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OPTIMISING THE DESIGN OF PUBLIC TRANSIT PRIORITY – RESEARCH PROGRESS

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ABSTRACT

This paper presents an overview of progress of a major international research program designed to optimise the design of public transport priority initiatives to improve the reliability and performance of on-road public transport including bus and tram. The program aims to monitor the performance of initiatives, develop new tools to plan for priority and to examine the performance of spot vs corridor and network wide initiatives and to examine planning approaches in general.

Preliminary findings show that published performance evidence uses limited method with highly variable outcomes. Reports tend to avoid reporting negative outcomes on transit although some negative effects are likely. Overall performance is generally positive with larger schemes having larger benefits. Dwell time studies demonstrate significant time/ reliability savings from new tram platform stops but these erode at high passenger volume. Research explores wider ridership growth, mode shift and resource savings resulting from priority schemes which are shown to be significant and increase as a function of travel time savings. Fleet (and crew) resource savings from priority are notably high; in one case a 30 second saving from priority saved 6 trams worth $Aust36M. An interesting finding when it is rare to find transit fleet resource impacts included in priority scheme appraisals/planning. Road safety effects are also rarely associated with priority yet a comprehensive analysis of bus priority established a 14% net reduction in crashes particularly serious and fatal injury accidents.

New diagnostic tools to plan priority schemes are presented including new analytical impact measures and innovative mapping and animation tools.

Research development tasks and futures of the research program are also discussed.

Keywords: Bus priority, Tram priority, Bus lane, Tram lane, Traffic signal priority, Roadspace management

INTRODUCTION

The provision of specific roadspace or intersection timing preferences to on-road public transport (ORPT, buses and trams) to provide priority access over private cars is growing internationally (Hounsell et al. 2008, Gardner et al. 2009). However there are significant challenges associated with the design and implementation of these schemes:

i. **Competing Uses** - In general priority measures involve trading off competing interests for the use of road space and time. Planners must make difficult and politically sensitive decisions about providing priority to one group of road users over others. There is little guidance and few tools to assist in making these difficult decisions (Currie et al. 2007).
ii. **Limited Strategic Methodologies** - Despite many decades of development of priority systems throughout the world, the rationales and methodologies applied have been remarkably simplistic. A review by the authors showed that most of the research literature in the field had based decisions on road space allocation on only limited criteria such as travel time impacts alone omitting the wider environmental, operational or infrastructure impacts (Currie et al. 2007).
iii. **Marginal Outcomes from a Strategic Perspective** – Although public transport priority has clear efficiency benefits, outcomes from priority schemes have tended to be small and marginal. This is because competing objectives and localised planning have obscured wider strategic outcomes. Research has shown methodologies to be limited with regards to mode shift, trip retiming and trip suppression (Waterson et al. 2003). There is a need to develop new methodologies which focus on strategic objectives such as maximising throughput of people. These approaches can act to support 'strong' bus priority measures rather than marginal changes to existing infrastructure (Waterson et al. 2003).
iv. **Overly Generic Design Guidance** – a number of guidelines are available to assist in developing priority systems both nationally (Austroads 2007) and locally (VicRoads 2003b, VicRoads 2003a). However these are usually generic in nature. They describe the types of treatment possible but don't show where they do and don't work and hence provide little practical assistance for implementing schemes in the field.
v. **Limited Diagnostic Tools** – designing priority schemes requires a multidisciplinary approach combining the skills of traffic engineering with the operational concerns of ORPT scheduling and management. Schemes have tended to be designed with a road planning bias with little consideration of operational, time or in particular ORPT resource and reliability impacts. There is a need to develop diagnostic tools which can more readily identify appropriate locations and types of measures.
vi. **Problem of 'Spot' vs 'Combination' Treatments** – Two main approaches have been used to develop priority treatments; 'spot' (localised single treatment) and 'combination' or corridor based approaches combining many measures in a package of treatments. While little is understood about the impacts of individual measures even less is understood about how measures in packages act to improve the operation of ORPT or affect the impacts these schemes have on other road users. For example increasing returns to scale might well be expected when treatments are combined.
vii. **Limited Understanding of New Technologies** – There is evidence that advances in implementing active traffic signal priority schemes is being constrained by limited

technical knowledge and understanding of how they can be implemented in the field (Currie 2006). There have been some good examples of innovation. For example the Dynamic Fairway and Intermittent Bus Lane project in Melbourne and Lisbon involve the use of dynamic signals to provide bus lane when only buses are present. While this was a world first development a review has shown their implementation was inappropriate to traffic conditions based on international evidence (Currie and Lai 2008).

viii. **Limited Performance Monitoring** – A common recommendation of guidelines for the introduction of priority schemes (e.g. (Department of Transport Local Government and Regions 1997, Smith et al. 2005)) is that post implementation monitoring programs should be undertaken to build an understanding of performance impacts. Unfortunately performance monitoring has been limited to date despite the large number of schemes implemented.

ix. **Local/Corridor not Network Focus** – Almost all research studies in this field have examined priority design in relation to a single road or road link. However the authors work has clarified that network based assessment is important when considering traffic diversion impacts which can be significant with priority projects(Mesbah et al. 2008).

This paper presents the first status report on an international research project[1] aimed at addressing the above issues by researching approaches to optimise the design of public transport priority schemes.

The paper starts with a review of the major objectives of the project. It then presents a summary of the preliminary findings of the research to date including results on the measurement of impacts, platform stop dwell time studies, the secondary benefits of priority schemes and road safety impacts. It then describes some of the new diagnostic tools developed as part of the project. Developing areas of the research program are then outlined. The paper concludes with a short summary of the research program outcomes and plans for the future of the research.

RESEARCH PROGRAM OBJECTIVES

The overall objective of the research program is to 'improve methodologies and guidance to enable the optimisation of design and implementation of public transport priority initiatives'. The project has the following research aims:

- Development of new objective oriented methodologies focussing on maximising throughput of people not vehicles within the context of the wider social, economic and environmental impacts of transport.

