Risk Factors for Killed and Serious Injury Intersection Crashes in Metropolitan Perth: 2006 - 2015

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September 2016

CURTIN-MONASH ACCIDENT RESEARCH CENTRE
DOCUMENT RETRIEVAL INFORMATION

Report No.	Project No.	Date	Pages	ISBN	Version
16-044	RSC	September 2016	31+	-	2

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Abstract
This study aimed to identify risk factors for killed and serious injury (KSI) intersection crashes in the Perth metropolitan area of Western Australia from 2006 to 2015. Crash data from the Integrated Road Information System (IRIS) was supplied by Main Roads Western Australia (MRWA). Multivariate logistic regression modelling was undertaken to analyse the likelihood of a metropolitan intersection crash resulting in a death or a seriously injury. Variables included in the multivariate model were: season, day of the week, time of day, atmospheric conditions, intersection type, traffic controls, road grade and nature of the crash (single or multiple vehicle). The analysis identified several risk factors for an increased risk of a KSI crash which included a crash on the weekend, at night time, at non-level intersections and at 3-way and 4 or more-way intersections versus roundabouts. Factors that reduced the risk of KSI crashes included rainy conditions, signalised traffic controls and multiple versus single vehicle crash types. These results will provide the Road Safety Commission and other organisations with reliable, objective information for enhancing intersection safety in Western Australia.

Keywords
Metropolitan intersection crashes, KSI crashes, risk factors

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EXECUTIVE SUMMARY

Aim

The aim of this study was to identify risk factors for killed and serious injury (KSI) intersection crashes in the Perth metropolitan area of Western Australia from 2006 to 2015. Crash data was obtained from the Integrated Road Information System (IRIS) which is maintained by Main Roads Western Australia (MRWA).

Methods

A retrospective population-based, longitudinal study of KSI road crashes that occurred from 1st January, 2006 to 31st December, 2015 at intersections in the Perth metropolitan area was undertaken. KSI crashes included all fatal and hospitalisation crashes. Non-KSI crashes included all medical treatment and property damage only crashes. Multivariate logistic regression modelling was undertaken to analyse the road and crash factors associated with a metropolitan intersection crash resulting in the death or serious injury crash. The following potential contributing factors were included in the multivariate model: *season, day of the week, time of day, atmospheric conditions, intersection type, traffic controls, road grade and nature of the crash (single or multiple vehicle).*

Results

A total of 175,804 crashes were included in the study, 7181 KSI crashes and 168,623 non-KSI crashes. Based on the results of the multivariate analysis, weekend crashes were 1.149 times more likely to be KSI crashes than weekday crashes (p-value < 0.001). Afternoon crashes were less likely (OR=0.938) to be a KSI crash compared to daytime morning crashes (p-value = 0.029) but night time and early morning (dark) crashes were 1.381 and 1.310 times more likely to be KSI crashes (p-values < 0.001). In terms of atmospheric conditions, a crash that occurred during rainy conditions was less likely (OR=0.686) to be a KSI crash (p-value < 0.001) than a crash that occurred when conditions were clear. Other atmospheric conditions (such as overcast, fog, smoke, dust or mist) were combined as one group and were not significantly associated with the odds of a KSI crash (p-value = 0.562). Season was also not significantly associated with the odds of a KSI crash in the multivariate model. In terms of intersection type, crashes occurring at 3-way intersections (T-junctions) were 1.902 times more likely (p-value < 0.001) and crashes at intersections with 4 or more legs were 2.017 times more likely to be KSI crashes than those occurring at roundabouts (p-value < 0.001). There was no significant difference in the odds of a KSI crash at intersections with non-

signalised traffic controls (stop sign, give way sign etc.) and intersections with no traffic control of any kind (p-value = 0.672). Signalised traffic controls however, had significantly lower odds (OR=0.610) of being associated with a KSI crash, compared with no traffic control (p-value < 0.001). When the intersection was located at a road section that was not level, then the odds of a KSI crash were 1.173 times that of a level intersection (p-value < 0.001). In terms of the number of vehicles involved, multiple vehicle crashes were less likely (OR= 0.364) to be a KSI crash compared with single vehicle crashes (p-value < 0.001).

