MONASH University

Engineering

Road Safety Benefits From Bus Priority Schemes? - Unexpected Results from a Bus Safety Research Program

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April 28th-May 2nd, 2014

Agenda

1 Introduction
2 'At Fault' Bus Accident Risk
3 Bus Routes With/ Without Priority
4 Total Traffic Effects?
5 Traffic Micro Simulation
6 Trams?

This paper presents an overview of a series of research programs exploring road safety and bus services…

- Background:
  - Bus Road Safety:
    - Project started as a study of bus safety
    - Found important effects of bus priority (signal and lane priority) on bus crashes so explored wider effects on all traffic
    - Found BIG impacts so the question was why?
    - Undertook a series of studies to identify why
  - Tram/Streetcar
    - Summarises early results for a similar new study of tram (streetcar) priority measures

…all research is published in a series of research papers

Bus

Factors Affecting 'At Fault' Bus- Involved Accidents (Including Bus Priority)

•Goh, K, Currie, G, Sarvi M and Logan, D (2014) 'Factors Affecting the Probability of Bus Drivers Being At-Fault In Bus-Involved Accidents' ACCIDENT ANALYSIS AND PREVENTION Volume 66, May 2014, Pages 20-26

Exploring Road Safety of Bus Routes With/Without Priority

•Goh, K, Currie, G, Sarvi M and Logan, D (2014) 'Bus Accident Analysis of Routes With/Without Bus Priority' ACCIDENT ANALYSIS AND PREVENTION Volume 65, April 2014, Pages 18-27

Before/After Effects of Bus Priority on Road Safety

•Goh K, Currie G, Sarvi M and Logan D (2013) 'Road Safety Benefits from Bus Priority? – An Empirical Study' TRANSPORTATION RESEARCH RECORD, No. 2352, Transportation Research Board of the National Academies, Washington,D.C., 2013, pp. 41–49

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

Tram

Before/After Effects of Tram Priority on Road Safety

•Naznin F Currie G Sarvi M Logan D (2015) 'Road Safety Impacts of Tram/Streetcar Priority Measures – A Before-After Study Using Empirical Bayes Method' Transportation Research Board 94th Annual Meeting

Tram Stops and Road Safety

•Currie, G., Tivendale K and Scott R (2011) 'Analysis and Mitigation of Safety Issues at Kerbside Tram Stops' TRANSPORTATION RESEARCH RECORD No 2219 No 4 pp 20-29

•Currie, G., & Reynolds, J. (2010). Vehicle and Pedestrian Safety at Light Rail Stops in Mixed Traffic. TRANSPORTATION RESEARCH RECORD, Vol. 2146, pp. 26-34

Hook Turns and Road Safety

•Currie, G. and Reynolds J (2011) 'Managing Trams and Traffic at Intersections with Hook Turns – Safety and Operational Impacts' TRANSPORTATION RESEARCH RECORD No 2219 No 4 pp 10-19

The research is part of a program funded by the Australian Research Council & partners

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

Australian Government
Australian Research Council

PUBLIC TRANSPORT VICTORIA PT

PhD Research

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

Farhana Naznin – PhD Thesis Road Safety Impacts of Tram Priority Measures

Co-supervisors

Dr David Logan – Monash University Accident Research Centre

Assoc. Prof Majid Sarvi – ITS (Monash)

..it is structured as follows

1. 'At Fault' Bus Accident Risk
2. Bus Routes With/ Without Priority
3. Total Traffic Effects?
4. Traffic Micro Simulation
5. Trams?

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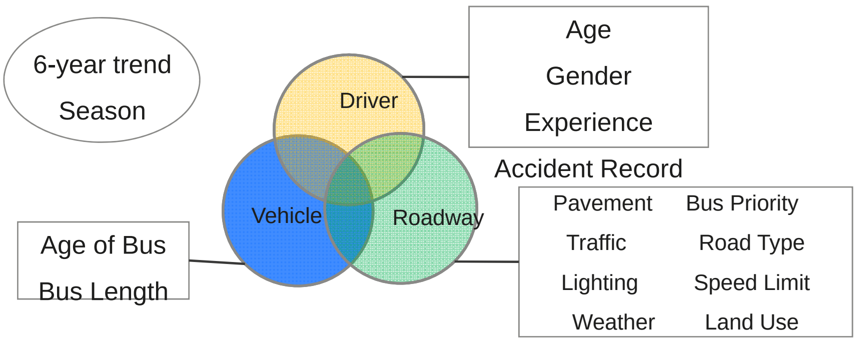
Analysis explored Bus drivers’ probability of being ‘at-fault’ in bus accidents including priority effect

- 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



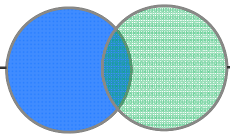
Reference

Goh, K, Currie, G, Sarvi M and Logan, D (2014) 'Factors Affecting the Probability of Bus Drivers Being At-Fault In Bus-Involved Accidents' ACCIDENT ANALYSIS AND PREVENTION Volume 66, May 2014, Pages 20-26

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	0.0370	-5.57
			(0.400)	(0.0363)	(11.03)
↓	Daylight	Random	-0.125	0.0449	-2.78
			(0.418)	(0.0297)	(14.05)
↓	Bus Priority	Random	-0.446	0.216	-2.07
			(2.26)	(0.447)	(5.05)

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

Reference

Goh, K, Currie, G, Sarvi M and Logan, D (2014) 'Factors Affecting the Probability of Bus Drivers Being At-Fault In Bus-Involved Accidents' ACCIDENT ANALYSIS AND PREVENTION Volume 66, May 2014, Pages 20-26

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 aimed to ‘predict’ bus accidents on 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

