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EXPLORING BUS LANE SAFETY IMPACTS USING TRAFFIC MICRO-SIMULATION

*Kelvin Chun Keong Goh, PhD Student, Public Transport Research Group, Institute of Transport Studies, Department of Civil Engineering, Building 60, Monash University, Clayton, Victoria 3800, AUSTRALIA
Phone: +61 3 9905 1848, Fax: +61 3 9905 4944, Email: kelvin.goh@monash.edu

Graham Currie, Professor, Chair in Public Transport, Public Transport Research Group, Institute of Transport Studies, Department of Civil Engineering, Building 60, Monash University, Clayton, Victoria 3800, AUSTRALIA
Phone: +61 3 9905 5574, Fax: +61 3 9905 4944, Email: graham.currie@monash.edu

Majid Sarvi, Dr, Senior Lecturer, Public Transport Research Group, Institute of Transport Studies, Department of Civil Engineering, Building 60, Monash University, Clayton, Victoria 3800, AUSTRALIA
Phone: +61 3 9905 9696, Fax: +61 3 9905 4944, Email: majid.sarvi@monash.edu

David Logan, Dr, Senior Reserach Fellow, Monash University Accident Research Centre, Building 70, Monash University, Clayton, Victoria 3800, AUSTRALIA
Phone: +61 3 9905 4376, Email: david.logan@monash.edu

*Corresponding author

ABSTRACT

The safety implications of implementing bus lanes on road corridors remain unclear given that findings from previous research have been mixed. In this study, a microscopic simulation modelling approach was adopted to understand the safety effects of implementing bus lanes on a road corridor. Using a selected road corridor in Metropolitan Melbourne as a case study, microscopic simulation models were developed to compare traffic conflicts patterns between three traffic configurations – (1) mixed traffic, (2) kerbside lane reallocated for buses only and (3) new kerbside lane for buses only. For each configuration, the safety performance of the road corridor including bus stop and intersection locations were measured through the use of two safety performance indicators – (1) Time to Collision (TTC) and (2) Deceleration Rate to Avoid a Crash (DRAC). Overall results showed that kerbside bus lanes reduce conflict occurrences at bus stop and intersection locations. However, safety benefits at the corridor-level vary depending on whether the kerbside lane had been reallocated or newly created for buses. Just as important is the traffic volume level, as increases in conflict occurrence are particularly pronounced when traffic volume is high. These findings point to the need for careful consideration of traffic volume levels by road agencies when deciding on the type of bus priority measure to implement.

Keywords: Traffic conflicts, Safety performance, Time to collision, Deceleration rate to avoid a crash

1 INTRODUCTION

Various types of bus priority initiatives exist internationally, each differing essentially by the amount of road space or time (or combination of both) that has been allocated for buses. Regardless of its form, there has been overwhelming evidence to show that bus priority measures bring about higher service levels and operational benefits (Sakamoto et al., 2007, Furth and Muller, 2000). Whilst this bodes well for commuters and bus agencies, its safety implications to other road users remain unclear as findings from previous research have been limited and more importantly, mixed. This is not surprising as the majority of previous studies have relied on historical crash records, which often come with data and methodological issues that could lead to erroneous results if not dealt with appropriately. The recent emergence of surrogate safety measures in micro-simulation modelling has now presented an opportunity to examine the safety effects of bus priority in a controlled experiment setting thus overcoming the aforementioned issues. In this study, a microscopic simulation modelling approach is undertaken to understand the road safety effects of implementing two common types of bus lanes on a selected road corridor in Metropolitan Melbourne. Key findings from this study could act to inform bus and road management agencies in their operational and safety-related decisions.

This paper starts with a review of previous research with a focus on studies that had examined safety performance of roads with bus priority implemented as well as studies that had used surrogate safety measures in micro-simulation modelling for safety evaluation purpose. The research aims are then outlined followed by a description of the bus priority case study. Details of data and methodology are then provided after which a summary of the major study findings is done. Discussion of results and conclusions finalize the paper.

2 RESEARCH CONTEXT

Studies on the road safety implications of bus priority have yielded mixed results (Goh et al., In Press). In one of the earliest studies, accident data on selected roads in New Delhi for a 2-year period before and after dedicated bus lanes were introduced were examined. The results however did not provide any definite evidence of safety impacts. (Sarna et al., 1985). Another study found reductions in bus and pedestrian accidents following the implementation of contra-flow bus lanes in Chicago (LaPlante and Harrington, 1984). Mulley (2010) examined personal injury accidents that occurred over a 3-year period on stretches of roads that are within 50m of a bus priority lane in Tyne and Wear, UK, and found that 5.3% of all personal accidents were due to priority measures along the corridor. However, whether priority measures had actually resulted in more accidents overall is not known. In Bus Rapid Transit (BRT) systems, Levinson et al. (2003) found that buses using Seattle's bus tunnel (with exclusive rights-of-way for buses only) experienced 40% fewer accidents than in mixed traffic operations. The Bogota TransMilenio BRT system saw a larger reduction (93%) of fatalities among transit users. While the above studies pointed to bus priority bringing about positive safety effects, there have been other studies that have found otherwise (Cooner and Ranft, 2006, Skowronek et al., 2002).

A common characteristic in the aforementioned studies is that they have all relied on historical crash data, with a majority using these data to identify key characteristics in crashes. A recent review of crash-frequency literature highlighted that the use of historical crash data comes with data and methodological issues, which could lead to incorrect statistical model specification (Lord and Mannering, 2010) and erroneous results interpretation.

The emergence of a new conflict analysis based on surrogate safety measures in micro-simulation modelling has presented a promising avenue for safety assessments, as treatment effects can be examined in a controlled environment setting. This addresses the issue of having to handle confounding factors often inherent in historical crash data that could lead to incorrect model results (Goh et al., 2012). Much of previous work in micro-simulation based safety assessments were based on by the pioneering work of Gettman and Head's work (2003), where five safety surrogate measures (SSM) are eventually recommended for the purpose of safety evaluation in micro-simulation modelling - (1) Time to Collision (TTC); (2) Post-Encroachment Time (PET); (3) Greater of two maximum values of two conflicting vehicles (MaxS); (4) Maximum speed difference between two conflicting vehicles (DeltaS) and (5) Deceleration Rate (DR). The usefulness of a sixth surrogate measure – headway (H) – for safety evaluation at junctions was also investigated by Vogel (2003). Results showed that there was a greater variation in the TTC values as compared to H values, and was therefore a better indicator of actual danger. H values on the other hand would be useful for checking for tailgating behaviour.