Conclusion and Recommendations

The analysis has identified several risk factors for KSI crashes at intersections. These include increased risk of KSI crashes on the weekend, at night time, at non-level intersections and at 3-way and 4 or more-way intersections *versus* roundabouts. Factors that reduced the risk of KSI crashes included rainy conditions, signalised traffic controls and multiple *versus* single vehicle crash types. Therefore the following recommendations can be made:

1. Improve the recording of speed limits in the database so that analyses of the impact of speed limits on crash severity at intersections can be accurately undertaken.
2. Consider the increased use of traffic lights at intersections where appropriate.
3. Consider the increased use of roundabouts at intersections where appropriate.
4. Conduct further investigations into the safety benefits of non-signalised traffic controls (stop signs, give way signs) versus no traffic controls at intersections.
5. Conduct further investigations into the safety issues associated with intersections located on roads that are not level.

ACKNOWLEDGEMENTS

This report was funded by the Road Safety Commission, Western Australia. We would like to thank Dr Fritha Argus for her help with all aspects of the project.

1. INTRODUCTION

Each year approximately 3,000 people are seriously injured on Western Australian (WA) roads (Corben, Logan, Fanciulli, Farley, & Cameron, 2010). Reducing this figure is the goal of the *Towards Zero* strategy which is to reduce the number of persons killed or seriously injured in Western Australian roads by 11,000 between 2008 and 2020 (The Government of Western Australia, 2009). To achieve this, *Towards Zero* has adopted the four guiding principles of the *Safe System* approach to road safety: "*safe road users*", "*safe roads and roadsides*", "*safe speeds*", and "*safe vehicles*" (The Government of Western Australia, 2009).

Corben et al. (2010) outlined a strategy for implementing the *Safe System* approach to the WA road network to facilitate the realisation of the *Towards Zero* vision through the use of a *Safe System Matrix*, highlighting the areas of focus for the strategy that will have the greatest impact on road safety. The *Safe System Matrix* highlights intersection crashes as a key area of focus for road safety in WA, particularly in metropolitan Perth (Corben et al., 2010). This priority is reflected in the statistics pertaining to intersection crashes on WA roads. Intersection crashes (including those occurring at roundabouts and railway crossings) accounted for nearly half of the total crashes in WA between 1995 and 2004 (Data Analysis Australia, 2006). Over the same time period, 41% of crashes that resulted in a death or a serious injury (KSI crashes) occurred at an intersection (Data Analysis Australia, 2006). The large proportion of KSI crashes attributable to intersections has been consistent over time with one third of KSI crashes reported between 2005 and 2007, occurring at intersections (Office of Road Safety, 2009). Of these, 44% occurred on metropolitan roads (Office of Road Safety, 2009). These findings are consistent with those of Palamara, Kaura, and Fraser (2013) who found that between 2005 and 2009, crashes at intersections, particularly those involving right angle and right turn through vehicle movements, were the main crash type for serious injury crashes in the metropolitan area.

There is a clear relationship between KSI collisions and intersections indicated in the findings reported by Data Analysis Australia (2006), the Office of Road Safety (2009) and Palamara et al. (2013). In light of this, attempts to reduce KSI collisions in WA using the *Safe System* approach require the identification of influential risk factors at intersections. This report will focus primarily on the environmental risk factors associated with increased KSI risk at intersections. A thorough review of available peer-reviewed literature (findings summarised in Table 1.1) identified several consistent features that were associated with increased KSI crash risk.

1.1 Risk factors in KSI intersection collisions

After reviewing the current available literature, it is clear that the relationship between multiple risk factors for KSI collisions at intersections is complex. The impact of risk factors on KSI collisions is varied and occasionally conflicting, depending on a variety of factors examined including the existing infrastructure and surrounding road networks, pedestrian and traffic volumes, traffic demographics which include the proportion of trucks, motor vehicles, motorcycles and public transport utilising the road network, as well as other compounding factors including driver behaviour (Chen, Cao, & Logan, 2012; Xu, Wong, & Choi, 2014; Liu, 2007). The apparent complexity associated with identification of risk factors for KSI intersection collisions presents a clear need for a local investigation to identify risk factors that are specific to the WA road network.