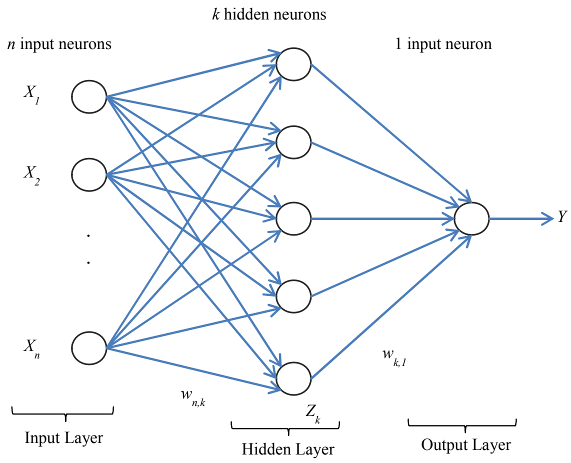
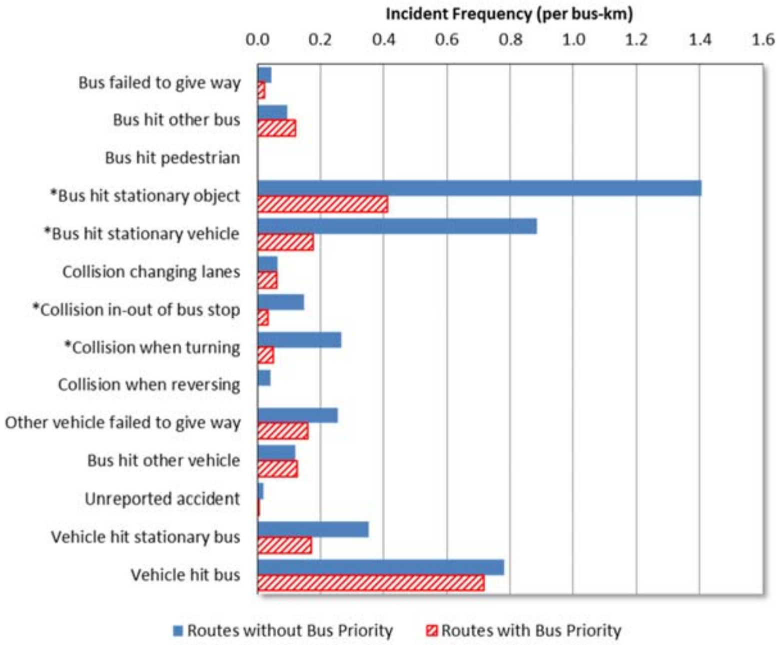


Figure 1: Topology of a Three-Layered Feed-Forward Neural Network

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).
- the presence of bus priority is associated with a 54% reduction in bus accident occurrence, 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

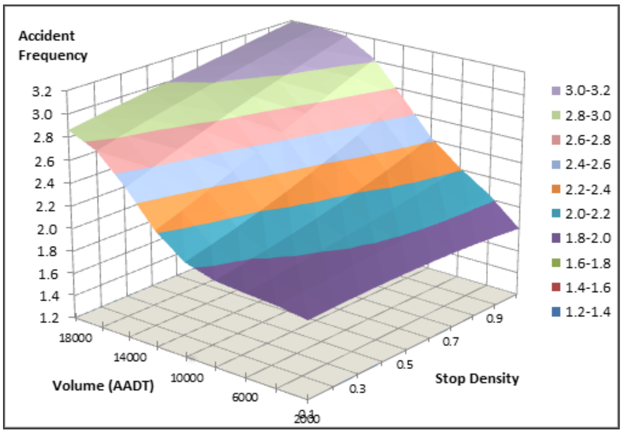


Figure 3: Effect of AADT and stop density on accident frequency (route-section 25)

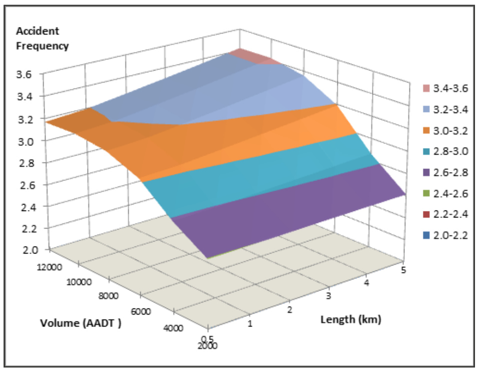


Figure 4: Effect of AADT and route length on accident frequency (route-section 25)

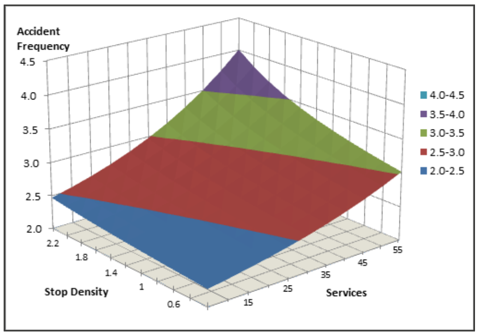


Figure 5: Effect of stop density and service frequency on accident frequency (route-section 25)

