MONASH University

Engineering

Exploring the Road Safety Impacts of Bus Priority

- Overview of Current Findings

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Institute of Transport Studies
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Transportation Research Board Annual Meeting
ANB70(2) Motorcoach Safety Subcommittee,
Wednesday 15th January, 2014
Marriott, Park Tower Suite 8206
Washington DC, USA

Agenda

1 Introduction

2 Before/ After Study

3 Bus Routes With/ Without Priority

4 ‘At Fault’ Bus Accident Risk

5 Traffic Micro Simulation

This paper presents an overview of a research program exploring the road safety impacts of bus priority

- Background:
  - ANB70 Cmte sponsored our paper 14-1894 'Investigating the Road Safety Impacts of Bus Priority Using Experimental Micro-Simulation Modelling' presented in last nights poster session
  - This part of a much wider research program exploring safety impacts and why they occur from many viewpoints
  - Brenda Lantz (ANB70 (2) Chair) invited us to present on paper 14-1894
  - I suggested a wider presentation on the whole research program as well as 14-1894
  - Why?: BUS PRIORITY CREATES SAFER ROADS – WE ARE TRYING TO FIND OUT WHY AND HOW
  - Why?: WE NEED AS MANY REASONS AS WE CAN TO PROMOTE BUS PRIORITY – SAFETY MIGHT BE A NEW ONE

The research is a PhD project as part of a wider research program

Research Program

Goal

to improve methodologies and guidance to enable the optimisation of design and implementation of public transport priority initiatives

Team

Graham Currie, Majid Sarvi, Research Fellow, 3 PhD Students

ITS (Monash)

University of Southampton **Nick Hounsell**

vicroads

PUBLIC TRANSPORT VICTORIA PT

Australian Government

Australian Research Council

PhD Research

Kelvin Goh – PhD Thesis
Road Safety Impacts of
Bus Priority Measures

Co-supervisors

Dr David Logan –
Monash University
Accident Research Centre

Assoc. Prof Majid Sarvi
– ITS (Monash)

The research involves 4 keys areas…

- Research fits around 4 key areas (and publications)
  - Before/After Effects of Bus Priority on Road Safety
    - Goh K, Currie G, Sarvi M and Logan D (In Press) ‘Road Safety Benefits from Bus Priority? – An Empirical Study’ TRANSPORTATION RESEARCH RECORD Journal of the Transportation Research Board (Accepted 13-02-2013)
  - Exploring Road Safety of Bus Routes With/Without Priority
    - Goh, K, Currie, G, Sarvi M and Logan, D (In Press) ‘Bus Accident Analysis of Routes With/Without Bus Priority’ ACCIDENT ANALYSIS AND PREVENTION accepted 6-12-2013
  - Factors Affecting ‘At Fault’ Bus- Involved Accidents (Including Bus Priority)
    - Goh, K, Currie, G, Sarvi M and Logan, D (Under review) ‘Factors Affecting the Probability of Bus Drivers Being At-Fault In Bus-Involved Accidents’ ACCIDENT ANALYSIS AND PREVENTION
  - Road Safety, Bus Priority and Experimental Micro-Simulation
    - Goh K, Currie G, Sarvi M and Logan D (2014) ‘Investigating the Road Safety Impacts of Bus Priority Using Experimental Micro-Simulation Modelling’ Transportation Research Board 93rd Annual Meeting, 2014 Washington DC USA Paper 14-1894

…which comprise the focus of todays presentation

- Before/ After Study
- Bus Routes With/ Without Priority
- ‘At Fault’ Bus Accident Risk
- Traffic Micro Simulation

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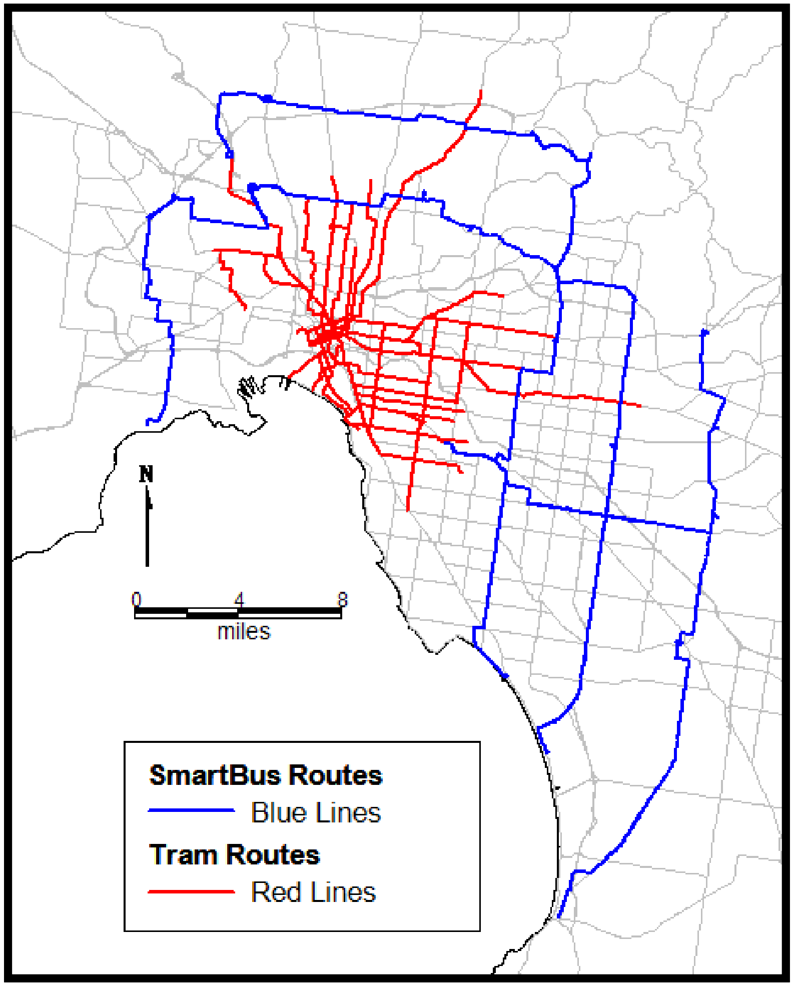
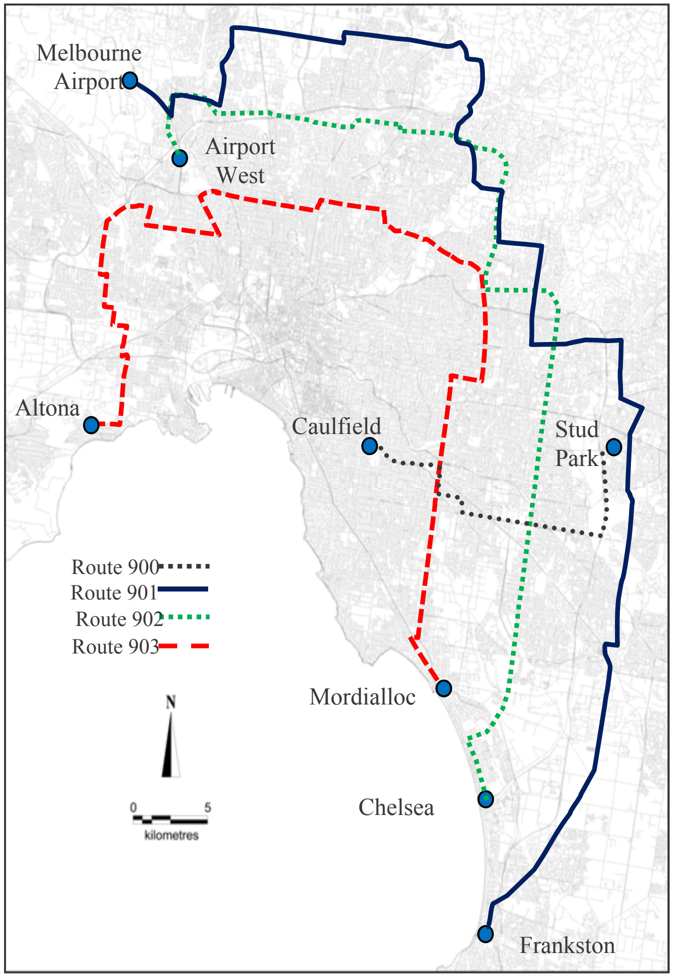
The focus of study is the new SmartBus network in Melbourne, Australia



