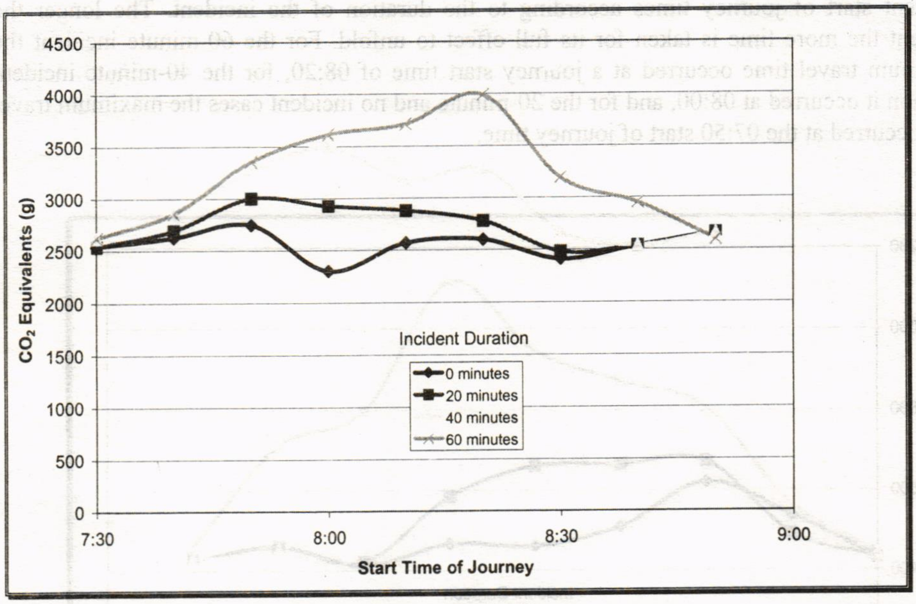

Figure 5. CO_2-equivalents (g/veh) as a function of start of journey time for different incident durations on the Southern Expressway

All of the emissions modelled for the simulated incidents show much the same trend. If the duration of the incident can be reduced then both greenhouse gas and emissions affecting air quality can also be reduced. This applies to both the analysis of the aggregated journeys over a period of start times and to the individual journeys themselves, for the same incident duration. This implies that, in this case study at least, an INMS should have the ability to both reduce travel times and modify the nature of the driving style to produce an overall effect of containing the extra emissions generated from the incident. Table 2 shows the increase in emissions with respect to the base case of no incident.

Table 2. Emission impacts (percentage increases relative to no incident)

Incident Duration (min)	Percentage increase in emissions relative to no incident					
	CO_2 (%)	CO_2 equiv (%)	CH_4 (%)	NO_x (%)	NMVOC (%)	CO (%)
20	6.2	6.6	13.7	11.8	13.7	8.4
40	15.0	15.5	30.9	24.2	30.9	11.8
60	25.1	25.6	52.5	40.4	52.5	13.1

6. INCIDENT MANAGEMENT USING ATIS

One feature of an INMS for freeway traffic could be the use of an ATIS to provide drivers with real-time information about the incident and possible alternative routes. In general, ATIS provide drivers with information pertinent to their journey, either prior to their departure or during the journey. Information on delays, parking guidance and alternative routes allow drivers to make informed decisions about their journey (e.g. Ramsay *et al*, 1997). For the SEC the role of ATIS is to influence driver behaviour so that the entire traffic corridor operates more efficiently: the role of an ATIS in the SEC would simply be to assist drivers to make an informed choice on which of the two routes to take.

The ATIS being considered for the expressway is the use of Variable Message Signs (VMS) for traffic condition monitoring. VMS display short messages to drivers passing the signs and may provide safety, amenity and congestion information. The literature suggests that VMS can induce diversions of between five and 80 per cent of passing traffic (Pedic and Ezrakhovich, 1999). These figures were used to set the bounds of traffic diversion to be modelled in this study. As previous Australian research (Ramsay and Luk, 1997) suggested that only quite low diversion rates could be expected, the ATIS modelling reflected the range of possible outcomes (five per cent to 80 per cent diversion of traffic flow) but with attention to the lower half of this range.