Subsequent studies have also explored other surrogate safety measures. Ismail et al. (2009) for example assessed the adequacy of Gap Time (GT) and Deceleration-to-safety time (DST) in addition to TTC and PET as safety indicators for pedestrian-vehicle conflicts. Results showed that conflicts were better identified when all four indicators were used together instead of any on their own. Of the four, PET was most reliable in detecting important incidents, which is defined as a conceivable chain of events that could lead to a collision between road users. In a separate study, Pirdavani et al. (2010) used PET as an indicator in their investigation on intersection safety. The results revealed PET to be a useful safety indicator as its values varied with different speed limits and volume. However, the authors argued that PET would only be useful for investigating transverse collisions and as such, other indicators such as TTC should be adopted if other types of collisions, e.g. rear-end and converging are of interest. Archer and Young (2009) used post-encroachment time (PET) and the number of red light violations as SSMs to evaluate the safety and traffic system efficiency of 5 alternative signal treatments at a metropolitan highway intersection. Using micro-simulation (VISSIM), the software was able to generate results to show that amber extension treatment yielded the greatest effect in terms of reducing red-light violations. Saccomanno et al. (2008) used TTC, deceleration rate to avoid the crash (DRAC) and a crash potential index (CPI) to compare traffic conflicts at roundabouts and signalized intersections. The latter, which is based on the DRAC and the maximum available deceleration rate, was used as the authors argued that DRAC alone would fail to consider vehicle-specific braking capability and varying traffic conditions. Results showed all three indicators were able to reflect the effect of geometry, weather and traffic volume. In a similar study, DRAC, TTC and proportion of stopping distance (PSD), which is the ratio between the remaining distance to the potential collision point and minimum acceptable stopping distance were used as indicators to evaluate the safety effect of converting stop sign controlled intersection to a roundabout (Astarita et al., 2012). The authors found that TTC and DRAC, in particular, were better safety indicators in showing that the number of vehicle interaction would decrease with the introduction of a roundabout.

It is worth mentioning that all of the above safety evaluation studies have focussed on intersections. As for road corridors, only two studies have been found. In Meng and Weng's (2011) work, the authors used DRAC as a SSM to develop a model relating rear-end crash risk and various contributing factors at a merging area in work zone area. Another SSM - Crash potential Index as a function of DRAC – was used by Cunto et al. (2009) in evaluating the safety performance on a segment of freeway. The results showed that this safety measure was able to reflect the crash risk well.

In summary, previous research on the safety implications of bus priority have been few and far between. From the limited studies that had been done, results have generally been mixed. Readers have to also content with potential data and methodological issues, which are inherent in historical crash data that had been used in these studies. As such, our understanding on why certain bus priority schemes had led to positive safety benefits while others have yielded opposite effects remain unclear. With the emergence of surrogate safety measures in micro-simulation modelling, there is now an opportunity to examine the safety effects of bus priority in a controlled experiment setting.

3 RESEARCH AIM

This research aims to explore the road safety performance of a selected 3-lane road corridor in Melbourne across three road configurations - Base case: mixed traffic; Option 1: kerbside lane relocated for bus use only; and Option 2: new kerbside lane created for bus use only (**Figure 1**).

