

## Title Page

# Safety at Kerbside Tram Stops – Accident Analysis and Mitigation

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## POST REVIEW SUBMISSION

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**Abstract**

This research examines safety issues at kerbside tram stops (KTS) in Melbourne, Australia. KTS passengers wait on the kerb and access trams arriving in the middle of the road by walking across unprotected traffic lanes. Auto traffic rules say stop when trams do but are the only protections for passengers crossing at KTS. There are 1,785 KTS (61% of all stops) including local, arterial, interchange and terminus stops with varying risk exposure. Previous research identifies KTS as being more dangerous than other stop designs.

Accident data shows that 1999-2009 between 38-53 accidents occur p.a. (no trend). Ridership growth means accident rates/rider have fallen 50% in 10 years. Most accidents aren't serious however one fatality occurs triennially (all involve aged 55+). A high share of accidents involve children/ teenagers, 65% occur at KTS with most occurring at terminus and transfer KTS.

Mitigation measures are developed and evaluated. Overall investment in platform stops, greater separation of passengers at stops and the use of formal pedestrian crossings is recommended. Barriers and increasing the width of safety zones is recommended as is narrowing roads to reduce driver speeds including general traffic restriction measures and the use of warning signs on trams. Closing KTS is also highlighted as a useful measure on all criteria.

Overall research demonstrates that KTS have inherent safety concerns but that mitigation measures are available at various cost and effectiveness. More research is needed about stop safety in streetcar contexts and areas for this are suggested.

Abstract = 245 words (limit = 250 words)

## INTRODUCTION

Safety is a major concern for all transit agencies including those involved in light rail transit [1-3]. Recent research has identified particular safety concerns with light in mixed traffic or streetcar conditions but there is surprisingly little research investigating the causes of higher accident rates or studies aiming to find solutions to mitigate these problems [4]. Melbourne, Australia has one of the worlds largest light rail systems which is also the largest mixed traffic or streetcar system [5]. Studies of the Melbourne streetcar system have shown that most tram stops in the network are of kerbside design [6]. These have limited infrastructure and usually involve a sign on a streetside pole where passengers wait and access trams arriving in the middle of the road by walking across unprotected traffic lanes i.e. with no traffic signals or pedestrian crossing protection. Kerbside stops have been identified as the single biggest safety concern for streetcar operations in a number of studies [4, 7-9]. However no consolidated research has been undertaken to understand the scale of the issue, to assess factors influencing safety performance or to identifying measures to mitigate safety problems.

This paper presents a summary of a research project undertaken to identify a strategy to address safety issues at kerbside tram stops in Melbourne, Australia. The project was undertaken by consultants Booz & Co in association with the Monash University Accident Research Centre for the Victorian Department of Transport.

This paper is structured as follows. First a short summary of kerbside stops and their features is presented. Then a review of the relevant research literature is presented including a summary assessment of studies in Melbourne examining safety issues at kerbside stops. An analysis of safety records associated tram usage is then presented to provide a more recent overview of factors driving safety concerns. The paper then presents a discussion and assessment of potential safety mitigation measures. An analysis evaluating these is then presented including prioritisation of those most likely to be effective. The paper closes with a review and discussion of the research findings and also suggestions for future research in the field.

## KERBSIDE STOPS

Kerbside stops are tram stops where “passengers wait at the curb and cross traffic lanes without signal protection for access to and from light rail vehicles running on tracks in the centre lanes of mostly two-by-two-lane undivided roads” [7, p 39] . Passengers only protection from on-coming traffic are road rules which require traffic to stop when trams are approaching and slowing at tram stops. Figure 1 presents a summary of kerbside tram stops in Melbourne including a set of summary photographs of typical designs in each of four typologies of stops. Table 1 presents a typology of the 4 designs including details of typical traffic environment and road conditions, features of tram operations, car and passenger viewpoints of each stop type. There are current 1,785 kerbside tram stops in Melbourne mostly located in CBD fringe and suburban tram route sections.