Taylor *et al* (2000b) showed that under normal driving conditions Main South Road had a mean travel time 2.5 minutes (36 per cent) greater than the Southern Expressway. In addition, the travel time variability on Main South Road was significantly higher than for the Southern Expressway. This variability could make drivers reluctant to divert to Main South Road even if there was an incident on the Southern Expressway, providing further reason for concentrating on lower diversion rates for the Southern Expressway.

6.1 Modelling strategy for ATIS

The INMS modelling showed that the worst traffic conditions existed when an incident of 60 minutes commenced at 07:30. In addition, the time at which traffic was heaviest corresponded to probe vehicles commencing their journey along the Southern Expressway at 08:20. This was became the base case for comparison of diversions achieved via ATIS. The modelling simulated various rates of diversion following warnings of an incident on the Southern Expressway though an ATIS. The modelled diversion percentages were 0, 5, 10, 20, 30, 40 and 80 per cent from the expressway.

From an emissions perspective, Main South Road constitutes an undesirable route due to the nine sets of traffic signals along the route and a large degree of 'side friction' from abutting retail and commercial land uses in some sections. Consequently traffic using the arterial road will experience more acceleration and deceleration phases than that using the expressway, which is largely free flowing. Therefore, high diversion rates of expressway traffic onto Main South Road would be expected to result in an increase in emissions.

For each diversion rate, three vehicles were traced for each alternate route with the trip time beginning at 08:20. Unlike the INMS modelling which was concerned only with traffic impacts on the Expressway, diversions in the ATIS model affected traffic on both the expressway and Main South Road. Therefore the modelled results were viewed as:

1. the impact of the ATIS in relieving traffic conditions on the Southern Expressway when an incident occurred for differing diversion proportions and in the consequent emissions output; and
2. the net emissions output in the SEC caused by ATIS diversion, i.e. taking into account both Main South Road and the expressway.

6.2 Modelling outcomes for the ATIS in the corridor

Figure 6 shows the vehicle hours of travel (VHT) in the SEC and its two component routes for each diversion rate, given that an incident has occurred. It indicates that the VHT on the expressway exceeds that on Main South Road under normal morning peak conditions when there is no diversion. As traffic is diverted from the expressway to the arterial road the VHT on the expressway decreases until the 20 per cent diversion rate is reached, then plateaus. On Main South Road the VHT increases with increasing diversion from the expressway, but the initial increase is at a rate slower than the decrease on the expressway, implying that the arterial road has some capacity to deal with small extra volumes of traffic without causing significant additional delays. Total VHT is minimised at a diversion rate of 30 per cent, but once the diversion rate increases further the VHT increases significantly.

Figure 7 shows the variations in greenhouse gas emissions (CO_2-equivalents) under different diversion rates. The minimum emissions in the corridor occur at the 20 per cent diversion rate, with only a marginal increase at 30 per cent. This suggests a relationship between the amount of time spent on the journey and the amount of greenhouse gas produced and that if ATIS can reduce overall VHT then they could also offer reductions in greenhouse gas emissions.

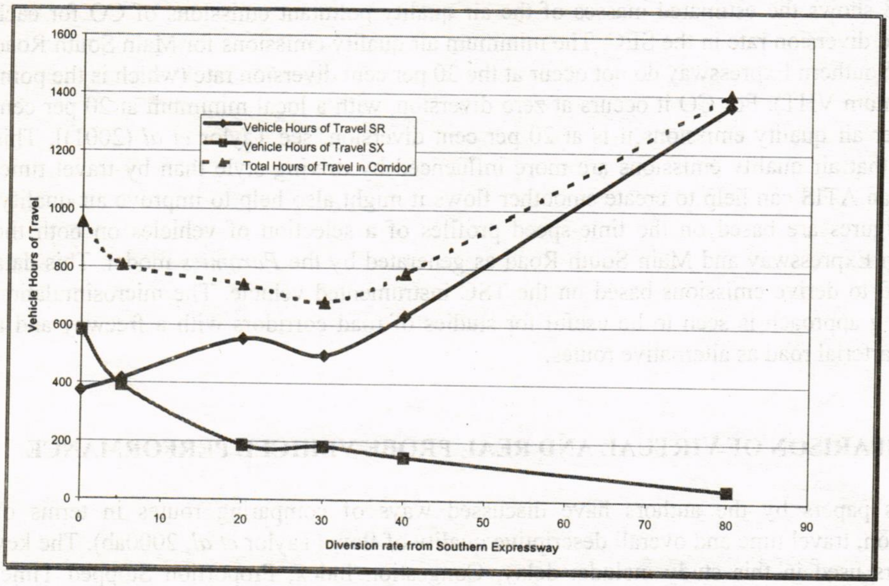

Figure 6. Total VHT in the corridor (SEC) and on Main South Road (SR) and the Southern Expressway (SX) for various diversion rates given an incident on the expressway

