Australasian Transport Research Forum 2016 Proceedings
16 – 18 November 2016, Melbourne, Australia
Publication website: http://www.atrf.info

Assessing key engineering treatments addressing major pedestrian serious casualties in Victoria, Australia

Amir Sobhani[1], Chris Jurewicz[1], Tariro Makwasha[1], Hafez Alavi[2], Michael Nieuwesteeg[2]

[1]ARRB Group Ltd, Victoria, Australia

[2]Transport Accident Commission, Victoria, Australia

Email for correspondence: amir.sobhani@arrb.com.au

Abstract

Pedestrian injury and mortality are a global issue, with more than 270,000 pedestrians killed worldwide each year. In Victoria, 249 road fatalities were reported in 2014, 18% of which were pedestrians. These statistics convinced the Victorian road safety partners to develop a major program to reduce the number of severe pedestrian casualties. One of the main challenges in development of pedestrian safety programs is selection of engineering crash treatments leading to the most effective reduction in number of pedestrian crashes. This approach relies on accurate quantification of the effectiveness of such treatments. This study conducted a literature review of the effectiveness of different pedestrian treatments in Australia and in other countries. This literature review assessed the availability and accuracy of reported crash modification factors (CMF) and/or crash reduction factors (CRF) for each treatment type. Then, four major treatment types, which have not been evaluated accurately, were selected for evaluation. These treatment types included 'median', 'kerb extension', 'full-time fully controlled right turn signals' and 'part-time fully controlled right turn signals'. A quasi-experimental before-after treatment/control evaluation design was utilised to assess the effectiveness of these treatment types. Required data for treated and control sites were collected from Local Government Areas (LGAs) and VicRoads. The control sites were matched on surrounding land use, speed zones and pedestrian crash history. A log-linear Poisson model was applied to analyze the quasi-experimental road safety evaluation design. This study improves the cost-effectiveness and accuracy of pedestrian road safety treatment programs through updated and more accurate CRF/CMF values for the most effective pedestrian safety treatments. The findings will be useful to road agencies seeking to reduce incidence and severity of pedestrian casualties.

1. Introduction

Pedestrian injury and mortality are global issues, with more than 270,000 pedestrians killed worldwide each year (World Health Organization 2013). This represents approximately 22% of all global road trauma.

On average, each year 366 people were killed and 5022 seriously injured in pedestrian crashes in urban and rural areas in Victoria over the eight years between 2006 and 2013. The typical severity of pedestrian casualty crashes is higher than other crash types. On average, one out of two urban pedestrian casualty crashes results in death or serious injury. This places pedestrian safety among the top road safety concerns in Victoria, as recognised by the current Victorian Road Safety Strategy (VicRoads 2013).

Recent literature reviews conducted for Austroads (Austroads 2012) identified the need to strengthen the efficacy evidence for installation of common road crossing treatments for pedestrians. The crash reduction factors used in the economic evaluation of candidate blackspot projects were found to lack robustness, currency and local relevance.

This study aimed to select treatments which show promise of addressing the main pedestrian casualty risk factors but lack strong efficacy evidence. These treatments were then evaluated using a before-after approach with control sites, to produce crash reduction factors for use in future road safety programs.

2. Literature review

A comprehensive literature review of pedestrian treatment types was conducted. In the literature review, the following information was extracted:

- the effectiveness of treatments in reducing pedestrian and total casualty crashes
- the impacts of these treatments on individual and overall crash injury severity
- the robustness of existing crash reduction/crash modification factors in the Victorian context, including the accuracy of the findings, the evaluation undertaken and the quality of the research.
- the impact of these treatments on serious pedestrian casualties.

For each study reviewed, a ‘study rating’ was assigned to provide an indication of the robustness of the study methodology, including whether appropriate controls were used and a robust statistical method was employed. This is in accordance with the procedure outlined in Austroads (2010). The study rating system is shown in Table 1.

Table 1: Study rating system (Austroads 2010)

Study type	Descriptive statistics only	Simple statistical analysis	Complex statistical analysis
Simple study – no controls and no traffic volume	1	1	(not likely)
Study without control group but traffic volume	2	2	(not likely)
Study using control group/all crashes, etc. to control for general crash trends	3	4	5
Study controlling for general crash trends and the regression-to-the-mean effect, generally using controls based on similar sites	3	4	5
Study using matched control group, based on crash rates controlling for general trends and regression-to-the-mean	3	4	5

In order to highlight the local relevance, the literature review was conducted to summarise the effectiveness of the treatments assessed in Australia and in other countries. Results of the literature review are summarised below.

2.1. Pedestrian treatments in Australia

The studies which used robust methodologies sourced from Australia are summarised in Table 2.