[1] *Australian Research Council Industry Linkage Program project LP100100159, 'Optimising the Design and Implementation of Public Transport Priority Initiatives' conducted by the Institute of Transport Studies, Monash University in association with the Transport Research Group, University of Southampton, UK. The Principal Chief Investigator is Professor Graham Currie, Dr Majid Sarvi is the Chief Investigator and Dr Nick Hounsell a Partner Investigator. Research Fellows on the project are Dr Mahmoud Mesbah and Ms Alexa Delbosc. Mr Kelvin Goh is one of three PhD students on the project. The Industry Sponsors include VicRoads and the Victorian Department of Transport.*

- Develop diagnostic tools to identify appropriate problems to be addressed by priority treatments on ORPT routes
- Evaluate the performance of priority treatments in a series of road configuration and traffic condition contexts
- Identify optimal conditions for the implementation of traffic priority treatments of different kinds
- Investigate the performance of priority treatment as single isolated or 'spot' treatments and the impact of combinations of treatments on performance in group or corridor treatment conditions
- Provision of practical guidelines for implementation of treatments based on the above objectives

The project focus is on the following priority treatments in relation to bus and tram (or streetcar) services:

- Road space reallocation measures (including new lanes, queue jump lanes, set back and mid-block designs, clearway and traffic turn ban concepts including full time, part time and the new dynamic lane concept)
- Traffic signal design measures (including passive and active signal design measures, B/T lights, clear phase combinations and conditional and un-conditional priority measures) ;and
- Road and traffic management measures (including bottleneck removal, stop removal and relocation and the removal of indented bus bays and new treatments such as platform stop design to address issues such as dwell time delays).

The major tools used in the program are literature, policy and practice review, primary research on performance monitoring of priority schemes and traffic micro-simulation experimental modelling to understand design impacts of priority in more depth. There are 5 task areas in the program including

A. Field Data Collation – including before/after monitoring of priority schemes,

B. Simulation Test Beds – where experiments on the performance of design features are undertaken using micro-simulation modelling.,

C. Planning Processes – where approaches to identifying and planning how to determine where and how much priority to provide are considered,

D. Network Priority – where new concepts in designing priority from a network wide, rather than a corridor only approach are developed, and

E. Strategic Priority Evaluation – where methods to evaluate and justify priority schemes are considered.

The project commenced in 2010 and is expected to run for broadly 5-6 years.

PRELIMINARY FINDINGS TO DATE

The major research findings to date have concerned impact measurement (Task Area A) and Strategic Priority Evaluation (Task Area E).

Measuring Priority Impacts

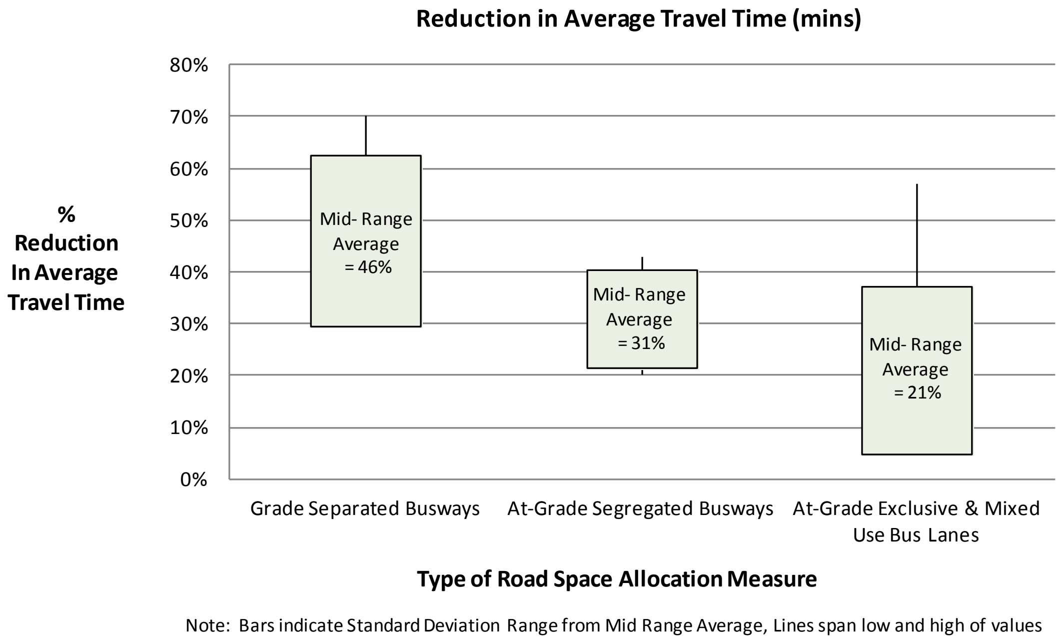
A review of published literature and an examination of before-after study evidence in Melbourne where the study team was based are included in this section. The latter included a review of local studies of before/after impacts and an analysis of automatic vehicle (AVM) monitoring data before/after tram priority schemes were introduced (and are reported in Goh and Currie 2012, Currie G et al. 2013b).

International published studies suggest priority has very positive outcomes but there is much variability in performance in the literature. This may be expected given the diverse geographical and contextual coverage of schemes. Figure 1 illustrates some of the results of this literature scan. On average the data suggests that:

- Road space allocation measures, notably those with busway type treatments achieve the highest benefits in terms of travel time (typically 30-50% reductions). At grade/mixed use transit lanes have savings around 20% in travel time.
- Transit signal priority (TSP) savings are noteworthy in reducing intersection delay with the data suggesting a broad average/mid range impact at around 16%
- Data on the impacts of road and traffic management measures is patchy and limited and is hence inconclusive.

Previous Melbourne based studies have tended to focus on tram (streetcars) with limited data on bus. All used simple before tram travel time measures compared to after travel time measures. Little focus on travel time variability impacts was apparent. Overall 75% of tram initiatives have reduced travel time however some evidence of increases were available in previous studies. On average tram schemes reduced travel time by 4.2% while 3 bus based schemes where data was available reduced travel time by 24% on the road sections measured. Previous studies of tram identified a general reduction in variability of travel time (average reduction was 13%) however some isolated examples of increases in variability were noted. It is apparent that the internationally published data shows consistent improvements in performance of ORPT resulting from priority but localised study data shows this is not always the case. It is thought that transit performance outcomes are not likely to always be positive and that only positive results are published in the literature perhaps overemphasising positive outcomes.