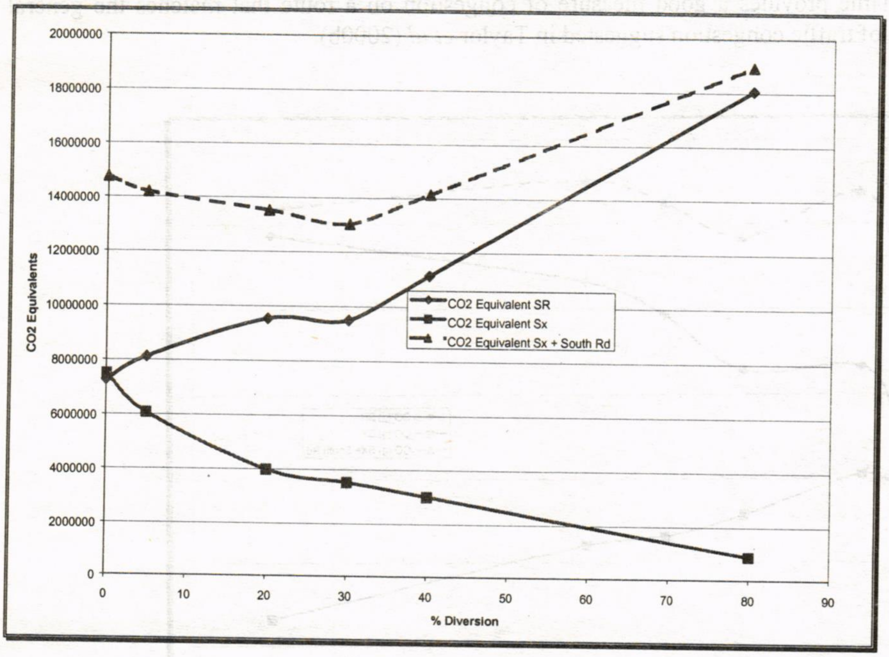

Figure 7. Emissions of CO_2-equivalents in the corridor (SEC), on Main South Road (SR) and on the Expressway (SX)

Figure 8 shows the estimated masses of the air quality pollutant emissions of CO for each modelled diversion rate in the SEC. The minimum air quality emissions for Main South Road and the Southern Expressway do not occur at the 30 per cent diversion rate (which is the point of minimum VHT). For CO it occurs at zero diversion, with a local minimum at 20 per cent [for other air quality emissions it is at 20 per cent diversion, see Taylor *et al* (2001)]. This implies that air quality emissions are more influenced by driving style than by travel time. Thus if an ATIS can help to create smoother flows it might also help to improve air quality. These figures are based on the time-speed profiles of a selection of vehicles on both the Southern Expressway and Main South Road as generated by the *Paramics* model. This data was used to derive emissions based on the TSC instrumented vehicle. The microsimulation modelling approach is seen to be useful for studies of road corridors with a freeway and a parallel arterial road as alternative routes.

7. COMPARISON OF VIRTUAL AND REAL PROBE VEHICLE PERFORMANCE

Previous papers by the authors have discussed ways of comparing routes in terms of congestion, travel time and overall descriptive quality of flow (Taylor *et al*, 2000ab). The key indicators used in this study include: delay, Congestion Index, Proportion Stopped Time, Acceleration Noise and Velocity Gradient. Of these, the dimensionless parameter Congestion Index is seen as the most useful in comparing different routes in terms of overall congestion. Acceleration Noise is useful for describing the quality of flow and captures elements such as roadway and traffic conditions, driver behaviour and vehicle characteristics. Proportion Stopped Time provides a good measure of congestion on a route that matches the general definition of traffic congestion suggested in Taylor *et al* (2000b).