A number of studies reported a 17.4–23% reduction in pedestrian casualty crashes following the lowering of default speed limits in New South Wales, Victoria, Queensland and Western Australia (Hoareau et al. 2007; Hoareau & Newstead 2004; ARRB Transport Research 2000). ARRB Transport Research (2000) also reported a 51.2% reduction in all pedestrian crashes, whilst Hoareau et al. (2007) reported a 41% reduction in pedestrian FSI crashes. Furthermore, installation of 'wombat crossing' reduced total number pedestrian crashes by 31% (Austroads 2000) and total number of pedestrian casualty crashes by 73% (Makwasha and Turner 2015).

For the following treatments, only one robust study paper was found in the literature review:

- countdown signal timers: no conclusive evidence of improved safety (Levasseur & Brisbane 2011)
- dwell-on-red-light signal treatment: 40% reduction in mean speed (Lenné et al. 2007)
- flashing amber turning arrow at intersection: no statistically significant evidence to support treatment as effective (Mak et al. 2006)
- school crossing: 2 km/h reduction in 85th percentile speeds (Roberts 2009)
- tram signal and lane priority: 13% reduction in pedestrian crashes (Naznin et al. 2016)

Table 2: Pedestrian treatments evaluation within Australia

Source	Description	Treatment type	Efficacy	Study rating
ARRB Transport Research (2000)	New South Wales Before/after study analysing 3 years before and 1.5 years after	50 km/h default speed limit	• 22.3% reduction in pedestrian casualty crashes (statistically significant) • 51.2% reduction in all pedestrian crashes	4 – Log-linear regression analysis
Hoareau et al. (2007)	South East Queensland Before/after analysis (62 months before and 39 months after), with control	50 km/h default speed limit	• 23% reduction in pedestrian casualty crashes (statistically significant)	4 – Poisson regression analysis, with control, simple statistical analysis
Hoareau & Newstead (2004)	Western Australia Before/after study analysing police reported crash data for 1996–2003	50 km/h default speed limit	• 61% reduction in all pedestrian injury crashes on 50 and 60 km/h roads relative to 70 km/h roads (statistically significant)	4 – modified quasi-experimental design, 70 km/h roads used as control, Poisson regression analysis
Hoareau et al. (2006)	Victoria Before/after study analysing 5 years before and almost 3 years after, with control	50 km/h default speed limit	• 41% reduction in pedestrian fatal and serious injury (FSI) crashes (statistically significant) • 17.4% reduction in all injury crashes involving pedestrians	4 – Poisson regression analysis, with control, simple statistical analysis
Levasseur & Brisbane (2011)	Sydney 2 treatment sites and 2 control sites used	Countdown signal timer	• No conclusive evidence of improved safety • 11.9% increase in late starters with minimal change to late finishers • Decrease in pedestrian compliance at wider intersections • Some potential improvement in pedestrian amenity	4 – simple statistical analysis, controls used
Lenné et al. (2007)	Ballarat, Victoria Before/after speed analysis on approach to intersection.	Dwell-on-red-light signal treatment	• 40% reduction in mean speed at treatment site (statistically significant) • 47% reduction in number of vehicles travelling	5 – complex statistical analysis (logistic regression, ANOVA), controls used

Source	Description	Treatment type	Efficacy	Study rating
			faster than 40 km/h 30 m from intersection • 68% reduction in number of vehicles travelling over 50 km/h 30 m from intersection	
Mak et al. (2006)	Australia Before/after crash analysis, conflict survey, comprehension survey, driver simulator study	Flashing amber turning arrow at intersection	• No statistically significant evidence to support treatment as effective	4 – simple statistical analysis, paired controls used
Roberts (2009)	Victoria Boy and girl figures painted onto crosswalks near schools at 3 treatment sites. 3 control sites used.	School crossing	• Anticipated reduction of 2 km/h in 85th percentile speeds • Magnitude of change was similar to previous evaluations; site was already a low-speed environment	4 – simple statistical analysis, use of controls and traffic volumes
Naznin et al. (2016)	Melbourne Empirical Bayes analysis of 29 four-leg intersections and 23 roadway sections, both with tram signal priority. 82 intersections and 65 roadway sections used as controls	Tram signal and lane priority	• 13% reduction in all pedestrian casualty crashes at sites with tram signal priority • Vehicle/pedestrian crashes reduced by 17%, and FSI crashes by 19% at sites with both tram signal priority and lane priority measures	5 – complex statistical analysis (Empirical Bayes analysis), controls used
Geoplan (1994), as cited in Austroads (2000)	New South Wales Adjusted before/after analysis of pedestrian treatment installations between 1985 and 1993	Wombat crossing	• 31% reduction in pedestrian crashes, adjusted to 8%	3 – descriptive statistics only, control group used, original paper unseen
Makwasha and Turner (2015)	Australia Adjusted before/after analysis of pedestrian treatments	Wombat crossing	• 73% reduction in pedestrian casualty crashes	4 – simple statistical analysis, use of controls and traffic volumes

2.2. Pedestrian treatments outside Australia

The main robust international studies are summarised in Table 3.