Both models show similar results; MENB had slightly lower error

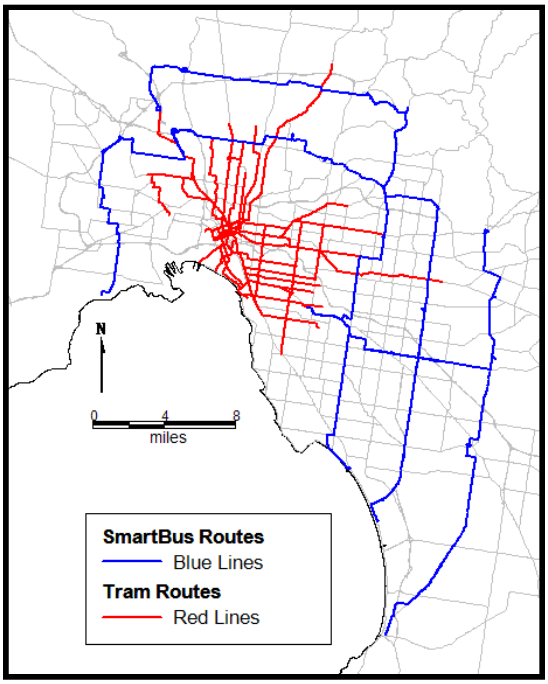
- Key Findings – Method
  - MENB model and BPNN model generally similar results
  - MENB model has lower error (RMSE=2.59 vs 2.75)
- Key Findings Bus Priority:
  - The safety effect of bus priority is apparent for all datasets. T-test results revealed that the safety effect of bus priority effect was 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)

Agenda

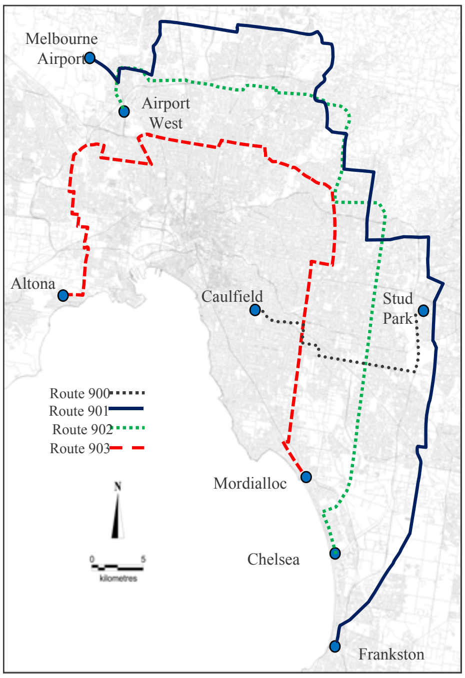
The focus of study is the new SmartBus network in Melbourne, Australia



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



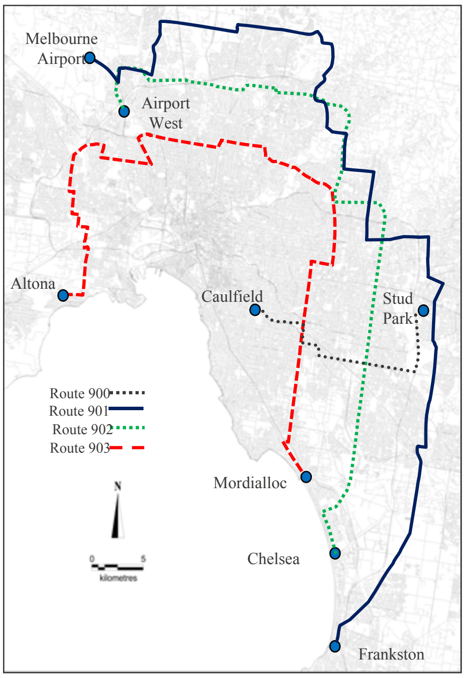
- Extensive implementation of priority measures on routes 900 to 903

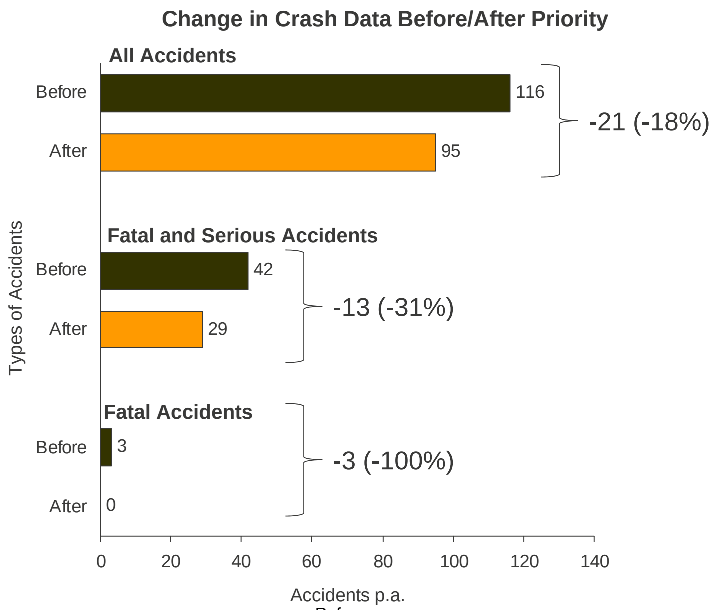
Treatment	Type of Measures	Description
Transit Signal Priority (TSP) – 31 locations	Actuated Transit Phase with or without Queue Jump Lane	"B" Signal activated when presence of bus is detected
	Phase Insertion / Deletion / Red Truncation / Green extension	Adjustment of cycle / phase timing when bus is 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 and Logan D (2013) 'Road Safety Benefits from Bus Priority? – An Empirical Study' TRANSPORTATION RESEARCH RECORD, No. 2352, Transportation Research Board of the National Academies, Washington,D.C., 2013, pp. 41–49