**TABLE 1 : Key Features of Typical Kerbside Tram Stop Types**

<b>Features</b>	<b>Local</b> E.g. Melville Rd	<b>Arterial</b> E.g. Raleigh Rd	<b>Terminal</b> E.g. Gilbert Rd	<b>Interchange</b> E.g. Cotham/Burke Rd
<b>Traffic environment</b>	<ul style="list-style-type: none"> <li>Local Roads</li> <li>Minimal thru traffic</li> </ul>	<ul style="list-style-type: none"> <li>Main Roads</li> <li>Through traffic dominates</li> </ul>	<ul style="list-style-type: none"> <li>Confusing for car drivers</li> </ul>	<ul style="list-style-type: none"> <li>Intersection</li> <li>Through traffic and turning movements</li> </ul>
<b>Road conditions</b>	<ul style="list-style-type: none"> <li>1 left lane</li> <li>No clearways</li> </ul>	<ul style="list-style-type: none"> <li>1-2 left lanes</li> <li>Clearway at peak times</li> </ul>	<ul style="list-style-type: none"> <li>1-2 left lanes</li> <li>Clearway at all times</li> </ul>	<ul style="list-style-type: none"> <li>1-2 left lanes</li> <li>Clearway at all times</li> </ul>
<b>Tram Operation Characteristics</b>	<ul style="list-style-type: none"> <li>Rarely stops</li> <li>Drivers known to let cars past before stop</li> </ul>	<ul style="list-style-type: none"> <li>Tram often stops</li> <li>Many other distractions</li> </ul>	<ul style="list-style-type: none"> <li>Trams lay over in termini</li> <li>Increased exposure time</li> <li>Confusion for drivers regarding road rules</li> <li>May stop on both sides of street</li> </ul>	<ul style="list-style-type: none"> <li>Tram often stops</li> <li>Mainly arrival side of intersection</li> <li>Many distractions</li> </ul>
<b>Car Driver 'View'</b>	<ul style="list-style-type: none"> <li>Local streets</li> <li>Looking out for own family &amp; friends</li> </ul>	<ul style="list-style-type: none"> <li>Rushing to pass tram</li> <li>Takes greater risk</li> </ul>	<ul style="list-style-type: none"> <li>Confusion regarding road rules</li> <li>Tram is stopped can I go?</li> </ul>	<ul style="list-style-type: none"> <li>Need to get through intersection</li> </ul>
<b>Passenger 'View'</b>	<ul style="list-style-type: none"> <li>Local streets with many breaks in traffic</li> <li>Single vehicles stand out</li> </ul>	<ul style="list-style-type: none"> <li>Many cars, more likely to take care</li> <li>Show the car who is boss</li> </ul>	<ul style="list-style-type: none"> <li>Get on the tram ASAP</li> <li>Run along road, increased risk taking</li> </ul>	<ul style="list-style-type: none"> <li>Rushing to connect with other service</li> <li>Takes greater risk</li> </ul>

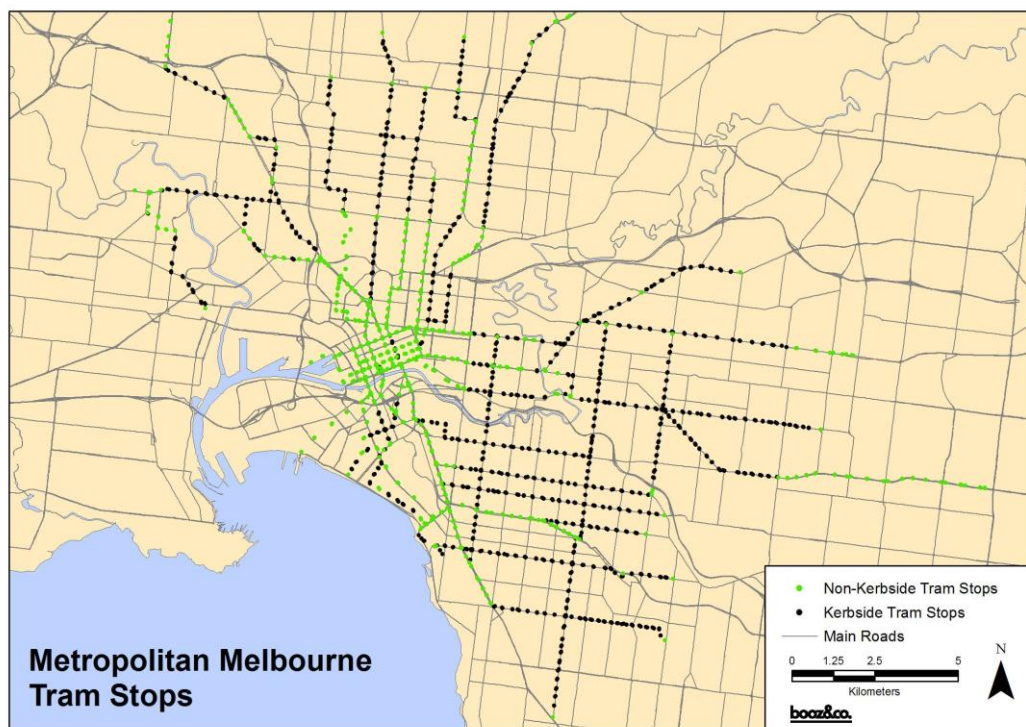


FIGURE 1 : Location of Features of Typical Kerbside Tram Stop Types

Kerbside stops of this design occur in the US but are not common. One reason for their abundance in Melbourne is their historical background. Many were developed before the private car became popular hence safety issues in the design of the stop were not important at this time.