Three studies on high-visibility (or ‘marked’) crosswalks were found to have varying levels of effectiveness. Two studies were in the USA, with total crash reductions between 29 and 37% (Feldman et al. 2010; Fitzpatrick and Park 2010). Fitzpatrick and Park (2010) also found a statistically significant 69% reduction in pedestrian crashes. Elvik et al. (2009) reported a variety of results for different scenarios: 8% reduction in pedestrian crashes on 2-lane roads, 88% reduction on multi-lane roads, and an overall pedestrian crash reduction of 44% on all roads.

For the following treatments, only one robust international paper was sourced:

- traffic calming and 20 mile/h speed limit: 50% reduction in pedestrian FSI crashes (Webster & Layfield 2003)
- countdown signal timer: perceived improvement on pedestrian safety (Wanty & Wilkie 2010)
- flush median: reduced pedestrian FSI crashes (Jurisich et al. 2003)

- pedestrian guard rail: pedestrian crashes 2.5 times more likely without guard rail (Zheng & Hall 2003)
- pedestrian refuges: 50% reduction in pedestrian crashes (Zegeer et al. 2005)
- puffin crossing: 26% reduction in pedestrian crash rates (Webster 2006)
- tram raised right of way (ROW): 48% reduction in pedestrian crashes (Richmond et al. 2014).

Table 3: Pedestrian treatment evaluations outside Australia

Source	Description	Treatment type	Efficacy	Study rating
Webster & Layfield (2003)	London Before/after analysis, with 5 years before data and at least 1 year after data	20 mile/h speed limit and traffic calming measures	• 50% reduction in pedestrian FSI crashes and 61% reduction in FSI crashes involving children as pedestrians (statistically significant)	4 – simple statistical analysis, control group and control for regression-to-the-mean
Wanty & Wilkie (2010)	Auckland CBD Before/after analysis of pedestrian behaviour at 1 site (2007–2009) and comparison with 1 previous trial site (2006–2007)	Countdown signal timer	• Decrease in number of pedestrians running to complete crossing (7% to 5%, statistically significant), pedestrians crossing during vehicle phases (4% to 3%). • Increase in pedestrians remaining on road at end of pedestrian phase (11% to 17%, statistically significant) • Perceived by majority of pedestrians to be improving their safety.	4 – simple statistical analysis, controls used
Jurisich et al. (2003)	Auckland, New Zealand, implementation between 1988 and 1994. Before/after study of 50 sites with at least 5 years of crash data.	Flush median	• Reduced number of pedestrian FSI crashes • Projected saving of $15.2 million.	4 – simple statistical analysis, controlling for regression-to-the-mean
Feldman et al. (2010)	San Francisco, California Before/predicted after study of 54 treated intersections and 54 controls.	High-visibility crosswalks	• Estimated 37% reduction in number of crashes at treated intersections (statistically significant)	5 – complex statistical analysis (Empirical Bayes analysis), controls used
Fitzpatrick and Park (2010)	Tucson, USA Empirical Bayes before/after study (3 years before and 3 years after) of 21 sites with HAWK (High intensity Activated crossWalK) crossings installed and 102 unsignalised intersections (controls).	High-visibility crosswalks	• 29% reduction in total crashes (statistically significant) • 15% reduction in severe crashes (non-significant) and 69% reduction in pedestrian crashes (statistically significant)	4 – simple statistical analysis, controls used
Elvik et al. (2009)	International Use of studies that controlled for pedestrian/vehicle volumes.	Marked crossings	• 8% reduction in pedestrian crashes on 2-lane roads (non-significant) • 88% increase in pedestrian crashes on	4 – simple statistical analysis, control for regression-to-the-mean