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





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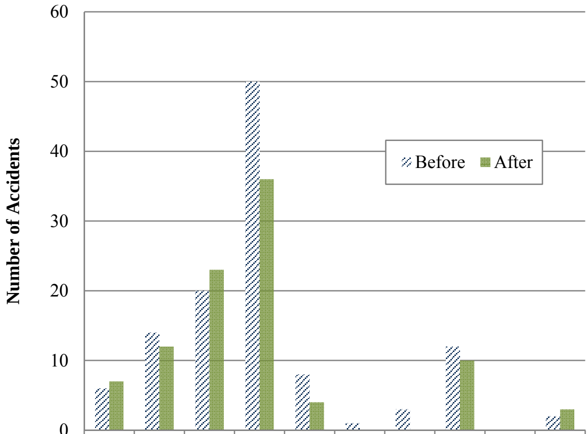
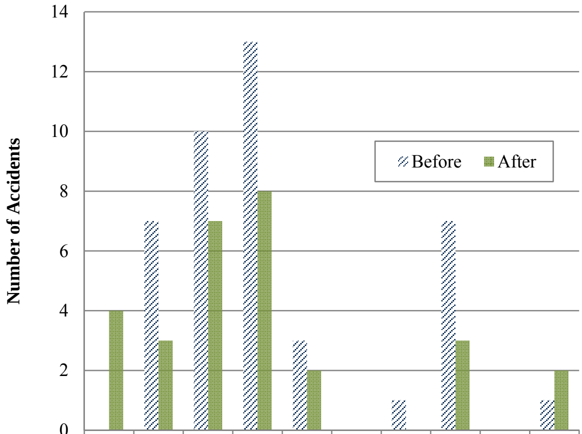
Accident Type analysis hints at likely bus priority effects

(A) All Accidents

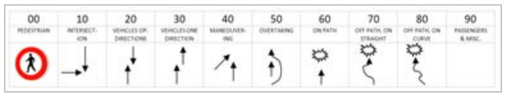


	10x	11x	12x	13x	14x	15x	16x	17x	18x	19x
Before	6	14	20	50	8	1	3	12	0	2
After	7	12	23	36	4	0	0	10	0	3

(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)

Reference

Goh K, Currie G, Sarvi M and Logan D (2013) 'Road Safety Benefits from Bus Priority? – An Empirical Study' TRANSPORTATION RESEARCH RECORD, No. 2352, Transportation Research Board of the National Academies, Washington,D.C., 2013, pp. 41–49

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

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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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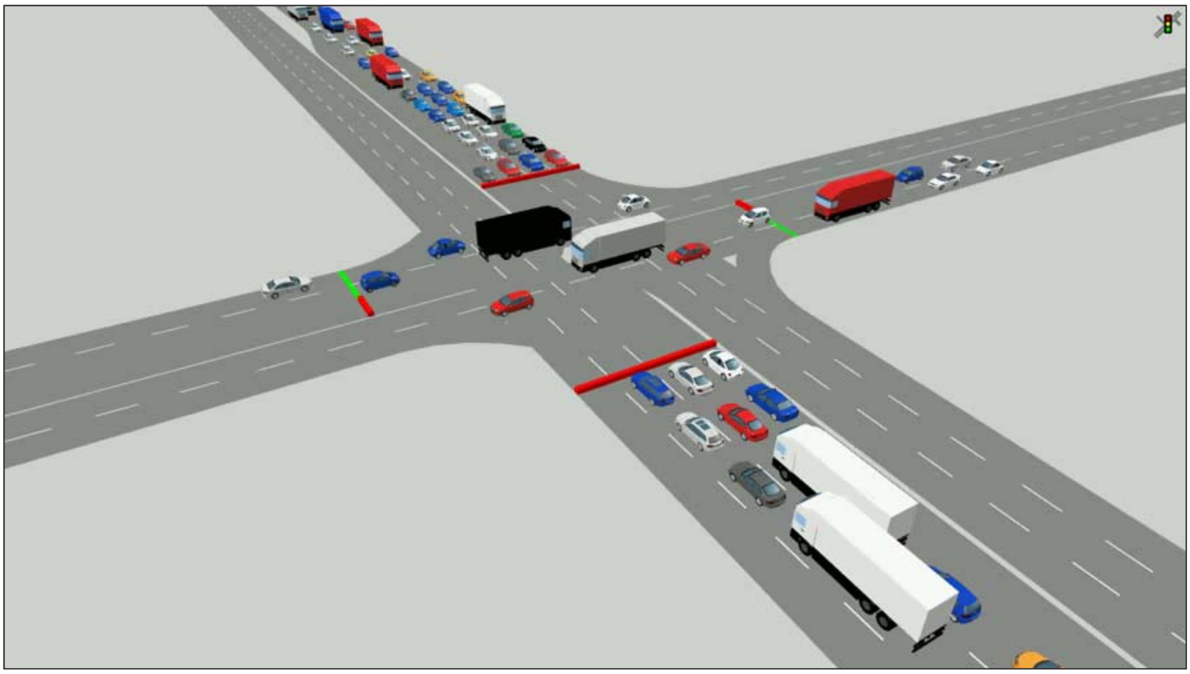
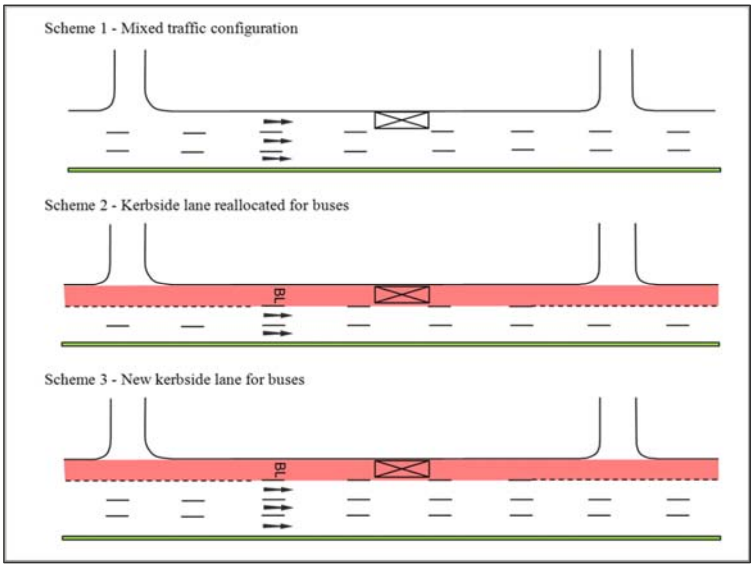
Traffic Micro Simulation (TMS) is now a common tool for road traffic engineering including bus (tram) priority