There were six potentially modifiable environmental risk factors that were consistently identified in the literature as playing a role in a crash at intersections: *vehicle speed*, *crash angle*, whether the intersection was *signalised* or *unsignalised*, the *intersection type* (roundabout or traditional T-intersection or four-legged intersection) and *the presence of exclusive right turn* or *uncontrolled left turn lanes*. These are further discussed in subsequent sections along with other modifiable environmental risk factors such as the *number of lanes on approach to the intersection* and the *lane widths*, the presence of *various intersection cameras to detect vehicle speeds,* and the presence of *bus facilities*. Inconsistent reports across the studies can be attributable in some cases to dramatic differences in driver demographics and small study power. They warrant further investigation using larger data samples to clarify the exact roles they play in intersection collision frequency and crash severity (Hassan & Al-Faleh, 2013; Zegeer et al., 2006). Finally, two additional unmodifiable environmental risk factors were also identified and are discussed in subsequent sections, these being the *weather* conditions at the time of the crash and the *time of day of the crash*.

1.1.1 Speed

Vehicle speed is a commonly accepted risk factor for the advent of a crash and the resulting injury severity, with the odds of a crash increasing by 2.2 to 10.5 times as travel speed increases. (Chen et al., 2012; Xu et al., 2014; Haque, Chin, & Huang, 2010). When approaching an intersection, increased travel speed reduces the time to react to hazardous situations thus reducing the ability of a road user to take necessary evasive action (Candappa, Logan, Van Nes, & Corben, 2015). Higher travel speeds subsequently translates to a higher level of kinetic energy at the point of impact, thus increasing the likelihood that any resulting injury will be severe (Candappa et al., 2015), particularly in the case of crashes involving vehicles with poor crashworthiness.

Previous research has identified speed to be a significant risk factor but it is limited by the fact that they did not quantify the effect of speed within their crash data sets (Zegeer et al., 2006, Schneider et al., 2010). Studies that have quantified speed as a risk factor in KSI collisions at intersections have shown that the effect is not linear, and that differing road condition standards associated with different speeds may interact with this relationship (Chen et al., 2012, Zhang et al., 2000). Chen et al (2012) reported an odds ratio (OR) of 4.4 for collisions in 70km/h speed zones, compared to 50km/h zones, and also reported a slightly lower OR of 3.68 for crashes in 80km/h speed zones. The suggested reasoning was that speed zones of 80km/h tended to have better facilities and maintained roads than those of 70km/h, and that the differing road conditions interacted in the relationship between speed and crash risk.

1.1.2 Crash Angle

Research has identified that a large proportion of crashes at intersections involve vehicles from opposing directions, thus resulting in right or side-angle crashes. The angle at which vehicles collide has an important bearing on the severity of the collision (Candappa et al., 2015). Side impact collisions, particularly those at 90^0 have the most severe impacts; collisions at these angles provide the least opportunity for impact forces to be dispersed (Candappa et al., 2015). The angle at which traffic is moved through an intersection has a clear relationship with the angles in which vehicles may collide. Several investigations into the geometric layout of intersections have found that increasing angles (ie. closer to 90^0) are associated with increased crash frequency, through impeding the line of sight of other vehicles, and increased crash severity (Xu et al., 2014, Zhou, Sun, Li, & Yang, 2013). The results of these studies have been consistent, reporting a relative increase of between 2.7 to 3.6 times the crash risk for each unit increase in the turning radius or trajectory of an intersection (Xu et al., 2014, Zhou et al., 2013). The increased injury severity associated with side impact or right angle collisions, relative to front or rear end collisions, may be due to a number of factors, including the size and mass differential between colliding vehicles (Desapriya, Pike, & Kinnney, 2005) and the increased likelihood of the colliding vehicle intruding into the passenger cell of the target vehicle (Fildes, Lane, Lenard, & Vulcan, 1994).

1.1.3 Controlled *versus* Uncontrolled Intersections

Intersections can be categorised by the presence or absence of infrastructure to regulate and control the movement of vehicles and thus the opportunities for conflict between them. The two classes of intersections relate to those with signalisation (i.e, traffic lights) and signage (i.e., stop and give way signs) to regulate vehicle movement and those without any form of traffic control.