Most kerbside stops are 'local' stops on lower order roads. Trams don't always stop at these locations since stopping is on demand. Tram drivers tend to let cars behind the tram get past the tram before stopping since traffic volumes are not high. Since streets only have local traffic auto drivers have some likely familiarity with passengers and can be very concerned to stop (these is little thru or non-local traffic). From a passenger viewpoint cars in the vicinity of local stops is not common and there are many expected breaks in traffic when getting to/from trams.

Arterial stops are much busier and congested with much through (non-local) traffic. There can often be more than one traffic lane between the kerb and the tram and tram stopping is much more frequent. Auto drivers are often keen to avoid delays when passengers access the road lanes so often rush past trams as they are slowing. Conversely passengers are aware of busier locations and may take greater care. Terminus tram stops are confusing for auto drivers since trams often wait for return trips in these stops so drivers are unclear if this is a tram with departing passengers or its empty. Road rules are unclear in these conditions. Passengers however are often keen to get to/from the tram before it leaves making for a dangerous mix of passenger and auto driver behaviour. Intersection stops are where passenger transfer between lines occur. Here road conditions are often ambiguous since two sets of trams are present at an intersection with turning traffic. Passengers rushing to make connections can add to safety concerns.

## RESEARCH CONTEXT

Kerbside tram stops by definition only occur in tram systems operating on roads. These are termed streetcars in North America [10]. Most research on safety in light rail [e.g. 1] focuses on design issues for segregated right of way systems since this is the most common design of light rail system worldwide [4]. For example German guides to design in light rail notes that for tram stops at ground level:

“building platforms ensures that passengers are not in any danger” and that “experience has shown that passengers who cross roads at or near a stop are exposed to a considerable degree of risk....For this reason safe level crossings, and, more rarely, bridges and underpasses are built for passengers crossing roads and/or rail tracks”.

[11, p135]

Table 2 presents a synthesis of evidence concerning accidents related to kerbside tram stops including an assessment of the relative annual rates of incidents inferred from the various available sources.

**TABLE 2 – Kerbside Tram Stop – Published Accident Rate History**

Source	Data	Implied Rate of Kerbside Tram Stop Accidents p.a.
[9]	<ul style="list-style-type: none"> <li>• 103 pedestrian-road vehicle accidents 1992-1997 whilst walking to/from trams (with pedestrian being struck)</li> <li>• It is not clear if these are all at kerbside stops</li> </ul>	17.2
[12]	<ul style="list-style-type: none"> <li>• 151 records of pedestrians being struck while walking to and from or boarding or alighting a tram between 1997 and 2002</li> <li>• This equates to an average of 23 kerbside stop and 7 safety zone recorded accidents per year.</li> </ul>	23.0
[7]	<ul style="list-style-type: none"> <li>• 25 p.a. identified</li> </ul>	25.0
[13]	<ul style="list-style-type: none"> <li>• 58 injuries in 2004-2008</li> <li>• 2001 9 serious injuries</li> <li>• Near misses of 16 / month reported</li> </ul>	14.5
[14]	<ul style="list-style-type: none"> <li>• July 2003-June 2008 Emergency Department Presentations related to injury on public transport = 1,758 cases (352 p.a.)</li> <li>• 31% were tram related whilst 1% were identified as tram stop related. Suggests 3.52 p.a.</li> </ul>	3.52



Accident rates vary by source and range between 14-25 incidents. Interestingly medical emergency department records suggest tram stops are the location for some 3.5 cases p.a. This may represent an occurrence rate for the more serious accidents however this is unclear since there are many concerns in defining locations of accidents in records. Emergency department records identified some 540 tram accident related admission cases between 2003 and 2008 suggesting a rate of 100p.a. but it is not clear where these incidents occurred.

There is very little published information available on the severity of incidents related to accidents at kerbside stops. It is also difficult to isolate tram related incidents and how they specifically relate to kerbside stops. The following quote suggests that many incidents may involve fatalities: “According to the pedestrian Safety Action Plan produced by the City of Melbourne, trams were involved in 8 of the 23 pedestrian fatalities (35 percent), twenty percent of all fatal and serious injury crashes and eighteen percent of all pedestrian casualty crashes in the City of Melbourne between 1983 and 1992.” [9p 12]. The research distinguished between incidents that occur:

- a. As pedestrian board/alight trams and are struck by road traffic
- b. As pedestrians walk to/from tram stops across roads and are struck by road traffic
- c. As pedestrians are struck by trams at tram stops.