The AVM analysis explored over 11,000 travel time records for each section of tram trips for priority scheme projects including a full month of before and a month of after scheme implementation. The after month was the year after the scheme and was the same month as the before month to remove seasonality effects from the data. Out of the 18 route sections/time periods where priority impacts were measureable, 9 or 50% had reductions in both travel time and the travel time variability (coefficient of variation, CoV). A further 14 cases (78%) had at least some positive impacts on either travel time or variability. In 4 cases (22%) there were negative impacts on both travel time and variability, 3 (17%) had negative impacts on travel time but positive impacts on variability and 2 (11%) had positive impacts on travel time but negative impacts on variability.



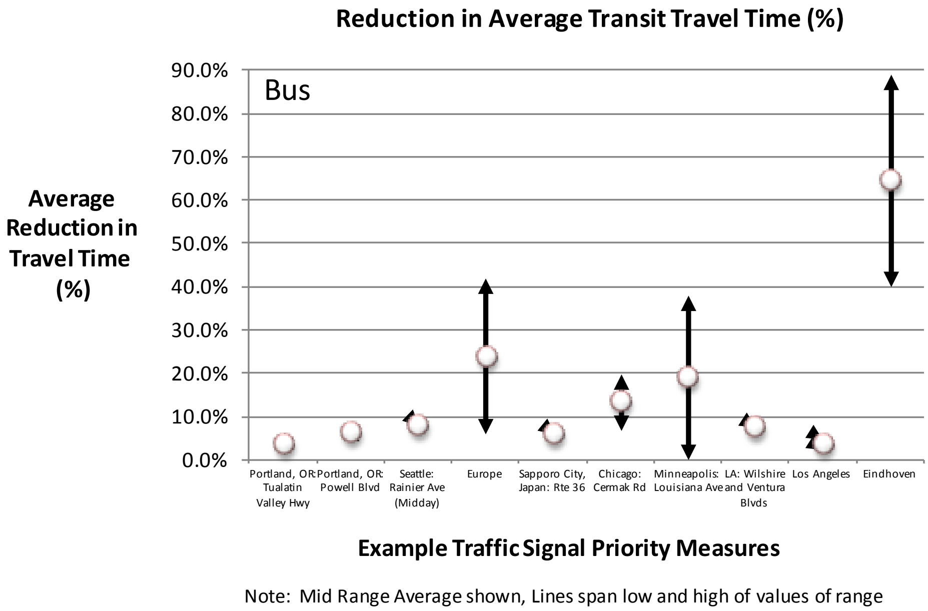


Figure 1: Range of Evidence from Published Literature – Roadspace and Traffic Signal Priority Measures

The analysis also explored performance by type of scheme however performance was so variable between scheme no consistent pattern was found.

A major outcome of this research was the finding that priority performance is generally positive but can have negative outcomes. Measurement approaches are weak and often use different measurement methods. A major limitation is organisational; road authorities (and their traffic consultants) typically undertake travel time based measurement but are not familiar with transit reliability measures (such as the coefficient of variation). They almost never consider impacts on transit fleet or ridership. Measures are also 'naive'; involving simple before after transit vehicle travel time comparisons. No consideration for traffic flow variation effects and often even seasonality is considered. No examples of 'control' monitoring was found i.e. using a control case without priority implemented to isolate wider network performance changes on schemes. This was therefore targeted as an area for improving 'diagnostic tools' (see later).

Platform Stop Dwell Time Studies

Bus and tram stops are not typically seen as part of transit priority however they represent infrastructure that can act to reduce travel (dwell) time which can also improve reliability performance. For trams (or streetcars) operating in the centre lanes of trafficked roads, curbside stops act to present major operational and reliability challenges because of the interaction of trams, passengers crossing traffic lanes to access trams in the centre of the road and traffic using the road. Replacing these stops with platform stops which remove traffic interaction is much akin to the concept of roadspace priority (bus or tram lanes) since traffic interactions are removed. Hence there are many similarities between stop design improvements and priority notably where platform type designs can act to improve operating performance. Melbourne trams represent the worlds largest streetcar network (Kittleson & Associates 2003) where trams operate in mixed traffic without much lane segregation. Melbourne has undergone one of the largest programs in the world to introduce platform stops (Currie and Cliche 2008) to reduce boarding in the centre of the road onto trams (from what are termed Curbside stops). Research therefore has focussed on measuring how platform stops have acted to improve transit operational performance.

The first Dwell Time study was an empirical comparative cross sectional study of dwell performance by tram stop type and also examined other factors affecting dwell time. Its focus was on average range passenger loadings rather than high loadings (the focus of the second study) The study included data collection in Toronto Canada as well as Melbourne to contrast performance of stop type (platform vs kerbside stops), fare system payment (pre-payment vs pay on entry), tram design (with/without steps), number of doors (2, 3 or 4) and volume of boarding/alighting passengers. Results are reported in (Currie et al. 2012)[2]. The methodology involved a series of dwell time surveys analysed using multiple regression modelling. Results are summarised in Table 1.

Results show payment of fares to drivers on entry (in Toronto) is the most significant factor influencing dwell time compared to pre-payment/on board validation in Melbourne (β =.27). For a typical 10 passengers boarding/5 alighting, the Melbourne approach saves 9 sec (48%) of dwell time compared to Toronto. Tram stop design, notably platform stops, was the next most significant factor affecting streetcar dwell time (β =-.16). For a typical 10 passenger boarding/5 alighting, platform stops reduce dwell time by 6.6 seconds or 34%. The results suggest that platform stops act to substantially reduce dwell times and have also been shown to reduce dwell time variability.

[2] Note this paper is winner of the William B Millar award for best paper in Public Transport at 2012 Annual Meeting of the Transportation Research Board in Washington DC

Table 1: Factors Affecting Tram Stop Dwell Time in Melbourne and Toronto

- Regression modelling results

With payment type variables			
R^2 (adjusted) = .81 $F(9, 232) = 112.9$, $p < .0001$			
Variable	B	SE B	Beta (β)
Constant	3.7	3.1	
Boardings	0.9	0.1	.61[a]
Alightings	0.7	0.1	.29[a]
3 doors	2.6	2.2	.06
4 doors	13.4	4.0	.12[a]
Presence of steps	3.4	2.2	.07
Platform stop	-6.0	1.6	-.16[a]
Safety zone	0.5	2.5	.01
Pay on Entry	9.8	1.7	.27[a]
Pre-payment	8.1	2.3	.12[a]

[a] *Variables significant to .01level*
Note Curbside stops are the reference case for these results.