Monash has been developing 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
- AIMSUN model adopted to test following configurations >>>>>



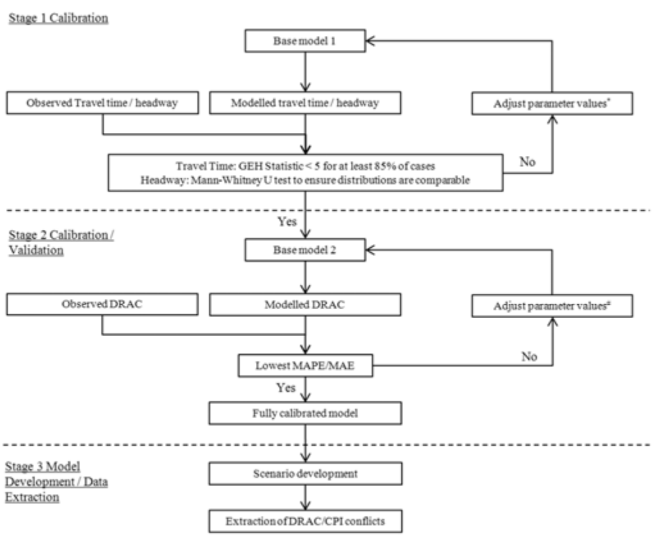
Not all risk behaviour is represented in TMS; hence only some safety effects can be tested

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

Bus Priority Scheme Effect - Methodology

- Two-stage modelling approach



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

Stage 1
Focused on modelling observed traffic and driving behaviour

Stage 2
Focused on replicating observed conflicts

Stage 3
SSAM software used to extract conflict information from vehicle trajectory files generated by AIMSUN

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

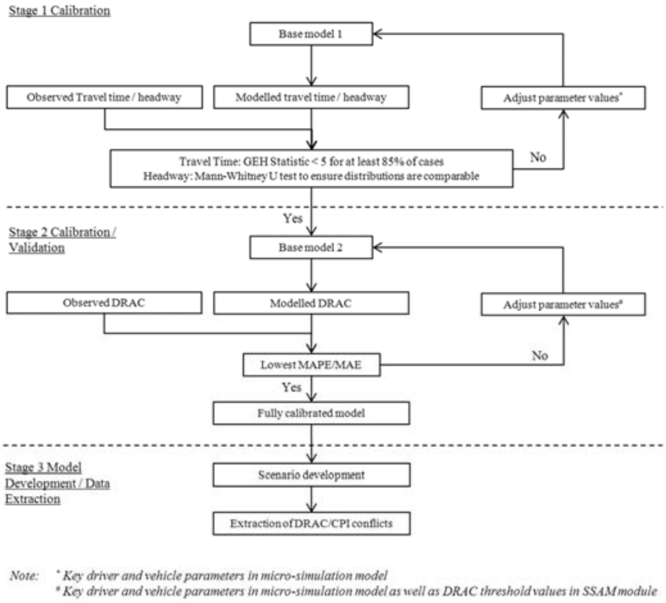
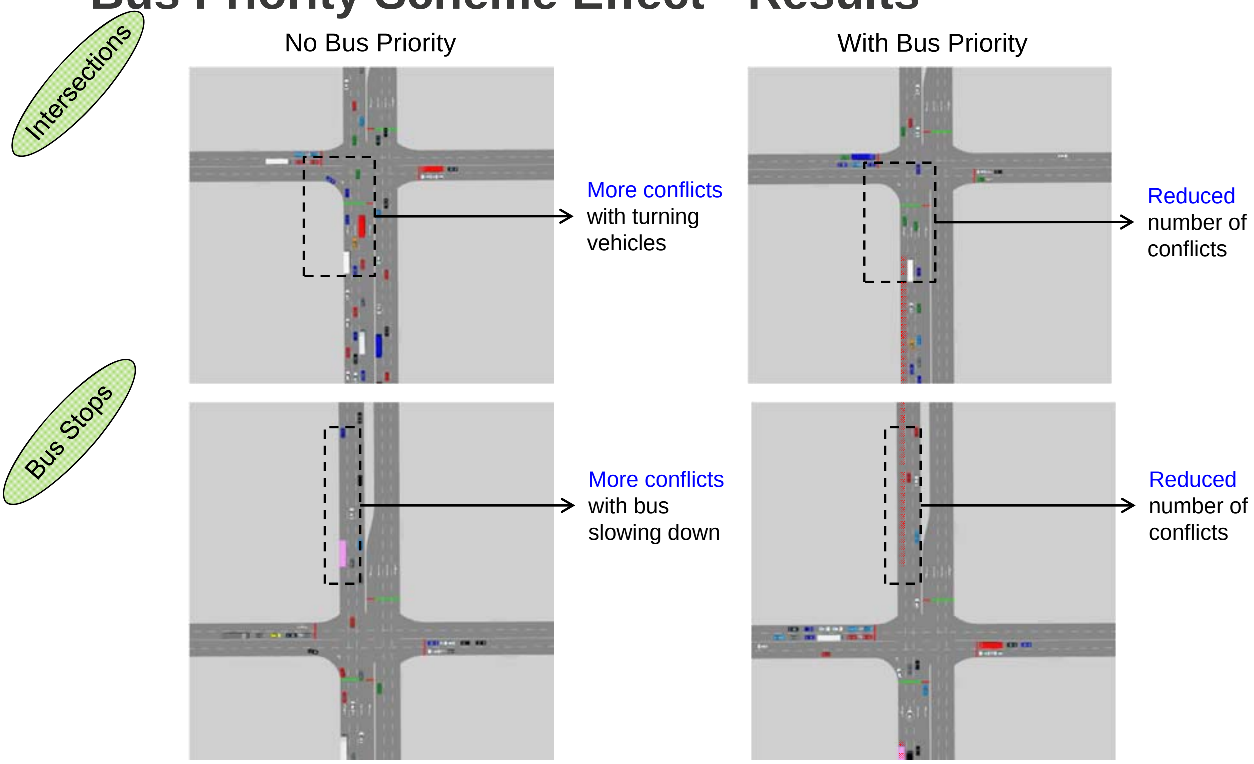