Unfortunately it is not always easy to identify which of the above occur at kerbside stops. In addition case a. and b. overlap when kerbside stops are being considered though this issue is not addressed in the published literature. However special attention is given in the literature to case c. in relation to safety zones since the confined nature of these locations is thought to be a major factor in accidents of this type at these locations. What is clear is that tram-pedestrian collisions involve greater fatalities; one fatal and 15 serious injuries p.a.

Some 84% of pedestrian-traffic incidents recorded between 1992-1997 while passengers access/egress trams involve alighting from the tram [8]. Table 3.3 shows the nature of accidents when tram related pedestrians cross roads.

**TABLE 3 – Incidents Types When Tram Related Pedestrians Cross Roads**

Incident Type	Share (%)
Pedestrian hit by vehicles from the right	35
Pedestrian hit from the left	19
Pedestrian playing, lying, working, standing on carriageway	10
Pedestrian struck walking to/from or boarding/alighting vehicle	10
Pedestrian walking with traffic	9
Pedestrian emerges from in front of parked/stationary vehicle	6
Pedestrian walking against traffic	1
Other	10

Source: [9]

Overall pedestrians being struck from the right is the single most common type of incident. Previous analysis of pedestrians crash statistics where they were struck while walking to and from or boarding or alighting a vehicle between 1997 and 2002 [12] identified that:

- Most of accidents occur in dry conditions (87%)
- Most of accidents occur at localities with no traffic control (74%)
- Most of accidents occur in mid block sections (56%)
- One quarter of accidents occur at dawn, dusk and night.
- Most of the accidents identified above were related to kerbside stops [12].

No specific data on who is involved in accidents at kerbside stops is available. However the vulnerability of older people to accidents involving trams has been highlighted; 73% of pedestrians who were killed by a tram were 60 years old or above [9]. However this data does not necessarily relate to kerbside stops.

A review of accident risks associated with elderly pedestrians identified a range of measures to address safety issues. Amongst these were recommendations that education needs to be improved of elderly

pedestrians about the care needed when crossing to/from a tram, that speed enforcement of drivers near tram stops was required and that speed warning signs be provided in the vicinity of tram stops.

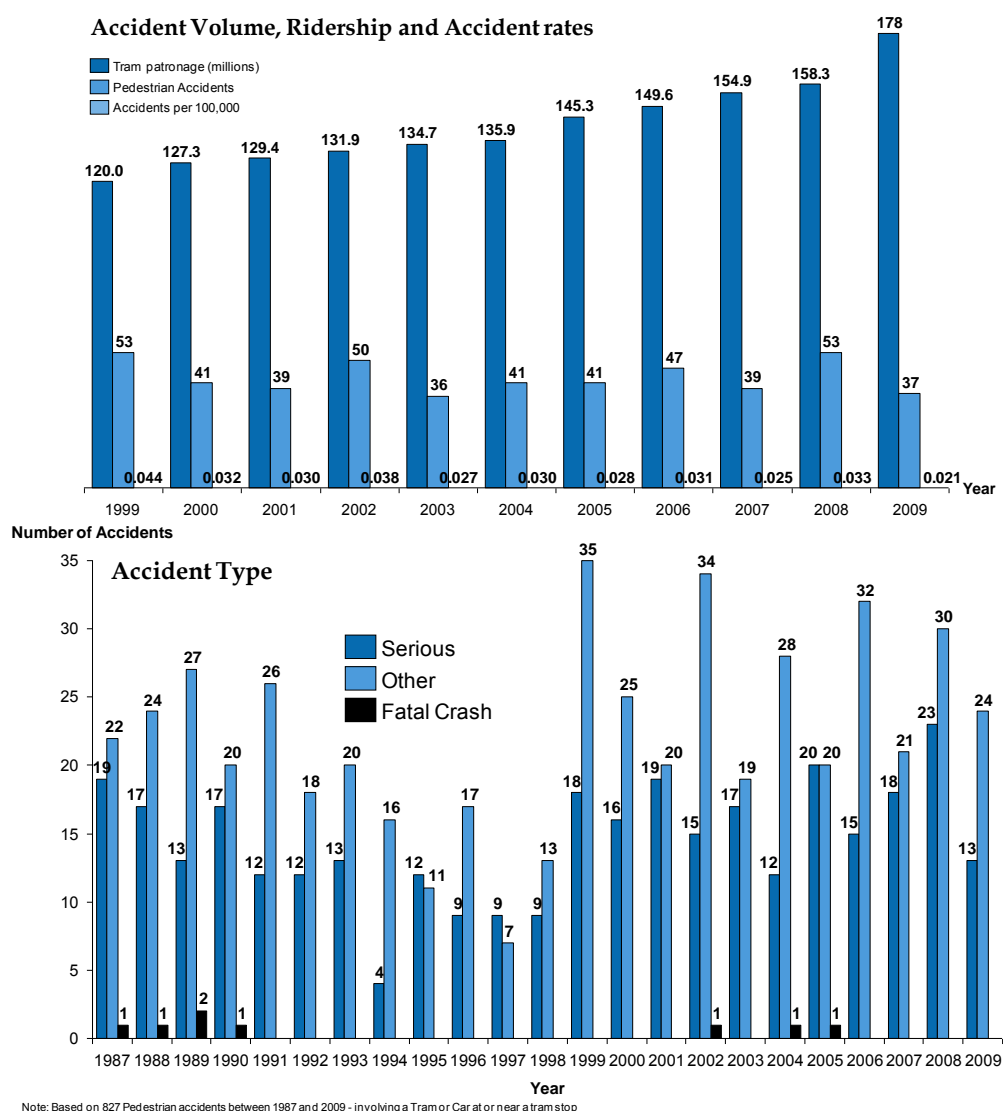
A recent study undertook a road safety risk assessment analysis of tram stop designs including kerbside stops [4]. The findings suggest that kerbside stops have the highest rate of risks and hence were the most unsafe. There were four 'Intolerable' safety risks for kerbside stops including:

