An investigation of pedestrian crashes at traffic intersections in the Perth Central Business District 2008-2012

RR 13-002

CURTIN-MONASH
ACCIDENT RESEARCH CENTRE

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December 2013

CURTIN-MONASH ACCIDENT RESEARCH CENTRE
DOCUMENT RETRIEVAL INFORMATION

Report No.	Project No.	Date	Pages	ISBN
RR 13-002	12-024 RSC	December 2013	55+	N/A

Title

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Abstract

Pedestrian crashes and injuries are a significant problem, particularly among lower-income countries and in pedestrian dense areas such as Central Business Districts and shopping precincts of higher-income countries. This project examined pedestrian crashes at traffic intersections in the Perth Central Business District, 2008-2012, to identify potential risk factors, including the recent conversion of signalised intersections from 'exclusive' to 'parallel' walk. Based on the findings and a review of the research literature, recommendations for future research were provided, along with recommendations for the trial of various countermeasures that have been identified to reduce the incidence of pedestrian crashes at traffic light controlled intersections.

Keywords

Road safety; pedestrian crashes; Central Business District; signal phasing; intersections

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EXECUTIVE SUMMARY

Introduction

Pedestrian crashes and injuries are a substantial road safety problem, particularly in developing, low-income countries. It is estimated that pedestrian crashes may account for up to 22% of road traffic fatalities globally, with the highest relative proportion of pedestrian deaths occurring in low-income countries (36%) in the African and South-East Asian regions. In comparison, pedestrians account for around 18% of road user deaths in high-income countries (WHO, 2013). The USA and Australia are two of the better performing high-income countries, with pedestrian fatalities accounting for around 13% of total road fatalities in the USA and Australia and 14% in Western Australia.

Pedestrians are a diverse group of road users, varying in ages and abilities. Most importantly they are a highly vulnerable road user group because of their limited capacity to withstand biomechanical forces. Within the shared roadway environment, pedestrians and vehicles encounter many opportunities for conflict and potential injury, including fatality. The risk of injury for pedestrians when involved in crashes with motorised vehicles is strongly and linearly associated with vehicle impact speeds – rising significantly at impact speeds of 30km/hour. This relationship provides strong support for the need to separate pedestrians from motorised vehicles – physically and temporally - and to reduce vehicle travel speeds in areas of high pedestrian activity where physical separation is not always possible.

Recent investigations of pedestrian crashes in Australia and elsewhere occurring at intersections (both signalised and un-signalised) and Central Business District (CBD) and shopping areas more specifically have highlighted the risk factors for crashes in these high pedestrian-high volume traffic locations. The importance of studying pedestrian crashes in pedestrian dense business, entertainment and shopping locations is amplified by the increased concern of 'distracted or inattentive' walking posed by the use of mobile phone and personal music devices and 'impaired walking' due to alcohol intoxication.

Detailed analyses of high pedestrian, high traffic volume locations such as Central Business Districts have yet to be undertaken in Western Australia. Additional incentive to do so is provided by the current program by Main Roads Western Australia of converting exclusive walk signalised intersections (where pedestrians are fully protected from vehicle movements and have exclusive use of the intersection) in the CBD to parallel walk (where traffic moves in parallel with pedestrians) to improve traffic flow. Over the period 2010 to 2013, a total of 10 exclusive walk intersections in the Perth CBD have been converted to parallel walk with more conversions planned in the near future (S. Forster personal communication 2013).

Aims and objectives

The overall aim of this study was to investigate the pattern of pedestrian crashes at traffic intersections in the Perth Central Business District, a high pedestrian, high traffic volume location. The specific objectives of the study were to:

1. Review the published literature (local, national and international) to document the characteristics of pedestrian crashes at intersections and the range of measures, including signalisation, to effectively reduce pedestrian crashes and injuries in these locations.
2. Analyse WA Police reported crashes for the period 2008-2012 to describe the pattern of pedestrian crashes at intersections in the Perth Central Business District.
3. Investigate, where possible, the impact on pedestrian crashes at signalised intersection in the Central Business District which have been converted from 'exclusive walk' to 'parallel walk' phasing.
4. Recommend cost-effective countermeasures to reduce pedestrian crashes at intersections in the Central Business District.

Method

A review of the scientific literature published in Australia and elsewhere was undertaken to:

- Identify the range of driver, pedestrian, road environment factors associated with pedestrian crashes; and
- Identify the range of countermeasures used to reduce the incidence of pedestrian crashes.

A literature search of databases including Google scholar, ProQuest, Current Contents, Scopus, Factiva and EconLit was undertaken using 'key words' to retrieve local, national and international publications (books, reports, scientific journal articles, conferences papers) relevant to the topic.

Main Roads Western Australia provided two data sets required for the analysis of pedestrian crashes in the Perth Central Business District and the impact of Main Roads Western Australia (MRWA) initiated changes in pedestrian signalisation on pedestrian crashes. The first was an Excel spread sheet of phasing and characteristics of signalised intersection in the CBD. This database had been prepared to inform the MRWA program of work for changing *Exclusive Walk* to *Parallel Walk* phasing. The second dataset provided by MRWA Western Australia was an extraction from their Integrated Road Information System (IRIS) of police reported crashes occurring during the period 2008-2012 in the area defined by MRWA as the Perth Central Business District and where the crash occurred at a designated road intersection. Intersection crashes are defined as those occurring within the intersection itself or within 20 metres of the intersection.

Summary of the main findings of a review of the literature

Younger and older age persons are more frequently involved in pedestrian crashes, with other evidence attesting to the greater involvement of males than females. One likely reason for this is that males are likely to be less inclined to wait on red signals and more likely to cross illegally. The literature review noted that pedestrian crashes are reasonably well spread across the day with some evidence of peaks at night, particularly late at night and early morning. Pedestrian crashes most frequently occur on urban roads though pedestrian injuries can be more severe when crashes occur in areas outside the urban area, mostly likely because of higher speed zones and resulting impact speeds. Other evidence points to a high frequency of crashes at midblock compared with intersections, with midblock crashes more likely to result in more serious injury outcomes. The behaviour of pedestrians has been identified as a significant factor in the likelihood of a crash occurring. The most common behaviours are crossing against the red signal and misjudging clearances required to cross. Alcohol has also been identified to compromise pedestrian safety, as has the use of mobile phone and using headphones for listening to music. In Western Australia there is limited information on the role of alcohol in pedestrian crashes and no information on distraction and pedestrian crashes. A number of countermeasures have been identified to reduce pedestrian crashes and injury, particularly at intersections. The most significant include signal timing modifications; the implementation of exclusive walk pedestrian phasing; leading pedestrian intervals to give pedestrians a head start to cross the road and avoid conflict with turning vehicles; dwell on red; improved clearance times; the introduction of countdown timers to advise pedestrians of the remaining crossing time, and reduced speed limits to minimise impact speeds and associated injuries. Some of these initiatives operate in Western Australia but it is also noted that many exclusive walk intersections in the Perth CBD are being converted to parallel walk. This has the potential compromise pedestrian safety.

Summary of the main findings of the analysis of the Perth CBD pedestrian crash data

- A total of n=4,326 crashes occurring at traffic intersections in the Perth Central Business District were reported to WA Police during the period 2008-2012.

- Disaggregating the data by the nature of the crash showed that n=88 (2%) of crashes at intersections in the Perth CBD reportedly involved a total of n=93 pedestrians.
- Injury information was available for n=4 of the n=90 drivers/riders and n=56 (60%) of the n=93 pedestrians involved in a crash. A total of n=23 involved pedestrians were either killed (n=1) or sustained injuries serious enough to require transportation to, if not admittance, to hospital (41.7% of those with an injury outcome). A further n=24 required medical attention at the scene, while another nine sustained injuries but did not require treatment (58.9% of those with an injury outcome).
- Compared with females, males were more frequently involved as both drivers/riders and pedestrians, accounting for around six in ten involved road users.
- The majority of involved drivers/riders and pedestrians were younger in age, that is, under 40 years. Around two-thirds (66.2%) of drivers/riders were aged 20-39 years, while a similar proportion (64%) of pedestrians were aged 17-39 years. Involvement was found to significantly vary with age for both drivers/riders and pedestrians.
- The available crash records provided incomplete information on the possible contribution of alcohol to the crash involvement of pedestrians. The BAC record for one pedestrian was found to be zero.
- The frequency of pedestrian crashes at intersections was noted to vary significantly with time of day. Most notably, seven in ten pedestrian crashes occurred in the 12 hours between 06:00 and 17:59.
- Though there were slight peaks in the distribution of pedestrian crashes on Wednesdays (19.3%) and Fridays (18.2%), crashes did not significantly vary by day of week.
- Where the speed limit of the crash location was recorded, it varied between 40km/hour and 60km/hour, with the majority (84.6%) of crashes recorded to have occurred in a 50 km/hour zone.

- Around three-quarters of crashes involved pedestrians (75.4%) reportedly being struck by a vehicle as they crossed the road (*near* and *far* side collisions).
- Around six in ten vehicles collided with pedestrians as they were travelling straight ahead, with a further three in ten colliding with pedestrians as they attempted to turn left or right.
- Eighty-five percent (n=75) of the identified pedestrian crashes occurred at intersections which were exclusively controlled by traffic lights. In effect, pedestrians in the CBD were 6.6 times more likely to be involved in a collision with a vehicle at a traffic light controlled intersection compared with intersections with other traffic controls or no control.
- The n=75 pedestrian crashes at traffic light controlled intersections occurred across 41 different sites and involved n=75 drivers and n=75 pedestrians.
- Of the n=41 traffic light controlled intersections in the CBD recording one or more pedestrian crashes between January 2008 and December 2012, around half continuously operated as parallel walk intersections, 41.5% were operated continuously as exclusive walk with another three converted from exclusive to parallel walk during 2010 and 2011.
- Approximately six crashes were recorded at the three converted intersections in the period after January 2008 and prior to the upgrade (noted to occur in 2010 and 2011), and four crashes following the conversion (2010/2011 – 2012).
- Investigation of the reported movements of pedestrians at the time of the crash for exclusive and parallel walk signalized intersections showed very few differences. The proportion of pedestrians involved in a collision near side (45.7%) while crossing the road was slightly higher at exclusive walk intersections while the proportion of pedestrians involved in a collision far side while crossing the road was slightly higher (39.5%) at parallel walk intersections.