SmartBus

- 8 routes
- 200 buses
- Low frequency; 15 min headway
- Long Routes; Round Trip Time = 238 mins

CrashStats Before/After Data explored to understand road safety impacts of BUS priority measures



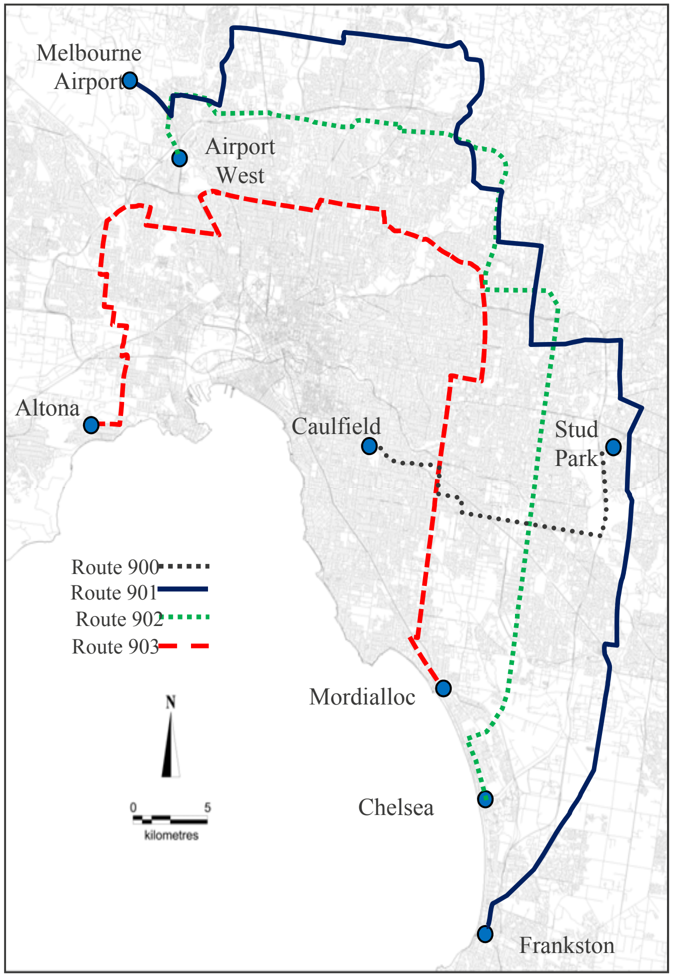
- Extensive implementation of priority measures on routes 900 to 903

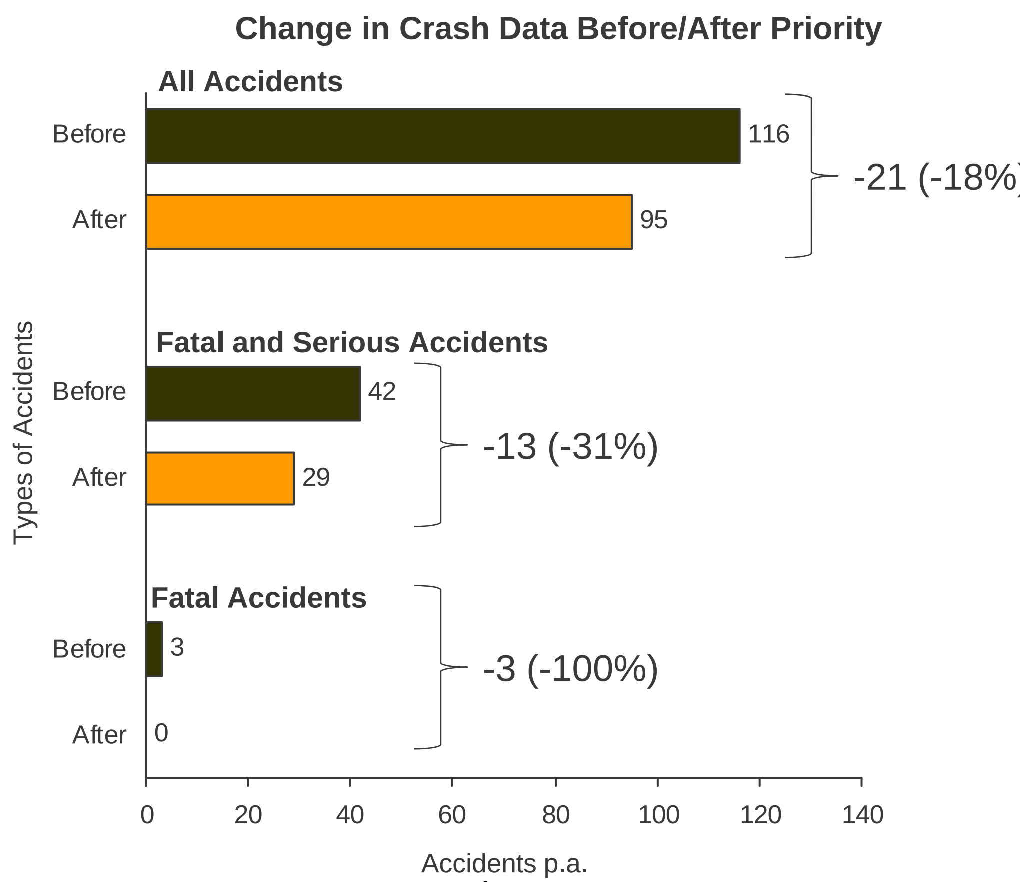
Treatment	Type of Measures	Description
Transit Signal Priority (TSP) – 31 locations	Actuated Transit Phase with or without Queue Jump Lane	"B" Signal activated when presence of bus is detected
	Phase Insertion / Deletion / Red Truncation / Green extension	Adjustment of cycle / phase timing when bus is detected
Non-Transit Signal Priority (non-TSP) – 25 locations	Clearways	Restricted parking on kerbside lane to facilitate to bus flows
	Curb Extension	Widening of carriageway to facilitate bus movements
	Full-Time or Part-Time Bus Lane	Dedicated lane for bus use only

Reference

Goh, K., Currie, G., Sarvi, M., Logan, D. (In Press). Road safety benefits from bus priority? – an empirical study. Transportation Research Record - Journal of the Transportation Research Board.

Results show accident reduction particularly in the important FSI group; why?



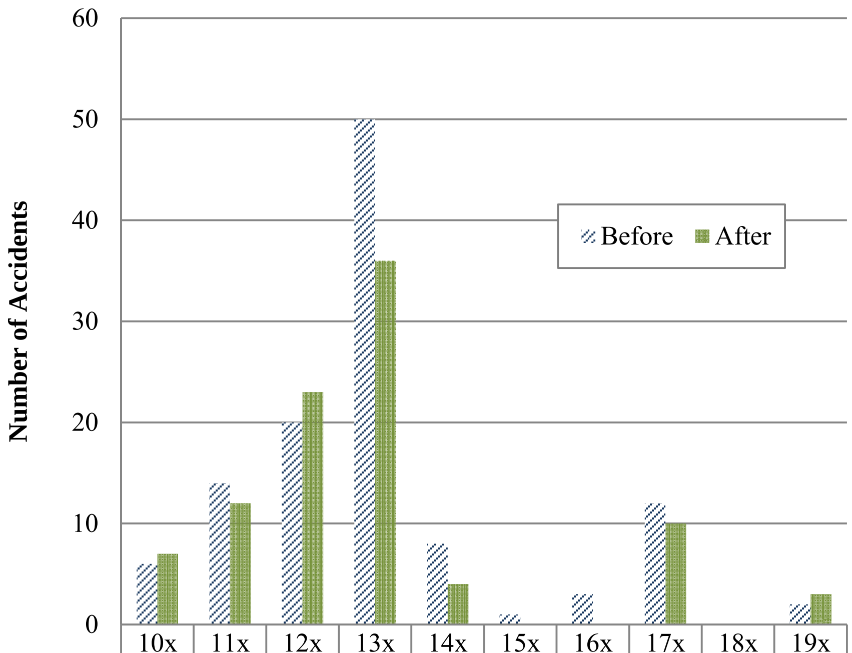


Reference

Goh, K., Currie, G., Sarvi, M., Logan, D. (In Press). Road safety benefits from bus priority? – an empirical study. Transportation Research Record - Journal of the Transportation Research Board.