- i. Reliance on drivers obeying law (frequency; probable, severity; serious)
- ii. Passengers step onto road on tram arrival (frequency; probable, severity; serious)
- iii. Alighting passengers cross to opposite kerb (frequency; probable, severity; serious)
- iv. No protection for passengers at stop (frequency; occasional, severity; catastrophic).

The same analysis established that platform stops, where platforms are next to tram arrival and departure doors were the most safe of the stop options available [4]. This has in part been recognized by the development of a program of works to convert stops to platform design. In 2008 a program for conversion was underway and at that time 187 stops had been converted to platform stops with an additional 73 stops in the last 8 months [6]. This still leave a high majority of stops with kerbside design and there is clearly room for understanding and addressing safety risks with kerbside stops.

## SAFETY ANALYSIS

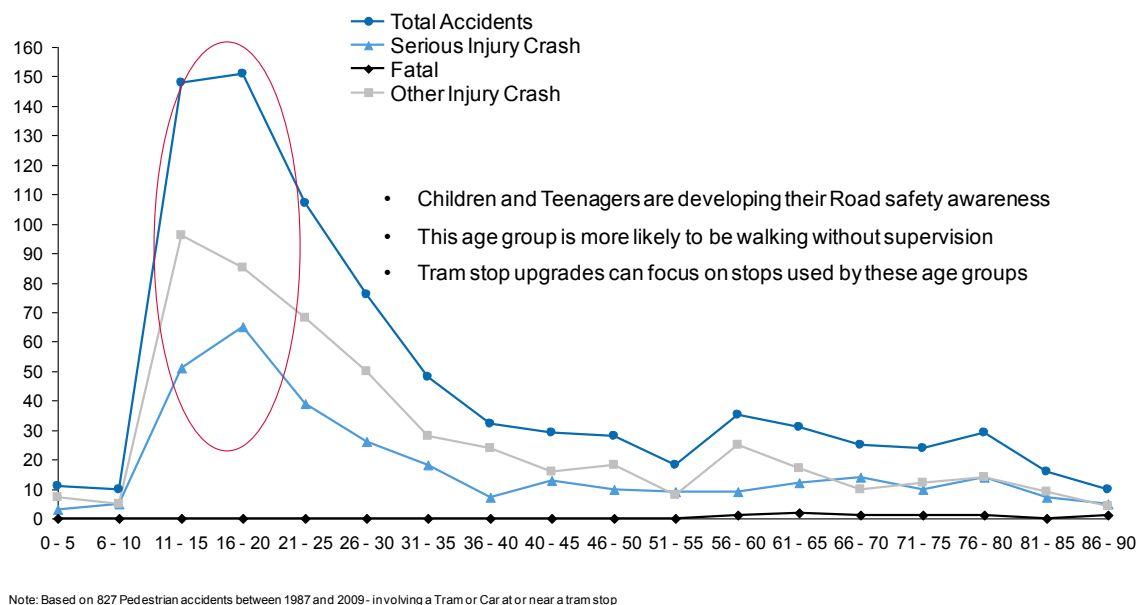
An in-depth analysis of the VicRoads Crashstats database [15] was undertaken for the period between 1987 and 2009 where all incidents involving a Tram or Car at or near a tram stop were included. Figure 2 shows an analysis of historical accident volume, how this compares to ridership and the resulting accident rates.