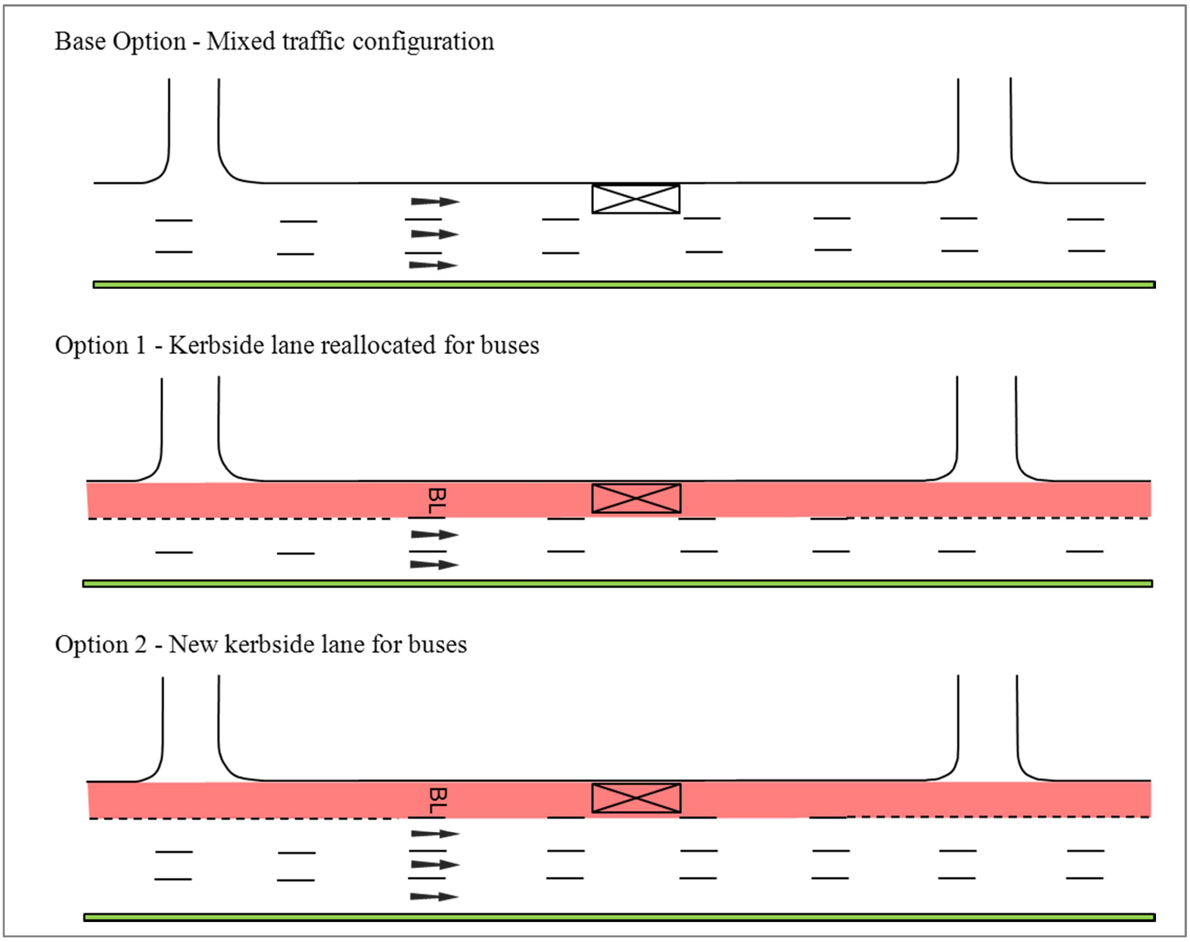

Figure 1: Exploring Safety Impacts of Different Bus Priority Schemes

4 CASE STUDY CONTEXT

4.1 Bus Priority in Melbourne

The majority of bus priority in Melbourne was implemented along with the introduction of SmartBuses in 2006, which was promoted as a premium bus service that offers more frequent and reliable service for passengers. The type of priority measures falls under one of two general categories: Traffic Signal Priority (TSP); and non-TSP. TSP treatments for SmartBus involve the use of existing signal control system (Lowrie, 1992), vehicle detection technology and its infrastructure, while non-TSP treatments include clearways and full-time or part-time bus lanes. The latter is implemented by either adding a new lane to the existing carriageway or reallocating existing road space for buses exclusive use. In this study, a key objective is to examine how road safety performance differs between these two configurations.

4.2 Road Corridor Characteristics

The road corridor selected for this case study is a 1.6km stretch of three-lane divided arterial road in Metropolitan Melbourne - Blackburn Road from Wellington Road to Ferntree Gully Road (**Figure 2**). There are four intersections along this route, which has a speed limit of 70kph. Two bus services ply along this north-south route (with an additional from Normanby to Ferntree Gully Road) and they operate in a mixed traffic condition where no priority is provided for buses. There are five bus stops along each bound, and of these, only one is provided with a bus bay.

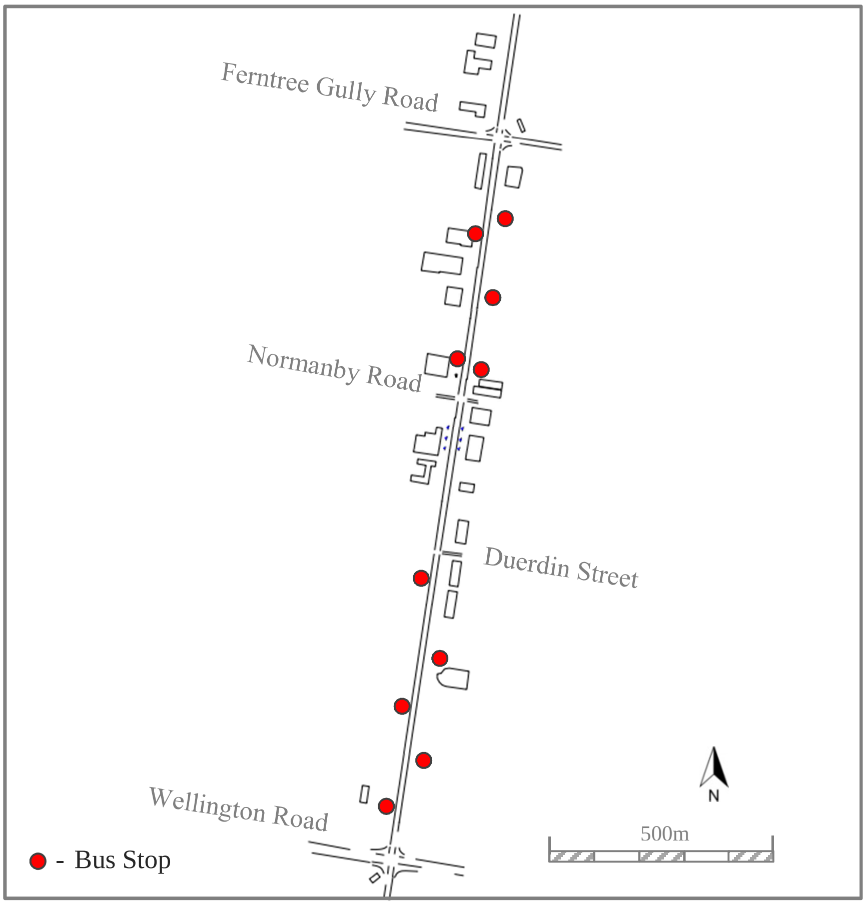

Figure 2: Snapshot of Road Corridor for the Case Study

5 METHODOLOGY

5.1 Data Collection

Traffic data collected for this study was obtained from the signal control (or SCATS) system maintained by the Traffic Operations Unit of VicRoads, Australia. These included turning volume at the intersections, which act to inform the micro-simulation model on the turning percentage at each intersection. In addition, video recordings on a representative section of the road corridor were done for 2 weeks in December 2012 (**Figure 3**). Video data of the afternoon peak period (17:00-19:00hrs) was then extracted for model development. Empirical data were also collected through a northbound travel time survey on 3 weekdays during the afternoon peak period. From the video and travel time information, it was possible to check against the SCATS data to ensure traffic volume was comparable and help facilitate model calibration and validation, which is a crucial step in the micro-simulation modelling process.

As highlighted earlier, a number of surrogate safety measures could be used for safety evaluation. From the literature, TTC, PET and DRAC are found to be most commonly used as they are considered to have stronger relevance to safety. For this study, TTC and DRAC were chosen as the surrogate safety measures for the case study, and a conflict is registered when either TTC or DRAC exceeded the threshold values of 1.5s and 3.35m/s^2 respectively. These values were selected as previous studies have shown values exceeding these levels appear to reflect unsafe conditions (Archer, 2005, van der Horst, 1991). Video analysis was subsequently done using the motion analysis software MotionView (Advanced edition), which allows video data to be processed on frame-by-frame basis. Through this, TTC and DRAC conflicts over the 2-week period were recorded for model calibration and validation purposes.