Controlled intersections are consistently recognised in the literature as having a lower crash risk than uncontrolled intersections. The risk of a crash at an intersection with some form of traffic control (e.g., lights, signage) is consistently reported to be about half that of uncontrolled intersections (Chen et al., 2012, Montella & Mauriello, 2012, Zhang, Lindsay, Clarke, Robbins, & Mayo, 2000). This safety effect appears to be magnified for vulnerable road users, with motorcyclists, bicyclists and pedestrians reported to experience a reduction in collisions of around 75% (Mitani &Yamanaka, 2005, Zhao &Chen, 2016).

Previous studies of specific types of traffic control however, such as stop signs versus traffic lights, have produced inconsistent results as to the magnitude and direction of their specific role in intersection crash risk and severity (Chen et al., 2012, Miller et al., 2011).

Many investigations controlled for the increased risk at unsignalised intersections by examining a sub-set of data for crashes that occur at signalised intersections only (Haque et al., 2010, Huang et al., 2008, Liu, 2007, Wang et al., 2006). The present study provides the opportunity to investigate the effects of different types of traffic control.

Two features of traffic light controlled intersections that have been shown to reduce both the frequency of crashes and their severity are dedicated right turn green arrows and speed and red-light camera combinations. In relation to the former, Chen and Meuleners (2013) identified that dedicated right turn green arrows were associated with a 69% reduction in right angle/right turn thru crashes and 58% reduction in serious injury crashes when installed at Perth metropolitan intersections. Significant reductions in intersection crashes were also noted by Newstead, Diamontopoulou, Lawrence, Clark and Palamara (2015) in their evaluation of the combined speed and red-light camera program operating in metropolitan Perth. The authors reported that the program was associated with a 36.7% reduction in serious injury crashes and 17.7% reduction in all casualty crashes. Other, earlier studies have suggested that the presence of red light and speed cameras at intersections may reduce intersection collision frequency, particularly for vulnerable road users such as motorcyclists (Chin & Quddus, 2003, Huang et al., 2008).

1.1.4 Intersection Type

The design of an intersection is another well-documented risk factor in both crash frequency and severity. Typical three-legged (T-intersections) and four-legged intersections promote collisions at a 90^0 angle, which is associated with more severe crashes (Figure 1.1) (Candappa et al., 2015, Flannery & Datta, 1996). There has been additional research that has suggested that these traditional intersections also provide poor line-of-sight for drivers who are crossing traffic, and so increase the likelihood and frequency of a crash occurring (Flannery & Datta, 1996, Hydén & Várhelyi, 2000).

Roundabouts are an alternative design (Figure 1.1) that has reduced intersection crash frequency, when replacing existing traditional intersections (Flannery and Datta, 1996, Hydén and Várhelyi, 2000). The design of a roundabout reduces the angles of possible conflict points, reducing the likely severity of potential impacts. Traffic flowing through the roundabout does so in one direction, again reducing likely impact severity, but also allowing for more simple and efficient decision making by motorists (Flannery and Datta, 1996, Hydén and Várhelyi, 2000). The requirement of those entering a roundabout to yield to those already on it, is suggested to reduce right of way misunderstandings that result in a crash (Flannery and Datta, 1996, Hydén and Várhelyi, 2000).