- Pedestrians crossing the road at both crossing signal types (exclusive and parallel) are more likely to be involved in a collision (near and far side) with a vehicle that was reportedly proceeding straight ahead through the intersection as opposed to turning into the intersection.
- When near and far side pedestrian crossing collisions are aggregated, n=18 (70%) of the n=26 crashes at Exclusive Walk intersections involved collision with a vehicle travelling straight through. This pedestrian/driver/vehicle movement scenario also accounted for 90% (n=25/28) of collisions at Parallel Walk intersections.
- Analysis was undertaken of the distribution of n=39 pedestrian crashes across head start and non-head start phased parallel walk traffic light controlled intersections. The slightly higher proportion of pedestrian crashes at non-head start intersections (56.4%) was found not to be statistically significant.
- Cross-tabulation of head start phasing by driver/vehicle movement showed that drivers were somewhat more likely to collide with pedestrians when proceeding straight ahead at non-head start intersections (72.7%) compared with head start intersections (64.7%).
- Analysis of the distribution of pedestrian crashes in relation to the operation of Walk-Don't Walk pedestrian signals showed that more than nine in ten pedestrian crashes at traffic light controlled intersections occurred when Walk-Don't Walk lights were in operation.

Summary Discussion and Recommendations

This study has shown that for the period 2008-2012 around 4.8 pedestrian crashes occurred every 100 days at intersections in the Perth Central Business District. These crashes involved 93 pedestrians and 90 driver/riders. Where personal injury information was available, it showed that the majority of involved pedestrians sustained minor injuries, even though the crashes were observed to occur in speed zones of 50-60km/hour. Given the relatively low proportion of pedestrians experiencing death and serious injury, it is likely that the associated impact speeds were less than the posted speed limits. Notwithstanding this point, the risk of pedestrian collision and injury could be further reduced if speed limits in this high pedestrian-high traffic volume area were reduced to speeds within biomechanical tolerances, eg., ≤ 30km/hour.

Males and younger age persons (under 39 years) were more likely to be involved in pedestrian crashes. Suggested reasons for this include greater risk taking by way of illegal crossing behaviour and distracted walking behaviours and potentially greater exposure, particularly at night when younger age pedestrians were somewhat more likely to be involved in a crash.

The findings also showed that 85% percent of crashes occurred at traffic light controlled intersections, which is not surprising given the CBD location where traffic light controls dominate intersections. Analysis of these crashes showed a very clear and dominant pattern of pedestrians being struck on the near and far side by vehicles proceeding straight ahead through the intersection as opposed to turning. This pattern occurred across exclusive walk and parallel walk intersections. Illegal crossing behaviours and pedestrians failing to clear intersections (late completers) are proposed as likely scenarios underlying this crash pattern and mitigating the crash protection properties of exclusive walk intersections. These behaviours could be addressed by:

- a change in cycle times to reduce the length of time pedestrians wait on red;
- providing real time information on the ‘time to the next green signal’; and,
- the installation of countdown timers to advise pedestrians on time left to cross.

Despite the fact that exclusive walk phasing for pedestrians has been shown to be an effective measure to reduce pedestrian crashes and injuries when pedestrians cross legally, since 2010 a number of exclusive walk intersections have been converted from exclusive walk to parallel walk with more expected in the last quarter of 2013. Unfortunately a number of methodological issues (e.g., too few converted sites, few crashes, and limited post conversion follow up time) the study was not able to determine whether the conversion program has to date increased the frequency of pedestrian crashes. The issue should be reinvestigated after more intersections have been converted and a longer post-conversion period has occurred.

Investigation of pedestrian crashes at signalised intersections in relation to head start phasing and Walk-Don't Walk pedestrian signals showed crashes were equally likely to occur at intersections with and without head start phasing and that nearly all of the signalised intersections recording a crash utilised Walk-Don't Walk signals. Notwithstanding the small number of crashes available for analysis, these findings suggest again that the safety benefit associated with these measures is perhaps being undermined by illegal crossing behaviours. This presumption should be investigated through observational surveys at intersections. This undertaking would also provide valuable information on the level of pedestrian activity at intersections required for a more valid and reliable estimate of the risk of pedestrian collision.

Following on from these findings it is recommended that Main Roads Western Australia:

1. Undertake observational surveys of pedestrian crossing behaviour at traffic light controlled intersections in the CBD to determine the type and frequency of behaviours that increase pedestrian crash risk; some characteristics of those undertaking the behaviours, and data on the level of pedestrian activity at intersections (for use as a denominator of 'exposure').

2. Undertake surveys to document pedestrians' understanding and awareness of Walk-Don't Walk signals. If warranted, education campaigns should be developed and implemented to address misperceptions and misunderstanding of legal and safe crossing behaviours and reinforced with appropriate police enforcement.

3. Investigate the development of trials to examine the impact on crossing behaviour of the following countermeasures for application in the Perth Central Business District:
    - A change in signal cycle time to reduce the length of time pedestrians 'wait on red'.
    - Providing real time information on the 'time to the next green signal'.
    - The installation of countdown timers to advise pedestrians on time left to cross.
4. Continue to the monitor the frequency and pattern of crashes at intersections converted from exclusive to parallel walk and develop a comprehensive plan for a future evaluation of this program on the impact on both crashes and crossing behaviour.
5. Investigate the appropriateness of further reductions in posted speed limits in high pedestrian locations in the CBD to comply with known biomechanical tolerance to reduce injury severity.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the assistance Ms Sharon Forster and Mr Tony Radalj of Main Roads Western Australia for their assistance with information on the Parallel Walk program in the Perth Central Business District, the supply of pedestrian crash data, and comments on drafts of this report. Thanks are also extended to Ms Julie Dalla-Costa and Ms Claire Thompson of the Office of Road Safety for their comments on drafts of this report.

1. INTRODUCTION

Pedestrian crashes and injuries are a substantial road safety problem, particularly in developing, low-income countries (WHO, 2013). It is estimated that pedestrian crashes may account for up to 22% of road traffic fatalities globally, with the highest relative proportion of pedestrian deaths occurring in low-income countries (36%) in the African and South-East Asian regions (WHO, 2013). In comparison, pedestrians account for around 18% of road user deaths in high-income countries (WHO, 2013). The USA and Australia are two of the better performing high-income countries, with pedestrian fatalities accounting for around 13% of total road fatalities in the USA (National Highway Traffic Safety Administration [NHTSA], 2012) and Australia (BITRE, 2013) and 14% in Western Australia (BITRE, 2013). However, unlike the USA were the proportion of pedestrian fatalities has remained relatively stable since 2001 (NHTSA, 2012), pedestrian road deaths in Australia have gradually declined by 3.4% per annum since 2003 (BITRE, 2013).

Pedestrians are a diverse group of road users, varying in ages and abilities. Most importantly they are a highly vulnerable road user group because of their limited capacity to withstand biomechanical forces. Within the shared roadway environment, pedestrians and vehicles encounter many opportunities for conflict and potential injury, including fatality (World Health Organisation [WHO], 2004). As reported by McLean, Anderson, Farmer, Lee and Brooks (1994) the risk of injury for pedestrians, as measured by the Injury Severity Scores (ISS), when involved in crashes with motorised vehicles is strongly and linearly associated with vehicle impact speeds – rising significantly at impact speeds of 30km/hour. This relationship provides strong support for the need to separate pedestrians from motorised vehicles – physically and temporally - and to reduce vehicle travel speeds in areas of high pedestrian activity where physical separation is not always possible.

Recent investigations of pedestrian crashes in Australia and elsewhere occurring at intersections (both signalised and un-signalised) and Central Business District (CBD) and shopping areas more specifically (eg., Loo & Tsui, 2005; Lee & Abdel-Aty, 2005; Carter, Hunter, Zegeer, Stewart & Huang, 2006; King, Soole & Ghafourian, 2009; Liu & Yue, 2011; Oxley, Yuen, Corben, Hoareau & Logan 2013) have highlighted the risk factors for crashes in these high pedestrian-high volume traffic locations. The importance of studying pedestrian crashes in these pedestrian dense business, entertainment and shopping locations is amplified by the increased concern of 'distracted or inattentive' walking posed by the use of mobile phone and personal music devices (Liu & Yue, 2011) and 'impaired walking' due to alcohol intoxication (NHTSA, 2012).

In Perth, Western Australia, recent investigations of pedestrian crashes have been limited to whole of state analyses (eg., Hill, Thompson, Yano & Smith, 2012) and descriptions by urban, regional and remote locations (eg., Palamara, Kaura & Fraser, 2013). More detailed analyses of high pedestrian, high traffic volume locations such as Central Business Districts have yet to be undertaken. Additional incentive to conduct a more detailed investigation of pedestrian crashes in the Perth CBD is provided by the current program by Main Roads Western Australia of converting exclusive walk signalised intersections (where pedestrians are fully protected from vehicle movements and have exclusive use of the intersection) in the CBD to parallel walk (where traffic moves in parallel with pedestrians) to improve traffic flow. This program has the potential to increase opportunities for conflict between pedestrians and vehicles. Over the period 2010 to 2013, a total of 10 exclusive walk intersections in the Perth CBD have been converted to parallel walk with more conversions planned in the near future (S. Forster personal communication 2013).

1.1 Aims and objectives

The overall aim of this study was to investigate the pattern of pedestrian crashes at traffic intersections in the Perth Central Business District, a high pedestrian, high traffic volume location. The specific objectives of the study were to:

- Review the published literature (local, national and international) to document the characteristics of pedestrian crashes at intersections and the range of measures, including signalisation, to effectively reduce pedestrian crashes and injuries in these locations.
- Analyse WA Police reported crashes for the period 2008-2012 to describe the pattern of pedestrian crashes at intersections in the Perth Central Business District.
- Investigate, where possible, the impact on pedestrian crashes at signalised intersection in the Central Business District which have been converted from ‘exclusive walk’ to ‘parallel walk’ phasing.
- Recommend cost-effective countermeasures to reduce pedestrian crashes at intersections in the Central Business District.

2. METHOD

2.1 Ethics approval

This research was undertaken with the approval of the Human Research Ethics Committee of the School of Public Health, Faculty of Health Sciences, Curtin University.

2.2 Literature search and retrieval

A review of the scientific literature published in Australia and elsewhere was undertaken to:

- Identify the range of driver, pedestrian, and road environment factors associated with pedestrian crashes; and to,
- Identify the range of countermeasures used to reduce the incidence of pedestrian crashes.

A literature search of databases including Google scholar, ProQuest, Current Contents, Scopus, Factiva and EconLit was undertaken using ‘key words’ to retrieve local, national and international publications (books, reports, scientific journal articles, conferences papers) relevant to the topic.