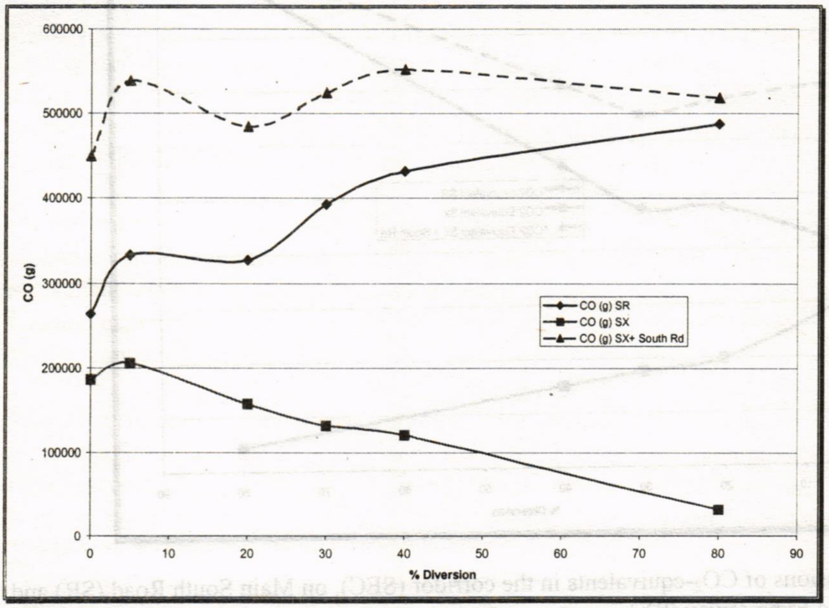

Figure 8. Total CO emissions in the corridor (SEC), on Main South Road (SR) and on the Expressway (SX) as a function of diversion rate

Comparisons were made between runs from the GPS equipped probe vehicle in the real world and those derived from the *Paramics* model. Figure 9 shows speed time profiles for South Road for both modelled (virtual) probe vehicles and the real probe vehicle. Tables A.1 and A.2 show summaries of the congestion parameters for South Road and the Southern Expressway for real world and modelled data for the morning peak period in the northbound direction.

Exploratory statistical t-tests reveal that for the Proportion Stopped Time, there is no significant difference ($p<0.05$) between the modelled and real world runs for South Road ($n = 7$ paired runs). Acceleration noise was significantly different for both routes as was the Congestion Index for the Southern Expressway and the modelled runs ($n = 10$ paired runs). Further probe vehicle sampling is required to conduct more thorough paired statistical tests.

In general terms, the comparative congestion characteristics on South Road between the modelled and real world data are better than those for the Expressway. Acceleration noise is consistently different between the models reflecting differences between target behaviours of real world drivers and those modelled in *Paramics*. It seems that for the model runs completed, the driver aggression exhibited in *Paramics* in achieving target speeds and headways was higher than that encountered in the real world. Scope therefore exists for further calibration of the model in relation to these two variables. Others have suggested that target headway and reaction time are all that is necessary for calibrating *Paramics* at a general level (Lee and Yang, 2000). Further research is under way to test this issue. Other discrepancies arise due to the natural variation in real world conditions such as the number of times a vehicle is stopped by traffic signals in the simulation and in the real world. Enlargement of the sample sizes is underway to address this issue.