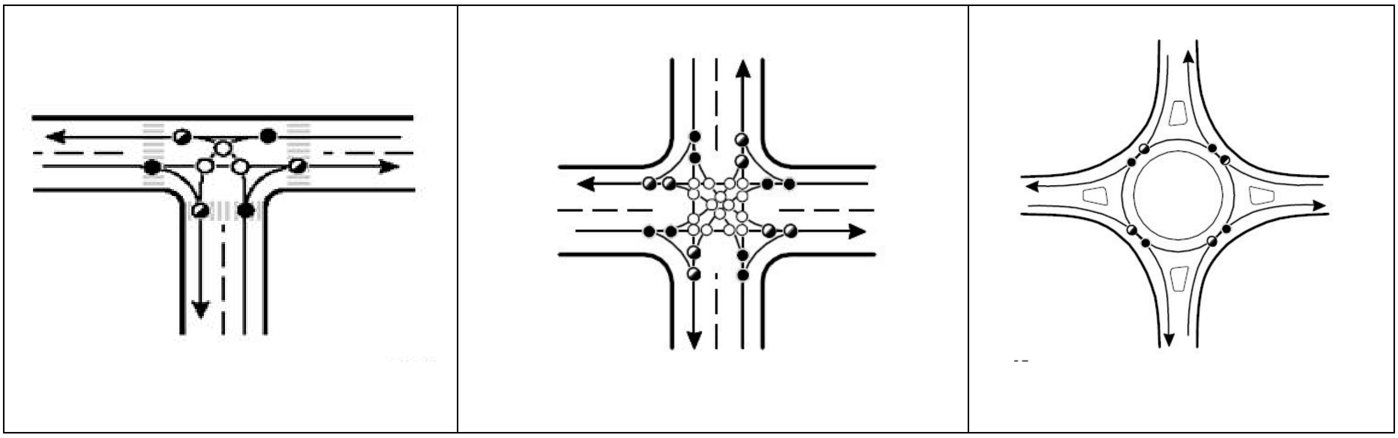

Figure 1.1 A three-legged or T-intersection, a four-legged intersection and a roundabout

1.1.5 Presence of an exclusive right turn lane

Two studies have proposed that the presence of an exclusive right turn lane increases the risk of a crash at an intersection (Haque et al., 2010, Kumara& Chin, 2003). Both studies were conducted in Singapore, and contained datasets with over 2,000 crash records each from 1992 to 2006 (Haque et al., 2010, Kumara and Chin, 2003). The earlier study reported a 32% increased risk of a crash, while the more recent study, was looking particularly at crashes involving motorcyclists and reported a 250% increase risk of a crash for this vulnerable group of road users.

Initial suggestions for this increased risk include the addition of an extra lane to the intersection, hence increasing volume and exposure to potential hazardous scenarios (Haque et al., 2010, Kumara and Chin, 2003). Additionally, the presence of an exclusive right turn lane allows through traffic to continue through the intersection at maintained higher speeds, which is already an established risk factor for a crash at an intersection (Haque et al., 2010, Kumara and Chin, 2003).

Although the overall size of an intersection, including the number of lanes and their width, is a feature that has been investigated in multiple studies, there has not been a consensus reached on the impact of this feature on intersection collision risk. The literature search identified six investigations, with three reporting an increased risk of collision with additional lanes – including the dedicated right turn lane - and lane width (Haque et al., 2010, Wang et al., 2006, Zhao and Chen, 2016). However, three additional studies reported a decreased risk with the same feature (Liu, 2007, Mitani & Yamanaka, 2005, Xu et al., 2014).

This relationship may be influenced by multiple, differing features unique to different road networks. Investigation in a local setting would provide locally applicable information on this relationship; however data on the number of lanes approaching each leg of an intersection and their width is not readily available in the current data set and would need to be sourced for other databases held by Main Roads Western Australia.

1.1.6 Presence of an Uncontrolled Left Turn Lane

Previous research has found that the presence of an uncontrolled left turn lane may increase the risk of an intersection crash as well the presence of an exclusive right turn lane (Haque et al., 2010, Kumara and Chin, 2003). This is further supported by a third Singaporean study undertaken by Chin and Quddus (2003). A left turn lane with no signals provides the opportunity for traffic to flow through at higher speed and with no protection from through traffic. The additional lane, combined with the traditional right angled intersection design can reduce the effective line of sight of drivers, also adding to the potential of a crash through poor decision making (Haque et al., 2010). As reported by Haque et al (2010), left turn lanes that expand the width of the intersection have the potential to magnify the exposure, and the collision risk for motorcyclists, who are vulnerable road users already at increased crash risk due to their visibility on the road. Motorcyclists were reported to have an increased crash risk of 1.2 times at an intersection that has an exclusive left hand turning lane, even when these turns are signalised (Haque et al., 2010).