2.3 Data sources for the analysis of pedestrian crashes occurring in the Perth Central Business District

Main Roads Western Australia provided two data sets required for the analysis of pedestrian crashes in the Perth Central Business District (CBD) and the impact of Main Roads Western Australia (MRWA) initiated changes in pedestrian signalisation on pedestrian crashes. The first was an extraction from the MRWA Integrated Road Information System (IRIS) of police reported crashes 2008-2012 occurring at designated road intersections in the area defined as the Perth Central Business District. Intersection crashes are defined as those occurring within the intersection itself or within 20 metres of the intersection. The second dataset was an Excel spread sheet of phasing and characteristics of signalised intersection in the CBD. This database had been prepared to document changes in the pedestrian signal phasing from *Exclusive Walk* to *Parallel Walk.*

2.4 Data management and analysis

The signalised intersection database and the extract of crash records from the IRIS database were imported into SPSS (Version 19) and merged. Descriptive analyses were subsequently undertaken of the crash and person level data to describe the incidence and pattern of pedestrian crashes and the relationship with characteristics of the intersection, particularly the pedestrian signal phasing information, and the occurrence of crashes.

3. LITERATURE REVIEW

This Chapter presents a review of the published and 'grey literature' on factors related to pedestrian crashes and injury and information on countermeasures to reduce the incidence of pedestrian crashes, particularly at intersections.

3.1 Sex and age of involved pedestrians

It has been noted elsewhere that males are more likely than females to be involved in pedestrian crashes (NHTSA, 2012; Transport Canada, 2009). This trend has been similarly observed in Australia with males accounting for 67% of pedestrians killed across Australia in 2013 (BITRE, 2013). In Western Australia, males accounted for 62% of pedestrians killed or hospitalised in the period 2005-2009 (Palamara et al., 2013). Other evidence suggests that the relationship between gender and risk of pedestrian crash and injury is moderated by environmental factors. For example, Palamara et al. (2013) noted that males were significantly more likely to be seriously injured as pedestrians in remote (74%) versus urban locations (61%), while Oxley et al. (2013) found that males and females were near equally represented in pedestrian injury crashes in the Melbourne Central Business District.

Age appears to be a critical factor in relation to the risk of a pedestrian crash and injury, with children (under 16 years) and older age persons ($\geq$ 70 years) recording higher proportions of pedestrian deaths. In both the USA (NHTSA, 2012) and Australia (BITRE, 2013) pedestrian deaths account for approximately 20% of road deaths, and 15.3% and 26% of deaths in person aged 70+ years in the USA (NHTSA, 2012) and Australia (BITRE, 2013) respectively. In Western Australia, pedestrians accounted for around 28% of all children aged up to 16 years killed or seriously injured on the road and 9% for those aged 60+ years (Thompson, Hill, Beidatsch & Bramwell, 2013).

Developmentally, children are far more vulnerable than adults for involvement in a pedestrian collision. Before twelve years of age, as well as taking smaller steps than adults and being less visible, children are not able to accurately judge the road environment and make safe and sound decisions for their own safety (Department of Transport WA, 2011). Typical pedestrian behaviours of younger age children include crossing between parked cars (Martin, 2006; Transport Canada, 2009) or running out into the street (Transport Canada, 2009) which places them at risk of collision. Multiple regression modelling of children's responses in a simulated road crossing environment indicated that six year olds made a critically incorrect decision to cross the road one in six times compared to one in 39 times for ten year olds (Congiu, Whelan, Oxley, D'Elia, & Charlton, 2006). Further, it is interesting to note that responses to the Adolescent Road User Behaviour Questionnaire in New Zealand indicated that there was no gender difference in road crossing behaviours for 13-16 year olds (Sullman & Mann, 2009).

Like children, those aged 65 years or above are typically over-represented in pedestrian fatalities (Chang, 2008; Gitelman, Balasha, Carmel, Hendel, & Pesahov, 2012; Naumann et al., 2010; Transport Canada, 2009) and have a greater risk of fatal injury or death due to a pedestrian-vehicle conflict (Dunbar, Holland, & Maylor, 2004; Oxley, 2010) for a number of reasons. Slower walk speeds (Ishaque & Noland, 2008; Martin, 2006) and inappropriate road crossing decisions (Oxley, Ihsen, Fildes, Charlton, & Day, 2005) contribute to this, although older individuals are more likely to use pedestrian crossings (Martin, 2006) than younger individuals (Allsopp et al., 2007). It has been reported however, that 10% of those aged 65 - 74 years hit by a vehicle were crossing a road where there was no intersection or crosswalk (Transport Canada, 2009).

3.2 Temporal characteristics

Pedestrians are most likely to be injured or killed from a vehicle collision towards the later hours of the day. In fact, around two thirds of pedestrian deaths occur in low-light conditions (Zegeer & Bushell, 2012) although slightly lower figures of 41% - 59% have been reported (Gitelman et al., 2012; Transport Canada, 2009). In accordance with low light conditions, the NHTSA report that pedestrians were more likely to be killed on weekdays between 6pm and 9pm (24.3%) and on weekends between 6pm and 9pm and 9pm to midnight (NHTSA, 2012). Additionally, pedestrian injury was more likely to occur at 3pm to 6pm or 6am to 9am on weekdays, and 6pm to 9pm at weekends (NHTSA, 2012). Devlin, Hoareau, Logan, Corben, and Oxley (2010) reported that serious injury or fatal pedestrian accidents were greater at 3pm to 7pm with a 3pm to 4pm peak. Transport Canada (2009) reported that 54% of pedestrian fatalities occurred between 3pm and midnight, with a 6pm to 9pm peak, which accounted for 22% of pedestrian fatalities. Additionally, it is often reported that pedestrian crashes increase toward the end of the week (Devlin et al., 2010; Florida Department of Highway Safety and Motor Vehicles, 2011; Transport Canada, 2009) or on weekends, where fatality is more likely (Chang, 2008).

For Western Australia, Palamara et al. (2013) reported a statistically significant association between time of day and location of killed and serious injury pedestrian crashes. Pedestrians were significantly more likely to be killed or seriously injured in metropolitan Perth in the midday to midnight period, while pedestrians were more likely to be killed or seriously injured midnight to 6.00 am in remote Western Australia.

3.3 Road characteristics

Fatal or injurious pedestrian accidents most commonly occur on urban roads (Antonucci, Hardy, Slack, Pferfer, & Neuman, 2004; Gitelman et al., 2012). Data for Western Australia 200and although they are more likely to involve older pedestrians at intersections (Dunbar et al., 2004), it has been reported that mid-block fatality rates are often higher. Early research into mid-block and intersection fatality rates found that between 1986 and 1993, 8.7/100 and 6.6/100 total pedestrian injuries occurred at mid-blocks and intersections respectively (Chu, 2006). Over the next nine years these rates decreased slightly to 8.2/100 and 5.6/100 (Chu, 2006). Similarly Devlin et al. (2010) reported that 54% of pedestrians were killed or seriously injured at mid-blocks and 45% at intersections. More detailed information about mid-blocks and signalised intersections is provided below.

3.3.1 Mid-blocks

It is consistently reported that mid-block pedestrian crashes are more likely to result in higher severity injury or death than those which occur at signalised intersections (Rothman, Howard, Camden, & Macarthur, 2012). Rothman et al. (2012) reported an adjusted confidence interval (CI) of 1.00 for injury severity at signalised intersections compared to 1.75 for uncontrolled mid-blocks. Research conducted in Florida also highlighted the increased injury risk for pedestrians crossing at mid-block locations (Chu, 2006). It was reported that pedestrians were 49% less likely to sustain a fatal injury at an intersection than a mid-block in daylight (Chu, 2006).

3.3.2 Signalised intersections

Pedestrian conflicts at signalised intersections can occur for four main reasons: vehicles turning right on red, vehicles turning right on green, vehicles turning left on green, and vehicles running a red light (Rodegerdts et al., 2004). While some state that left turning vehicles are at a four times increased risk to pedestrians than right turning vehicles (Lord, Smiley, & Haroun, n.d.), the visibility of pedestrians under right turn conditions is also low (Austroads, 2012) and some European countries eliminate right turns under certain conditions (Fong et al., 2003). In Victoria, a study on signalised intersections found that just over nine percent of signalised intersection crashes over a five year period involved pedestrians (Ogden & Newstead, 1994). Similarly, in Tasmania during the 2007 – 2011 period, 11% of serious casualty crashes involved pedestrians, 6% of which occurred at intersections (Department of Infrastructure Energy and Resources, 2012).

In a study of the association between intersection characteristics and pedestrian crash risk in California, intersections with more right-turn-only lanes were associated with more pedestrian crashes (Schneider et al., 2010).

3.4 Pedestrian behaviour and impairment/distraction

Pedestrian behaviour including illegal activities and poor judgement are thought to be major contributing factors to their involvement in crashes, accounting for up to one third of fatal crashes (US Department of Transportation, 2004). Behavioural characteristics can include crossing on the red signal or without adequate clearance on unsignalised intersections to save time or increase convenience (Sisiopiku & Akin, 2003). Typically, males are more likely to cross away from designated crossing areas (Martin, 2006) and violate signals (Hurwitz & Monsere, 2013) which are fairly common pedestrian behaviour. Twenty-one percent of the pedestrians observed in a study conducted in Vancouver committed some sort of road-rule violation, with a range of 12% - 39%, compared with 5.9% (1,051) of vehicles (Cinnamon, Schuurman, & Hameed, 2011). In a study by Ragland, Markowitz and

MacLeod (2003) the most often reported signal violation-based behaviour committed by pedestrians was failure to yield. Tiwari, Bangdiwala, Saraswat & Guarav (2007) noted that crossing on red was more common among males than females due largely to males having shorter wait times on red. In another study of pedestrian crossing behaviour by Rosenbloom (2009) it was noted again that males crossed illegally more frequently than females and that doing so was most likely when no other pedestrians were present. Finally, King, Soole, Ghafourian (2009) found high levels of illegal crossing in the Brisbane CBD and that this behaviour increased the risk of crashing per crossing by a factor of eight compared with legal crossing at signalised intersections.

Alcohol affected pedestrians pose a significant risk to themselves and other road users due to their compromised ability to make logical decisions. Overseas research reports that pedestrians who sustain an injury whilst under the influence of alcohol are most likely to be young males and unemployed (Dultz & Frangos, 2013). The National Highway Traffic Safety Administration in the US reported that 18.4% of pedestrians were killed whilst under the influence of alcohol, medication or drugs (National Highway Traffic Safety Administration [NHTSA], 2012). However, for alcohol-related pedestrian deaths alone figures reported range from 9.43% - 46% (Chang, 2008; Florida Department of Highway Safety and Motor Vehicles, 2011). In Western Australia for the year 2012, Blood Alcohol Concentration levels were known for seven of the 24 pedestrians killed in that year. All seven returned BAC levels in excess of 0.05gm%, with six recording BACs in greater than or equal to 0.15gm%. These cases were equally distributed across regional and remote Western Australia (Thompson et al., 2013).