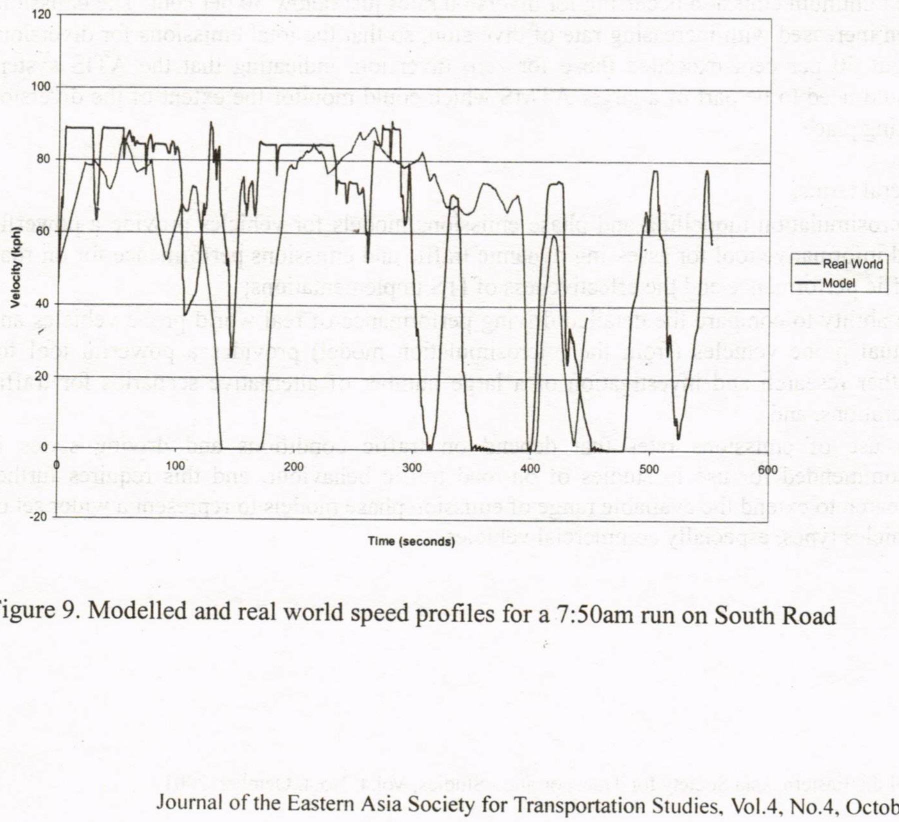

Figure 9. Modelled and real world speed profiles for a 7:50am run on South Road

8. CONCLUSIONS

This study has lead us to draw a number of conclusions relating to emissions outcomes stemming from the implementation of INMS and ATIS systems for freeway corridors, and on the usefulness of phase-based emissions models and microsimulation modelling of traffic networks.

In terms of the emissions outcomes of traffic incidents and INMS:

- both greenhouse gas and air quality emissions per vehicle increase with increasing duration of an incident, so that incident management systems that can reduce the duration of an incident stand to reduce the additional emissions generated as a consequence of the incident;
- travel times for vehicles also increase with increasing incident duration. Further, the nature of the driving style changes under incident conditions. INMS should be designed to modify driving styles as well as to reduce travel times to produce overall outcomes that minimise both excess travel time and emissions output;
- on the basis of the modelling reported in this paper suggests the following conclusions, for an ATIS used as part of an INMS in the face of a serious incident on the expressway, the diversion of traffic from an expressway experiencing a traffic incident to a parallel arterial road route led to significant changes in the total VHT experienced in the corridor and on the greenhouse gas and air quality emissions produced in it. Optimal performances in terms of travel and emissions could be determined;
- for the total VHT in the case study corridor, a minimum value was achieved at a diversion rate of about 30 per cent. For diversion rates exceeding 30 per cent, the increase in VHT on the parallel arterial road from the diversion greatly outweighed the decrease of VHT of the vehicles remaining on the expressway, and
- total greenhouse gas emissions in the corridor showed similar behaviour to the VHT, with the minimum emission occurring for diversion rates just below 30 per cent. The emissions then increased with increasing rate of diversion, so that the total emissions for diversions about 50 per cent exceeded those for zero diversion, indicating that the ATIS system would need to be part of a larger ATMS which could monitor the extent of the diversion taking place.

In general terms,

- microsimulation modelling and phase emissions models for vehicles provide a powerful and informative tool for assessing dynamic traffic and emissions performance for on-road traffic performance and the effectiveness of ITS implementations;
- the ability to compare the detailed driving performance of real world probe vehicles and virtual probe vehicles (from the microsimulation model) provides a powerful tool for further research and investigation of a large number of alternative scenarios for traffic operations, and
- the use of emissions rates that depend on traffic conditions and driving styles is recommended for use in studies of on-road traffic behaviour, and this requires further research to extend the available range of emission phase models to represent a wider set of vehicles types, especially commercial vehicles.

REFERENCES

Biggs, D.C. and Akçelik, R. (1985) Further work on modelling car fuel consumption. ARRB Internal Report 390-10, Australian Road Research Board, Melbourne.