**FIGURE 2 : Historical Trends – Accident Rates by Type**

Accident volumes between 1999-2009 have occurred at between 38 and 53 p.a. with no particular trend. However ridership has grown considerably so accident rates per rider have fallen. Rates per 100,000 riders have fallen by over half from 0.044 in 1999 to 0.021 in 2009. There are no clear patterns in type of accident however fatalities are rare (one every 3 years on average) however interestingly all accidents during this period involved people aged over 55. 'Other' accidents tend to be the most common type. No trends in type of accident are apparent.

Analysis was undertaken on the nature of the accidents recorded. Some 65% occurred at intersections. Of accidents between 2007 and 2009, 70 % of accidents relate to alighting and boarding with 40% alighting. Figure 3 shows the incidents of accident rates by type by age group.



**FIGURE 3 : Tram Accident Types by Age Group**

Children over the age of Ten and Teenagers are at greatest risk. Issues associated with this group are road safety awareness, lack of supervision and groups of boisterous unruly school children carrying school bags without a high degree of concern for road safety.

An analysis of accident rates by time of day showed higher rates during the school peak times. However there was also a smaller peak in evening accident rates which might be associated with alcohol related activities.

Figure 4 shows the results a plot of accident volume by stop for all kerbside and other stop types. It is clear from this that kerbside stops are the most concerning from a design viewpoint. Indeed the analysis established that 65% of all accidents occurred at Kerbside stops while they actually represent only 61% of stops. By volume of passengers however this ratio is far more alarming. CBD stops, which are now mainly of platform design, are much busier but have very low accident rates.

Figure 4 also demonstrates some very important findings about the uneven spatial distribution of accidents within the system. Terminus kerbside stops (at the end of lines) have an abnormally high representation in the data as do interchange kerbside stops located where two sets of lines intersect. There is also a very concerning 'hot spot' of kerbside accidents to the West of the network on services operating on route 82 in Footscray. Some localised accident rates are very high. It is estimated that commuters consistently using selected tram stops each weekday will have a 10% change of an incident within a 20 year period.

All of this analysis presents excellent opportunities to target high rate stop locations with a targeted site specific (or 'blackspot') program. However there is also a need to address general design concerns in the development of mitigation strategies for all kerbside stops.





FIGURE 4 : Tram Accident Volume by Stop – Kerbside and Other Stops

## SAFETY MITIGATION MEASURES

Table 4 presents a framework developed as part of the project to better understand safety measures which might address different aspects of the risks identified (this was informed by earlier work at MUARC on this subject [9]).

**TABLE 4 – Framework for Kerbside Tram Safety Mitigation Measures**

	Road Environment	Vehicle	Road User (Pedestrian or Motorist)
<b>Exposure</b>	Traffic restrictions Separation		Information Enforcement
<b>Crash Risk</b>	Speeds Road Markings Position of Tram Stops Barriers Platforms Safety Zone width Pedestrian crossings Surfaces Road Narrowing Visibility Warning signals Street parking regulation	Tram brakes Tram brake lights Tram appearance Fibre-optic board on trams Warning signals on Trams ITS	Information Enforcement
<b>Injury Risk</b>	Speeds Barriers	Tram front design Tram Brakes	Information Enforcement

Measures are categorised in relation to the road environment, vehicles and road user (pedestrian or motorists). For each, approaches to address exposure, crash risk or injury risk are itemised.

**Road Environment Measures** - These involve restricting traffic and lowering traffic speeds around trams and are proposed to reduce exposure of pedestrians to accidents which might be applicable to kerbside stops. Use of speed bumps (or traffic cushions) and raised pedestrian crossings at tram stops has been suggested in relation to this [9]. A strong relationship between speed of traffic movement and death risk from pedestrian collisions has been identified by previous research (see [9] page 20). The rationale for speed restriction is to reduce exposure of this kind. Easy Access Stops are a new type of tram stop designed with safety exposure reduction in mind (see [7]). They involve providing a speed cushion which acts as a platform between the kerb and the tram. The tram right of way is not raised and traffic is banned from using the tram right of way. In general these stops are converted from kerbside designs for safety reasons. An assessment of the relative performance of kerbside stops compared to easy access stops was undertaken using road safety risk assessment methodology [4]. This shows that the easy Access Stop as well as Platform stops have much lower 'high risk' safety attributes

While most easy access stops have been implemented by replacing kerbside stops it is unlikely they will be widely implemented across the network because of their impact on traffic speed and road capacity [4]. There are concerns about the potential for cars to fall over the lip of the easy access right of way onto the tram right of way. In addition pedestrian falls could occur when crossing roads due to the step between the tram right of way and the platform. However no evidence of accidents of this type have been identified despite at least 5 years of experience in operation of this design of stop.