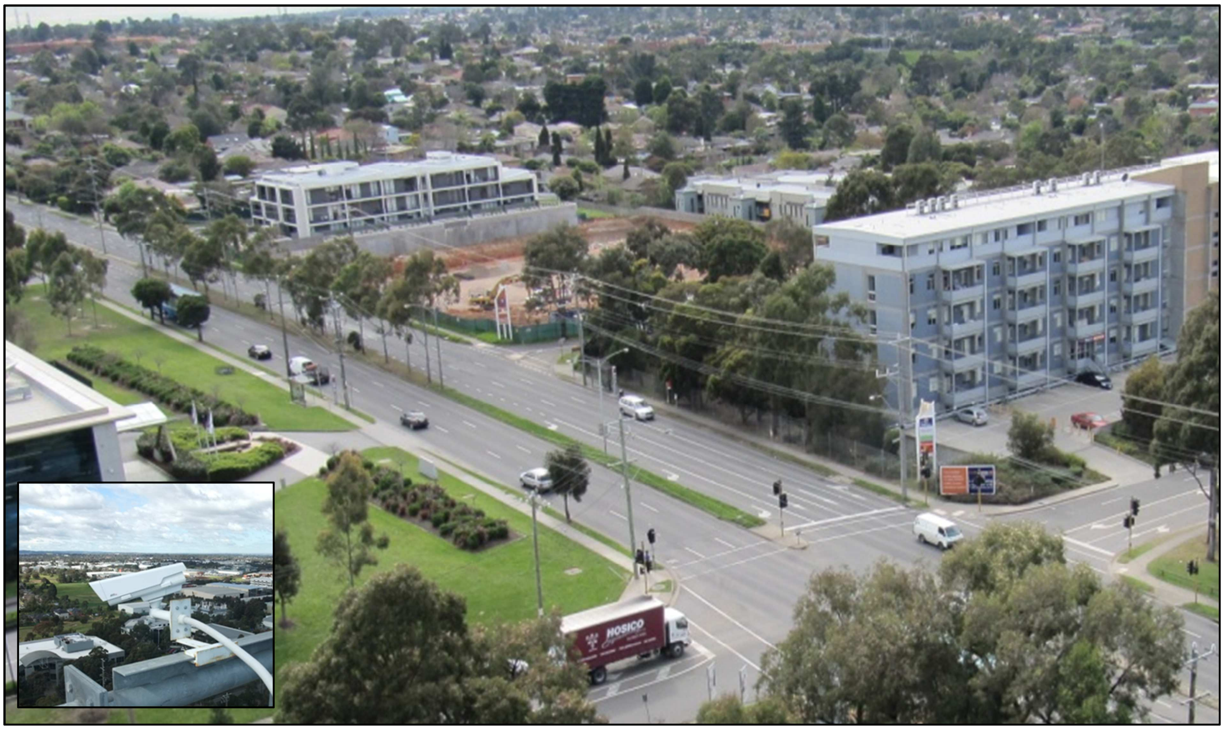

Figure 3: Video equipment used (inset) and coverage of road corridor

5.2 Micro-simulation Modelling Approach

In this study, the AIMSUN (Advanced Interactive Microscopic Simulation for Urban and Non-urban Networks) micro-simulation tool (Version 7.0) was used to model the road corridor and explore the safety implication of implementing different bus priority measures. AIMSUN allows for both microscopic and mesoscopic modelling of various networks including public transport operations (TSS-Transport Simulation Systems, 2012). It is a useful tool for the analysis and assessment of different transport planning schemes and traffic management measures. The AIMSUN base model was developed using an aerial photograph and map based GIS data of the site. Traffic data collected which included vehicle counts and traffic composition as described in the preceding section, were then used as inputs to the base model.

Given the danger that inappropriately calibrated models could lead to misleading findings (Park and Qi, 2005), much effort was focussed on model calibration and validation to ensure the base model reflected actual driving behaviour well. Following the work by Huang et al. (2013), a two-stage approach is similarly adopted for the model calibration and validation. In stage 1, vehicle and behaviour parameters were fine-tuned so that the model accurately represents the observed traffic and driving behaviour (Fang, 2005, Cunto and Saccomanno, 2008). This step centred on ensuring that (1) travel time along the northbound carriageway of the road corridor and (2) queue discharge headway distribution of a selected intersection closely matched the observed data. The GEH-statistic was used to compare empirical and modelled travel time, while the Kolmogorov-Smirnov (K-S) and Mann Whitney U test statistic were used to compare observed and modelled headway distributions. Model parameters were adjusted until a GEH-value of less than 5 was achieved in more than 85% of the cases, and K-S and Mann Whitney U test results indicate that the observed and modelled headway are comparable. In stage 2, efforts were focussed on fine-tuning of model parameters to replicate observed safety-related behaviour and conflicts. To extract modelled conflicts, a separate software module titled "Surrogate Safety Assessment Model (SSAM)" (Federal Highway Adminstration, 2008) was used to extract conflict information from vehicle trajectory files generated by AIMSUN. Two commonly used error measures - mean absolute percentage error (MAPE) and mean absolute error (MAE) – were used to find the optimal TTC and DRAC threshold values:

$$Observed\ Conflicts = \overline{C}_O = \frac{1}{m}\sum_{i=1}^{m} C_O^i \tag{1}$$

$$Modelled\ Conflicts = \overline{C}_M = \frac{1}{n}\sum_{i=1}^{n} C_M^i \tag{2}$$

$$MAPE = \left|\frac{\overline{C}_M - \overline{C}_O}{\overline{C}_O}\right| \tag{3}$$

$$MAE = \left|\overline{C}_M - \overline{C}_O\right| \tag{4}$$

In Huang et al.'s (2013) work, the optimal TTC threshold level was found to minimize the difference between simulated and observed conflicts. The above steps represents a minor deviation to as it aims to find the optimal TTC and DRAC threshold values in the model that best replicate pre-defined observed conflicts (TTC<1.5s and DRAC<3.35m/s^2).