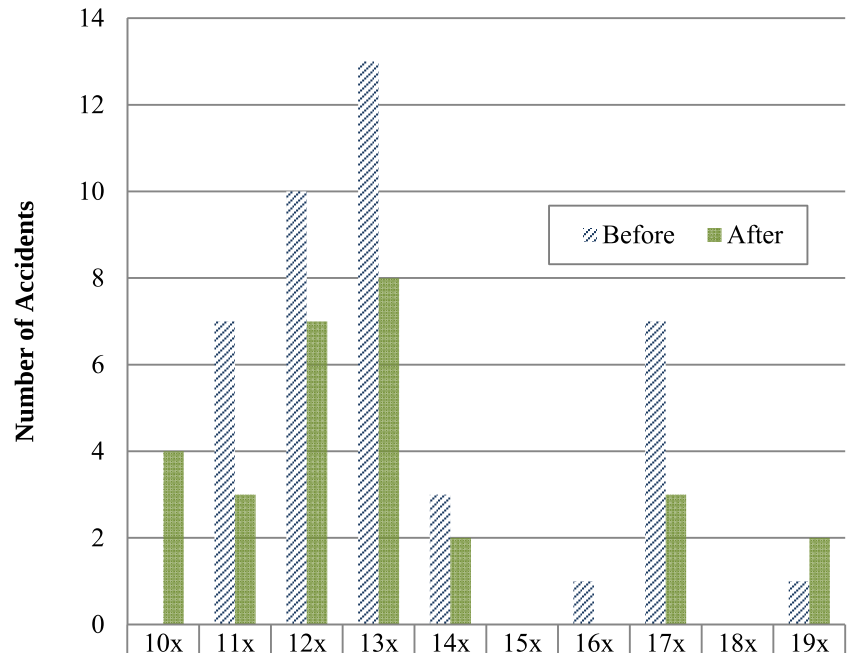
Accident Type analysis hints at likely bus priority effects

(A) All Accidents



	10x	11x	12x	13x	14x	15x	16x	17x	18x	19x
Before	6	14	20	50	8	1	3	12	0	2
After	7	12	23	36	4	0	0	10	0	3

(B) Fatal and Serious Accidents



	10x	11x	12x	13x	14x	15x	16x	17x	18x	19x
Before	0	7	10	13	3	0	1	7	0	1
After	4	3	7	8	2	0	0	3	0	2

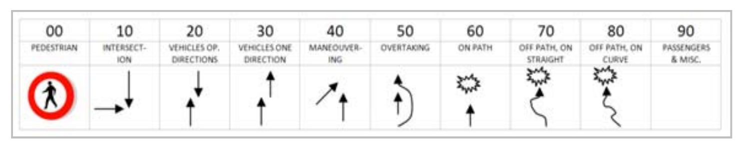
Key Findings:

✓66% drop in on & off-path accidents

✓28% drop in rear-end accidents

✓50% drop in side collisions

✓31 % drop in FSI accidents (42 to 29)



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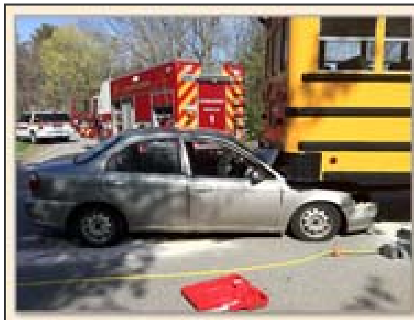
Accident Type analysis hints at likely bus priority effects

66% drop in on & off-path accidents

50% drop in side collisions



28% drop in rear-end accidents

Bus Lanes as a Roadside Buffer?

Bus Lanes as a Roadside Buffer?

Removing Bus Merges from The Traffic Stream?

Slower Traffic in Lanes & at Intersections?

Reference

Goh, K., Currie, G., Sarvi, M., Logan, D. (In Press). Road safety benefits from bus priority? – an empirical study. Transportation Research Record - Journal of the Transportation Research Board..

Analytical impact is a 14% crash reduction; space based priority -18%; time based -11%

- Robust before-after evaluation (Empirical Bayes method) employed

  - Final results show 14% reduction in accidents

Parameter	Types of Treatments		
	Time Based	Space Based	Overall
Number of Locations	31	25	56
Total observed crash counts in the "after" period	94	66	160
Expected crash counts in the "after" period	105.38	80.29	185.7
OR'	0.892	0.822	0.862
OR	0.889	0.818	0.860
SE(OR)	0.11	0.12	0.08
Safety Effect, θ	11.1%	18.2%	14.0%*
90% confidence level	(-7%,29%)	(-1.5%,38%)	(0.8%,27%)

* Significant at 90% level

- Time based measures opposite to those by study in Toronto, Canada (tram) – Likely due to lower bus frequency / pedestrian volume in Melbourne

Reference

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5 Traffic Micro Simulation

This study aimed to ‘predict’ accidents on bus routes with/without priority using 2 methods (MENB, NNM)

- Approach:
  - Empirical analysis of bus accident type and frequency analysis to gain a broad understanding of the safety implications of implementing bus priority measures at a bus route-section level
  - Two accident prediction models developed to identify key traffic, transit and route factors associated with accident frequency as well as for model comparison purposes
    - mixed-effects negative binomial regression approach (MENB)
    - neural network principles (NNM), as recent studies have pointed to excellent function approximation abilities of neural network models to predict collisions/ accidents
- Data
  - Traffic Incident Management System Grenda Transit (Ventura) – 2009-2011; 1,099 incidents on 99 bus routes

MENB is a regression model predicting accidents using traffic, frequency, stop density and bus priority variables

- Method 1 - Mixed-Effects Negative Binomial (MENB) Modelling of Bus Accidents
  - E(Aij) representing the predicted number of accidents along bus route segment i at time j, the structure of the MENB model is given as:

$$E(A_{ij}) = \exp(X_{ij}\beta + L_i l_i + T_j t_j + \varepsilon_{ij})$$

where
X_{ij} = Matrix representing factor contrasts and covariates
β = Vector of pooled coefficients (fixed effect)
L_i = Matrix to account for location-specific effect
l_i = Vector of coefficients representing location-specific effects
T_j = Matrix to account for time-specific effect
t_i = Vector of coefficients representing time-specific effects
ε_{ij} = Vector of residual errors

Table 1: Summary Statistics of Variables Used in MENB Model

Variable	Min	Max	Mean	S.D.
Accident Frequency (Collisions/year)	0	29	3.68	4.89
Year[a] (2009=1; 2010=2; 2011=3)	1	3	2	0.82
Location[a] (Segment 1 =1 to Segment 99 = 99)	1	99	50	28.58
Length of bus route segment[b] (km)	2.5	55.0	15.94	10.11
Average Annual Daily Traffic (AADT) of segment[c]	1,495	78,433	7,335	6,286
Number of bus services per week	6	314	111.43	87.63
Stop Density (Number of bus stops/km)	0.53	7.33	2.50	0.941
Presence of bus priority (With = 1; otherwise = 0)	0	1	0.15	0.36
Total Observations, n = 297				

Note: [a] *Coded as string variable as required in R software*
[b] *Defined based on bus service route and presence of bus priority*
[c] *The weighted average method is applied to compute the AADT value for segments that comprise more than one road sections*

NNM can explore complex data relationships without need for functional forms;

- back-propagation algorithm adopted BPNN
- BPNN model was developed in MATLAB
- Single neuron output layer (accident frequency)
- Range of hidden neurons adopted
- Model run 10 times to obtain RMSE for comparison with MENB model