The second, and most recent, dwell time study explored the performance of new stop designs under high passenger loading and crowding (reported in Currie G et al. 2013a) examining crowding both at stops and on vehicles. Results are reported in Table 2.

Table 2: Factors Affecting Tram Stop Dwell Time in Melbourne at High Passenger Loads
- Regression modeling

	Step one (no platform Crowding)				Step two (with platform Crowding)			
	Regression weight	Std. Error	Beta weight	t-value	Regression weight	Std. Error	Beta weight	t-value
Constant	**2.89**	0.54		**5.33**	**3.27**	0.53		**6.14**
Boardings	**0.70**	0.03	**.47**	**27.60**	**0.61**	0.03	**.41**	**22.14**
Alightings	**0.47**	0.02	**.50**	**27.78**	**0.50**	0.02	**.53**	**29.28**
curbside	ref.	ref.	ref.	ref.	ref.	ref.	ref.	ref.
Safety zone	**1.27**	0.35	**.08**	**3.59**	0.07	0.39	.00	0.17
Platform	0.20	0.37	.01	0.54	-0.14	0.37	-.01	-0.37
Steps on tram	**2.38**	0.30	**.13**	**7.96**	**2.23**	0.29	**.12**	**7.61**
Onboard crowding - light	ref.	ref.	ref.	ref.	ref.	ref.	ref.	ref.
- medium	0.07	0.39	.00	0.19	0.06	0.38	.00	0.17
- high	**0.96**	0.40	**.06**	**2.39**	**0.90**	0.39	**.06**	**2.32**
- crush	**4.58**	0.48	**.23**	**9.47**	**4.08**	0.48	**.20**	**8.55**
platform crowding	-	-	-	-	**3.73**	0.52	**.14**	**7.19**
R^2adjusted	.717				.729			
Change in R^2	-				.012			
F-test	364.2				343.9			

Note: Variables in bold significant to .05 level

The first step of the regression was statistically significant, $F(8, 1138) = 364.2$, $p < .001$, with a relatively high R^2 value of .717. In this step six variables were found to significantly increase dwell time (in order of size): alightings, boardings, crush-capacity onboard crowding, steps on the tram, safety zones (compared to curbside stops) and high onboard crowding. Interestingly platform stops and medium crowding had no significant effect on passenger flow time. This suggests that platform stop performance is no different to curbside stops when crowding is included in modelling. This finding contrasts strongly with the authors previous research (above) which showed significant dwell time benefits for platform stops at average (lower) passenger volumes. These benefits are clearly removed when crowding effects are considered. In the second step, platform crowding was added to the regression model. This resulted in an increase in R^2 value to .729. platform crowding was a significant predictor of dwell time and when it was added to the model, stop type of any design was no longer statistically significant. This suggests that it is not stop type per se that impacts dwell time but the amount of crowding at the stop.

Results demonstrate that crowding acts to significantly deteriorate the dwell time benefits which platform stops provide compared to curbside stops at lower passenger volumes. A critical threshold of 14 passenger movements (board+alight) was established, below which platform stop design was preferred and above which curbside stops had better performance. On-vehicle crowding in particular was found to be a significant variable affecting dwell times followed by stop crowding. Crowding effects act to dominate dwell time and are more important than the number of entrance steps in influencing dwell time.

Benchmarking the Secondary Benefits of Priority

A major focus of the Strategic Priority Evaluation (Task Area E) of the research was to better understand the wider impacts priority schemes could have on ridership growth and also on fleet resource savings. Evidence on ridership impacts was therefore collated and operations and fleet resource modelling was also undertaken to understand the secondary impacts of priority. Results were used to develop a new conceptual model of how priority schemes might act to improve performance (results are reported in Currie and Sarvi 2013).

Figure 2 illustrates some of the ridership/market impact results benchmarked from available impact data. Overall some positive statistically significant links between travel time savings resulting from priority schemes and both ridership growth and mode shift from auto to transit are evident. Ridership growth has a best fit curvo-linear link to travel time savings but mode shift is more linear in nature. The impact which priority can have on transit fleet resources were explored by developing a model which predicts the peak vehicle requirements of a transit service. This was applied to predict vehicle requirements for a selection of bus and tram routes in Melbourne, Australia. The model was validated by cross checking predictions with known resource deployments. The model was then used to predict vehicle requirements for a range of reductions in travel time on the routes modelled.

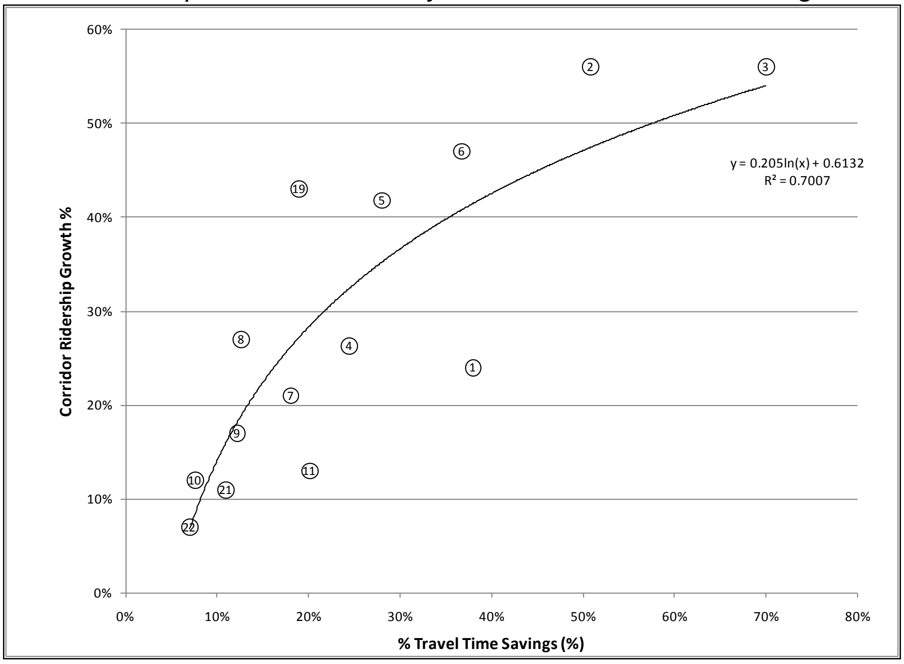
In predicting fleet resources the following formula was adopted:

$$Vcl = \left(\frac{(RTT + L) * (1 + DR)}{Hdwy} \right) \qquad \text{Formula 1}$$