Following model calibration, validation is done by collecting an additional 4 hours of video data on two separate weekdays. Similar to the calibration process, the GEH, K-S and Mann Whitney U test were used to assess the model's ability to replicate observed travel time and headway. Another criterion for successful model validation is that the observed number of conflicts should be within the 90% confidence intervals obtained from 10 simulation runs. With the completion of model calibration and validation, simulation models were developed for each of the three scenarios. To ensure stable results (Young et al., 1989), each model was run 10 times with different random seed numbers. For each run, the number of modelled conflicts was extracted at the following locations:

(a) Intersection approaches (on two leftmost lanes only);
(b) Bus stops (two leftmost lanes up to 50m upstream of all bus stops); and
(c) Entire corridor (all lanes of the carriageway)

Each model was also subjected to 5 levels of traffic demand to test the effect of volume on conflicts. The number of conflicts recorded over 10 runs was averaged and its value used as a basis for comparing the safety effects of different traffic and bus priority schemes. **Figure 4** summarizes the approach adopted in this study to obtain the conflicts from the micro-simulation models.

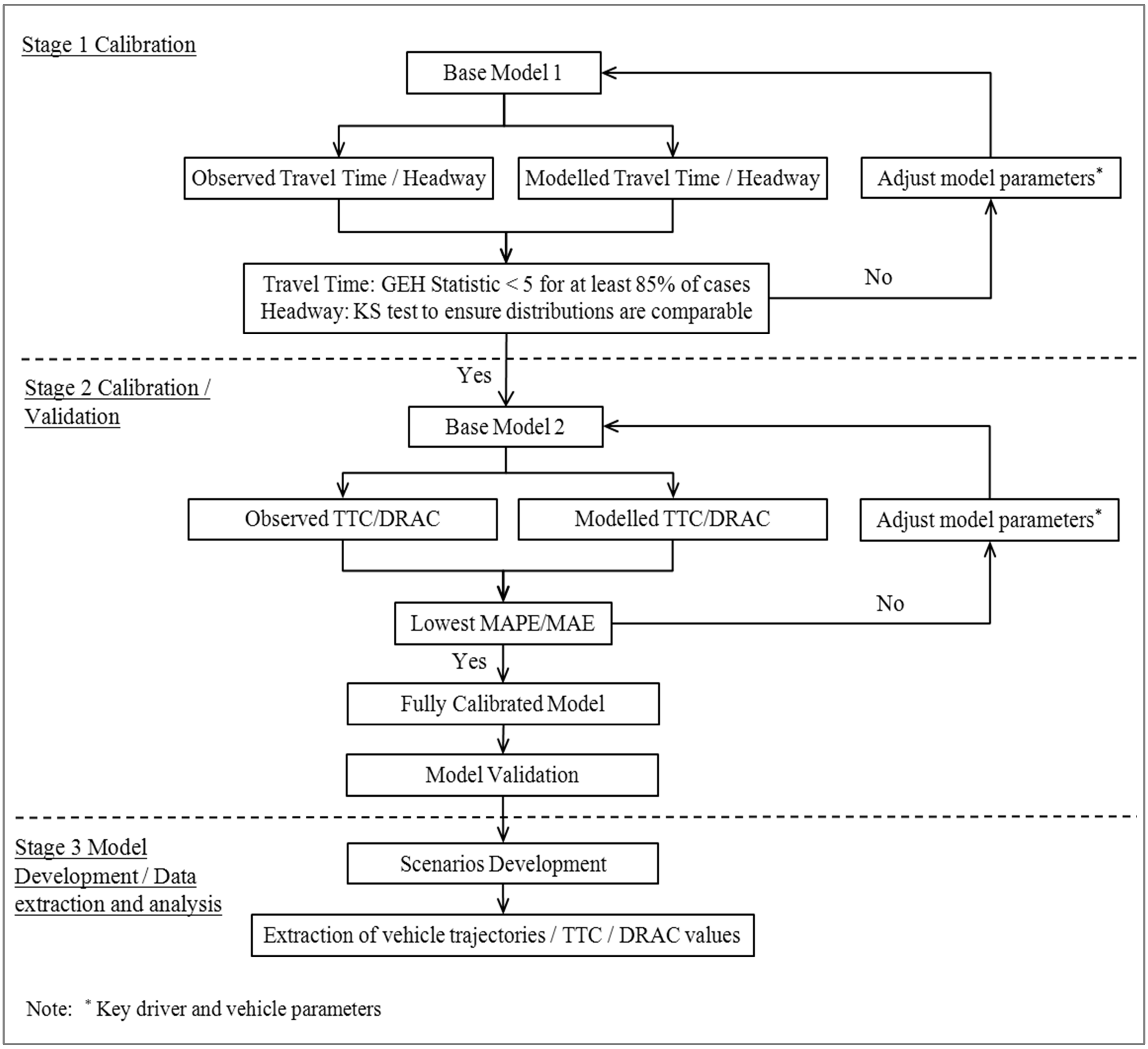

Figure 4: Staged Approach to Extraction of Conflicts from Micro-simulation Models

6 RESULTS

6.1 Model Development

Results from Stage 1 of the calibration process are presented in **Appendix A**. In stage 2, a sensitivity analysis revealed that the parameters that had the greatest impact on the number of modelled conflicts were the threshold values of TTC and DRAC in SSAM. Based on the MAPE and MAE results, it was found that best goodness-of-fit was achieved when the TTC and DRAC threshold values were set at 1.7s and 3.30m/s^2 respectively (**Figure 5**). These values were subsequently adopted for the conflict analysis in SSAM. The final calibrated model (with adopted parameter values provided in **Appendix B**) was validated using data extracted from the video recordings on 2 separate weekdays.