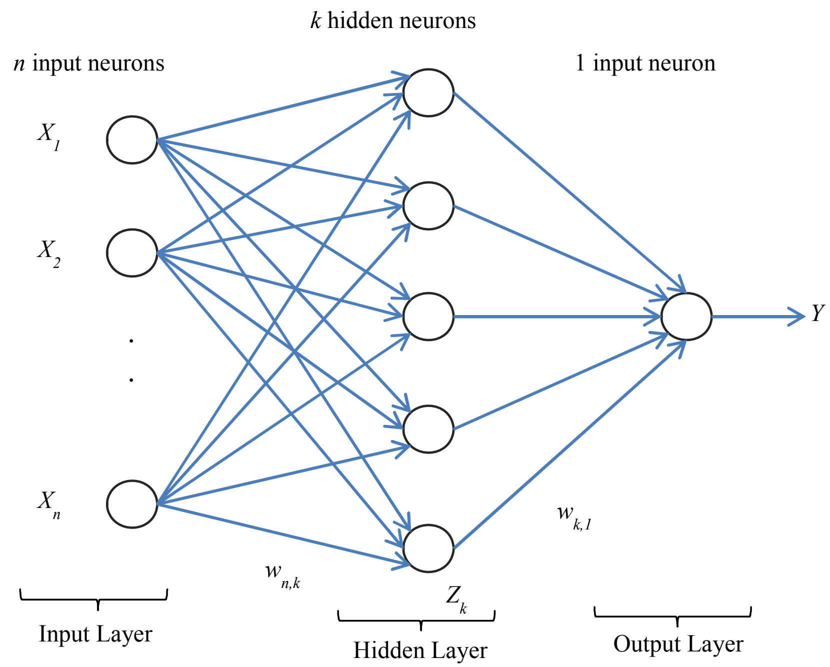
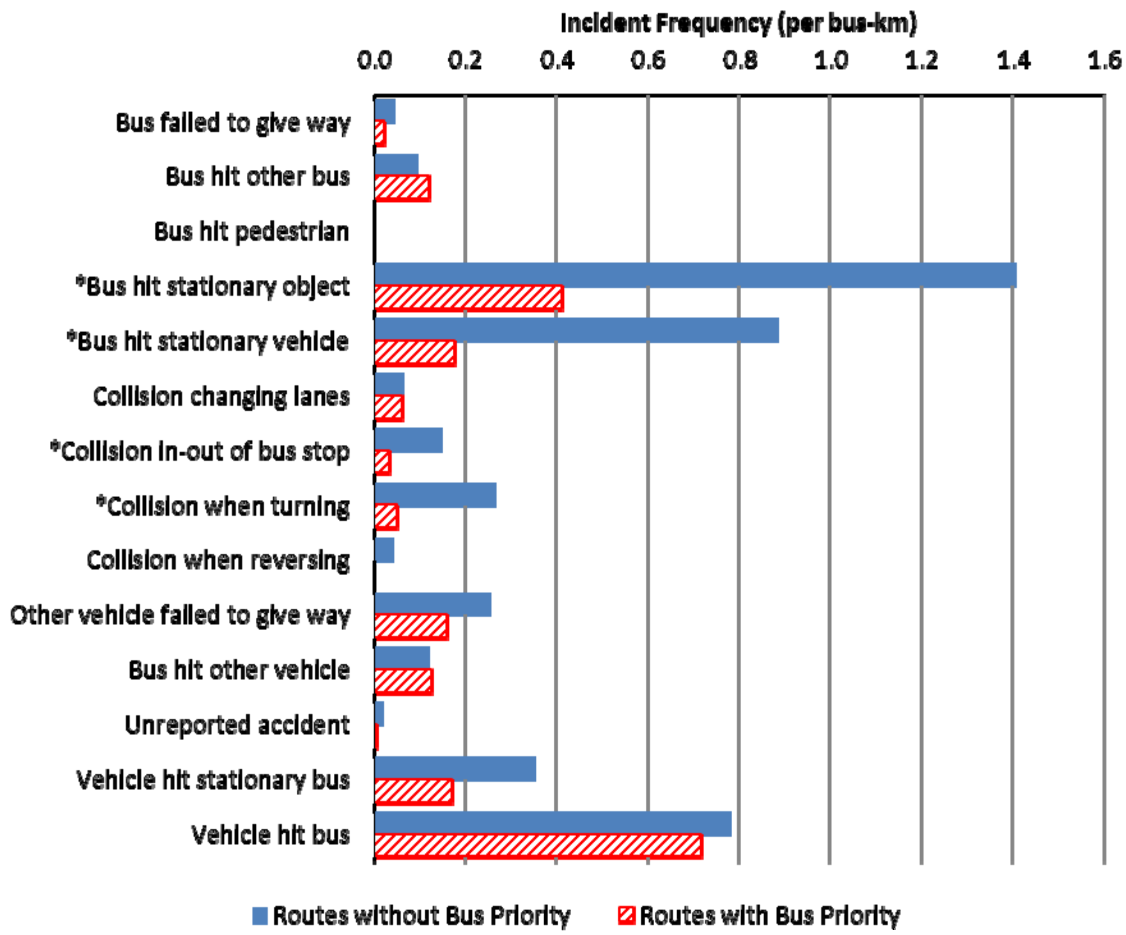


Figure 1: Topology of a Three-Layered Feed-Forward Neural Network

The raw data show significant reductions in incident frequency for routes with bus priority

- 70% reduction in accidents with buses hitting stationary objects
- 80% reduction in buses hitting stationary vehicles
- 80% reduction in collisions in-out of bus stops
- Cause hypothesis – Bus Priority facilitates safer bus movements on roads with traffic



The MENB model shows risk factors are AADT, Rte Length, Service Frequency, Stop Density and NO bus priority

- bus accident frequency at the route-section level increases with:
  - traffic volume (AADT),
  - route length and
  - service frequency
- that having more bus stops per route km increases accident risks (p=0.000), while
- the presence of bus priority reduces accident risks (p=0.002).
- <u>the presence of bus priority is associated with a 54% reduction in bus accident occurrence</u>, of all severity levels. *[This data includes all accident types including property – not only police recorded accidents)*

Table 1: MENB Model Results for Bus Accident Frequency

Variable	**Estimate**	**P-value**
Intercept	-6.640	0.000
Services per week	0.006	0.000
Ln(AADT)	0.431	0.001
Ln(Route Section Length)	0.773	0.000
Stop Density	0.389	0.000
Bus Priority = Yes	-0.766	0.002
Bus Priority = No	0 (Reference)	
Random Effect:	**Variance**	**Standard Deviation**
Year	0.357	0.598
Location	0.195	0.441
Dispersion parameter, α	0.242	
95% CI for α	[0.169,0.429]	
Log likelihood	-607.205	
AIC	1232.4	
R_α	0.807	

BPNN Model can be used to predict accident rates for specific sites

- Best model had 1 hidden layer with 4 neurons – example outputs

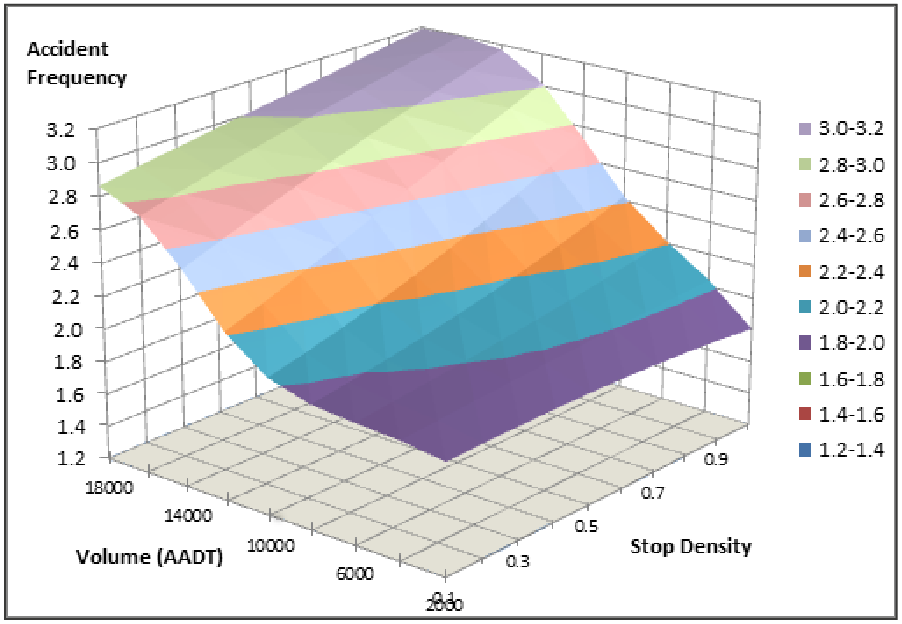


Figure 3: Effect of AADT and stop density on accident frequency (route-section 25)