In more recent years attention has been directed to distracted walking, largely as a result of the increase in use of mobile phones and portable music devices. Hatfield and Murphy (2007) noted from an observation study of pedestrian behaviour at signalised and unsignalised intersections that the use of a mobile phone was associated with cognitive distraction and served to compromise pedestrian safety. Pedestrians were noted to move more slowly and to be less frequent observers of traffic. Similarly, Schwebel et al. (2102) found that pedestrians undergoing tasks in a 'virtual street' while talking or texting on a phone or listening to music were more likely to be distracted and to be 'hit' by a vehicle. Finally, an analysis of pedestrian crashes in the US noted a relationship between use of headphones and fatal injury for persons under 30 years. No information is currently available in Western Australia to quantify the risk associated with distraction for pedestrians.

3.5 Countermeasures to improve pedestrian safety

Two main strategies exist to reduce pedestrian-vehicle crashes; the separation of pedestrians and vehicles by time and the separation of pedestrians and vehicles by space (Retting, Ferguson, & McCartt, 2003).

3.5.1 Signal timing modifications

Signal timing optimises the interaction between vehicles and pedestrians at signalised intersections in a safe and effective manner. Effective implementation of signal timing depends on four factors; location, intersection geometry, characteristics of the road user and characteristics of the transportation network (Koonce et al., 2008). In one study that up to sixty percent of pedestrian signal intervals were deficient when the average walk speed of 4ft/second was used in determining pedestrian signal length (Nguyen & Ragland, 2007). Various studies have focused on changing signal timing to improve pedestrian compliance and decrease pedestrian vehicle conflicts. However, although signalised intersections provide some protection to pedestrians, it is well known that pedestrians will take the quickest possible route to their destination to minimise delay and reduce walking distance (Martin, 2006) therefore pedestrian signals are not always adhered to; the timing of signals can significantly effect this outcome.

Various modifications of signal timing exist to separate pedestrians and vehicles by time. While re-timing traffic signal intervals has been shown to reduce pedestrian crashes by 37% ($p = 0.03$) compared to control intersections (Retting, Chapline, & Williams, 2002), a closer look at specific treatments provides a more focused insight. The implementation of exclusive pedestrian intervals, leading pedestrian intervals and dwell-on-red treatments have been shown to be somewhat effective in reducing the likelihood of pedestrian-vehicle collisions at signalised intersections (US Department of Transportation, 2004).

3.5.2 Exclusive pedestrian interval

An exclusive pedestrian interval stops all intersection traffic, allowing pedestrians to cross in any intended direction, including that of a diagonal nature. In such cases pedestrians are said to be ‘fully protected’ from the likelihood of colliding with all vehicles, all of whom are facing a red signal. An exclusive pedestrian phase was implemented at eight intersections in Beverly Hills in 1987. A follow up study ten years later found that six of the eight intersections which retained the exclusive pedestrian phase resulted in pedestrian-intersection crash reductions of 66% within the 10 year period at a cost of $500-700 per intersection (Vaziri, 1996). Similarly, Campbell, Zegeer, Huang, and Cynecki (2004) reported a 50% reduction in pedestrian motor vehicle collisions where exclusive pedestrian intervals were added. However, the authors did conclude that exclusive pedestrian intervals are most appropriate where there are many pedestrians who comply to signals and a low volume of vehicles (Campbell et al., 2004).

3.5.3 Leading pedestrian interval

As the name suggests, a leading pedestrian interval allows pedestrians a *head-start* in crossing an intersection, a time period (typically 3-5 seconds) within which vehicle signals remain red. A problem intersection in Orlando made use of a four second leading pedestrian interval (LPI) to give pedestrians a head start in crossing the road before cars could start to turn left on the green phase for parallel vehicles. Although accident rates remain unchanged at this intersection, the separation of vehicle and pedestrian in time ultimately yields benefits to the pedestrian, as they are more visible to drivers and are therefore safer as a result of this phasing change (Holland, n.d).

Three intersections in St. Petersburg, Florida similarly trialled an LPI phase of three seconds by increasing the all red signal phase. Of the 44 pre-treatment observation periods, 34 had no conflicts after the three second LPI phase was implemented (Van Houten, Retting, Farmer, Van Houten, & Malenfant, 2000).

3.5.4 Dwell-on-red treatment

A trial-based study by Lenné, Corben, and Stephan (2007) investigated signal phasing for improved signalised intersection safety of alcohol-affected pedestrians via the introduction of a dwell-on-red signal phase. Two vehicle speed measurement points were used: stop line and thirty meters prior to the stop line, indicative of speed at which vehicles would impact with a pedestrian and the distance at which the speed and resulting braking distances indicate crash risk, respectively. Speed reductions of 28% were observed at the intersection stop line, and 9% thirty metres prior to the stop line (Lenné et al., 2007).

3.5.5 Clearance intervals

The period of time between the end of a green phase for one traffic stream, and the start of a green phase for the opposite traffic stream is known as the clearance interval (Antonucci et al., 2004). Short clearance intervals can cause an increase in run-on red traffic violations (Antonucci et al., 2004). However, increasing clearance intervals often leads to an increase in total cycle length (Antonucci et al., 2004) but pedestrian compliance is encouraged by *shorter* cycle length, a characteristic of intersection phasing that has been noted and applied in Sweden and Germany, where signal cycle lengths are a maximum of 100 seconds and 120 seconds, respectively (Fong et al., 2003). Consequently, clearance interval timings should be optimised to allow for efficiency for both pedestrians and vehicles, keeping in mind that both road users may violate traffic signals at the onset of a clearance interval (Fugger Jr, Randles, Stein, Whiting, & Gallagher, 2000; Retting et al., 2002).

In their analysis of recommended walking speeds based on pedestrian characteristics Gates, Noyce, Bill, and Van Ee (2006) recommend the following pedestrian clearance interval timings;

- 3.8ft/second where pedestrian demographics are unknown;
- Walk speeds of 3.6 – 3.3ft/second when pedestrians aged 65 or above are around 20% - 50% of intersection users; and
- Walk speeds of 2.9ft/second where pedestrians aged 65 or above are the dominant intersection user.

3.5.6 Pedestrian behaviour-focused countermeasures

Pedestrian countdown timers

Recent research has focused on pedestrian countdown timers (PCTs) and their effectiveness on pedestrian behaviour. PCTs numerically display how much time is left during each phase of the pedestrian signalling cycle. An early evaluation of PCTs in Buena Vista found that pedestrian compliance with the Walk signal significantly decreased at PCTs intersections compared to controls ($p = 0.005$) (Huang & Zegeer, 2000). A more recent before-after observational study to trial PCTs during the flashing Don't Walk phase conducted in the Sydney CBD showed that at one of two intersections, late starters increased by 19.2% (1606 pedestrians) (Cleaver et al., 2011). Pedestrians were more likely to increase their walk speed as a result of PCTs (Cleaver et al., 2011). Similar results were found in a trial-based study conducted in Wellington, New Zealand (Wanty & Wilkie, 2010). Trial based studies have limitations such as small sample size and subjectivity. However, insights are made into the effectiveness of PCTs at a small-scale level.

A crash ratio investigation conducted in Charlotte, North Carolina found that intersections which experienced high and medium crash levels experienced a decrease in the number of crashes, but low crash intersections saw an increase after PCT installation (Pulugurtha, Desai, & Pulugurtha, 2010). Pedestrian-vehicle crashes decreased by 13%, a statistically insignificant reduction in comparison to overall crash reduction frequencies (Pulugurtha et al., 2010). Pedestrian and motorists made safer decisions at signalised intersections where PCTs were installed, however (Pulugurtha et al., 2010). Camden, Buliung, Rothman, Macarthur, and Howard (2012) reported that PCTs had no impact on the number of pedestrian-vehicle collision rates at 1965 signalised intersections.

Animated eyes

Animated eyes are a behavioural intervention which reminds pedestrians to look both ways before crossing. A pilot study conducted by Vasudevan, Pulugurtha, Nambisan, and Dangeti (2011) reported that animated eyes effectively improved pedestrian crossing behaviour. In evaluating the effectiveness of animated eyes on reducing the number of pedestrian-vehicle conflicts at 8 intersections, the Florida Department of Transportation (2000) reported a significant decrease ($p < .05$) in median conflicts at seven of 8 intersections which translated to a drop from 8.5/400 pedestrian conflicts, to only 1/400 across all intersections (Florida Department of Transportation, 2000). The Florida Department of Transportation (2000, p3) suggested "*…animated 'eyes' produce a significant reduction in motor vehicle/pedestrian conflicts that could be expected to translate into meaningful reductions in crashes at signalised intersections…*". Further, a small sample of vision impaired people were more able to accurately identify the Walk interval when animated eyes were present (Florida Department of Transportation, 2000).

Automated video detection of pedestrians to adjust signal timing

Research has identified a slight but non-significant reduction in pedestrians who finished crossing on solid red (14% - 12%), but the video detection device did successfully extended crossing time for late crossing pedestrians (AASHTO, 2010)

3.5.7 Additional road treatments to safeguard pedestrians: Refuges, barriers, islands

To decrease the likelihood of a pedestrian-vehicle collision, separation of both parties can be implemented through refuge islands, pedestrian barriers/fences, pedestrian overpasses, advance stop lines and sidewalks (Retting et al., 2003).

Firstly, there are two types of pedestrian refuge islands which can be implemented to separate pedestrians and vehicles: isolated concrete islands and refuge islands with push buttons. Isolated concrete refuge islands are a relatively low cost pedestrian safety measure (Department of Transport WA, 2011) which breaks pedestrian exposure and crossing time into smaller increments (Institute of

Transportation Engineers [ITE], 2004) and decreases the cognitive load of crossing a road for older individuals where vehicles travel in both directions (Oxley, Corben, Fildes, & Charlton, n.d.). Refuge islands with push buttons allow pedestrians to cross intersections in stages, which allows for signal cycle length reduction without detriment to those who may not be able to cross all of the way in a shorter time period (ITE, 2004).

There is minimal evidence on the effectiveness of barriers and bollards to either protect pedestrians from vehicles, or to prevent pedestrians from crossing at points in the road which may be dangerous.

As part of the San Francisco FHWA Pedsafe Project, a pre/post analysis of 13 potential countermeasures to reduce pedestrian collisions was conducted (Hua, Gutierrez, Markowitz, Banerjee, & Ragland, 2008). The effectiveness of pedestrian refuge islands was inconclusive (Hua et al., 2008).