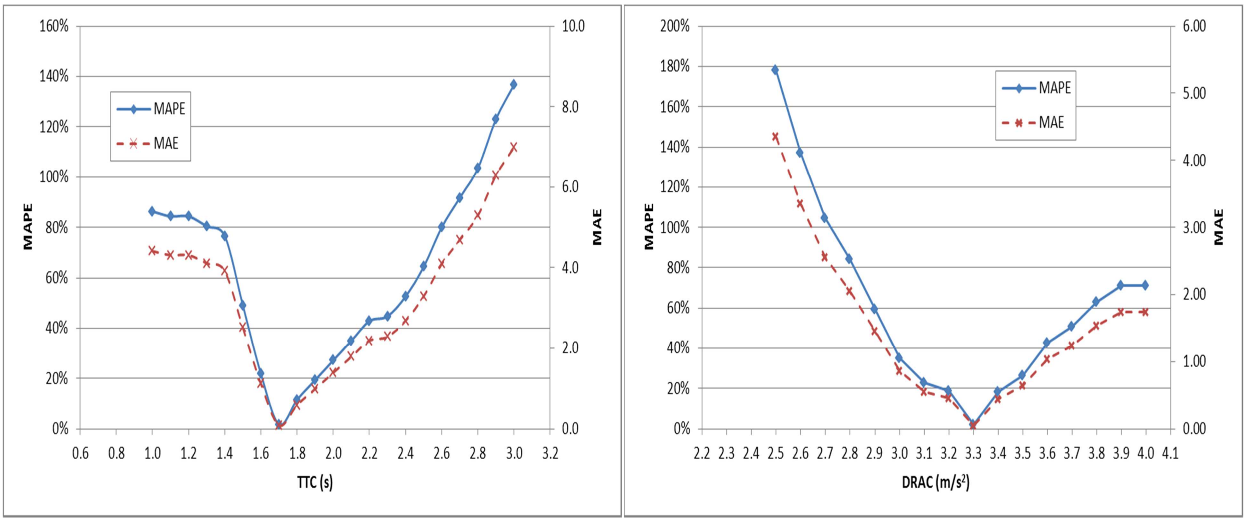

Figure 5: MAPE and MAE values for observed and modelled conflicts across different TTC and DRAC threshold values

6.2 Conflict Analysis

Conflicts from the micro-simulation runs are recorded based on the traffic scheme, traffic volume (for northbound carriageway) and locations where conflicts took place. **Table 1** summarizes the number of conflicts (averaged over 10 simulation runs) from the micro-simulation model in terms of DRAC and TTC. Based on the model results, the following observations are made:

1. Traffic volume has a direct effect on number of conflicts in all three traffic schemes at the corridor-level, as results of the Kruskal-Wallis H test showed that the number of conflicts were statistically significant different across the five levels of traffic volume in each scheme tested in the micro-simulation model. A plot of conflicts and traffic volume suggest that there exist a curvilinear relationship between the two variables, i.e. the rate of increase in the number of conflicts increases with higher traffic volume (**Figure 6**).

Table 1: Number of Conflicts from Simulated Traffic Scenarios

Traffic Scheme	Location	Traffic Volume (Vehicle per hour)									
		600		900		1200		1500		1800	
		DRAC	TTC	DRAC	TTC	DRAC	TTC	DRAC	TTC	DRAC	TTC
Mixed	Intersections	5.0	14.3	6.1	17.7	8.0	18.8	9.6	28.3	20.7	46.6
(Base)	Bus Stops	0.9	2.4	3.1	7.1	3.6	7.2	6.1	12.9	7.1	14.0
	Corridor	25.0	57.1	56.4	134.2	98.1	233.7	161.5	384.9	309.5	723
Reallocation	Intersections	0.7	2.4	1.0	2.1	1.1	2.9	1.0	4.2	1.1	4.1
(Option 1)	Bus Stops	0.8	1.2	2.2	4.1	2.8	4.3	2.1	3.1	1.7	2.4
	Corridor	25.6	69.2	60.5	143.2	121.3	284.4	233.1	580.1	455.3	1226.7
New lane	Intersections	1.5	4.9	2.1	5.9	1.3	3.7	1.2	4.4	0.8	4.7
(Option 2)	Bus Stops	0.1	0.8	0.1	0.6	0.3	1.3	0.9	1.7	0.5	1.1
	Corridor	26.0	58.8	58.7	127.1	85.7	197.4	149.8	330.7	229.5	523.7

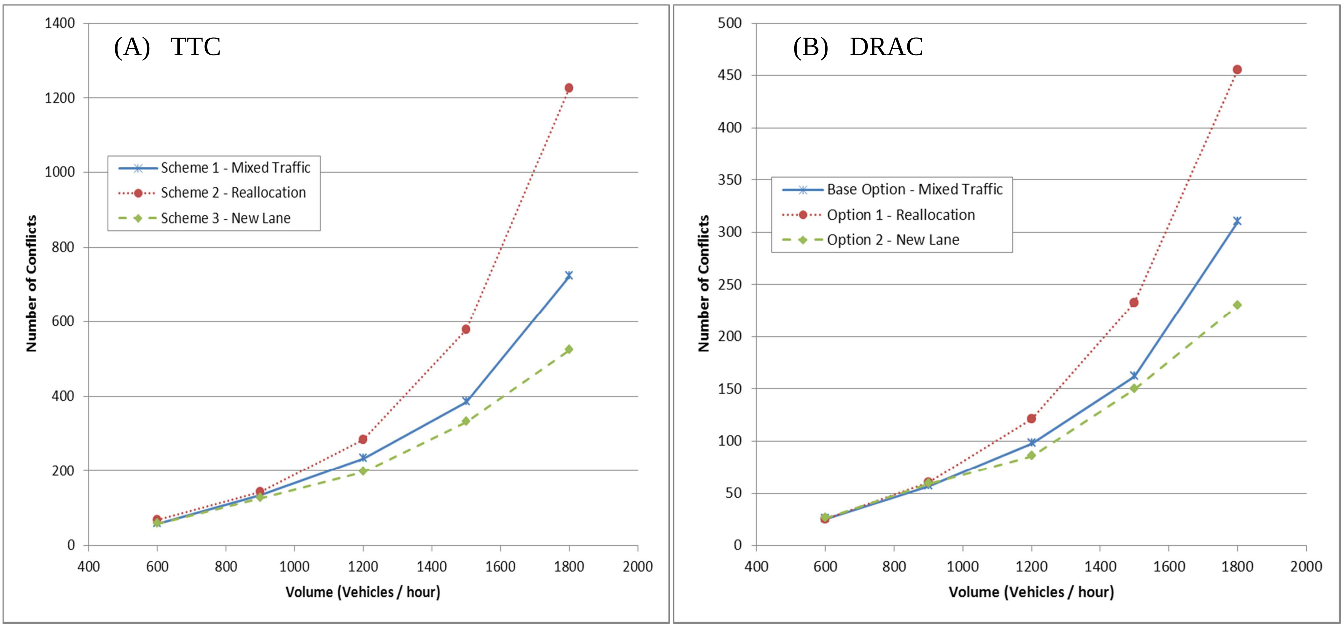

Figure 6: Number of Conflicts at Various Traffic Volume Levels

2. Whilst traffic volume has an effect on conflicts in the mixed traffic configuration (base case), its effect is less obvious at intersection approaches and bus stop locations when space reallocation (option 1) or space creation for buses (option 2) were applied. Kruskal-Wallis H test results showed that the differences in the number of conflicts at intersection locations in options 1 and 2 when traffic volume varied from 600 to 1800 vehicles per hour were not statistically significant. A similar finding, albeit only in option 1, was obtained at bus stops locations. These findings appear to be reasonable because we would expect traffic in two leftmost lanes to be much lower in the schemes involving space reallocation and new lane creation for buses (**Table 2**).