Source	Description	Treatment type	Efficacy	Study rating
			multi-lane roads (statistically significant) • 44% increase in pedestrian crashes on all roads	
Zheng & Hall (2003)	London Evaluation of 37 sites with and without pedestrian guard rails	Pedestrian guard rail	• Pedestrian crashes 2.5 times more likely at a site without guardrail compared to one with guard rail (statistically significant)	4 – study used similar sites without guardrails as a control, and checked for statistical difference between traffic conditions (none found) Used simple statistical analysis
Zegeer et al. (2005)	USA Poisson and negative binomial regression models fitted to crash data at 1,000 marked crosswalk locations and 1,000 matched unmarked comparison sites across 30 cities.	Pedestrian refuges	• On roads with less than 2 lanes and less than 15,000 veh/d, pedestrian crash rate at locations with marked crossings and raised medians was approximately half that of locations without raised medians • Crash rate at unmarked crossings with raised medians was 40% less than unmarked crossings without raised medians	5 – complex statistical analysis, matched comparison group
Webster (2006)	UK Before/after study of 23 new puffin crossings	Puffin crossing	• 26% reduction in pedestrian crash rates (not statistically significant) • No statistically significant evidence that they are more dangerous than other crossing types	4 – simple statistical analysis, Tanner test used for control
Liu et al. (2011)	China Before/after study of 366 treatment sites with comparison group	Rumble strips at crosswalks	• Expected 25% reduction in all crashes due to average and 85^{th} percentile speed change • Speed reductions of 9.2 km/h and 9.1 km/h respectively in 60 km/h limit zones, and 11.9 km/h and 12.0 km/h respectively in 80 km/h limit zones	4 – simple statistical analysis (Empirical Bayes), controls used
Richmond et al. (2014)	Toronto, Canada Quasi-experimental design evaluating changes in pedestrian-motor vehicle crashes after installation of a dedicated right-of-way (ROW) (between 2005 and 2010). Compared to rate of	Streetcar (tram) raised ROW (at-grade crossing at tram stop)	• 48% reduction in rate of pedestrian/vehicle crashes post-installation (statistically significant)	4 – simple statistical analysis (quasi-experimental), controls used

Source	Description	Treatment type	Efficacy	Study rating
	vehicle/pedestrian crashes across Toronto.			

A large number of studies were included in the literature review to summarise the level of effectiveness for different pedestrian treatment types. Tables 2 and 3 only listed the pedestrian treatments which were evaluated using a robust methodology. A summary of pedestrian crash and injury reduction rates for all the reviewed engineering treatments, is presented in Table 4.

Table 4: Pedestrian crash and injury reduction rates of engineering treatments

Treatment type	Pedestrian crash and injury severity reduction	Robustness of results
50 km/h default speed limits	▪ 51% reduction in all pedestrian crashes ▪ 41% reduction in pedestrian FSI crashes ▪ 17–23% reduction in pedestrian casualty crashes	High Medium
Ban parking	▪ 30% reduction in vehicle hits pedestrian crashes	Low
Barnes dance (stopping traffic and allowing diagonal pedestrian flow)	▪ 9% reduction in vehicle/pedestrian crashes	Low
Countdown signal timers	▪ No conclusive evidence	N/A
Dwell-on-red-light signal treatment	▪ No conclusive evidence	N/A
Footpath and shoulder provision	▪ 88% reduction in ‘walking along roadway’ pedestrian crashes	Low
High-visibility crosswalks (i.e. zebra crossings with additional markings, lighting, colouring, etc.)	▪ 44–69% reduction in pedestrian crashes overall ▪ 8% reduction in pedestrian crashes on 2-lane roads ▪ 88% reduction in pedestrian crashes on multi-lane roads	High
Flush median	▪ 50% reduction in vehicle hits pedestrian crashes	Low
Raised Median	▪ No conclusive evidence	N/A
Improved lighting	▪ 57–63% reduction in night-time pedestrian crashes, 30% reduction in pedestrian crashes in general	Low
Median barrier	▪ Unknown	N/A
Pedestrian guard rail/fencing alongside of road	▪ Pedestrian crashes 2.5 times more likely without guard rail ▪ 20–48% reduction in pedestrian crashes	High Low
Pedestrian overpass/ grade separation	▪ 70–95% reduction in pedestrian crashes	Low
Pedestrian refuge	▪ 50% reduction in pedestrian crashes ▪ 18–50% reduction in pedestrian crashes & 67% reduction in pedestrian fatalities	High Low
Kerb extensions	▪ No conclusive evidence	N/A
Traffic signals	▪ 30% reduction in vehicle hits pedestrian crashes	Low
Pedestrian signals at intersections	▪ 50–60% reduction in pedestrian crashes	Low

Treatment type	Pedestrian crash and injury severity reduction	Robustness of results
Fully-controlled right turn phases (eliminates filtering right turners hitting pedestrians)	▪ No conclusive evidence	N/A
Puffin crossing	▪ 26% reduction in pedestrian crashes	High
	▪ 25–75% reduction in pedestrian crashes & 60% reduction in pedestrian casualties ▪ crash modification factor (CMF) between 0.61 and 0.78 for vehicle/pedestrian crashes when converting from Pelican to Puffin crossing	Low
Raised crosswalk (Wombat) at roundabout	▪ Unknown	N/A
Raised intersection platforms	▪ 8% reduction in pedestrian crashes ▪ 20–70% reduction in all crashes ▪ 25–80% reduction in all casualties	Low
Raised pedestrian crossing (Wombat)	▪ 73% reduction in pedestrian casualty crashes	High
Raised tram stop	▪ 48% reduction in pedestrian crashes	High
Reducing pedestrian delay at traffic signals	▪ No conclusive evidence	N/A
Roundabout	▪ 27–80% reduction in pedestrian crashes ▪ 30% **increase** in vehicle hits pedestrian crashes	Low
School crossing	▪ Unknown	N/A
Shared zones	▪ Little to no crash reduction	Low
Textured crosswalk markings	▪ No conclusive evidence	Low
Traffic calming and 20 mph (32 km/h) speed limit	▪ 50% reduction in pedestrian FSI crashes ▪ 60% reduction in pedestrian crashes and 65% reduction in pedestrian injury crashes	High Low
Tram signal and lane priority (when in mixed traffic)	▪ 13% reduction in pedestrian crashes	High
Turbo roundabout (signalised)	▪ Reduction in pedestrian crashes from 7 to 1 per year	Low