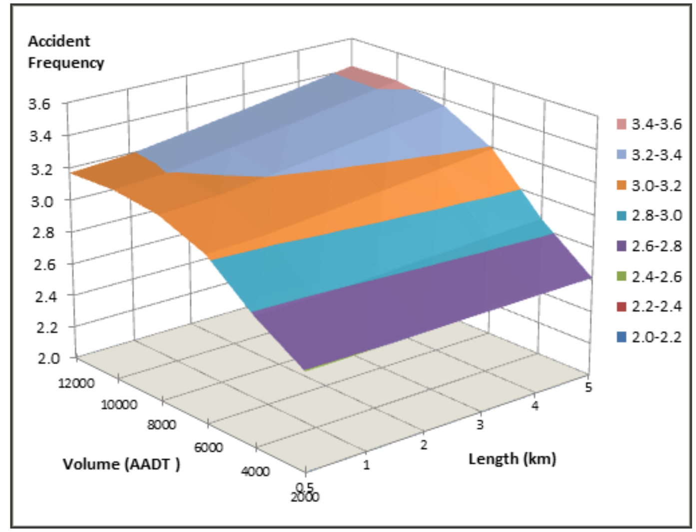


Figure 4: Effect of AADT and route length on accident frequency (route-section 25)

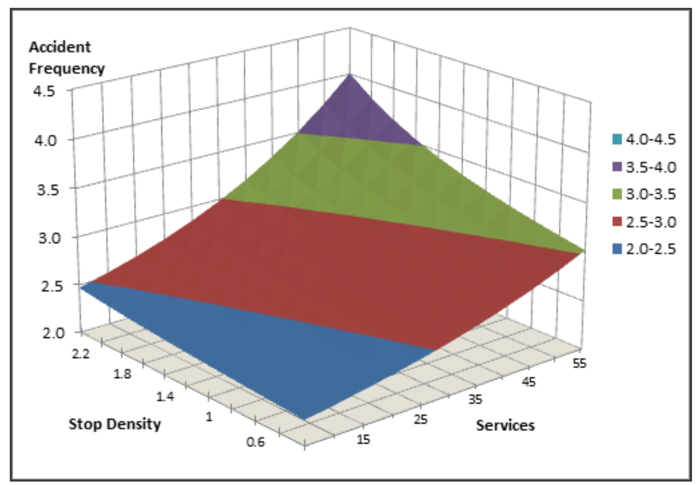


Figure 5: Effect of stop density and service frequency on accident frequency (route-section 25)

Both models show similar results; MENB had slightly lower error

- Key Findings – Method
  - MENB model and BPNN model generally similar results
  - MENB model has lower error (RMSE=2.59 vs 2.75)
- Key Findings Bus Priority:
  - The safety effect of bus priority is apparent for all datasets. T-test results revealed that the safety effect of bus priority effect was statistically significant ($p<0.05$) in all datasets for both models.
  - The BPNN model showed that bus priority has the effect of reducing route-section level accident frequency by 53.4%.
  - Results from the MENB model showed that this effect was 53.5% (which is equivalent when using the parameter estimate obtained from the NB model in the previous section

Table 1: Sensitivity Analysis for Bus Priority

Model	Route-section Dataset	Predicted Accident Frequency (per km)	
		With Bus Priority	Without Bus Priority
MENB (RMSE=2.59)	Without bus priority (N=252)	0.093 (S.D.=0.090)	0.201 (S.D.=0.194)
	With bus priority (N=45)	0.499 (S.D.=0.293)	1.073 (S.D.=0.629)
	All route-sections (N=297)	0.167 (S.D.=0.226)	0.359 (S.D.=0.486)
BPNN (RMSE=2.75)	Without bus priority (N=252)	0.173 (S.D.=0.216)	0.234 (S.D.=0.259)
	With bus priority (N=45)	0.432 (S.D.=0.289)	1.682 (S.D.=1.421)
	All route-sections (N=297)	0.213 (S.D.=0.247)	0.457 (S.D.=0.800)

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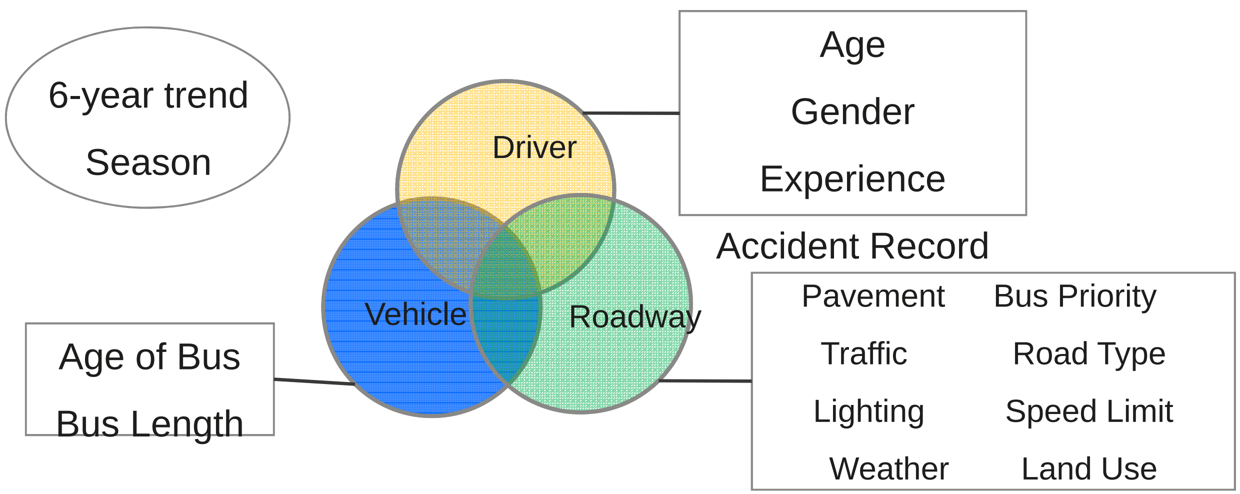
Separate analysis explored Bus drivers' probability of being 'at-fault' in accidents including bus priority effects

- Mixed Logit Model of driver being at-fault:

$$F_{in} = \beta_i X_{in} + \varepsilon_n$$

where i = at-fault (=1) or not at-fault(=0) for driver n

X = Vector of 16 driver, vehicle, roadway and evironment factors



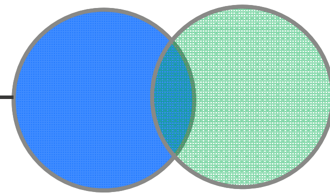
Reference

Goh, K., Currie, G., Sarvi, M., Logan, D., 2013. Factors Affecting the Probability of Bus Drivers Being At Fault in Bus-Involved Accidents, Accident Analysis and Prevention (Under Review).

Bus Priority/Divided Roads key accident reduction factors

- 2 vehicle and 5 roadway / environmental factors found significant

Age of Bus
Bus Length



Pavement	Bus Priority*
Traffic*	Road Type
Lighting*	Speed Limit
Weather	Land Use

Factor	Type	β	S.E.	t-Statistic
Bus age - 25 years or more	Fixed	0.273	0.0969	2.82
Bus Length - 12m or less	Fixed	-0.241	0.0415	-5.81
Divided Road	Fixed	-0.427	0.0501	-8.53
Speed Limit - 50kph & below	Fixed	0.313	0.0404	7.73
Traffic - Moderate/Heavy	Random	-0.206 (0.400)	0.0370 (0.0363)	-5.57 (11.03)
Daylight	Random	-0.125 (0.418)	0.0449 (0.0297)	-2.78 (14.05)
Bus Priority	Random	-0.446 (2.26)	0.216 (0.447)	-2.07 (5.05)

Indicative that divided roads and those with bus priority would help bus drivers

Reference

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Causal/risk factors measured

Driver-related

- Above 60 year old - possibly reflecting declining driving skills
- <2 years working experience - also found in previous study (Tseng, 2012)
- Female driver
- Previous at-fault record - presence of accident prone mentality

Vehicle-related

- Longer / older buses - not surprising given buses are likely to be less responsive and had been subjected to greater wear-and tear

Roadway / Environment

- Undivided / 50kph or lesser roads - indicate space issues faced by bus drivers, especially near bus stops (Wahlberg, 2002)
  - Light traffic - perhaps drivers letting guard down
  - Night time - lesser visibility
  - Lack of bus priority - space issue as highlighted