Table 2: Results of Kruskal-Wallis H Test for Volume Effect

Safety Measure	Location	Volume (Veh/hr)	Traffic Scheme		
			Base	Option 1	Option 2
TTC	Intersections	600 to 1800	0.00	0.09*	0.22*
	Bus Stops	600 to 1800	0.00	0.01	0.14*
	Corridor-level	600 to 1800	0.00	0.00	0.00
DRAC	Intersections	600 to 1800	0.00	0.92*	0.08*
	Bus Stops	600 to 1800	0.00	0.06*	0.10*
	Corridor-level	600 to 1800	0.00	0.00	0.00

*Note: *Indicates absence of statistical evidence to reject the hypothesis that the number of conflicts varies across different traffic volumes*

Table 3 captures the changes in the number of conflicts when options 1 and 2 are compared with the base option. The Mann-Whitney U test with statistical significance established at the 5% level is employed to detect statistical differences in the number of conflicts across traffic schemes. Results showed that:

3. At the corridor level, the difference in the number of conflicts in option 1 and 2 as compared to the base case are not statistically significant when traffic volume are below 900 vehicles per hour. This observation is independent of the type of safety performance measure adopted (TTC or DRAC). When traffic volume exceeds 900 vehicles per hour, the number of conflicts in option 1 was found to be consistently higher than in the base case ($p<0.05$). An opposite finding was obtained for option 2. The only exception was when DRAC was used, for which statistical difference in the number of DRAC conflicts was only significant when traffic volume exceeded 1500 vehicles per hour.
4. At intersection approaches, the number of conflicts were found to be consistently lower in options 1 and 2 ($p<0.05$) than the base case. This was independent of the type of safety performance measure adopted.
5. Similar observations were recorded at bus stop locations, in which the number of conflicts was found to be consistently ($p<0.05$) lower in options 1 and 2 than in the base case. The only exception was when the DRAC measure was used and traffic volume fell below 900 vehicles per hour in option 1.

Table 3: Change in Number of Conflicts Compared to Base Option – Mixed Traffic

Safety Measure	Option	Location	Traffic Volume (vehicles / hour)				
			600	900	1200	1500	1800
TTC	1	Intersections	-11.9*	-15.6*	-15.9*	-24.1*	-42.5*
	2		-9.4*	-11.8*	-15.1*	-23.9*	-41.9*
	1	Bus Stops	-1.2*	-3.0*	-2.9*	-9.8*	-12.9*
	2		-1.6*	-6.5*	-5.9*	-11.2*	-12.9*
	1	Corridor	12.1	9.0	50.7*	195.2*	503.7*
	2		1.7	-7.1	-36.3*	-54.2*	-199.3*
DRAC	1	Intersections	-4.3*	-5.1*	-6.9*	-8.6*	-19.6*
	2		-3.5*	-4.0*	-6.7*	-8.4*	-19.9*
	1	Bus Stops	-0.1	-0.9	-0.8*	-4.0*	-5.4*
	2		-0.8*	-3.0*	-3.3*	-5.2*	-6.6*
	1	Corridor	0.6	4.1	23.2*	71.6*	145.8*
	2		1.0	2.3	-12.4	-11.7	-80.0*

*Note: *Statistically different ($p<0.05$) compared to number of conflicts in base option – mixed traffic*

6.3 Implications of Findings

For bus and road management agencies, key findings from this study could act to inform policy makers in their operational and safety-related decisions. Firstly, overall results suggest that as compared to a mixed traffic configuration (base option), the provision of bus lanes, regardless whether it was created though space reallocation (option 1) or space creation (option 2), act to lower the number of conflicts at intersection approaches and bus stop locations. This bodes well for bus drivers as this is likely to reduce risks of rear-end and lane-change (or side-swipe) conflicts significantly. Previous studies have shown that rear-end and side-swipe accidents ranks amongst the top three most common accidents for buses (Zegeer et al., 1993, Yang et al., 2009). Secondly, findings point to the importance giving due consideration to traffic volume levels when deliberating on the type of bus priority measure to implement. Model results showed that safety benefits of the three traffic schemes differ at the corridor-level, especially when traffic volume exceeds 900 vehicles per hour on a 3-lane arterial road. In this case study, an average traffic volume of 1450 vehicles per hour (on the northbound carriageway) was recorded. At this traffic volume level, results from the micro-simulation model point to option 2 as the best traffic configuration in terms of safety performance, as it outperforms option 1 and the base option significantly. Option 1 on the other hand would have provided lower road safety benefits as compared to the base option. Thirdly, findings suggest that the choice between option 1 or 2 is less critical when traffic volume falls below 900 vehicles per hour, as both schemes bring about significant benefits at intersection and bus stop locations, without having any significant bearing on road safety at the corridor level.

7 CONCLUSIONS

This paper explores the safety implications of implementing different bus priority schemes on a selected 3-lane road corridor in Metropolitan Melbourne. A microscopic simulation modelling approach was adopted, in which conflicts in terms of TTC and DRAC were analysed across three traffic configurations: Base case - vehicles in mixed traffic condition; Option 1 - kerbside lane relocated for bus use only; and Option 2- new kerbside lane implemented for bus use only.

Findings from this study suggest that the provision of bus lanes, regardless whether it was created though space reallocation (option 1) or space creation (option 2), act to lower the number of conflicts at intersection and bus stop locations. However, because safety benefits at the corridor-level of these schemes vary at different traffic volume levels, there is a need for an appreciation of traffic volume levels when deciding on the type of bus priority scheme to implement for each road corridor. Results from micro-simulation modelling revealed that an increase in traffic volume results in lower safety performances for all schemes at the corridor-level. Its effect was however generally found to be insignificant at intersection approaches and bus stop locations. When a comparison of schemes was made at the corridor-level, option 2 was found to have the best safety performance followed by the base case and option 1, especially when traffic volume exceeded 900 vehicles per hour.