Where:

Vcl =Peak Vehicle Requirement
RTT =Scheduled Peak Round Trip Time (mins)
L =Peak Layover (mins)
DR =Peak Dead Running (expressed as a % of peak time)
Hdwy =Headway

Ridership Growth vs Priority Induced Travel Time Savings



Transit Auto Mode Shift vs Priority Induced Travel Time Savings

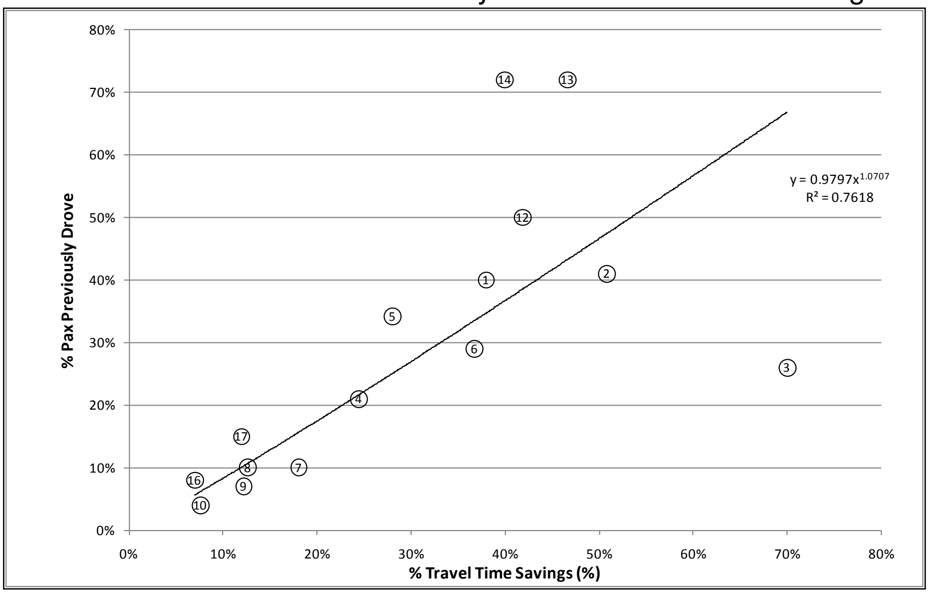


Figure 2: Transit Market Impacts if Priority Schemes relative to Resulting Travel Time Reductions

Results suggested that even a single minute of round trip travel time reduction (equivalent to a 30 second saving in any one direction) resulting from a priority scheme can act to save 6 trams from the fleet[3] while for the bus routes examined savings don't occur until 6 mins of travel time are saved. The differences are caused by relative route length, round trip travel time and frequency between tram and bus. Trams run shorter routes and have short base headways (7.5 min vs 15 mins) compared to bus. The bus routes examined include the

[3] There are 500 trams in the Melbourne fleet so this represents broadly a 1% reduction in fleet size. However the 30 second saving only applied in selected route sections which are particularly sensitive to travel time savings. In this case it occurs on 4 of the 30 or so tram routes in Melbourne.

Melbourne ‘orbital’ routes with round trip travel times of up to 8 hours. This makes it very difficult to save buses on some routes no matter how big travel time savings are.

A major implication of these observations is that in certain circumstances, priority can generate significant savings in fleet (and crew) resources. A single 30 second travel time saving in the Melbourne case can save 6 trams worth broadly $Aust 36M in saved capital funding. Operating costs savings would also be made and would apply on an annual basis. A critical point regarding these findings is that fleet resource savings (and ridership impacts) are rarely if ever considered in relation to priority scheme evaluation or design. Yet in the results examined, these benefits would act to substantially dominate the benefits of priority schemes, far outweighing any costs.

Priority and Road Safety Impacts

The road safety impacts of priority was another area explored in relation to the Strategic Assessment of priority schemes. This area of research was undertaken by Kelvin Goh, one of the PhD students on the research program with results widely reported including at this conference (Goh K et al. 2013b, Goh K et al. 2013a). A review of the research literature established that in general there is very little examination of the road safety impacts of public transport priority schemes. The little research that is available has mixed results; some with positive impacts and others with negative. No research was found explaining why positive or negative impacts occurred demonstrating that little assistance is available for planners in designing safer outcomes in priority schemes. An empirical analysis was therefore undertaken of accident records with bus priority schemes in Melbourne being the major focus for the research. A detailed analysis of crash records and also bus company incident data was completed. Crash monitoring analysis employed the sophisticated Empirical Bayes safety evaluation technique to ensure robust considerations of control/wider network impacts on road safety outcomes. Results demonstrate a net 14% reduction in road accidents (including general traffic as well as bus related accidents) as a result of the introduction of bus priority. Accident reductions were mainly in the fatal and serious injury accident group. This is a statistically robust outcome. An empirical analysis of the incident types revealed significant changes in the proportion of incidents involving buses hitting stationary objects and vehicles, which suggest the effect of bus priority addressing manoeuvrability issues for buses. A mixed-effects Negative Binomial regression modelling of bus incidents considering wider influences on incident rates at a route section level also showed significant safety benefits when bus priority is provided. Key hypothesis being explored to explain causes of accident reduction suggest bus lanes are acting as a roadside buffer reducing “run off” road accidents. Bus lanes also seem to enable better ‘lines of sight’ for traffic emerging from side roads. Again they act as a buffer for traffic making early movements emerging into traffic. Rear end accidents are also reduced suggesting removing bus movements within traffic is reducing traffic stopping manoeuvers. Other explanations being explored including the impact of slower traffic speeds (known to be safer) caused by squeezing traffic into less lanes.

A major implication of this research is that bus priority in this context acts to improve road safety and should be a major consideration for road management agencies when implementing bus priority and road schemes. This research area is continuing to explore the design features of priority which act to improve road safety.