Crash and injury severity reduction results were collated from multiple references for the same treatment type. If the statistic type reported (e.g. reduction in all pedestrian crashes, reduction in pedestrian casualty crashes, pedestrian crash reduction factor) was the same between two papers, and the conditions between the two studies were similar, then they were reported together (e.g. 17–23%).

As shown in Table 4, there was a general lack of evidence for treatment effects on injury severity from the papers reviewed. For many treatments there is no robust analysis of effectiveness for Australia. Therefore it is necessary to evaluate these treatments using a robust methodology.

3. Methodology

The previous section outlined the pedestrian treatment types which were not evaluated using a robust methodology. This section presents an approach to prioritize and evaluate four major pedestrian treatment types which show promise of addressing the main pedestrian risk factors but lack strong evidence.

This study evaluates major pedestrian safety treatments addressing the majority of pedestrian serious casualty problems in Victoria. Four steps were followed to achieve this objective:

In the first step, an understanding was gained of the main factors influencing pedestrian serious injury problem in Victoria. This step involved an analysis of the key factors affecting the number and severity of pedestrian serious casualties/crashes. A comprehensive literature review was conducted to identify factors affecting pedestrian serious casualty problem in Victoria. Then a binary logistic regression model was developed to complement the results of the literature review. The database which was used to conduct the analysis was provided by the Transport Accident Commission (TAC). This database merged Road Crash Information System (RCIS) and TAC insurance claim data. This database contained relevant information for pedestrian traffic injuries that occurred between 2006 and 2013. Details of this analysis can be found in Sobhani et al. (2016).

In the second step, a crash typology was defined according to the most significant factors affecting pedestrian serious casualty problem in Victoria. The crash typology is used to identify the problematic crash types, which were associated with the most number of pedestrian fatalities and serious injuries.

In the third step, four major pedestrian safety treatments, addressing the majority of the problematic crash types, were prioritised. These countermeasures prioritised according to the following criteria:

- whether there was a robust evaluation of the effectiveness of the treatment
- the number of key problematic crash types which could be addressed using these treatments
- applicability in Victoria
- Safe System alignment for pedestrians
- TAC's strategic priorities relevant to pedestrian safety
- the effect of the treatment on level of walkability

The last three criteria were assessed by a group of experts from TAC, VicRoads and Local Government Authorities (LGAs) in a workshop which was held in Victoria.

In the fourth step, the effectiveness of the treatments was evaluated. This study utilised before-after studies with comparison sites. A quasi-experimental retrospective matched-control approach was used in this evaluation (Bruhning and Ernst, 1985; Scully et al. 2008).

Each treatment site was matched to an untreated similar site (comparison). The comparison sites accounted for the effect of the underlying socio-economic conditions and other road safety initiatives but excluded any effects from the treatments under consideration. The treatment effects were measured by comparing the number of crashes occurred within three years before and after the treatment and within the treatment group while accounting for the underlying change in trends considering the comparison sites.

In order to determine whether changes in crashes at treatment sites were significantly different from those at the comparison sites, Poisson regression with a log-link function was applied.

The assumption was that the number of crashes followed a Poisson distribution. The Poisson log-linear model was developed to estimate a crash modification factor for each treatment type. It also tested the significance of differences in casualty and FSI crash changes (i.e. for all crashes and pedestrian crashes) at treatment and comparison sites. The model for each treatment type was specified as outlined in Equation 1.

$$ln(y_{ipt}) = \alpha + \beta_{ip} + \gamma_{it} + \delta_{ipt} + \varepsilon_{ipt} \quad (1)$$

where

y_{ipt}	=	cell crash count (casualty, FSI, pedestrian casualty or pedestrian FSI crash count)
α, β, γ, δ	=	model parameters to be estimated
ε	=	error term
p	=	before or after period index
i	=	site number
t	=	treatment or control group index

The interaction term was modified to estimate the average crash effects across all sites within the treatment and control groups.

The overall crash effectiveness of the different treatments accounting for comparison site crashes is defined as:

$$crash\ reduction\ factor\ (CRF) = 100 \times (1 - \exp(\delta_{ipt})) \quad (2)$$

where δ_{ipt} is the parameter for the after installation period at the treatment site.