De Maria, S. (1994) VEPMAS for performance monitoring and analysis of internal combustion engines. **Proceedings 3rd Australasian Instrumentation and Measurement Conference**. Adelaide, April.

Dentonkelaar, W.A.M. (1994) Effects of motorway speed limits on fuel consumption and emissions. **Science of the Total Environment, Vol. 147**, 201-207.

Lee, D.H. and Yang, X. (2000) Parameter optimization for Paramics using a genetic algorithm. **Proceedings 6th International Conference on Applications of Advanced Technologies in Transportation Engineering.** National University of Singapore, CD-ROM.

Paterson, D., Woolley, J.E. and Rose, G. (2001) Evaluating ITS applications using microsimulation. Submitted for presentation at the **8th World Congress on Intelligent Transport Systems**, Sydney, 30 September-4 October. ITS Australia Inc: Canberra.

Pedic, F. and Ezrakhovich, E. (1999) A literature review: the content characteristics of effective VMS. **Road and Transport Research, Vol. 8, No. 2**, 3-11.

Quadstone (2000). Paramics website www.paramics-online.com

Ramsay, E.D., Catchpole, J.E. and Luk, J.Y.K. (1997) An evaluation of VicRoads' drive time system. Research Report ARR 305. ARRB Transport Research Ltd, Melbourne.

Ramsay, E.D. and Luk, J.Y.K. (1997) Route choice under two Australian travel information systems. Research Report ARR312. ARRB Transport Research Ltd, Melbourne.

Taylor, M.A.P., Woolley, J.E. and Zito, R. (2000a) Measuring and modelling on-road fuel consumption, emissions and vehicle performance. **Proceedings 6th International Conference on Applications of Advanced Technologies in Transportation Engineering.** National University of Singapore, CD-ROM, Paper CR1038.

Taylor, M.A.P, Woolley J.E. and Zito, R. (2000b) Integration of the global positioning system and geographical information systems for traffic congestion studies. **Transportation Research C Vol. 8C**, 257-285.

Taylor, M.A.P., Zito, R. and Woolley, J.E. (2001). Effects of ITS implementations – INMS and ATIS – on greenhouse gas and air quality emissions in an urban road corridor, assessed using an instrumented probe vehicle and microsimulation modelling. Submitted for presentation at the **9th World Conference on Transport Research**, Seoul, 22-27 July.

Watson, H.C., Milkins, E.E., Holyoake, P.A., Khatib, E.T. and Kumar, S. (1985) Modelling emissions from cars. **Papers of the Australian Transport Research Forum, Vol. 10 No. 1**, 87-109.