FIGURE 1 Staged approach to extraction of conflicts from micro-simulation models

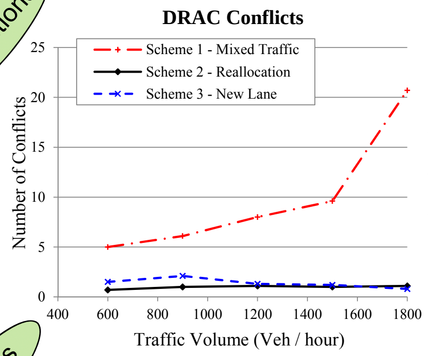
- Modelling Approach:
  - Modelled using AIMSUN TMS system
  - 3 lane road (70kph speed limit) and 3 bus routes modelled
  - Model conflict analysis at 3 locations:
    - Intersections
    - Bus Stops
    - Entire Corridor
  - 5 levels of traffic flow tested
  - Models run 10 times and average outcome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

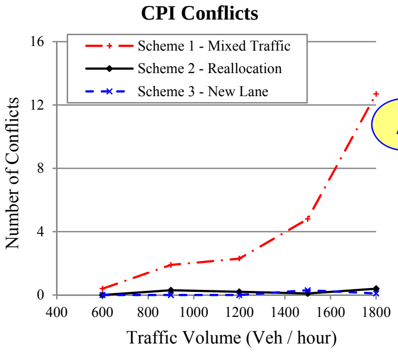
Bus Priority Scheme Effect - Results



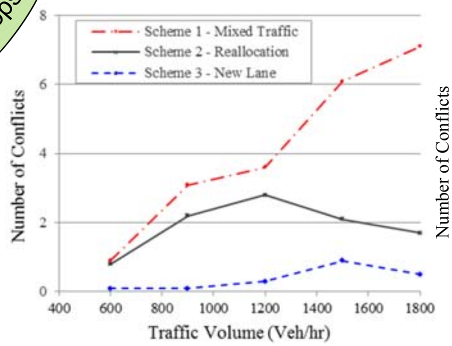
Bus Priority Scheme Effect - Results

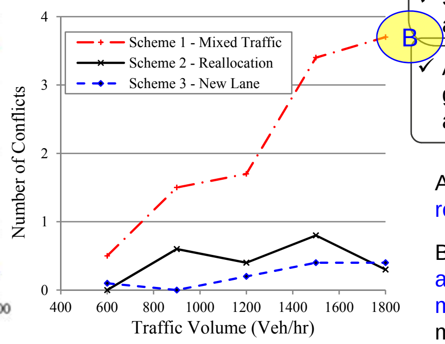
Intersections





Bus Stops





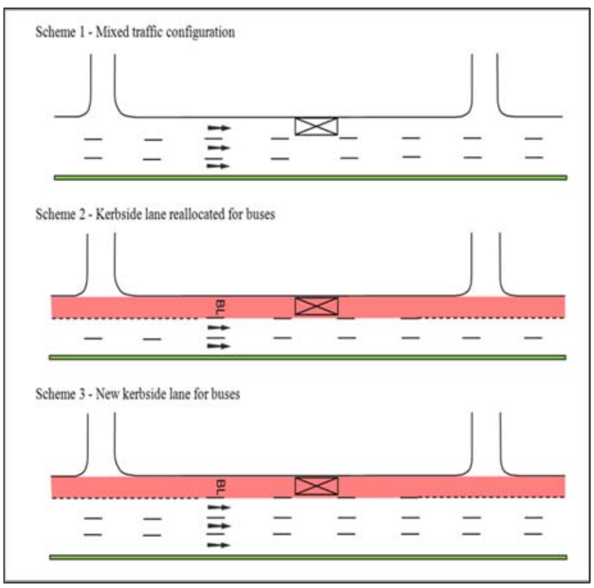
Key Findings

- ✓ Kruskal-Wallis H test showed traffic volume has effect on all schemes at corridor level
- ✓ However, volume effect not significant in schemes 2 and 3 at intersections and bus stops
- ✓ At intersections, conflicts found to be consistently lower in schemes 2 or 3 than scheme 1
- ✓ Similar observations recorded at bus stop locations
- ✓ At corridor level, conflicts were generally higher in scheme 2 and lower in 3 as compared to 1

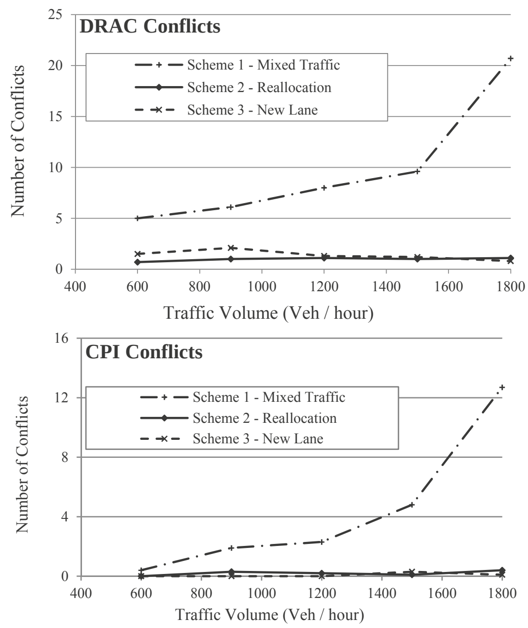
A - Bus priority schemes reduce rear-end / lane-change conflicts