NEW DIAGNOSTIC TOOLS

To date new diagnostic tools have been developed as part of the research program including improvement in measurement methods to understand the operational impacts of priority schemes and the use of innovative GIS and image animation methods for exploring the network/spatial performance of transit to assist targeting of priority to appropriate locations.

Improved Priority Impact Measurement

As noted earlier, prevailing approaches to measurement of the impacts of priority schemes have involved simple before/after measures of travel times and simple comparisons of these to estimate changes. These are generally 'naive' in nature because they don't account for other influential impacts.

An improved approach has therefore been developed (reported in Currie G et al. 2013b) where a more analytical approach is suggested. This involve use of a regression based analysis with the aim of establishing the relative effects of roadspace and time (signal) priority measures as well as other influences on operational performance. Two models were developed, one exploring the relative influences on run time and the other on run time variability. They were applied to tram projects in Melbourne. A major benefit of the approach was the way it could mine AVM records currently available on many transit systems worldwide; hence although more technically challenging than current simplistic/rule of thumb approaches the method could at least be reasonably easily applied using available (and emerging) data.

The results of the modelling are shown in Table 3. Results are presented for the base models, where all variables are included, and final models (1A/B and 2A/B) which only comprise variables that are found to be statistically significant. Results of the VIF values showed that the DIST (road section length) and JUNCTS (number of road junctions) variables were highly correlated. Hence, the latter was dropped in both the base and final models. In addition, the dependent variables RT and RTDev had to be log-transformed to ensure normality in the regression models. The best models 1A and 2A explained 83.5% of variability in the run time data and 51.8% of variability in the run time variability data respectively. In model 1A, the variables found to be the most influential on run time (in order of relative significance) were route length (β=0.59), scheduled run time (β=0.41), space priority (β=-0.16), weekday (β=0.09), direction of travel (β=0.07), and time priority (β=-0.03).

As for model 2A, the following variables were found to be most influential in run time variability (in order of relative significance) - route length (β=0.46), weekday (β=0.36), space priority (β=-0.28), scheduled run time (β=0.23), direction of travel (β=0.15), and time priority (β=-0.12).

Table 3: Regression Models – Factors Affecting Route Performance Including Space and Time Priority Measures

a. Results of Mean Run Time Model

Variables (X_i)	Model 1: ln(RT) = Constant + f(Xi)		
	Base	Model 1A	Model 1B
Constant	0.964	0.964	0.897
DIST	0.240	0.240(0.594)	0.387(0.956)
JUNCTS	#	#	#
SCH	0.041	0.041(0.406)	-
RAIN	^$4.8x10^{-5}$	-	-
INBOUND	0.097	0.097(0.073)	0.120(0.09)
WKDAY	0.146	0.146(0.085)	0.273(0.159)
SPACE	-0.074	-0.074(-0.162)	-0.064(-0.14)
TIME	-0.017	-0.017(-0.03)	-0.041(-0.07)
Goodness of Fit			
Adjusted R^2	0.835	0.835	0.813

Note: # - JUNCTS disregarded due to high correlation with DIST
Figures in parenthesis are standardized coefficient (β) values
Except for ^, all coefficient values presented above are significant at P<0.05

b. Results of Run Time Deviation Model

Variables (X_i)	Model 2: ln(RTDev) = Constant + f(Xi)		
	Base	Model 2A	Model 2B
Constant	-0.433	-0.436	-0.466
DIST	0.151	0.150(0.458)	0.217(0.661)
JUNCTS	#	#	#
SCH	0.019	0.019(0.228)	-
RAIN	-0.001^	-	-
INBOUND	0.162	0.162(0.151)	0.173(0.161)
WKDAY	0.506	0.506(0.363)	0.564(0.405)
SPACE	-0.105	-0.105(-0.283)	-0.100(-0.27)
TIME	-0.054	-0.055(-0.117)	-0.065(-0.14)
Goodness of Fit			
Adjusted R^2	0.518	0.518	0.511

Note: # - JUNCTS disregarded due to high correlation with DIST
Figures in parenthesis are standardized coefficient (β) values
Except for ^, all coefficient values presented above are significant at P<0.05

Explanatory variables are:

DIST	Section Length (km)
JUNCTS	Number of signalised junctions along section under study
SCH	Scheduled travel time along section based on timetable (min)
RAIN	Average rainfall amount per day (mm)
INBOUND	Direction of travel (1 if city-bound and 0 otherwise)
WKDAY	1 if weekday (Monday to Friday) and 0 otherwise
SPACE	Length of priority provided along corridor of tram's route (km)
TIME	Number of priority measures provided along tram's route

Previous research (Hofmann and O'Mahony 2005, Mazloumi E et al. 2010) suggests that more rainfall leads to longer run times and acts to lower run time variability. Findings in this analysis were generally consistent with these patterns. However, rainfall was found not to be a statistically significant and was omitted in the final output models.

It is possible to generalise the findings of the models to estimate overall effects of different types of priority initiative:

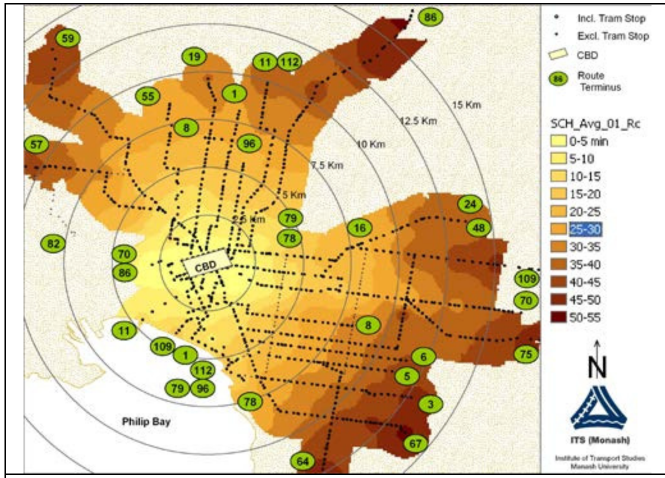
- Based on results from Model 1A, a kilometre of space allocation priority measure results in a change of exp(-0.074) or a 7.1% reduction in run time whereas a time related measure at one junction yields a change of exp(-0.017) or a 1.7% decrease in run time.
- Similar observations can be made in the model 2A, where the impact of providing a unit space allocation and time measure result in a 10.0% and 5.4% reduction in run time variability.
- Although units in km of bus lane or junction of signal priority are not necessarily comparable, the results suggest that the benefits of implementing space allocation outweigh that of time measures on a per unit basis. This might be expected given that the source data showed the extent of space priority measures implemented, as mentioned earlier, is larger than the time priority measures.
- Another noteworthy observation is that both sets of space and time priority measures produced a greater effect on run time variability than run time. This is an interesting observation because, as noted earlier, it is common to omit measurement of run time variability effects of priority schemes when it can be argued these are more influential to critical issues such as transit operational reliability.