In concluding, findings from this study suggest an important area for further research in bus safety given the financial and social impact to bus companies, road users, commuters and the community whenever an accident occurs. Whilst this study has provided new insights into the varying safety effects of different traffic schemes, it is acknowledged that certain limitations exist. Firstly, the focus of this study has been on a specific road corridor in Metropolitan

Melbourne. Although the chosen site is considered to be representative of main arterial roads in the suburb areas (with major intersections typically spaced 1.6km apart), it is likely that results will differ for road corridors with different geometrical and operational characteristics. Further research is certainly needed to further investigate these effects. Secondly, the use of the DRAC measure is plagued with the issue that it might not accurately reflect traffic conflicts as it does not consider varying braking capabilities of vehicles. To overcome this limitation, recent studies have adopted a form of crash potential index that takes into account into vehicle-specific braking capabilities (Cunto and Saccomanno, 2008, Saccomanno et al., 2008). Future research efforts will therefore centre on the adoption of a similar approach to address the abovementioned limitation. Thirdly, this study has not assessed the ability of the safety performance measure to reflect actual crashes. As such, establishing a statistical link between simulated conflicts and observed crashes is now being considered as an extension to this research.

8 ACKNOWLEDGEMENT

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APPENDIX A – Stage 1 Calibration Results

Tables A1 and A2 capture the observed and modelled travel times along Blackburn Road from Wellington Road to Ferntree Gully Road in each sub-stage of the calibration process. Travel time calibration is considered completed when the GEH-statistic is less than 5 for more than 85% of the cases.

Table A1: Observed Travel Time

Observed Travel Time (Afternoon Peak Period)			
Date	**Trip 1**	**Trip 2**	**Trip 3**
11th Dec 2012	185.5	122.0	96.0
12th Dec 2012	215.5	158.0	103.5
13th Dec 2012	201.0	135.0	123.0

Table A2: Modelled Travel Time in Stage 1 Calibration

Travel Time from Micro-Simulation Model			
Run	**Default**	**1st Calibration**	**2nd Calibration**
1	156.36	136.80	143.08
2	260.98	141.01	143.55
3	161.97	138.88	147.60
4	153.88	145.12	147.36
5	169.03	139.51	149.44
6	155.00	144.33	141.60
7	161.06	141.40	148.96
8	173.23	136.99	146.42
9	154.17	140.19	145.80
10	153.83	143.33	145.81
Average	**169.95**	**140.76**	**145.96**
Proportion of cases where GEH-Statistic < 5	0.778	0.889 (OK)	0.911 (OK)

Further calibration is done to ensure there is reasonable goodness-of-fit between observed and modelled queue discharge headway distribution for a 30-minute period (17:30-18:00hrs). To do so, non-parametric tests - Kolmogorov-Smirnov and Mann Whitney U tests - were employed to compare the observed and modelled distributions. These tests were chosen as they are suitable alternatives to the more restrictive t-test, in which the data is assumed to follow the normal distribution. Visual inspection of the headway distribution showed that this assumption cannot be fulfilled, hence the use of K-S and Mann Whitney U tests. **Table A3** presents results of these tests through the model calibration process.

Table A3: Non-Parametric Tests (at p<0.05) for Comparing Headway Distribution

Model	**Mann Whitney U Test**		**Kolmogorov-Smirnov Test**	
	Statistic	**Retain null hypothesis*?**	**Statistic**	**Retain null hypothesis*?**
Default	0.007	✗	0.024	✗
Stage 1 – 1st Calibration	0.032	✗	0.190	✓
Stage 1 – 2nd Calibration	0.098	✓	0.140	✓

*Note: * The null hypothesis is that the observed and modelled headway distributions are the same*

APPENDIX B – Parameter Values Adopted in Various Stages of Calibration

Parameters		Model			
		Default	Stage 1A	Stage 1B	Stage 2
Global					
Look-Ahead Model	Zone 1 Distance D_{Z1} (m)	15	**200**	200	200
	Zone 2 Distance D_{Z2} (m)	5	**150**	150	150
Reaction Time		0.75	0.75	**1.0**	1.0
Reaction Time at Stop		1.0	1.0	**1.35**	1.35
Vehicle					
Car – length / width (m)		4 / 2	4 / 2	**4.6 / 2**	4.6 / 2
Bus – length / width (m)		12 / 2.4	12 / 2.4	**12 / 2.4**	12 / 2.4
Rigid – length / width (m)		8 / 2.25	8 / 2.25	**7.5 / 2.3**	7.5 / 2.3
Semi-trailer – length / width (m)		-	-	**19 / 2.4**	19 / 2.4
Car - maximum acceleration (m/s^2)		3	3	**2.4**	2.4
Bus - maximum acceleration (m/s^2)		1	1	**1.18**	1.18
Rigid - maximum acceleration (m/s^2)		1	1	**1.18**	1.18
Semi-trailer - maximum acceleration (m/s^2)		-	-	**0.86**	0.86
Car - normal / max. deceleration (m/s^2)		4 / 6	4 / 6	**4 / 6**	4 / 6
Bus - normal / max. deceleration (m/s^2)		2 / 5	2 / 5	**2.5 / 5**	2.5 / 5
Rigid - normal / max. deceleration (m/s^2)		3.5 / 5	3.5 / 5	**2.5 / 5**	2.5 / 5
Semi-trailer - normal / max. deceleration (m/s^2)		-	-	**2.2 / 4.5**	2.2 / 4.5
Traffic					
Minimum headway (s)		0	0	**0.4**	0.4
Behaviour					
Car – Speed limit factor		1.0	1.0	**1.04**	1.04
Bus – Speed limit factor		1.0	1.0	**1.00**	1.00
Rigid – Speed limit factor		1.0	1.0	**1.04**	1.04
Semi-trailer – Speed limit factor		1.0	1.0	**1.04**	1.04
Surrogate Safety Measure					
TTC threshold value (s)		1.5	1.5	1.5	**1.7**
DRAC threshold value (m/s^2)		3.35	3.35	3.35	**3.30**

Note: Figures in bold represents changes in each subsequent calibration, while those underlined are values adopted from AustRoads Project NS1229 – Micro-simulation Standards (ARRB Group, 2007)

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