3.5.8 Vehicle speed management to reduce pedestrian crashes

Vehicle speed management can include modern roundabouts, traffic calming measures and multi-way stop-sign control (Retting et al., 2003). Speed reduction increases driver reaction time and decreases injury severity, and is an important consideration in regards to children, who have an increased likelihood of pedestrian crashes (Retting et al., 2003). It is known that relatively small speed reductions lead to large reductions in the risk of pedestrian fatality (Corben, D'Elia, & Healy, 2006).

3.6 Summary

Younger and older age persons are more frequently involved in pedestrian crashes, with other evidence attesting to the greater involvement of males than females. One likely reason for this is that males are likely to be less inclined to wait on red signals and more likely to cross illegally. The literature review noted that pedestrian crashes are reasonably well spread across the day with some evidence of peaks at night, particularly late at night and early morning. Pedestrian crashes most frequently occur on urban roads though pedestrian injuries can be more severe when crashes occur in areas outside the urban area, mostly likely because of higher speed zones and resulting impact speeds. Other evidence points to a high frequency of crashes at midblock compared with intersections, with midblock crashes more likely to result in more serious injury outcomes. The behaviour of pedestrians has been identified as a significant factor in the likelihood of a crash occurring. The most common behaviours are crossing against the red signal and misjudging clearance times required to cross. Alcohol has also been identified to compromise pedestrian safety, as has the use of mobile phone and using headphones whilst listening to music. In Western Australia there is limited information on the role of alcohol in pedestrian crashes and no information on distraction. A number of countermeasures have been identified to reduce pedestrian crashes and injury, particularly at intersections. The most significant include signal timing modifications; the implementation of exclusive walk pedestrian phasing; leading pedestrian intervals to give pedestrians a head start to cross the road and avoid conflict with turning vehicles; dwell on red; improved clearance times; the introduction of countdown timers to advise pedestrians of the remaining crossing time, and reduced speed limits to minimise impact speeds and associated injuries. Some of these initiatives operate in Western Australia but it is also noted that many exclusive walk intersections in the Perth CBD are being converted to parallel walk. This has the potential compromise pedestrian safety.

4. ANALYSIS OF PEDESTRIAN CRASHES AT INTERSECTIONS IN THE PERTH CENTRAL BUSINESS DISTRICT 2008-2012

4.1 Introduction

A total of n=4,326 crashes occurring at traffic intersections in the Perth Central Business District were reported to WA Police during the period 2008-2012. WA Police attended approximately n=830 (19.2%) of the recorded crashes, with no information on police attendance for n=27 crashes. Police attendance was substantially higher (85%) for crashes that resulted in either the death (n=1) or hospitalisation (n=144) of an involved road user.

Disaggregating the data by the nature of the crash showed that n=88 (2%) crashes at intersections in the Perth CBD reportedly involved one or more pedestrians (n=93)[1]. As shown in Table 4.1, Perth CBD intersection crashes most commonly involved collisions between two or more vehicles (eg., rear end collisions 52.3%; right angle collisions 16.8%; vehicles from the same direction sideswiping each other 15.6%; right turn thru collisions 10.7%).

Table 4.1 Nature of WA Police reported crashes occurring at intersections in the Perth Central Business District 2008-2012

Nature of Crash	n	%
Rear End	2183	52.3
Head On	4	0.1
Sideswipe Same Direction	649	15.6
Right Angle	699	16.8
Right Turn Thru	448	10.7
Hit Pedestrian	88	2.1
Hit Animal	84	2.0
Hit Object	16	0.4
Total	**4171**	**100**

n=155 missing information on nature of crash

[1] One pedestrian was struck while riding a skateboard and one while using rollerblades.

A detailed analysis of the n=88 pedestrian crashes at intersections – the primary focus of this research - will be presented in the following sections.

4.2 Injury outcomes for road users involved in pedestrian crashes

Injury information was available for n=4 of the n=90 drivers/riders and n=56 of the n=93 pedestrians involved in a crash. The remaining involved road users, for whom no injury information was recorded, may have either been uninjured or failed to have their injury recorded by police or reported. Of the n=86 drivers with no or missing injury information, police attendance was noted for approximately half of these. Of the n=37 pedestrians with no or missing injury information, police attendance was noted for 81%. Road users with missing or no injury information were excluded from the analysis presented in Table 4.2. Of the drivers/riders with a known injury outcome only one was said to be admitted to hospital while three required medical attention at the scene. A total of n=23 (41%) of the n=56 involved pedestrians were either killed (n=1) or sustained injuries serious enough to require transportation to if not admittance to hospital (41.7% of those with an injury outcome). A further n=24 required medical attention at the scene, while another nine sustained injuries but did not require treatment (58.9% of those with an injury outcome).

Table 4.2 Injury outcomes for road users involved in WA Police reported pedestrian crashes at intersections in the Perth Central Business District 2008-2012

Injury Outcome	Drivers/Riders		Pedestrians	
	n	%	n	%
Killed	0	0.0	1	1.8
Injured - Admitted to hospital*	1		22	39.3
Injured – Medical attention only	3		24	42.9
Injured – No medical attention	0	0.0	9	16.1
All	**4**	**100**	**56**	**100**

*As recorded by police and may differ to official hospital records. n=86 drivers/riders missing injury information. N=37 pedestrians missing injury information.

4.3 Sex of road users involved in pedestrian crashes

The sex of drivers/riders and pedestrians involved in the n=88 pedestrian crashes is presented in Table 4.3. Compared with females, males were more frequently involved as both drivers/riders and pedestrians, accounting for around six in ten involved road users.

Table 4.3 Sex of road users involved in WA Police reported pedestrian crashes at intersections in the Perth Central Business District 2008-2012

Sex	**Drivers/Riders**		**Pedestrians**	
	n	**%**	**n**	**%**
Male	47	60.3	44	60.3
Female	31	39.7	29	39.7
All	**78**	**100**	**73**	**100**

n=12 missing driver/rider sex; n=20 missing pedestrian sex

4.4 Age of road users involved in pedestrian crashes

Table 4.4 shows the frequency distribution of involved drivers/riders and pedestrians by age group. Involvement was found to significantly vary with age for both drivers/riders (Chi Square: X^2=62.9 df=6; $p \leq 0.001$) and pedestrians (Chi Square: X^2=40.9 df=7; $p \leq 0.001$). The majority of involved drivers/riders and pedestrians were younger in age, that is, under 40 years. Around two-thirds (66.2%) of drivers/riders were aged 20-39 years, while a similar proportion (64%) of pedestrians were aged 17-39 years.

Table 4.4 Age of road users involved in WA Police reported pedestrian crashes at intersections in the Perth Central Business District 2008-2012

Age Group (years)	**Drivers/Riders**		**Pedestrians**	
	n	**%**	**n**	**%**
0-16	0	0.0	4	6.6
17-19	2	2.9	5	8.2
20-24	15	22.1	15	19.7
25-39	30	44.1	19	36.1
40-49	9	13.2	8	13.1
50-59	7	10.3	6	9.8
60-69	3	4.4	2	3.3
70+	2	2.9	2	3.3
All	**68**	**100**	**61**	**100**

n=22 missing driver/rider age; n=32 missing pedestrian age

4.5 Blood Alcohol Concentration Level of road users involved in pedestrian crashes

The available crash records provided incomplete information on the possible contribution of alcohol to the crash involvement of pedestrians. Blood Alcohol Concentration (BAC) level information was available for one fatally injured pedestrian for whom a BAC of zero was recorded. No BAC level information was recorded for pedestrians reportedly admitted to hospital. BAC level information was available for n=28 (31.1%) of crash involved drivers/riders, all of whom recorded a BAC of zero.

4.6 Vehicle types involved in pedestrian crashes

Around eight in ten pedestrian crashes involved collision with a motor car, with a further 10% involving collision with a bus.

Table 4.5 Types of vehicle involved in WA Police reported pedestrian crashes at intersections in the Perth Central Business District 2008-2012

Unit Type	n	%
Motor car (*sedan, station wagon, utility, panel van, 4WD, people mover*)	72	80.8
Truck	1	1.1
Bus	9	10.2
Motorcycle	4	4.5
Bicycle	3	3.4
Total	**89**	**100**

n=1 missing unit type

4.7 Time of day of pedestrian crashes

The frequency of pedestrian crashes at intersections was noted to vary significantly with time of day (Chi Square: X^2=22.5 df=3; $p \leq 0.001$). Most notably, seven in ten pedestrian crashes occurred in the 12 hours between 06:00 and 17:59. This is the period when pedestrian movement through the CBD is most likely highest.

Table 4.6 Time of day of WA Police reported pedestrian crashes at intersections in the Perth Central Business District 2008-2012

Time of Day	n	%
00.00-05:59	7	8.0
06.00-11:59	23	26.4
12:00-17:59	38	43.7
18:00-24:00	19	21.8
Total	**87**	**100**

n=1 missing time of crash

Though no statistically significant relationship was computed between age of crash involved pedestrians (up to 39 years *versus* 40+ years) and time of day of crash (Chi Square: X^2=6.68 df=3; p=0.08), there was a trend for younger age pedestrians to be involved in crashes during the hours 18:00-05:59 (40%) relative to older age pedestrians (11.1%) for the same time period.

4.8 Day of week of pedestrian crashes

Though there were slight peaks in the distribution of pedestrian crashes on Wednesdays and Fridays, crashes did not vary significantly by day of week (Chi Square: X^2=4.75 df=6; p=.57).

Table 4.7 Day of week of WA Police reported pedestrian crashes at intersections in the Perth Central Business District 2008-2012

Time of Day	n	%
Monday	13	14.8
Tuesday	11	12.5
Wednesday	17	19.3
Thursday	13	14.8
Friday	16	18.2
Saturday	9	10.2
Sunday	9	10.2
Total	**88**	**100**

Similarly, no statistically significant relationship was found between day of week of crash (Monday-Friday *versus* Saturday-Sunday) and age of crash involved pedestrian (Chi Square: X^2=0.38 df=1; p=0.62).

4.9 Season of pedestrian crashes

The season of pedestrian crashes at CBD intersections is presented in Table 4.8. Just under two-thirds of crashes occurred during the Summer and Spring seasons. The higher than expected number of crashes during these seasons was statistically significant: (Chi Square: X^2=8.09 df=3; $p \leq 0.05$) and is likely due to increased pedestrian activity during these times of year.