Overall the analytical (regression) approach to exploring priority impacts provides a range of wider benefits to the simple before/after data comparison. The major benefit is that a wider number of contextual influential factors can be accounted for which also act to affect performance. In this case section length, number of intersections, weather effects and time and direction of travel were considered; all highly influential in affecting performance. Without consideration of these factors, simple before/after studies might be highly misleading.

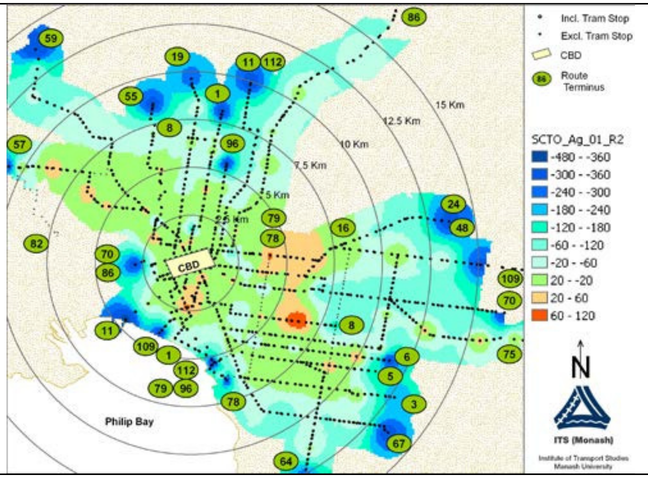
Spatial Diagnostics for Priority Performance

One of the areas for investigation targeted by the research program was the spatial or network wide patterns of transit operational performance and how this might act to inform planning for priority initiatives. A major drawback of existing methods of transit operational performance is that they are highly data intensive and hence not very appealing or easy to follow. Most analysis is numeric, involving lots of numbers and is also typically undertaken at a route level rather than with a network focus.

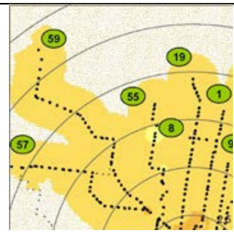
A new methodology to examine operational performance on a network basis was developed using Automatic Vehicle Location (AVL) data and advanced Geographical Information Systems (GIS) techniques. The latter included ‘Spatial Surface Interpretation’ and ‘Inverse Distance Weighting’ methodology to emphasise spatial patterns of variations in the data (Currie and Mesbah 2011, Mesbah et al. 2012).



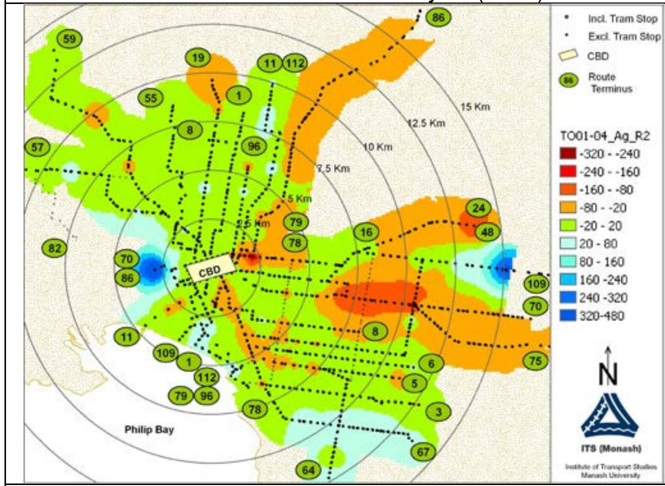
CBD Tram Travel Time Analysis (2001)



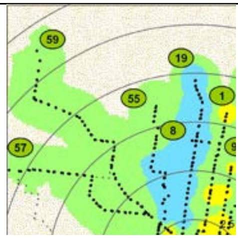
Actual Vs Scheduled Tram Travel Time (2001)



Coefficient of Variation of Tram Travel Time (2001)



Change in Average Tram Travel Time 2001-2004



Change in Tram Travel Time Reliability (Coefficient of Variation) Between 2001-2004

Figure 3: Example Diagnostic Operational Performance Maps – The Tram Network in Melbourne, Australia

A major rationale for the approach taken in these methods is to distil large sets of complex data on a spatial basis into a form which is easier for the planner to understand and communicate. This is primarily through use of visualisation using choropleth mapping. Figure 3 illustrates a range of the resulting graphics developed as part of the research. The results enable a focus on specific problem location on the network which are an identified issue within the context of performance of all services on the network. The travel time analysis (top left) illustrates increase travel time with distance but not consistently for all routes. The actual vs scheduled travel time analysis (top mid) highlights early running at route termini (blue) and late running on route 6 (shown in orange). The run time variability analysis (top right) shows problems for run time variability on CBD inner south routes whereas much of the rest of the network has reasonable run time variability. Each of these analysis has much potential to highlight issues where mitigation measures including transit priority might be targeted.

The change in time graphics (bottom left and centre) also illustrate the way this analysis can explore how trends in performance change over time. Changes in travel time (2001-2004, bottom left) illustrates problems east of the city (increased running times) and selected improvements (in blue), The change in tram travel time reliability (bottom middle) shows worsening reliability performance to the inner south of the city.

More recent innovations in the development of this technique have been exploring the use of digital image animation methods in the visualisation of changes in network performance over time. This involves the generation of moving images illustrating the changes in performance as a repeating movie (or transitioning 'morph') film which acts to highlight a much wider range of subtle changes in performance between years. These techniques have been reported separately (ESRI 2010) but as moving graphics they cannot be reported in a printed paper.