For this approach, statistical power analysis was conducted to indicate the level of reliability for the achieved results. The power analysis was conducted using sample size (number of treated sites included in the analysis) and the expected effect size of the treatment. Table 5 summarises different categories for the statistical power.

Table 5: Statistical Power Categories

Categories	Statistical power (SP)
High	>80%
Acceptable	70%<SP<80%
Low	40%<SP<70%
Very low	<40%

4. Results

The binary logistic regression model (first step in the methodology) illustrated that ‘age’, ‘speed zone’ and ‘pedestrian movement’ are the three most significant factors affecting the pedestrian serious injury problem in Victoria (Sobhani et al. 2016). Therefore, the definition of crash typology (second step in the methodology) could be based on one of these variables.

‘Pedestrian movement’ was selected for two main reasons:

- This variable is an alternative representation of definitions for classifying accidents (DCA) codes which have been used by Victorian road agencies to form collision diagrams and crash factor matrices for site investigations and road safety audits. Therefore, by using this typology, road authorities will make better sense of crash analysis that was conducted to understand problematic pedestrian crash types.
- More pedestrian safety treatments are associated with pedestrian movements, e.g. crossing the road. Therefore, more treatments could be included in prioritisation analysis.

Three main pedestrian movements, which were associated with increased likelihood of fatality and serious injuries, were selected to form the main crash types. The binary logistic regression model showed that three main pedestrian movements which were associated with higher pedestrian injury severity are ‘crossing carriageway’, ‘working/playing/lying or standing on carriageway’ and ‘not on carriageway’. ‘Working/playing/lying or standing on carriageway’ was excluded since very few infrastructure-based pedestrian road safety treatments address this problem. Instead of this movement, ‘walking on carriageway’, which was associated with more pedestrian casualties, was considered as the third problematic movement.

Table 6 revealed the share of the top 10 pedestrian movements in pedestrian fatal and serious injury crashes. That is the reason that the total percentage of the FSI crashes did not add up to 100%. This analysis was conducted using the RCIS data.

Table 6: Problematic pedestrian crash types

Rank	pedestrian crash type	Percentage of FSI crashes
1	Crossing carriageway at mid-block	25.9%
2	Crossing carriageway when vehicle entering intersection and going straight	11.0%
3	Crossing carriageway when vehicle leaving intersection and turning right	9.8%
4	Crossing carriageway when vehicle leaving intersection and going straight	7.4%
5	Crossing carriageway when the pedestrian emerged from behind the car	5.2%
6	Not on the carriageway at mid-block	2.2%
7	Walking on carriageway at mid-block	1.9%
8	Walking on carriageway when vehicle entering intersection and going straight	0.5%
9	Walking on carriageway when vehicle leaving intersection and going straight	0.3%
10	Walking on carriageway when vehicle leaving intersection and turning right	0.2%
Total		64.35%

The top 5 movements in the table were associated with ‘crossing carriageway’ accounted for 59.3% of FSI crashes.

Following a discussion of the results, which were achieved from the first and second steps of the methodology, the gaps identified in the literature review (Table 4) and industry stakeholder consultation (third step of the methodology), a number of treatments were prioritised for evaluation (Table 7). The choice also involved consideration of their importance to promoting walkability, alignment with the Safe System principles (Vision Zero, minimizing FSI outcomes) and availability of site data in metropolitan Victoria.

Table 7: Prioritised treatments to be evaluated in this study

Treatment	Coverage of targeted FSIs
Median on existing road (flush or physical)	85%
Kerb extension	67%
Traffic signals operation review/changes: Full-time fully controlled right turn Part-time fully controlled right turn	44%

These treatments are ‘the installation of medians (either flush or physical) on existing roads’, ‘kerb extensions’ (narrowing the carriageway to reduce crossing width), ‘full-time fully controlled right-turn phase’ and ‘part-time fully controlled right turn phase’.

Table 8 summarises the results of the evaluation analysis described in the methodology (fourth step of the methodology). For each treatment type, the evaluation was conducted for total casualty crashes, total FSI crashes, pedestrian casualty crashes and pedestrian FSI crashes.