Table 4.8 Season of WA Police reported pedestrian crashes at intersections in the Perth Central Business District 2008-2012

Time of Day	**n**	**%**
Summer	29	33.0
Autumn	20	22.7
Winter	12	13.7
Spring	27	30.7
Total	**88**	**100**

4.10 Weather conditions at the time of pedestrian crashes

As shown in Table 4.9, nearly nine in ten pedestrian crashes at intersections in the CBD occurred when the weather was clear.

Table 4.9 Weather conditions at the time of WA Police reported pedestrian crashes at intersections in the Perth Central Business District 2008-2012

Time of Day	**n**	**%**
Clear	75	88.2
Raining	5	5.9
Overcast	5	5.9
Total	**85**	**100**

n=3 missing weather conditions at time of crash

4.11 Lighting conditions at the time of pedestrian crashes

Consistent with the information in Table 4.6, the majority (71.8%) of pedestrian crashes occurred during daylight hours. With the exception of one crash, the remainder of crashes occurred when it was dark but street lights were on – which is to be expected given the Central Business District location of the examined crashes.

Table 4.10 Lighting conditions for WA Police reported pedestrian crashes at intersections in the Perth Central Business District 2008-2012

Lighting	n	%
Daylight	61	71.8
Dawn or Dusk	1	1.2
Dark-lights on	23	27.1
Dark-lights off	0	0.0
Dark-no lights	0	0.0
Total	**85**	**100**

n=3 missing lighting information

4.12 Speed limit at pedestrian crash locations

Where the speed limit of the crash location was recorded, it varied between 40km/hour and 60km/hour, with the majority (84.6%) of crashes recorded to have occurred in a 50 km/hour zone. Though speed limit information was missing for n=36 crashes it is reasonable to assume that the limit in these crash locations would similarly have varied between 40km/hour and 60 km/hour because of the predominance of these zones within the targeted CBD area.

Table 4.11 Speed limit for WA Police reported pedestrian crashes at intersections in the Perth Central Business District 2008-2012

Speed Limit (Kilometres per Hour)	n	%
40	4	7.7
50	44	84.6
60	4	7.7
Total	**52**	**100**

n=36 missing speed limit information

Despite the relatively low speed limit at the location of these crashes, it cannot be determined from the available crash information whether or not speed contributed to the occurrence of the crash.

4.13 Intersection location of pedestrian crashes

The intersection locations for the n=88 pedestrian crashes is presented in Table 4.12. The intersections of *Beaufort Street and Roe Street* and *William Street and Roe Street* accounted for 16% (n=14) pedestrian crashes, while four other intersections accounted for a further 18% (n=16) of reported pedestrian crashes.

Table 4.12 Location of intersections for WA Police reported pedestrian crashes in the Perth Central Business District 2008-2012

Intersection Location	n	%
Adelaide Terrace &		
- Hill Street	2	2.3
- Bennett Street	3	3.4
- Plain Street	3	3.4
Barrack Street &		
- Hay Street	1	1.1
- Murray Street	1	1.1
- Riverside Drive	1	1.1
Beaufort Street &		
- Newcastle Street	1	1.1
- Roe Street	8	9.1
Colin Street &		
- Murray Street	2	2.3
Fitzgerald &		
- Aberdeen Street	1	1.1
Francis Street &	2	2.3
- William Street	1	1.1
Hay Street &		
- Irwin Street	1	1.1
- Bennett Street	1	1.1
- Victoria Avenue	1	1.1
James Street &		
- Fitzgerald Street	2	2.2

- William Street	4	4.5
Lord Street &		
- Wellington Street	1	1.1
Mill Street &		
- St. Georges Terrace	4	4.5
Milligan Street		
- Murray Street	3	3.4
- Roe Street	3	3.4
Mounts Bay Road &		
- Mill Street	2	2.3
Murray Street &		
- Pier Street	1	1.1
Outram Street		
- Hay Street	1	1.1
Newcastle Street &		
- William Street	1	1.1
- Fitzgerald Street	1	1.1
St Georges Terrace &		
- Irwin Street	1	1.1
- nr King Street	3	3.4
- nr Sherwood Court	2	2.3
The Esplanade &		
- Barrack Street	1	1.1
Thomas Street &		
- Hay Street	1	1.1
- Kings Park Road	2	2.3
Wellington Street &		
- Elder Street	3	3.4
- King Street (nr bus station)	1	1.1
- Milligan Street (nr car park)	1	1.1
- Hill Street	3	3.4
William Street &		
- Aberdeen	1	1.1
- Hay Street	4	4.5
- St. Georges Terrace	4	4.5
- Murray Street	2	2.3
- Wellington Street	1	1.1
- Riverside Drive	2	2.3
- Roe Street	6	6.8
Total crashes	**88**	**100**

4.14 Intersection traffic controls at the location of pedestrian crashes

Eighty-five percent (n=75) of the identified pedestrian crashes occurred at intersections which were exclusively controlled by traffic lights. The four pedestrian crashes reported to have occurred at ‘Midblock Traffic Lights’ (Table 4.13) were, upon closer inspection of the location of the crash noted to have occurred adjacent to a T-intersection. In effect, pedestrians in the CBD were 6.6 times more likely to be involved in a collision with a vehicle at a traffic light controlled intersection compared with intersections with other traffic controls or no control.

Table 4.13 Reported traffic controls for WA Police reported pedestrian crashes at intersections in the Perth Central Business District 2008-2012

Traffic Controls	n	%
Intersection traffic lights	75	85.2
Give Way sign	2	2.3
Zebra Crossing	1	1.1
No sign or controls	1	1.1
Pointsman	1	1.1
Traffic lights and Give Way sign	4	4.5
Midblock traffic lights	4	4.5
Total	**88**	**100**

4.15 Pedestrian and vehicle movement across all intersection crash locations

The activity or movement of pedestrians at the time of the crash was recorded for 97% of those involved. Around three-quarters of crash involved pedestrians (75.4%) were reportedly struck by a vehicle when crossing from one side of the road to the other (near and far side collisions). Near side collisions (when the pedestrian is stuck by a vehicle from their right) accounted for just over four in ten collisions, while far side collisions (when the pedestrian has crossed the median to the far side and is struck by a vehicle to their left) accounted for just over three in ten crashes.

Table 4.14 Reported movement of pedestrians involved in WA Police reported pedestrian crashes at intersections in the Perth Central Business District 2008-2012

Pedestrian movement	n	%
Crossing road – near side	39	43.3
Crossing road – far side	29	32.2
Walking/running with traffic	1	1.1
Emerging from behind parked vehicle	5	5.6
Walking/running but not on carriageway	1	1.1
Activity not 'codeable'	3	3.3
Activity unknown	6	6.7
Working on carriageway	2	2.2
Stationary on carriageway	3	3.3
Stationary off carriageway	1	1.1
Total	**90**	**100**

n=3 missing pedestrian movement information

Restricting the analysis to pedestrian crashes occurring at traffic light controlled intersections only similarly showed that three-quarters (n=54) of the n=75 pedestrians collided with vehicles on the near and far side. Again, this information alone does not provide sufficient information to determine if the pedestrian was struck whilst obeying or disobeying the pedestrian signals.

Additional information about the circumstances of the collision and the conflict with the vehicle is provided by an analysis of the driver/vehicle movement data. As shown in Table 4.15, around six in ten vehicles colliding with pedestrians did so as they were travelling straight ahead, with a further three in ten colliding with pedestrians as they attempted to turn left or right. Again, this information does not per se provide sufficient information to determine if the pedestrian or driver were disobeying whatever traffic controls applied at the time of the crash.

Table 4.15 Reported movement of drivers (vehicles) involved in WA Police reported pedestrian crashes at intersections in the Perth Central Business District 2008-2012

Time of Day	n	%
Turning – left turn	15	16.7
Turning – right turn	13	14.4
Reversing or rolling back – straight line	3	3.3
Out of control – sun glare	3	2.2
Out of control – driver condition	3	2.2
Travelling straight ahead	55	61.1
Total	**90**	**100**

4.16 Traffic and pedestrian phasing at traffic light controlled pedestrian crash intersections

The n=75 pedestrian crashes at traffic light controlled intersections occurred across 41 different sites and involved n=75 drivers and n=75 pedestrians. Various traffic and pedestrian signal phasing of these intersections was investigated using data retrieved, where possible, from the local SCAT system. The information was provided by Main Roads Western Australia personnel in April 2013 and may not accurately represent the type of phasing/signalisation in operation at the precise time of the crash.

Parallel and Exclusive walk phasing

Of the n=41 traffic light controlled intersections in the CBD recording one or more pedestrian crashes between January 2008 and December 2012, around half continuously operated as parallel walk intersections (see Table 4.16). Of the remaining, 41.5% were operated continuously as exclusive walk with another three converted from exclusive to parallel walk during 2010 and 2011.

Table 4.16 Pedestrian crossing phasing of Perth Central Business District traffic light controlled intersections recording one or more WA Police reported pedestrian crashes 2008-2012

Pedestrian Crossing Signal Status*	No Intersections	%
Continuous Exclusive Walk 2008-2012	17	41.5
Converted from Exclusive to Parallel Walk during 2008-2012	3	7.3
Continuous Parallel Walk 2008-2012	21	51.2
Total	**41**	**100**

*As determined from MRWA data as at April 2013

The frequency of pedestrian crashes for the study period at the n=41 intersections cross tabulated by pedestrian crossing signal status is presented in Table 4.17. It shows that intersections that operated continuously throughout the study period as exclusive walk recorded 40% of reported pedestrian crashes while those operating continuously as parallel walk recorded 46.7% of crashes. The corresponding pedestrian crash rates per 1,000 days of operation for the study period were calculated to be 0.966 for exclusive walk intersections and 0.912 for parallel walk intersections. Approximately six crashes were recorded at the three converted intersections prior to the upgrade (noted to occur in 2010 and 2011) and four crashes following the conversion. The pre and post conversion pedestrian crash rates could not be reliably calculated for these converted intersections because of the small number of converted intersections and comparatively short follow-up period.

Table 4.17 Pedestrian crossing phasing of WA Police reported pedestrian crashes occurring at traffic light controlled intersections in the Perth Central Business District 2008-2012

Pedestrian Crossing Signal Status*	No Pedestrian Crashes	%
Continuous Exclusive Walk 2008-2012	30	40
Converted from Exclusive to Parallel Walk during 2008-2012		
- Pre-conversion to parallel walk	6	8
- Post-conversion to parallel walk	4	5.3
Continuous Parallel Walk 2008-2012	35	46.7
Total	**75**	**100**

*As determined from MRWA data as at April 2013

Investigation of the reported movements of pedestrians at the time of the crash for exclusive and parallel walk signalised intersections showed very few differences. The proportion of pedestrians involved in a collision *near side* while crossing the road was slightly higher at exclusive walk intersections while the proportion of pedestrians involved in a collision *far side* was slightly higher at parallel walk intersections.