For road / bus agencies, findings suggest benefits in assigning

✓Longer / older buses to experienced drivers

✓Routes with bus priority and mainly arterial roads to less experienced drivers

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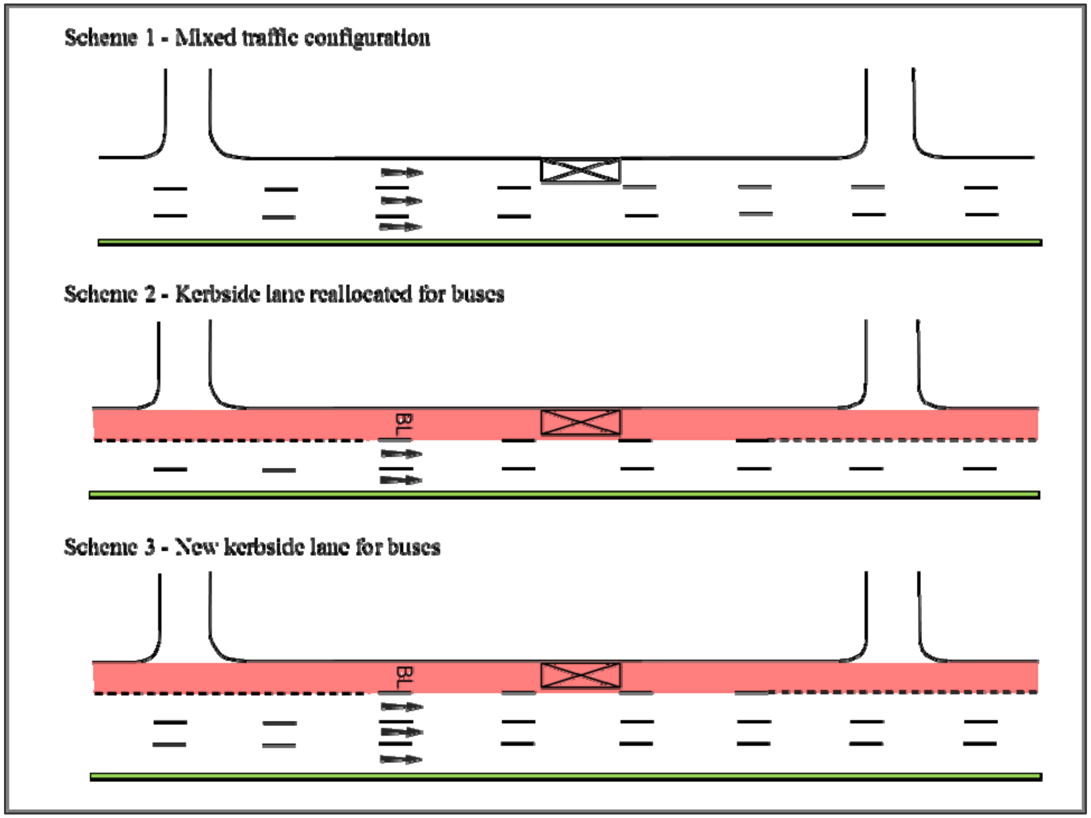
This study used Traffic Micro Simulation (TMS) as an experimental tool to explore bus priority and safety using DRAC/CPI metrics

- Surrogate Safety Measures (SSM) in Traffic Micro-Simulation Modelling:
  - DRAC - deceleration rate to avoid the crash
  - CPI – crash potential index
  - Can be used to relate accident risk in traffic
- VISSIM model adopted to test following configurations >>>>>



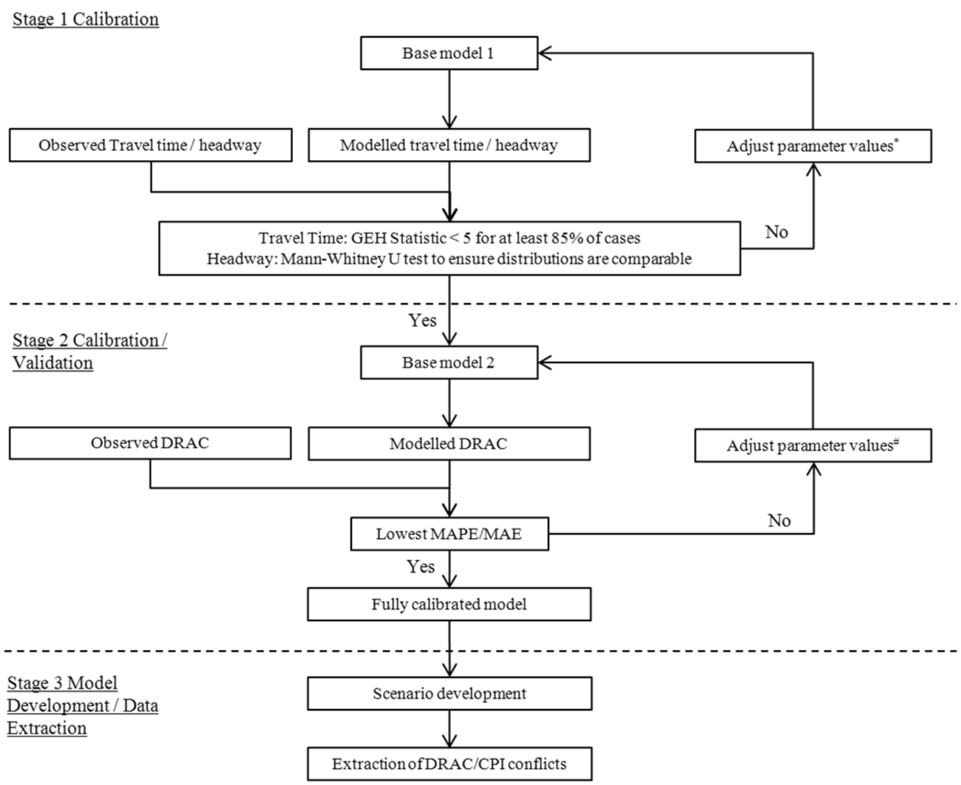
Example Traffic Micro-simulation

Not all risk behaviour is represented in TMS; hence only some safety effects can be tested

TABLE 1 Hypotheses on Safety Benefits of Bus Priority

No.	Location	Hypothesis	Testable Using Micro-simulation/SSM?
1	Corridor	Reduced risk of run-off accidents with bus lane acting as roadside buffer	No
2		Improved visibility for drivers with buses segregated from main traffic stream	Unclear
3	Uncontrolled Intersections	Reduced risk of rear-end accidents for vehicles entering side streets as bus lane allows vehicles (bus and turning traffic) to break away/separate from mainstream traffic and slow down before turning	Yes
4		Reduced risk of side-swipe accidents for vehicles entering main street as bus lane allows vehicle to pick up speed before joining mainstream traffic	Yes
5	Controlled Intersections	Reduced risk of rear-end accidents as vehicles move into bus lane before turning at intersection	Yes
6		Improved intersection visibility for vehicles with buses segregated from main traffic stream	Unclear
7	Bus Stops	Reduced risk of vehicles hitting rear of slowing or stationary bus	Yes
8		Reduced risk of side swipe accidents as a result of vehicle changing lane to overtake slowing or stationary bus	Yes
9		Reduced side-swipe accident risk for buses moving off	Yes

Methodology involves some careful calibration to ensure actual behaviour is represented in models…



Note: * *Key driver and vehicle parameters in micro-simulation model*
\# *Key driver and vehicle parameters in micro-simulation model as well as DRAC threshold values in SSAM module*