Provision of platform stops have also been seen to have safety advantages [4]. However in most cases platform stops have replaced safety zones rather than kerbside stops.

Separation of road users in terms of horizontal (lanes and footpaths) vertical (overpasses/tunnels) and time (traffic signals) has also been suggested as a countermeasure to incidents at kerbside stops [9]. Most of these have cost implication which would become problematic given the large number of stops involved. Nevertheless they remain viable though expensive options for priority and high volume locations with high safety risks.

Making pedestrian access paths on the road at kerbside stops clearer or more conspicuous has been suggested as a means of reducing exposure risks. Suggestions have included: a. Using coloured pavement b. Increasing no parking length at stops c. Improving lighting at tram stops (particularly when there are passengers waiting) d. Developing lighting standards for stops. [16] A trial of providing red paving on tram access sections of roads at kerbside stops was undertaken on Sydney Road Brunswick in 2006 [17]. The study found that the red paving did not reduce the potential conflict between vehicles and

passengers. There were however some positives about the trial. Drivers who stopped and proceeded to pass the tram drove more slowly.

A related road measure aimed at making kerbside stops more conspicuous which would also concern speed limitation would be the provision flashing signs signifying speed reduction limits at platform stops. No specific research has examined this issue related to tram stops however a program of 'strip shopping centre' safety measures involving variable message signs and reduced speed limits to 40 kph has been trialled at 18 shopping centres in Melbourne. A review of the program showed that casualty accidents reduced by 8.1% after the signs were introduced. Reductions in casualty accidents involving a pedestrian reduced by 16.9% (however this was not statistically significant due to data volume issues [18]). A benefit cost ratio for the program of 7.4 was suggested by the review.

These findings suggest that general pedestrian road safety measures at shopping centres including those associated with intersections and the reduction in urban default speed limits in 2001 to 50km/hr might all play an important role in improving kerbside stop safety for tram passengers.

The use of 'Rumble Strips' and improved line markings has also been suggested as a means to address speed as vehicles pass trams [9]. Positioning stops adjacent to fully protected pedestrian crossings would be one another approach suggested by the same source. Traffic calming was also suggested including raised crossing, speed bumps and road narrowing. Positioning of the crossing to allow a good 'line of site' for approaching traffic when a tram is present is also important.

Moving stops away from intersections has also been suggested. Stop lines at intersections put pressure on driver behaviour and relocation away from stop lines (approach side) would reduce these pressures. Barriers have mainly been suggested as a means of improved safety at safety zone stops. In theory however a temporary barrier could be provided as a 'drop down' (or spring up) mechanism on trams (and or the road surface).

**Vehicle Measures** - Enhancing brake lights on trams to flash or be larger when stopping has been suggested as a means of using the vehicle to increase the conspicuousness at kerbside stops. Stopping message boards and warning signals on trams have also been proposed.

A trial of dynamic signs at the rear of trams was undertaken in 2005. This involved a 'Prepare to Stop/ Stop' sign added to the rear of selected trams. An assessment of the results showed some significant improvements in driver behaviour. The most important was a decline in the share of vehicles failing to stop when the tram was stationary [19].

Another concept for increasing conspicuousness of kerbside stops was suggested as part of the Siemens Light Rail 2020 design competition held in 2006. The winning design from students at Monash University included provision of high lux beam lighting projected from above tram doors to light the path of boarding/alighting passengers at night.

#### Road User Measures

These incorporate the provision of information and training to road users to increase their awareness of road rules and of the dangers involved in using kerbside stops. They were specifically highlighted as a countermeasure in a study of driver approaches to reducing all accidents affecting older people [14].

VicRoads undertook a public education campaign including, print and television media, as part of the 'Think Tram' program to in particular address compliance of road rules associated with priority for tram lanes designated by solid yellow lines. Called 'obey the yellow' the program included innovative use media to explain the rules to road users. A review of the program found its impact on actual compliance was minimal. The main problem being the complex and difficult to understand rules themselves [20].

Improved enforcement of road rules has also been suggested. Due to the high costs associated with direct policing a program using CCTV cameras located on trams was trialled by the Department of Transport and VicRoads on two trams in 2007. A business case assessment of rolling out the program to a substantive proportion of the network had a low benefit cost ratio (0.1) [13] largely due to the high costs of providing the infrastructure.