DEVELOPING RESEARCH

A number of research streams are under development and a little too early to report specific findings. However some of general initial thoughts in these areas can be related. The first concerns early simulation modelling and the other network wide modelling of priority optimisation.

Traffic Micro Simulation Modelling

Simulation modelling is major part of the research program however nothing has been published in the research to date. The major focus is experimentation of the impacts of priority initiatives as single or 'spot' initiatives vs implementation of groups of initiatives in series. Figure 4 shows an inital theoretical model developed from early simulation modelling results which theorises a new concept; the priority 'multiplier' effect.

This effect theorises that when a priority measure is implemented on more than road section (or intersection) a 'multiplier effect occurs which generates greater than average benefits. In figure 3 this is shown as the 'increasing' return to scale line. If each treatment generates an average benefit (x=y) then there is no multiplier effect. However if the first treatment generated the main benefit and others have less of an effect, this is a 'decreasing' return to scale.

Early modelling results have shown both 'increasing' and 'decreasing' returns to scale in differing circumstances and at this stage we are reluctant to report results until we better understand why.

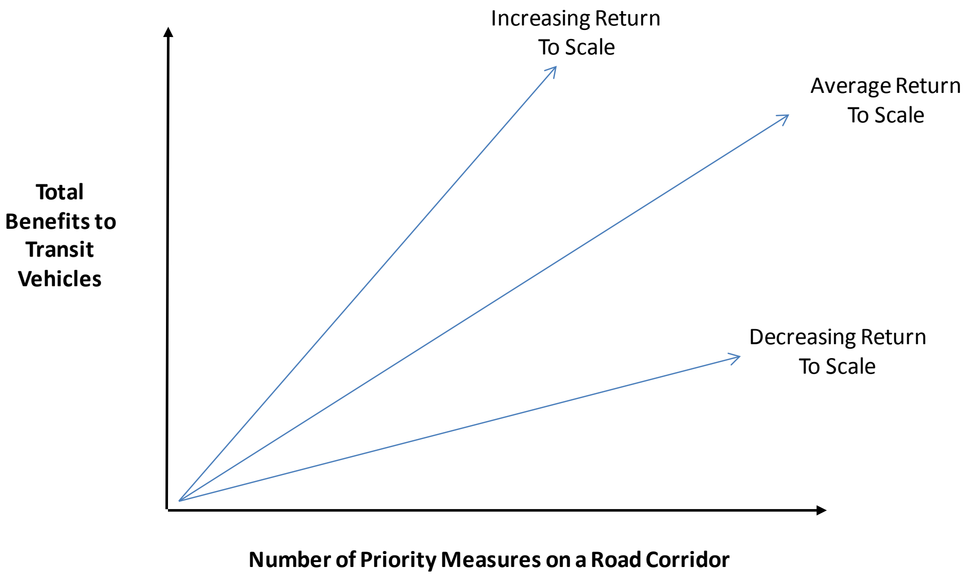


Figure 4: Theoretical Model of the Priority 'Multiplier' Effect

Network Optimisation

The research is also exploring approaches to optimise the allocation of roadspace and time to priority on a network basis rather than a route or corridor basis. Previous research has highlighted the failings of previous methodologies in the field in overly focussing on road and link based assessment (Mesbah et al. 2008). In practice, notably in congested inner city networks, changes in performance of one road link results in traffic diversion and secondary effects on other parts of the network. Hence priority, like any other aspect of road network management, has network wide impacts and requires a network wide perspective to identify optimal solutions. The authors have developed a range of previous tools to explore how analysing alternative priority network combinations might be evaluated and optimised using genetic algorithms and other analytical methods (Mesbah et al. 2008, Mesbah et al. 2010, Mesbah et al. 2011). It is proposed to test these methodologies at a practical level using an optimisation approach as part of the research.

DISCUSSION AND CONCLUSIONS

This paper presents an overview of progress of a major international research program designed to optimise the design of public transport priority initiatives to improve the reliability and performance of on-road public transport including bus and tram. The program aims to monitor the performance of initiatives, develop new tools to plan for priority and to examine the performance of spot vs corridor and network wide initiatives and to examine planning approaches.

Preliminary findings show that published evidence on performance is limited in the range of methods used and shows highly variable outcomes. There is a tendency to avoid reporting negative outcomes in published data although some negative effects are likely. Overall however performance is generally positive with larger schemes having larger benefits. Dwell time studies have demonstrated significant dwell time and reliability savings as a result of the introduction of platform stops for trams however when services are crowded (above 14 passenger movements per dwell), platform designs have no net benefit. Research has explored the wider ridership growth, mode shift and resource savings resulting from priority schemes. Significant ridership and mode shift effects to transit have been demonstrated and increase as a function of the scale of travel time savings associated with priority. Fleet (and crew) resource savings from priority initiatives were found to be significant in certain circumstances. In Melbourne, a 30 second saving from priority on selected routes would save 6 trams worth $Aust 36M, providing a significant net cost saving for relatively minor cost investment to provide priority. An interesting finding when it is rare to find transit fleet resource impacts included in the assessment of priority scheme appraisals and planning. Road safety effects are also rarely associated with priority schemes. However a comprehensive analysis of bus priority in Melbourne established a 14% net reduction in crashes particularly serious and fatal injury accidents.

New diagnostic tools to plan priority schemes are presented including an new analytical approach to measuring the impacts of priority and innovative mapping tools to better understand (and communicate) where priority schemes should be targeted.

The research development tasks are continuing in the field of micro-simulation modelling and network priority optimisation. A theoretical model for a priority 'multiplier effect' is proposed from the initial micro-simulation modelling which suggests there may be returns to scale when multiple schemes are implemented as a package on a corridor.

Although many research findings have been established from the research program in many ways the project has not fully commenced. The program is about half way progressed and two of the three project PhD students have yet to start work.

Most of the forthcoming research will focus on micro-simulation and experimental modelling of alternative designs of priority including 'spot' and 'group' treatments within and in combinations of treatment types. New operational impact measurement approaches are also being developed and network priority optimisation is yet to commence. Research on planning approaches to determine the location and scale of priority measures is also being undertaken. To date a synthesis of published approaches has been undertaken but a survey of international practices is being considered.

Overall the research program has presented a range of new perspectives on approaches to optimising the design and planning of priority however the field presents plenty of challenges and opportunities for further research.

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