Table 8: Results of the evaluation

Treatment	Crash type	Number of paired sites	S.E	CMF (CRF %)	95% Confidence interval (CMF)	Level of significance	Statistical power (SP)	Comments
Median	Casualty	30	0.166	0.645 (35.5)	[0.466, 0.893]	0.008	70.0%	Statistically significant, acceptable SP
	FSI	9	0.251	0.855 (14.5)	[0.522, 1.399]	0.533	11.5%	Not statistically significant, very low SP
	Casualty (Pedestrian)	6	0.315	0.446 (55.4)	[0.241, 0.826]	0.010	46.0%	Statistically significant, low SP
	FSI (Pedestrian)	-	-	-	-	-	-	Insufficient data
Kerb extension	Casualty	13	0.171	0.464 (53.6)	[0.326, 0.662]	<0.0001	73.0%	Statistically significant, acceptable SP
	FSI	6	0.873	0.247 (75.3)	[0.045, 1.366]	0.109	74.0%	Not statistically significant, acceptable SP
	Casualty (Pedestrian)	-	-	-	-	-	-	Insufficient data
	FSI (Pedestrian)	-	-	-	-	-	-	Insufficient data
FCRT (full time)	Casualty	35	0.086	0.479 (52.1)	[0.404, 0.567]	<0.0001	98.0%	Statistically significant, high SP
	FSI	16	0.167	0.311 (68.9)	[0.224, 0.431]	<0.0001	97.0%	Statistically significant, high SP
	Casualty (Pedestrian)	-	-	-	-	-	-	Insufficient data
	FSI (Pedestrian)	-	-	-	-	-	-	Insufficient data
FCRT (part time)	Casualty	31	0.121	0.888 (11.2)	[0.701, 1.124]	0.322	16.0%	Not statistically significant, very low SP
	FSI	16	0.252	0.644 (35.6)	[0.393, 1.054]	0.080	46.5%	Statistically significant, low SP
	Casualty (Pedestrian)	-	-	-	-	-	-	Insufficient data
	FSI (Pedestrian)	-	-	-	-	-	-	Insufficient data

5. Discussion of results and conclusion

For the ‘median’ treatments, significant reductions in the number of casualty crashes took place (number of sites = 30; level of significance = 0.008; SP = 70%). The crash reduction factor (CRF) was calculated as 35.5%. The results also showed that the 95% confidence interval of the crash reduction factor was between 10.7% and 53.4%. In addition, low and very low statistical power results were found for the effect of ‘median’ treatments on total FSI and pedestrian casualty crashes. A crash modification factor was not computed for the effect of this treatment on pedestrian FSI crashes since sufficient data was not available.

Similarly, for ‘kerb extension’ treatments, significant reduction was found in the number of total casualty crashes (number of sites = 13; level of significance < 0.0001; SP = 73%). The crash reduction factor was equal to 53.6% and the confidence interval of the CRF was between 33.8% and 67.4%. The effectiveness of this treatment on the total number of FSI crashes was not statistically significant (level of significance = 0.533). Although the statistical power was acceptable for total FSI crashes, the reliability of the results were classified as ‘low’ since the number of treated sites was less than 10 and this might cause bias in the results. Crash reduction factors could not be computed for pedestrian casualty and FSI crashes due to lack of data.

‘Full-time fully controlled right turn’ treatments caused a significant reduction in the total number of casualty and FSI crashes (number of sites = 35 and 16 respectively; level of significance = <0.0001; SP > 80%). The crash reduction factors for total casualty and FSI crashes were 52.1% and 68.9% respectively. Confidence interval for the effectiveness of this treatment on total casualty crashes was between 43.3% and 59.6%. The confidence interval was between 56.9% and 77.6% for total FSI crashes. No CRF was calculated for pedestrian casualty and FSI crashes as data was not sufficient.

For ‘part-time fully controlled right turn’ treatments the reliability of results was classified as ‘very low’ and ‘low’ for total casualty and FSI crashes. This analysis could not be conducted for pedestrian casualty and FSI crashes due to lack of data.

To summarise, the GLM method found that a significant reduction in total casualty crashes took place as a result of implementation of ‘median’, ‘kerb extension’ and ‘full-time fully controlled right turn’ treatments (with CRF of 35.5%, 53.6% and 52.5% respectively). In terms of casualty crashes, the effect of ‘full-time fully control right turn’ was statistically significant (CRF = 68.9%). For other crash types the results of GLM was either not significant or testing could not be conducted.

This study helped to maximise the benefits of road safety investment through providing current and accurate information regarding the effectiveness of treatments and the injury/crash reductions expected if these treatments are adopted. In future studies, this evaluation analysis should be repeated with larger data sets and/or including sites with high numbers of pedestrian crashes.

6. References

ARRB Transport Research 2000, ‘50 km/h urban speed limit evaluation’, contract reports RC90013 & RC1723, for Roads and Traffic Authority NSW, ARRB Transport Research, Vermont South, Vic.

Austroads 2010, *Road safety engineering risk assessment: part 6: crash reduction factors*, AP-T151-10, by B Turner, K Imberger, P Roper, V Pyta & J McLean, Austroads, Sydney, NSW.

Austroads 2012, *Effectiveness of road safety engineering treatments*, AP-R422-12, by B Turner, L Steinmetz, A Lim & K Walsh, Austroads, Sydney, NSW.

Bruhning, E & Ernst, G 1985, 'Log-linear models in effectiveness studies – an application to simultaneous before-after comparisons with control group', *Evaluation 85; international meeting on the evaluation of local traffic safety measures, Paris, France*.