B - Points to importance of additional capacity and implies mix of safety effects not being modelled

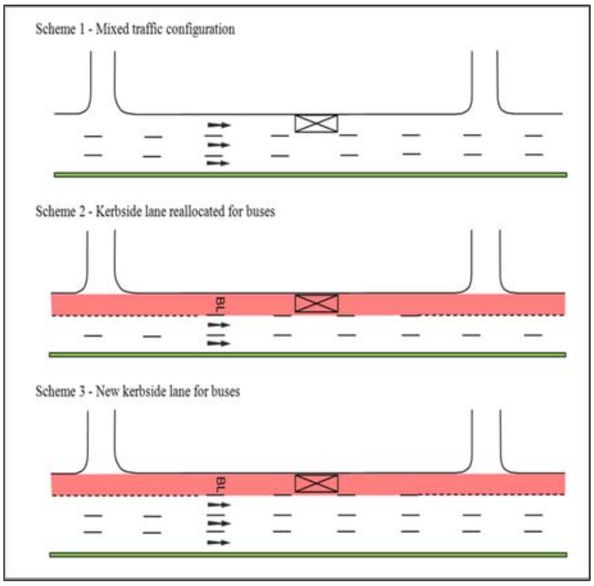
Bus priority schemes 2/3 have less conflicts at intersections…



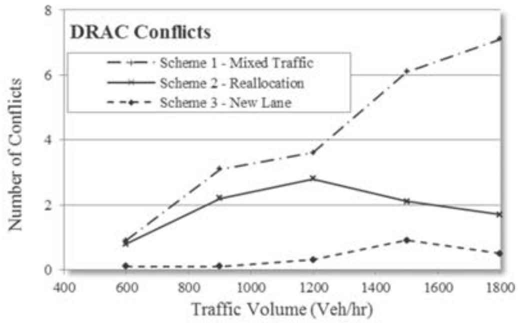
Conflicts at intersections

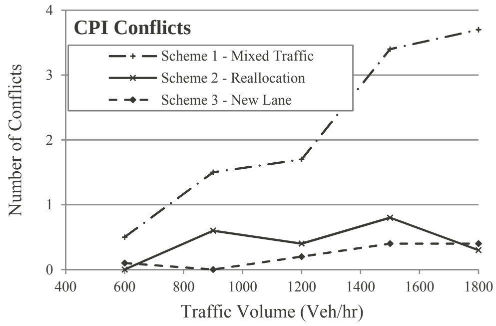


…and at bus stops; scheme 3 has less conflicts than 2



Conflicts at Bus Stops





Agenda

1 Introduction

2 ‘At Fault’ Bus Accident Risk

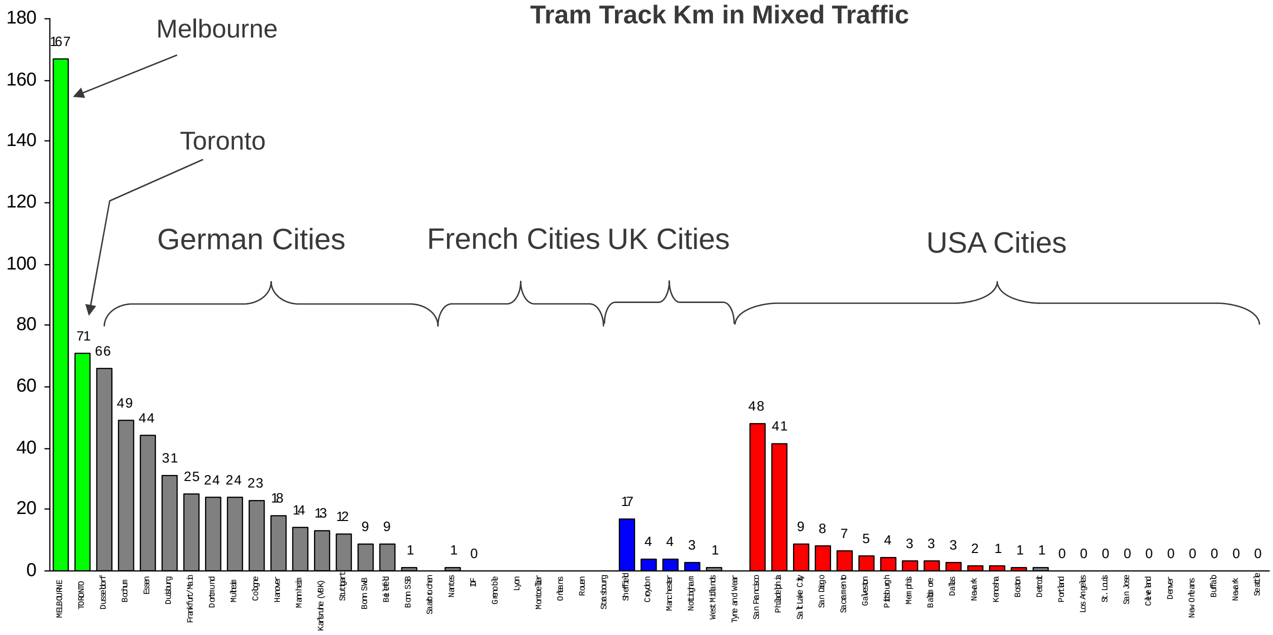
3 Bus Routes With/ Without Priority

4 Total Traffic Effects?

5 Traffic Micro Simulation

6 Trams?

Melbourne has the largest streetcar network in the world



Melbourne has the largest streetcar network in the world

Vital Statistics

- 250km of double track
  - 6 triple track sections increase capacity
- 28 Routes
  - Plus 9 other part-time routes
- 487 vehicles
- 23M in-service km p.a.
- 1785 Stops
- Serving 180M passengers p.a.