Table 4.18 Reported movement of pedestrians involved in WA Police reported pedestrian crashes at traffic light controlled intersections in the Perth Central Business District 2008-2012; by pedestrian crossing phasing at time of crash*

Pedestrian movement	Exclusive Walk		Parallel Walk	
	n	%	n	%
Crossing road – near side	16	45.7	13	34.2
Crossing road – far side	10	28.6	15	39.5
Walking/running with traffic	1	2.9	0	0.0
Emerging from behind parked vehicle	2	5.7	3	7.9
Walking/running but not on carriageway	0	0.0	1	2.6
Activity not 'codeable'	1	2.9	1	2.6
Activity unknown	3	8.5	3	7.9
Stationary on carriageway	2	5.7	1	2.6
Stationary off carriageway	0	0.0	1	2.6
Total	**35**	**100**	**38**	**100**

*As determined from MRWA data as at April 2013; n=2 missing pedestrian movement information.

Further analysis of near and far side crossing collisions at exclusive and parallel walk intersections in relation to driver/vehicle movement are presented in Table 4.19. Though the total number of crashes analysed is relatively small, the findings suggest that pedestrians crossing the road at both signal types are more likely to be involved in a collision (near and far side) with a vehicle that was reportedly proceeding straight ahead through the intersection as opposed to turning. For example, when near and far side pedestrian crossing collisions are aggregated, n=18 (70%) of the n=26 crashes at exclusive walk intersections involved collision with a vehicle travelling straight through.

This pedestrian/driver/vehicle movement scenario also accounted for 90% (n=25/28) of collisions at parallel walk intersections.

Table 4.19 Crossing road movement of pedestrians for WA Police reported pedestrian crashes at exclusive walk and parallel walk intersections in the Perth Central Business District 2008-2012; by vehicle/driver movement

	Exclusive Walk				**Parallel Walk**			
	Pedestrian Movement- Crossing Road							
Vehicle/Driver Movement	**Near**		**Far**		**Near**		**Far**	
	n	%	n	%	n	%	n	%
Turning – left turn	2	12.5	1	10.0	1	7.7	2	7.1
Turning – right turn	4	25.0	0	0.0	1	7.7	2	13.3
Reversing or rolling back – straight line	0	0.0	1	10.0	0	0.0	0	0.0
Out of control – sun glare	0	0.0	1	10.0	1	7.7	1	6.7
Travelling straight ahead	10	62.5	8	80.0	10	76.9	15	66.7
Total	**16**	**100**	**10**	**100**	**13**	**100**	**15**	**100**

Head-start phasing

Head start phasing does not operate at exclusive walk intersections. Consequently the analyses of this feature in relation to pedestrian crashes addressed only those intersections known to be parallel walk at the time of the crash. Table 4.20 shows the distribution of n=39 pedestrian crashes across head start and non-head start phased parallel walk traffic light controlled intersections. The slightly higher proportion of pedestrian crashes at non-head start intersections (56.4%) was found not to be statistically significant (Chi Square: X^2=0.641 df=1; p=0.42)

Table 4.20 Head start pedestrian phasing for WA Police reported pedestrian crashes occurring at parallel walk intersections in the Perth Central Business District 2008-2012

Head Start Phasing*	**No Crashes**	**%**
Yes	17	43.6
No	22	56.4
Total	**39**	**100**

*As determined from MRWA data as at April 2013

Cross-tabulation of head start phasing by driver/vehicle movement (Table 4.21) showed that drivers were somewhat more likely to collide with pedestrians when proceeding straight ahead at non-head start intersections (72.7%) compared with head start intersections (64.7%). Caution must be exercised in the interpretation of this result given the relatively small number of pedestrian crashes on which the analysis is based.

Table 4.21 Head start pedestrian phasing for WA Police reported pedestrian crashes occurring at parallel walk intersections in the Perth Central Business District 2008-2012; by driver/vehicle movement

	Head Start Phasing			
Driver/Vehicle movement	**Yes**		**No**	
	n	%	n	%
Turning – left turn	2	11.8	1	4.5
Turning – right turn	3	17.6	2	9.1
Reversing or rolling back – straight line	1	5.9	0	0.0
Out of control – sun glare	0	0.0	2	9.1
Out of control – driver condition	0	0.0	1	4.5
Travelling straight ahead	11	64.7	16	72.7
Total	**17**	**100**	**22**	**100**

Walk-Don’t Walk signals

The distribution of pedestrian crashes in relation to the operation of Walk-Don’t Walk pedestrian signals is presented in Table 4.22. As seen, over nine in ten pedestrian crashes at traffic light controlled intersections occurred where Walk-Don’t Walk lights were in operation.

Table 4.22 Walk-Don’t Walk signals for WA Police reported pedestrian crashes occurring at traffic light controlled intersections in the Perth Central Business District 2008-2012

Walk-Don’t Walk Lights*	**No Crashes**	**%**
Yes	68	90.3
No	7	9.3
Total	**75**	**100**

*As determined from MRWA data as at April 2013

5. DISCUSSION

The overall aim of the current project was to investigate the pattern of pedestrian crashes at traffic intersections in the Perth Central Business District over a five-year period 2008-2012. In the process, the investigation sought to examine the impact of the conversation of pedestrian signals from Exclusive Walk to Parallel Walk on the frequency of pedestrian crashes.

The analyses showed that approximately 2% (n=88) of traffic crashes occurring at intersections in the CBD reported to WA Police during the study period involved collision with one or more pedestrians. As previously reported, other studies of pedestrian crashes in Australian CBD locations (eg., Liu & Yue, 2011; Oxley et al, 2013) have similarly shown that pedestrians are at risk of collision at intersections – both controlled and uncontrolled - in this location.

Given the nature of the road environment of the Perth CBD, it was not surprising to find that 85% of pedestrian crashes occurred at signalised or traffic light controlled intersections. This equates to around 15 pedestrian crashes per year at traffic light controlled intersections over the study period. Compared with un-signalised intersections, signalised intersections are regarded as a comparatively safer crossing location (Carter et al., 2006). Even so, the findings of this study support those reported elsewhere (eg., Liu & Yue, 2011) regarding the risk of crash and injury for pedestrians at traffic light controlled intersections.

Where information on the injury outcome of the 95 crash involved pedestrians was available, it showed that four in ten sustained injuries that were fatal (n=1) or required transportation to and admission to hospital. These findings contrast with those reported by Oxley et al. (2013) who noted that 72% of pedestrian crashes in the

Melbourne CBD resulted in death or serious injury (admittance to hospital). The variation between the studies in the proportion of pedestrians killed and seriously injured does not appear to be related to differences in the speed zone of crash locations. This study noted that 92% of crashes occurred in 50-60km/hour zones compared with 94.6% of pedestrian crashes in the same speed zones reported by Oxley et al. (2013). The variation is more likely to be related to the fact that Oxley et al. (2013) also investigated CBD crashes at midblock locations which are known to result in more severe injuries compared with crashes located at intersections (see Rothman et al., 2012). Other factors that could explain the variation in injury outcomes include differences between Western Australia and Victoria and changes over time in the reporting of 'hospitalisations' (D. Logan, personal communication; J. Dalla-Costa, personal communication),

Speed zoning is an important issue in the protection of pedestrians. It was previously noted that the risk of injury increases substantially for pedestrians in speed zones greater than 30km/hour (McLean et al., 1994). Consequently, Oxley et al. (2013) argued that the risk of death and serious injury for pedestrians in the CBD could be reduced through lowering the speed zones so that in the event of a collision impact forces are within more tolerable limits (Oxley et al., 2013). Defined areas within the Perth CBD could be even more pedestrian oriented and present less risk of injury by reducing posted speed limits and potential impact speeds to 30km/hour – which is associated with a 5-10 percent risk of death (Oxley et al. 2013). It should be noted that road works at various locations in the Perth CBD have included a reduction in speed limits since 2011 to 40km/hour (G. Newson, Personal Communication 2013). Pedestrian crashes and injuries on these roads should be monitored to determine the impact of the reduction in speed limits and the need for further reductions.

The finding that males (60%) and younger age persons (70% under 40 years of age) constituted the majority of pedestrians involved in a collision at intersections in the CBD is reasonably consistent with that reported by Oxley et al. (2013) for all CBD pedestrian crashes. In that study it was noted that 53.6% of crash involved pedestrians were male and 56% were aged up to 34 years. The higher proportion of males relative to females could be due to factors such as their reluctance to wait for a green pedestrian signal (Tiwari et al., 2007) and the consequent increased likelihood of committing pedestrian related traffic violations such as crossing on red (see Diaz, 2002, Tiwari et al., 2007; Rosenbloom, 2009).

With respect to age, the increased proportion of younger age persons involved in pedestrian crashes may be due to a number of factors. A higher level of exposure as pedestrians in the CBD area - particularly during the evening and late at night – could be a contributing factor though there is no pedestrian survey data for Perth CBD to support this proposition. The increased propensity of younger age persons to engage in risk taking in the road environment may also be relevant to pedestrian behaviour. For example, as previously noted in a US study of pedestrians killed or injured wearing headphones, nearly 70% were aged under 30 years (Lichenstein et al., 2012). Unfortunately there is no contemporary West Australian information on the risk taking behaviours or impaired or distracted states (ie., alcohol, drug or fatigue affected; use of mobile phones or headphones) of pedestrians by age. Further to this, the available crash data was also of no particular use in relation to understanding the contribution of risk taking and/or impaired behaviours. BAC level data was available for one crash involved pedestrian (a fatally) only.

The distribution of pedestrian crashes by day of week and time of day showed no significant variation for the former but significant variation for the latter. The lack of variation in pedestrian crashes by day of week is perhaps testament to the fact that use of the Perth CBD has moved from being primarily a 'business district' to one that is both business and entertainment and as such more heavily frequented seven days a week. Longer time trend analysis using 10-15 years of crash data might provide insight into the effect of the diversification of the use of the CBD on pedestrian activity and crashes.

In relation to time of day, around seven in ten crashes occurred during the period 06:00-17:59. While Oxley et al. (2013) noted that 23% of all pedestrian crashes in the CBD of Melbourne occurred during the hours midnight to 6.00am, this study recorded just 8% during the same period (but for intersection crashes only). Also contrary to the findings of Oxley et al. (2013), this study did not find a significant effect of age group on time of crash, though there was a trend for younger age persons to be involved in pedestrian crashes early in the evening to late night/early morning. Notwithstanding the difference between the two studies in terms of the crash locations investigated, differences between Melbourne and Perth in the location of and trading hours of nightclubs and licensed premises in the Central Business Districts may potentially explain some of the observed variation in pedestrian crashes by time of day, particularly for younger age persons. Future spatial mapping of all Perth CBD pedestrian crashes by time of day and licensed premises may yield some important findings of an association and opportunities for intervention.