## EVALUATION OF SAFETY MITIGATION MEASURES

Table 5 presents the results of a multi-criteria assessment of the types of measures identified in Table 4. The assessment is based on the likely impact of measures on crash risk, exposure and injury risk. The evaluation also shows how measures would act to address physically accessibility barriers for persons with

disabilities and the Australian requirements for access in the 'Disability Discrimination Act [21] (very similar to the US ADA act).

**TABLE 5: Assessment of Safety Mitigation Measures – Kerbside Tram Stops**

Ranking	Option	DDA compliance	Crash Risk	Exposure	Injury Risk	Cost
1	Platforms	●	●	●	●	High
2	Separation	◐	●	●	●	High
3	Pedestrian crossings	◐	●	●	●	Medium
4	Barriers	◐	●	●	●	High
5	Safety Zone width	◐	●	◐	◐	High
6	Speeds	○	◐	◐	●	Low
7	Road Narrowing	○	●	●	◐	High
8	Traffic restrictions	○	●	◐	◐	Low
9	Warning signals on Trams	◐	●	◐	◐	Medium
10	Enforcement	○	●	◐	◐	Low
11	Visibility	◐	◐	◐	◐	Medium
12	Warning signals	◐	◐	◐	◐	Medium
13	Tram Brakes	○	●	◐	◐	Medium
14	Position of Tram Stops	○	◐	◐	◐	High
15	Tram front design	○	◐	◐	◐	Medium
-	Close stop	●	●	●	●	Low

Overall the analysis suggests that investment in platform stops have been a highly positive program in relation to the safety issues identified and that this is a priority for future conversion of kerbside stops. This measure also shares benefits for the DDA program. Greater separation of passengers at stops and the use of formal pedestrian crossings is also recommended. The provision of barriers and increasing the width of safety zones at stops is recommended as is narrowing roads to reduce driver speeds which are part of general traffic restriction measures and the use of warning signs on trams. Closing kerbside tram stops is also highlighted as a useful measure on all criteria. This will also help with the problem of short stop spacing which acts to slow trams in Melbourne [5].

## DISCUSSION AND CONCLUSIONS

This paper presents a summary of a research project undertaken to develop a strategy to address safety issues at kerbside tram stops in Melbourne, Australia. At kerbside stops passengers wait on the kerb and access trams arriving in the middle of the road by walking across unprotected traffic lanes. Traffic rules for autos to stop when trams do are the only protections for passengers crossing traffic lanes at these stops. There are 1,785 kerbside tram stops representing 61% of all stops including local, arterial, interchange and terminus stops each with varying degrees of risk exposure. Previous research has identified these stops as being more dangerous.

Analysis of accident data established that between 1999-2009 between 38 and 53 accidents occurred p.a. with no particular trend. However ridership has grown during this period resulting in a considerable fall in accident rates per rider (a fall of 50% in 10 years to 2009). Most accidents are not serious however fatalities have occur on average triennially and all involved people aged over 55. A high share of most other accident types involve children and teenagers. Analysis of accident volume by stop shows that that 65% of all tram accidents occur at kerbside stops with most occurring at terminus and transfer kerbside stops.

A range of mitigation measures are developed and evaluated. Overall the analysis suggests that investment in platform stops, greater separation of passengers at stops and the use of formal pedestrian crossings is recommended. Barriers and increasing the width of safety zones at stops is recommended as is



narrowing roads to reduce driver speeds including general traffic restriction measures and the use of warning signs on trams. Closing kerbside tram stops is also highlighted as a useful measure on all criteria.

The strategy being developed from this research is likely to include a targeted program of addressing more dangerous (blackspot) stops as well as general measures for addressing safety at all stops.

There is much scope for additional research associated with these issues. There is a role for innovative thinking about the protection measures for passengers as they move across traffic lanes. New technologies and the use of cameras for enforcement have been suggested. It would also be beneficial to monitor the performance of mitigation measures to both ensure they have addressed accident risks but also as a means to assess the relative cost effectiveness of measures.

This project is the latest in a number of research papers addressing safety issues in the Melbourne streetcar system. There is a role for research associated with similar streetcar systems elsewhere notably the larger and older systems in Eastern Europe. There is also an emerging trend towards the development of streetcars in North America and thus a need to learn from safety performance in these contexts.

Overall the research demonstrates that kerbside stops have inherent safety concerns but that a range of mitigation measures are available to address these issues at varying cost and effectiveness. There is a need to increase research associated with stop safety in streetcar contexts and a range of areas where this can be progressed are suggested.

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