APPENDIX

Table A.1. Congestion parameters for South Road

Run code	Total distance (m)	Travel time (s)	Stopped time (s)	Mean journey speed (km/h)	Proportion stopped time	Acceleration noise	Mean velocity gradient	Congestion index
REAL WORLD DATA								
Morning peak direction					South Road, north-bound free travel time = 384.0 s			
301198amn2	8202.9	685.0	113.0	43.1	0.1650	0.6195	0.0517	0.7839
011298amn3	8213.7	564.0	85.0	52.4	0.1507	0.6727	0.0462	0.4688
011298amn5	8192.7	540.0	113.0	54.6	0.2093	0.6842	0.0451	0.4063
021298amn2	8195.5	496.0	4.0	59.5	0.0081	0.5690	0.0344	0.2917
021298amn4	8216.6	500.0	57.0	59.2	0.1140	0.6821	0.0415	0.3021
031298amn2	8216.7	558.0	86.0	53.0	0.1541	0.6528	0.0443	0.4531
031298amn4	8242.8	503.0	76.0	59.0	0.1511	0.7156	0.0437	0.3099
041298amn1	8243.5	505.0	38.0	58.8	0.0752	0.5860	0.0359	0.3151
041298amn3	8210.9	523.0	111.0	56.5	0.2122	0.6570	0.0419	0.3620
Mean	**8215.1**	**541.6**	**75.9**	**55.12**	**0.1377**	**0.6488**	**0.0427**	**0.4103**
St dev	**18.1**	**59.5**	**37.3**	**5.27**	**0.0645**	**0.0483**	**0.0052**	**0.1549**
MODELLED DATA								
Morning peak direction					South Road, south-bound free travel time = 383.0 s			
sr0i07301	8317.1	578.5	52.0	51.8	0.0899	1.1470	0.0798	0.5065
sr0i07302	8293.6	577.5	54.5	51.7	0.0944	1.3550	0.0944	0.5039
sr0i07303	8281.6	544.0	23.5	54.8	0.0432	1.2118	0.0796	0.4167
sr0i07304	8269.7	521.5	5.5	57.1	0.0105	1.2172	0.0768	0.3581
sr0i07401	8274.3	563.0	35.0	52.9	0.0622	1.182	0.0804	0.4661
sr0i07402	8276.9	656.5	71.5	45.4	0.1089	1.333	0.1058	0.7096
sr0i07403	8279.3	593.5	53.5	50.2	0.0901	1.246	0.0893	0.5456
sr0i07501	8270.0	552	51.5	53.9	0.0933	1.261	0.0842	0.4375
sr0i07502	8271.7	660.5	22.5	45.1	0.0341	1.661	0.1326	0.7201
sr0i07503	8271.7	660.5	22.5	45.1	0.0341	1.661	0.1326	0.7201
sr0i08001	8273.0	660	86.5	45.1	0.1311	1.214	0.0969	0.7188
sr0i08002	8293.1	665.5	128	44.9	0.1923	1.405	0.1127	0.7331
sr0i08003	8298.6	595.5	9.5	50.2	0.0160	1.796	0.1289	0.5508
sr0i08101	8293.1	589.0	118.0	50.7	0.2003	1.499	0.1064	0.5339
sr0i08102	8284.4	551.5	4.0	54.1	0.0073	1.456	0.0969	0.4362
sr0i08103	8280.6	673.0	84.5	44.3	0.1256	1.201	0.0976	0.7526
sr0i08201	8284.9	508.5	6.0	58.7	0.0118	1.254	0.0769	0.3242
sr0i08202	8252.4	487.5	44.0	60.9	0.0903	1.497	0.0885	0.2695
sr0i08203	8284.4	541.5	49.5	55.1	0.0914	1.195	0.0781	0.4102
sr0i08301	8281.0	457.0	11.5	65.2	0.0252	1.414	0.0780	0.1901
sr0i08302	8282.8	515.5	8.0	57.8	0.0155	1.179	0.0734	0.3424
sr0i08303	8274.4	574.0	134.0	51.9	0.2334	1.815	0.1259	0.4948
sr0i08401	8277.6	524.0	47.5	56.9	0.0906	1.342	0.0849	0.3646
sr0i08402	8271.4	463.5	6.0	64.2	0.0129	1.245	0.0698	0.2070
sr0i08403	8268.4	460.5	17.5	64.6	0.0380	1.273	0.0709	0.1992
sr0i08501	8288.1	494.5	45.5	60.3	0.0920	1.695	0.1011	0.2878
sr0i08502	8275.7	489.0	50.0	60.9	0.1022	1.731	0.1023	0.2734
sr0i08503	8290.3	503.0	7.5	59.3	0.0149	1.34	0.0813	0.3099
Mean	**8280.7**	**559.3**	**44.6**	**54.0**	**0.0768**	**1.3866**	**0.0938**	**0.4565**
St Dev	**12.1**	**67.6**	**37.6**	**6.4**	**0.0608**	**0.2057**	**0.0189**	**0.1760**