FIGURE 1 Staged approach to extraction of conflicts from micro-simulation models

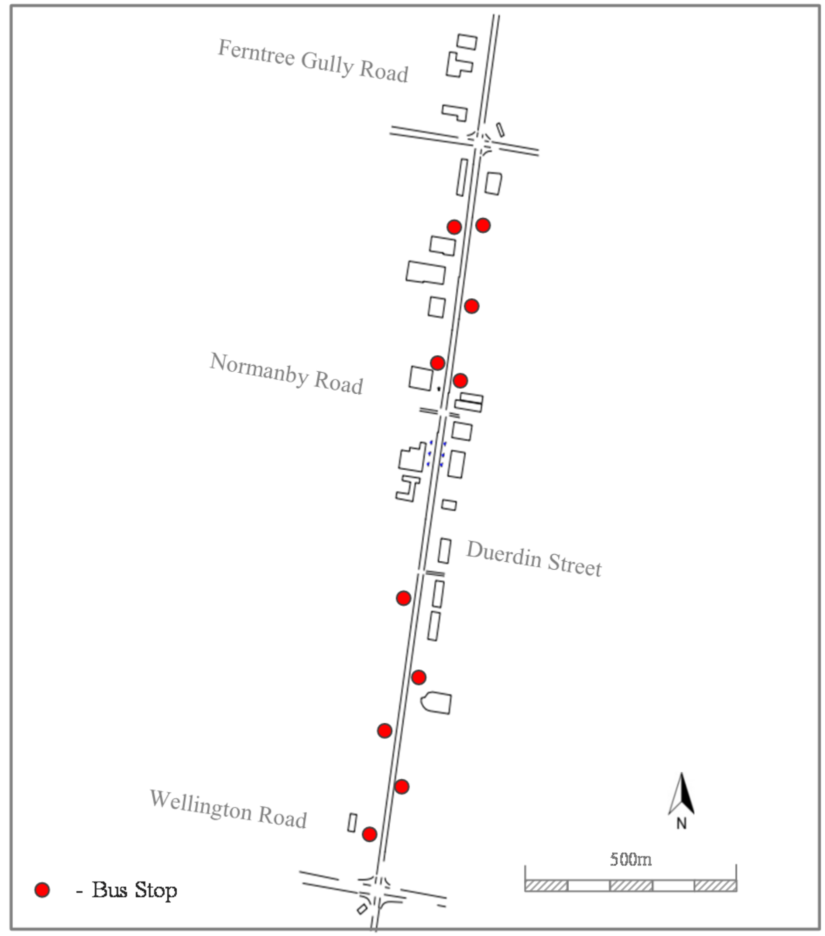
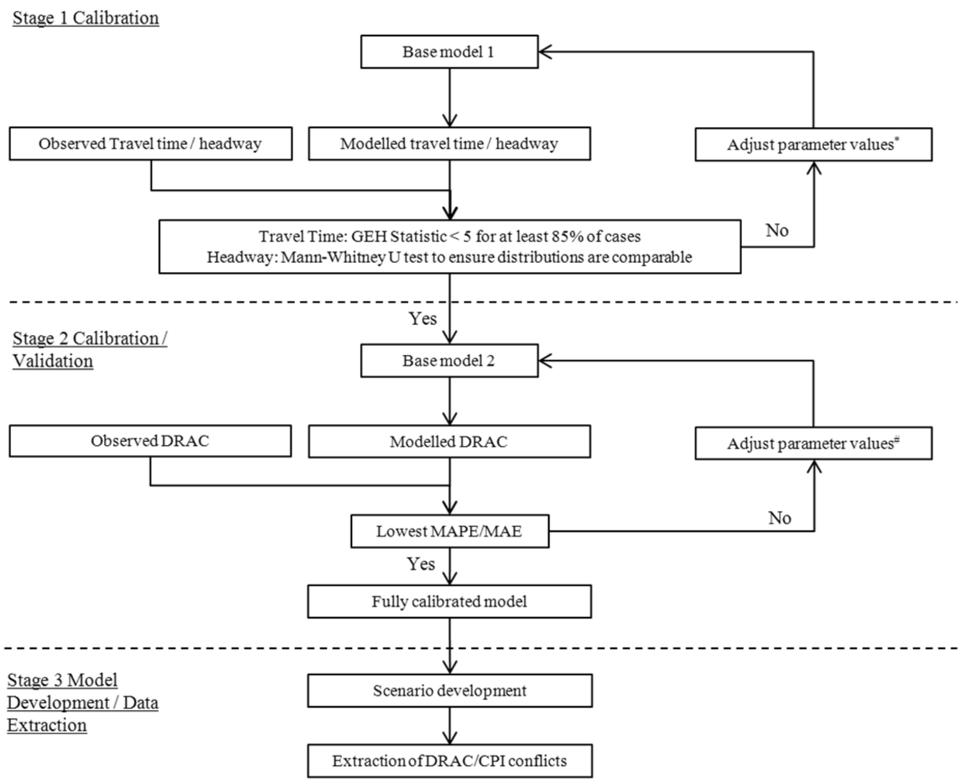


FIGURE 1 Snapshot of road corridor in case study.

…and testing of the 3 road schemes at intersections/bus stops for 5 levels of traffic flow

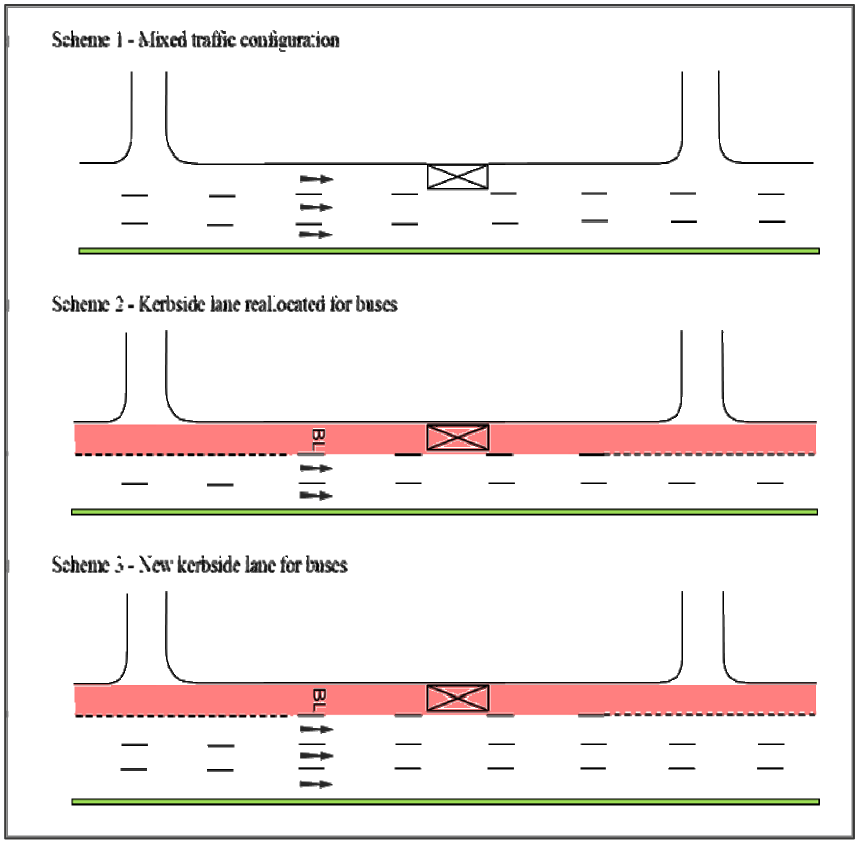


Note: * *Key driver and vehicle parameters in micro-simulation model*
Key driver and vehicle parameters in micro-simulation model as well as DRAC threshold values in SSAM module

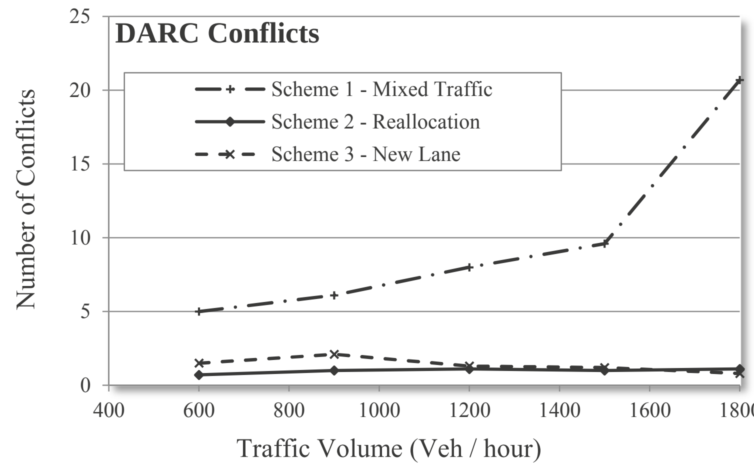
FIGURE 1 Staged approach to extraction of conflicts from micro-simulation models

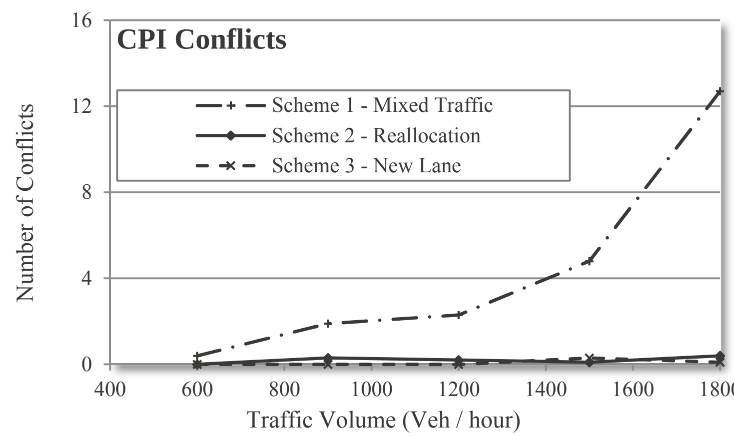
- Modelling Approach:
  - Modelled using AIMSUN TMS system
  - 3 lane road (70kph speed limit) and 3 bus routes modelled
  - Model conflict analysis at 3 locations:
    - Intersections
    - Bus Stops
    - Entire Corridor
  - 5 levels of traffic flow tested
  - Models run 10 times and average outcome used