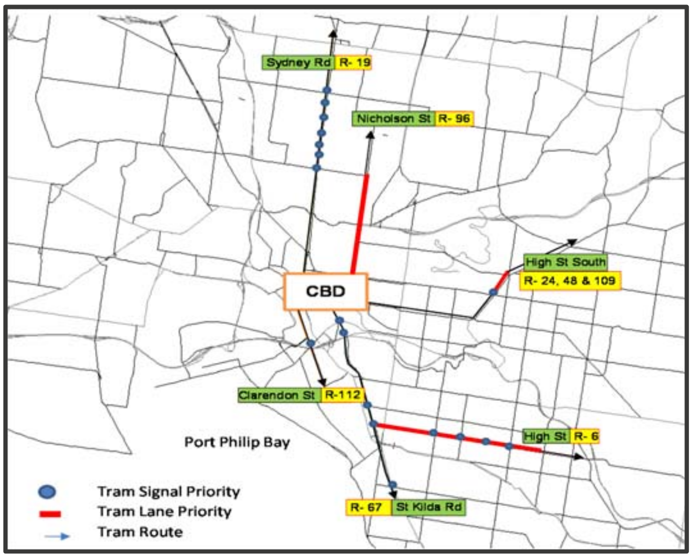

Le Pine


96 East Brunswick
5011


Malvern


72 University
3507
221
67

A recent project explored tram priority impacts on road safety



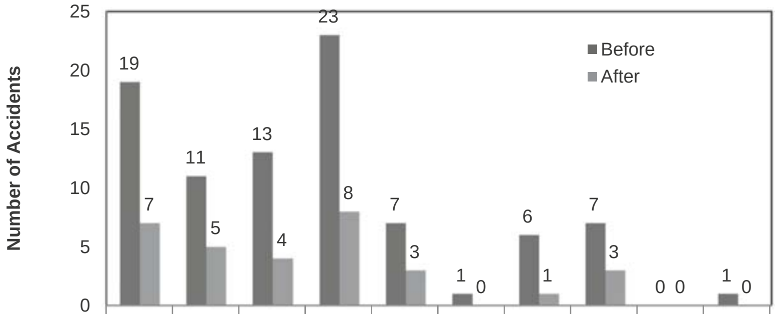
Simple Before/After results suggest a 16% decline in crashes; -30% in serious accidents

Table 1: Severity, Accident Type and Vehicle involved in accidents along Roadway Segment

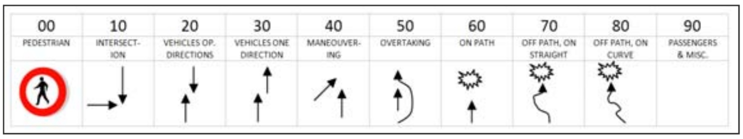
	Crash Severity				Accident type				Vehicle type			
Period	Fatal	Serious	Others *	Total	Vehicle	Pedestrian	Others**	Total	Cars	M/C***	HGV****	Total
Before	2	27	59	87	59	19	9	87	120	27	7 (3)	154
After	0	19	54	73	51	15	7	73	98	22	11 (6)	131
Change	-2	-8	-5	-14	-8	-4	-2	-14	-22	-5	4 (3)	-23
% Change	-200	-30	-8	-16	-14	-21	-22	-16	-18	-19	57 (100)	-15

*Others: Light or no injury
** Others: All Accidents including striking animal or objects
*** M/C: Motor Cycles including moped Vehicle and bicycle
****HGV: Heavy Goods Vehicle, including semi-trailers, trucks, (tram), buses and coaches

By accident type; pedestrian, same and opposing direction accidents have reduced most



	1	2	3	4	5	6	7	8	9	10
Before	19	11	13	23	7	1	6	7	0	1
After	7	5	4	8	3	0	1	3	0	0



Category:

1: Types 100 to 109- Pedestrian involved
2: Types 110 to 119- Vehicles from adjacent directions (Intersection only)
3: Types 120 to 129- Vehicle from opposing directions
4: Types 130 to 139- Vehicles from same directions
5: Types 140 to 149- Vehicle/s manoeuvring
6: Types 150 to 159- Vehicle/s overtaking
7: Types 160 to 169- On path
8: Types 170 to 179- Off path on straight
9: Types 180 to 189- Off path on curve
10: Types 190 to 199- Passenger and miscellaneous

Crash Type Changes

- Pedestrian involved accidents fell by 63% (from 19 to 7).
- Collision in same direction fell by 65% notably rear end and side swipe accidents
- Opposing direction accidents reduced by 69% (right/opposing turn removal)
- 55% decrease in crossing intersection accidents (hook turns and turn bans)
- 57% decline in U-turn and parking manoeuvring accidents (U-turn and parking removal)

Empirical Bayes method suggests a -9.2% crash reduction effect; 12.4% for tram lane treatments

Table 1: Results of Before-After analysis using the EB method

Parameters	Type of treatment		
	Signal Treatment	Lane Treatment	Overall
Number of locations	18	14	32
Total ***observed*** crash counts in the 'after' period	83	61	144
Total ***expected*** crash counts in the 'after' period	92	70	162
Adjusted Odd Ratio (OR)	0.930	0.876	0.908
Standard Error of OR	0.0907	0.102	0.07
Safety Effectiveness	**+7.0%**	**+12.4%**	**+9.2%**

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