Table A.2. Congestion parameters for the Southern Expressway

Run code	Total distance (m)	Travel time (s)	Stopped time (s)	Mean journey speed (km/h)	Proportion stopped time	Acceleration noise	Mean velocity gradient	Congestion index
REAL WORLD DATA								
Morning peak direction					Southern Expressway, free travel time = 326.0 s			
301198amn1	8154.7	424.0	22.0	69.2	0.0519	0.4589	0.0239	0.3006
3011981mn3	8149.1	374.0	0.0	78.4	0.0000	0.4197	0.0193	0.1472
011298amn2	8141.8	469.0	61.0	62.5	0.1301	0.5483	0.0316	0.4387
011298amn4	8166.4	396.0	11.0	74.2	0.0278	0.5735	0.0278	0.2147
021298amn1	8142.8	365.0	0.0	80.3	0.0000	0.4808	0.0216	0.1196
021298amn3	8164.9	416.0	29.0	70.7	0.0697	0.5152	0.0262	0.2761
021298amn5	8167.6	376.0	18.0	78.2	0.0479	0.4403	0.0203	0.1534
031298amn1	8165.3	350.0	0.0	84.0	0.0000	0.4940	0.0212	0.0736
031298amn3	8153.3	378.0	0.0	77.7	0.0000	0.4001	0.0185	0.1595
031298amn5	8150.7	454.0	70.0	64.6	0.1542	0.5806	0.0323	0.3926
041298amn2	8144.2	379.0	5.0	66.4	0.0132	0.4732	0.0220	0.1626
041298amn4	8155.8	421.0	57.0	69.7	0.1354	0.5620	0.0290	0.2914
041298amn5	8158.9	382.0	24.0	76.9	0.0628	0.5029	0.0235	0.1718
Mean	8155.0	398.8	22.8	74.14	0.0533	0.4961	0.0244	0.2232
St dev	9.1	35.6	24.9	6.34	0.0554	0.0584	0.0046	0.1091
MODELLED DATA								
Morning peak direction					South Road, south-bound free travel time = 383.0 s			
0i07301	8314.45	430	34	69.6	0.0791	1.1436	0.0591	0.3190
0i07302	8316.4	431.5	6.5	69.4	0.0151	0.9608	0.0499	0.3236
0i07303	8302.3	436	29	68.6	0.0665	1.1251	0.0591	0.3374
0i07401	8308.6	572	5	52.3	0.0087	0.9086	0.0626	0.7546
0i07402	8316.6	572.5	5	52.3	0.0087	0.9082	0.0625	0.7561
0i07403	8316.55	466	8.5	64.2	0.0182	0.9960	0.0558	0.4294
0i07501	8330.75	635.5	58.5	47.2	0.0921	1.1580	0.0883	0.9494
0i07502	8337.95	589	5.5	51.0	0.0093	0.8574	0.0606	0.8067
0i07503	8340.35	636.5	58.5	47.2	0.0919	1.1645	0.0889	0.9525
0i08001	8332.95	463.5	3.5	64.7	0.0076	0.6760	0.0376	0.4218
0i08002	8348.35	464.5	3.5	64.7	0.0075	1.0873	0.0605	0.4248
0i08003	8327.3	598	27	50.1	0.0452	0.7233	0.0519	0.8344
0i08101	8322.45	449	21	66.7	0.0468	0.9783	0.0528	0.3773
0i08102	8313.2	464	16.5	64.5	0.0356	1.4033	0.0783	0.4233
0i08103	8317.55	467	5.5	64.1	0.0118	1.0697	0.0601	0.4325
0i08201	8313.5	561	6.5	53.3	0.0116	0.8963	0.0605	0.7209
0i08202	8313.5	561	6.5	53.3	0.0116	0.8963	0.0605	0.7209
0i08203	8313.5	561	6.5	53.3	0.0116	0.8963	0.0605	0.7209
0i08301	8294.8	411.5	69	72.6	0.1677	1.5438	0.0766	0.2623
0i08302	8312.1	412.5	69	72.5	0.1673	1.5430	0.0766	0.2653
0i08303	8294.8	411.5	69	72.6	0.1677	1.5438	0.0766	0.2623
0i08401	8322.85	431.5	13.5	69.4	0.0313	1.7313	0.0898	0.3236
0i08402	8309.5	537.5	55	55.7	0.1023	1.0558	0.0683	0.6488
0i08403	8318.45	410.5	6.5	73.0	0.0158	1.1302	0.0558	0.2592
0i08501	8316.7	427	17.5	70.1	0.0410	1.2372	0.0635	0.3098
0i08502	8310	426.5	17.5	70.1	0.0410	1.2369	0.0635	0.3083
0i08503	8304.55	426	13.5	70.2	0.0317	1.2371	0.0635	0.3067
Mean	**8317.4**	**490.8**	**23.6**	**62.3**	**0.0498**	**1.1151**	**0.0646**	**0.5056**
St Dev	**12.7**	**75.9**	**23.2**	**8.92**	**0.0511**	**0.2608**	**0.0124**	**0.2329**