This study showed a clear pattern of both pedestrian and driver/vehicle movement associated with pedestrian crashes. Overall, the majority of pedestrian crashes at traffic light controlled intersections – which accounted for 85% of all intersection crashes – involved a collision between a pedestrian crossing to the near and far side and a vehicle proceeding straight ahead through the intersection. Fewer crashes involved pedestrians colliding with right and left turning vehicle. The relatively high frequency of near (43.3%) and far side (32.2%) pedestrian crashes is comparable to the near (40%) and far side (27%) pedestrian crash types identified by Corben and Diamantopoulou (1996) following their investigation of high frequency pedestrian crash location (midblock and intersections but excluding the Melbourne CBD) in Victoria. The finding that between half and two-thirds of pedestrians collide with a vehicle approaching from their left about half way across the road highlights the importance of median refuges and sufficient protected walk time for pedestrians to complete their crossing.

Interestingly, the identified pattern of pedestrian and driver/vehicle movement was observed with near equal frequency across exclusive and parallel walks intersections. Exclusive walk phasing technically provides pedestrians with the highest level of protection against collision, with studies (see Carter et al., 2006; Fernandes et al, 2012) showing that an exclusive/all red pedestrian phase significantly reduces the risk of a pedestrian crash by as much as 34% (US Department of Transportation, 2008). This study showed however, that the rate of pedestrian crashes per 1,000 days of operation over the study period was near identical for exclusive and parallel walk intersections. The qualification to this observation is that the rates do not take account of the level of pedestrian activity at the various intersections.

The contributing risk factors for the observed pedestrian crashes at these intersections – whether exclusive or parallel walk - cannot be readily determined from the crash data as no information is available on the point in the signal phase at which the crash occurred and which road user ,pedestrian or driver, *may* have disobeyed a signal. It is nevertheless disconcerting that the safety benefit of exclusive walk phasing is perhaps being undermined by illegal road user behaviour. The likely scenarios for this pattern of crashes include pedestrians deliberately and illegally entering the intersection against the red signal and colliding with a vehicle to the near side or far side, and secondly, pedestrians who legally enter the intersection but fail to clear it and collide with a vehicle to the far side.[2]

The first scenario is consistent with the commonly held belief that a good many pedestrians will place themselves at risk of collision because they commonly violate pedestrian traffic controls (US Department of Transportation, 2004). In the case of signalized intersections, crossing on red can increase the crash risk per crossing event by a factor of eight compared with legal crossing at signalized intersections (King et al, 2009). There is thus a strong need to implement countermeasures that reduce the risk of red light crossing. These could include a change in signal cycle times to reduce the length of time pedestrians wait on red to cross, and secondly, the availability of real time information on time to the next green signal (for intersections where pedestrian crossing is not pedestrian activated).

The second crash scenario also suggests there is a need to provide pedestrians with real time information on the actual time left to cross the intersection to reduce the incidence of crossings outside the pedestrian phase. This information can be provided by countdown timers (Wanty & Wilkie, 2010). At present, there is mixed evidence in regard to the safety benefit of countdown timers with some suggestion that the effectiveness is dependent on the nature of the site and the available crossing time (Wanty & Wilkie, 2010). It is however, favorably regarded by pedestrians (York et al., 2011).

[2] Assuming that drivers have legally entered the intersection

An important objective of the study was to evaluate the potential impact of the progressive decommissioning of exclusive walk intersections in the Perth CBD on the occurrence of pedestrian crashes. This objective could not be adequately addressed because of the relatively low number of intersections that have been converted since 2010 and the associated short post-conversion follow up time and low number of crashes. For these reasons the evaluation should be redone following the anticipated conversion of more intersections in the last quarter of 2013 and an increase in the number of years post-conversion to increase the statistical validity of the evaluation.

It is reported that the decommissioning of exclusive walk intersections has been necessitated by the need to improve traffic flow through the CBD to accommodate the increase in traffic volume expected with the impending closure of Riverside Drive (because of key infrastructure developments in that vicinity). There is nevertheless, good reason to question the appropriateness of converting exclusive walk intersections to parallel. The decommissioning of exclusive walk intersections contravenes the promotion of pedestrian-only phasing for increased pedestrian safety at intersections (see US Department of Transportation, 2004) and is inconsistent with research citing the significant reduction in pedestrian crashes associated with the introduction of exclusive walk, fully protected intersections (see Campbell et al., 2004).

This study also investigated the association between other traffic light controlled intersection measures known to safeguard pedestrians such as 'head start' phasing and 'Walk-Don't Walk' signals and pedestrian crashes. Of the n=75 traffic light controlled intersections recording a pedestrian crash, data provided by Main Roads Western Australia in April 2013 indicate that nine in ten crash intersections had Walk-Don't Walk signals in operation. This figure most likely reflects the general use of this measure at high pedestrian activity intersections in the Perth CBD. The extent to which pedestrians may have been crossing in violation of these signals could not be determined from the data. Though information on the pedestrian actions permissible under the Green Man and Red man signals is displayed at Walk-Don't Walk locations (on the pole), no relevant local evidence could be found attesting to pedestrians' understanding of the Red Man signals in particular. There may be a need to better educate pedestrians on the meaning of the Red Man signals to facilitate safer crossing behaviour. This could be determined from surveys of pedestrians at traffic light controlled intersections operating Walk-Don't Walk signals.

As noted, head start phasing or leading pedestrian interval provides pedestrians at parallel walk intersections with an opportunity to commence their crossing behaviour three to five second in advance of vehicles moving in the same direction and those turning left or right (where permissible). As with exclusive walk, head start phasing has been promoted as an important countermeasure to reduce conflict between pedestrians and vehicles by allowing the pedestrian time to particularly clear the near side of the road (Zegeer & Bushell, 2012). While this study noted slightly more pedestrian crashes at non-head start intersections, particularly involving vehicles proceeding straight ahead, the numbers are too small to reliably estimate the potential benefit of head start phasing or what additional benefit might be obtained by increasing the head start time, or, the increased risk of pedestrian collision that might be associated with the removal of head start intervals.

6. SUMMARY AND RECOMMENDATIONS

This study has shown that for the period 2008-2012 around 4.8 pedestrian crashes occurred every 100 days at intersections in the Perth Central Business District. These crashes involved 93 pedestrians and 90 driver/riders. Where personal injury information was available, it showed that the majority of involved pedestrians sustained minor injuries, even though the crashes were observed to occur in speed zones of 50-60km/hour. Given the relatively low proportion of pedestrians experiencing death and serious injury, it is likely that the associated impact speeds were less than the posted speed limits. Notwithstanding this point, the risk of pedestrian collision and injury could be further reduced if speed limits in this high pedestrian-high traffic volume area were reduced to speeds within biomechanical tolerances, eg., ≤ 30km/hour.

Males and younger age persons (under 39 years) were more likely to be involved in pedestrian crashes. Suggested reasons for this include greater risk taking by way of illegal crossing behaviour and distracted walking behaviours and potentially greater exposure, particularly at night when younger age pedestrians were somewhat more likely to be involved in a crash.

The findings also showed that 85% percent of crashes occurred at traffic light controlled intersections, which is not surprising given the CBD location where traffic light controls dominate intersections. Analysis of these crashes showed a very clear and dominant pattern of pedestrians being struck on the near and far side by vehicles proceeding straight ahead through the intersection as opposed to turning. This pattern occurred across exclusive walk and parallel walk intersections. Illegal crossing behaviours and pedestrians failing to clear intersections (late completers) are proposed as likely scenarios underlying this crash pattern and mitigating the crash protection properties of exclusive walk intersections. These behaviours could be addressed by:

- a change in cycle times to reduce the length of time pedestrians wait on red;
- providing real time information on the 'time to the next green signal'; and,
- the installation of countdown timers to advise pedestrians on time left to cross.

Despite the fact that exclusive walk phasing for pedestrians has been shown to be an effective measure to reduce pedestrian crashes and injuries when pedestrians cross legally, since 2010 a number of exclusive walk intersections have been converted from exclusive walk to parallel walk with more expected in the last quarter of 2013. Unfortunately a number of methodological issues (e.g., too few converted sites, few crashes, and limited post conversion follow up time) the study was not able to determine whether the conversion program has to date increased the frequency of pedestrian crashes. The issue should be reinvestigated after more intersections have been converted and a longer post-conversion period has occurred.

Investigation of pedestrian crashes at signalised intersections in relation to head start phasing and Walk-Don't Walk pedestrian signals showed crashes were equally likely to occur at intersections with and without head start phasing and that nearly all of the signalised intersections recording a crash utilised Walk-Don't Walk signals. Notwithstanding the small number of crashes available for analysis, these findings suggest again that the safety benefit associated with these measures is perhaps being undermined by illegal crossing behaviours. This presumption should be investigated through observational surveys at intersections. This undertaking would also provide valuable information on the level of pedestrian activity at intersections required for a more valid and reliable estimate of the risk of pedestrian collision.

Following on from these findings it is recommended that Main Roads Western Australia:

1. Undertake observational surveys of pedestrian crossing behaviour at traffic light controlled intersections in the CBD to determine the type and frequency of behaviours that increase pedestrian crash risk; some characteristics of those undertaking the behaviours, and data on the level of pedestrian activity at intersections (for use as a denominator of 'exposure').
2. Undertake surveys to document pedestrians' understanding and awareness of Walk-Don't Walk signals. If warranted, education campaigns should be developed and implemented to address misperceptions and misunderstanding of legal and safe crossing behaviours and reinforced with appropriate police enforcement.
3. Investigate the development of trials to examine the impact on crossing behaviour of the following countermeasures for application in the Perth Central Business District:
    - A change in signal cycle time to reduce the length of time pedestrians 'wait on red'.
    - Providing real time information on the 'time to the next green signal'.
    - The installation of countdown timers to advise pedestrians on time left to cross.
4. Continue to the monitor the frequency and pattern of crashes at intersections converted from exclusive to parallel walk and develop a comprehensive

plan for a future evaluation of this program on the impact on both crashes and crossing behaviour.

5. Investigate the appropriateness of further reductions in posted speed limits in high pedestrian locations in the CBD to comply with known biomechanical tolerance to reduce injury severity.

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