Bus priority schemes 2/3 have less conflicts at intersections…

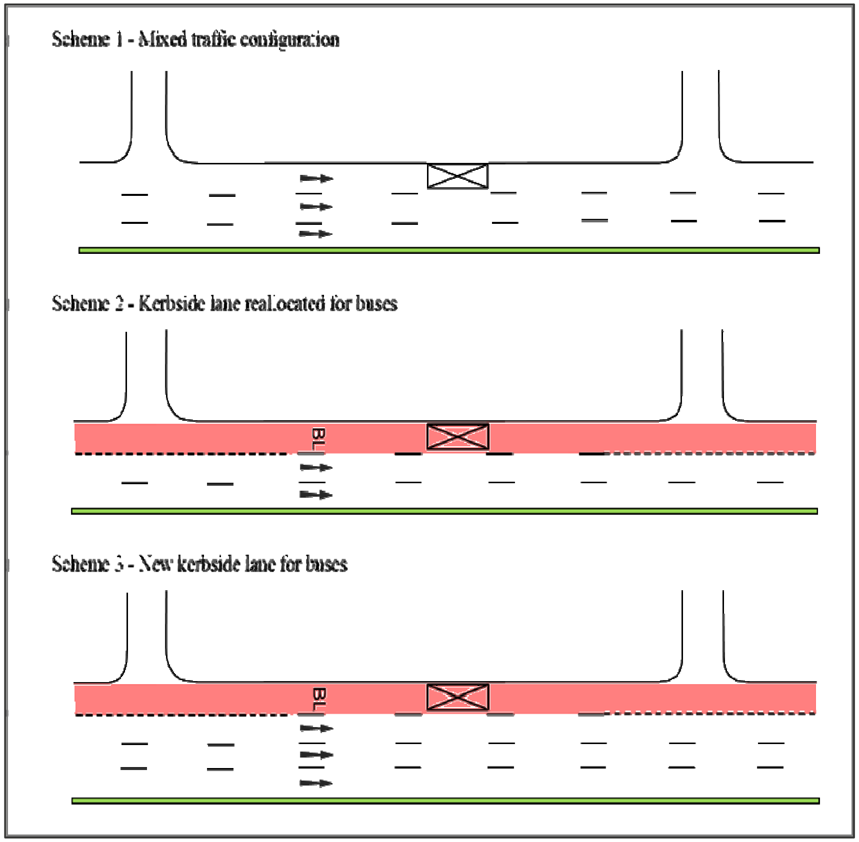


Conflicts at intersections

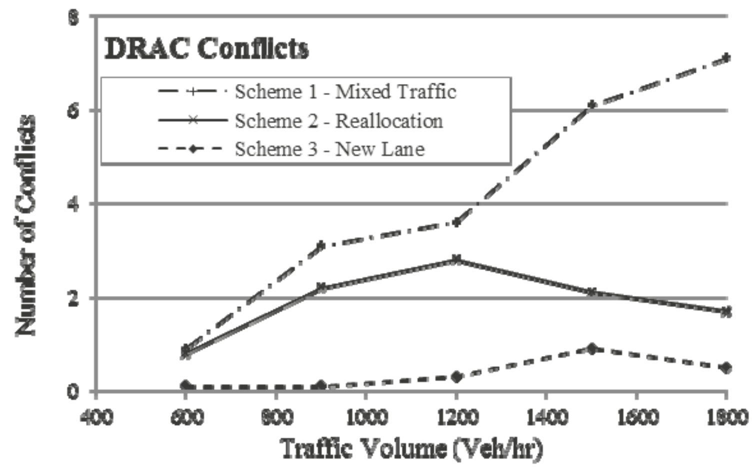


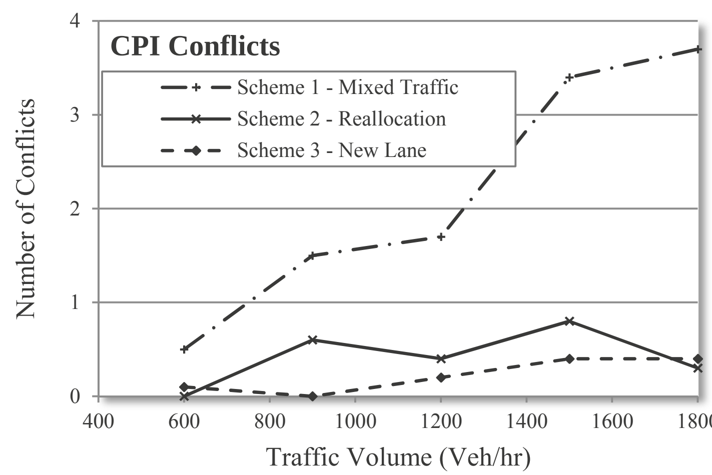


…and at bus stops; scheme 3 has less conflicts than 2



Conflicts at Bus Stops



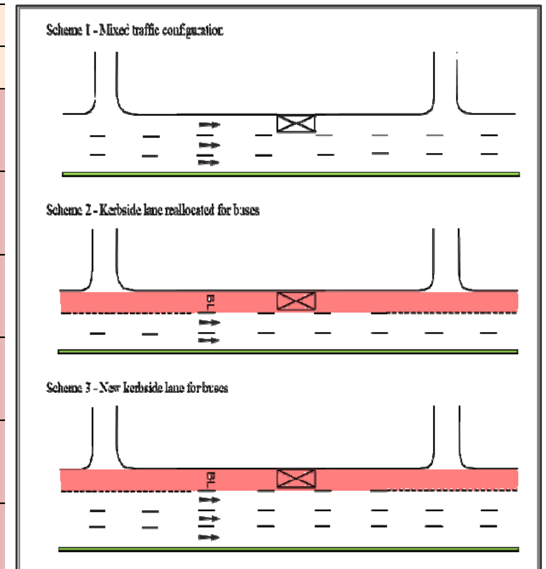


Both bus priority schemes reduce conflicts at intersections/bus stops; 3 more than 2

TABLE 1 Change in Number of Conflicts Compared to Scheme 1 (Mixed Traffic)

Safety Measure	Traffic Scheme	Location	Traffic Volume (vehicles / hour) 600	900	1200	1500	1800
DRAC	2	Intersections	-4.3*	-5.1*	-6.9*	-8.6*	-19.6*
	3		-3.5*	-4.0*	-6.7*	-8.4*	-19.9*
	2	Bus Stops	-0.1	-0.9	-0.8*	-4.0*	-5.4*
	3		-0.8*	-3.0*	-3.3*	-5.2*	-6.6*
	2	Corridor	0.6	4.1	23.2*	71.6*	145.8*
	3		1.0	2.3	-12.4	-11.7	-80.0*
CPI	2	Intersections	-0.4	-1.6	-2.1*	-4.7*	-12.3*
	3		-0.4	-1.9*	-2.3*	-4.5*	-12.6*
	2	Bus Stops	-0.5	-0.9	-1.3*	-2.6*	-3.4*
	3		-0.4	-1.5	-1.5	-3.0	-3.3*
	2	Corridor	2.2	1.1*	14.8*	53.9*	144.4*
	3		1.4	2.6*	2.6*	-4.3*	-45.2*

*Note: *Statistically different (p<0.05) as compared to number of conflicts in scheme 1 (mixed traffic)*



- Intersections - conflicts are lower ($p<0.05$) in schemes 2 or 3 than scheme 1
- Bus stops - similar observations recorded, but only when traffic volume exceeds certain level
- Corridor-level - conflicts higher in scheme 2, lower in 3 as compared to scheme 1 - actual evidence shows net reductions, which implies some safety effects not modelled (Table 1)

➢ Results suggest bus priority facilitates turning/merging movements & thus reduce traffic conflicts

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