Elvik, R, Høye, A, Vaa, T & Sørensen, M 2009, *The handbook of road safety measures*, 2nd edn, Emerald Publishing Group, Bingley, UK.

Feldman, M, Manzi, JG & Mitman, MF 2010, 'Empirical Bayesian evaluation of safety effects of high-visibility school (yellow) crosswalks in San Francisco, California', *Transportation Research Record*, no. 2198, pp. 8-14.

Fitzpatrick, K & Park, ES 2010, *Safety effectiveness of the HAWK pedestrian crossing treatment*, report no. FHWA-HRT-10-042, Federal Highway Administration, McLean, VA, USA.

Hoareau, E & Newstead, S 2004, *An evaluation of the default 50 km/h speed limit in Western Australia*, report 230, Monash University Accident Research Centre (MUARC), Clayton, Vic.

Hoareau, E, Newstead, S, Oxley, P & Cameron, M 2007, *An evaluation of 50 km/h speed limits in South East Queensland*, report 264, Monash University Accident Research Centre (MUARC), Clayton, Vic.

Jurisich, I, Segedin, T, Dunn, R & Smith, M 2003, 'Experience of using flush medians in Auckland City', *Australasian Transport Research Forum*, *26th*, *2003*, *Wellington, New Zealand*, NZ Institute of Highway Technology Ltd, New Plymouth, New Zealand, 21 pp.

Lenné, MG, Corben, BF & Stephan, K 2007, 'Traffic signal phasing at intersections to improve safety for alcohol-affected pedestrians', *Accident Analysis & Prevention*, vol. 39, no. 4, pp. 751-6.

Levasseur, M & Brisbane, G 2011, 'Trial of pedestrian countdown timers in the Sydney CBD: final report', contract report 002878, ARRB Group, Vermont South, Vic.

Liu, P, Huang, J, Wang, W & Xu, C 2011, 'Effects of transverse rumble strips on safety of pedestrian crosswalks on rural roads in China', *Accident Analysis & Prevention,* vol. 43, no. 6, pp. 1947-54.

Mak, J, Hosking, S, Regan, M, Brisbane, G, Triggs, T, Horberry, T & Young, K 2006, 'Do amber flashers make pedestrians safer?', *ARRB conference*, *22nd*, *2006*, *Canberra, Australia*, *ACT,* ARRB Group, Vermont South, Vic, 18 pp.

Naznin, F, Currie, G, Sarvi, M & Logan, D 2016, 'An empirical Bayes safety evaluation of tram/streetcar signal and lane priority measures in Melbourne', *Traffic Injury Prevention*, vol. 17, no. 1, pp. 91-7.

Richmond, SA, Rothman, L, Buliung, R, Schwartz, N, Larsen, K & Howard, A 2014, 'Exploring the impact of dedicated streetcar right-of-way on pedestrian motor vehicle collisions: a quasi-experimental design', *Accident Analysis & Prevention*, vol. 71, pp. 222-7.

Roberts, P 2009, 'Trial of school crossing markings in school zones', contract report 001157, ARRB Group, Vermont South, Vic.

Scully, J, Newstead, S & Corben, B 2008, *Evaluation of the crash effects of strip shopping centre treatments in Victoria*, report 279, Monash University Accident Research Centre (MUARC), Clayton, Vic.

Sobhani, A, Jurewicz, C, Alavi, H and Nieuwesteeg M 2016, ‘Pedestrian serious casualty risk in Victoria, Australia: a logistic regression analysis of road, environmental and human demographic factors’, Proceedings of the Australasian Road Safety Conference, Canberra, Australia

VicRoads 2013, *Victoria's road safety strategy: 2013-2022*, VicRoads, Kew, Vic.

Wanty, DK & Wilkie, SM 2010, *Trialling pedestrian countdown timers at traffic signals*, report 428, NZ Transport Agency, Wellington, New Zealand.

Webster, N 2006, ‘The effect of newly installed Puffin crossings on collisions’, research report, London Road Safety Unit, UK.

Webster, DC & Layfield, RE 2003, *Review of 20 mph zones in London boroughs*, project report PPR243, Transport Research Laboratory (TRL), Crowthorne, UK.

World Health Organization 2013, *Pedestrian safety: a road safety manual for decision-makers and practitioners*, WHO, Geneva, Switzerland.

Zegeer, C, Stewart, R, Huang, H & Lagerwey, P 2005, *Safety effects of marked versus unmarked crosswalks at uncontrolled locations: executive summary and recommended guidelines*, FHWA-RD-01-075, Federal Highway Administration, McLean, Virginia, USA.

Zheng, P & Hall, RD 2003, *Pedestrian guard railing: a review of criteria for installation: final report*, report 1505, Transport for London, London, UK.