1.1.7 Time of Day

A commonly identified risk factor for a crash is the time of day. Four separate studies have produced similar results, highlighting the increased risk for a crash and severity during the evening and through the night (Chen et al., 2012, Hassan and Al-Faleh, 2013, Huang et al., 2008, Miller et al., 2011). One particular time period, between midnight and 6am has been highlighted by Chen et al. (2012), with all other time periods having a decreased odds ratio of between 0.27 and 0.54. Other studies have used simple night/day classifications, and have still reported increased odds ratios of approximately 1.2 times for a crash at an intersection (Hassan & Al-Faleh, 2013, Huang et al., 2008). Reasons for the increased crash severity occurring at intersections at night may be attributed to reduced visibility, increased driver fatigue as well as the reduced typical traffic volumes allowing for increased travelling speeds (Chen et al., 2012, Martiniuk et al 2013).

1.1.8 Weather Conditions

Wet weather conditions have been reported to increase the number of crashes, particularly in specific locations of an intersection (Zhang et al., 2000). As well as increasing the frequency of crashes, wet weather has also been associated with increased severity of collisions (Hassan and Al-Faleh, 2013). However the extent of this association has not been consistently quantified.

Wet road surfaces, resulting from wet weather conditions, are suggested to affect crash frequency through driver error in changed conditions, reduced visibility and possible loss of traction (Zhang et al., 2000). These same factors in turn affect the potential severity of a collision. Zhang et al. (2000) supported the role of reduced visibility in increased collision frequency through their reports of increased odds of a collision while it was snowing, but reduced odds of a collision when there was snow on the road, but it was not snowing; suggesting that problems with visibility may be the most influential factor.

Whilst wet conditions have been identified as a risk factor for increased and more severe collisions in several instances, the variation between the climate of these studies (Saudi Arabia, China and Canada) and the WA climate could potentially affect the magnitude of this relationship, warranting further investigation.

Table 1.1 Summary of reviewed intersection crash risk literature according to identified risk factors

	Risk Factor *										
								Presence of:			
Study	Speed	Crash Angle	Number and Width of Lanes on Approach	Evening / Night	Signalised Intersection	Wet Weather	Roundabout (Vs Traditional)	Speed/Red Light/ Surveillance Cameras	Exclusive Right Turn Lane	Uncontrolled Left Turn Lane	Bus Lanes/ Bays
(Chen et al., 2012)	+	+		+	–						
(Xu et al., 2014)	+	+	–								
(Haque et al., 2010)	+		+					–	+	+	
(Wang et al., 2006)	+		+								
(de Rome and Senserrick, 2011)	+										
(Zhang et al., 2000)	+				–	+					
(Miller et al., 2011)	+			+	–						
(Zhou et al., 2013)		+									
(Liu, 2007)			–								
(Zhao and Chen, 2016)			+		–	+					
(Mitani and Yamanaka, 2005)			–		–						
(Chin and Quddus, 2003)								+		+	–
(Huang et al., 2008)				+				+			
(Montella and Mauriello, 2012)					–						
(Lan et al., 2009)					–						
(Hassan and Al-Faleh, 2013)				+		+					
(Kumara and Chin, 2003)									+	+	
(Goh et al., 2013)											–
(Flannery and Datta, 1996)							–				
(Hydén and Várhelyi, 2000)							–				

* + = increased presence/extent of factor associated with increased collision frequency, risk or odds.
– = increased presence/extent of factor associated with decreased collision frequency, risk or odds.

1.2 Summary and Conclusion

A significant proportion of collisions resulting in severe injury, or death, occur at intersections in WA. To date, no in-depth local investigation into the risk factors for these collisions has been undertaken. The identification of risk factors for KSI collisions at WA intersections is required to achieve the goal of the *Towards Zero* strategy which is to reduce the number of persons seriously injured or killed in collisions on WA roads.

This review of the literature has supported the investigation of speed, crash angles, intersection traffic control and type, weather conditions, and time of day as potential factors that influence the risk of a KSI collision at intersections. The available Integrated Road Information System data facilitates an investigation of all of these features. In many instances literature has investigated these factors in isolation, or without looking at various degrees of treatments or treatment combinations, for example, limiting their investigations to intersections in rural locations, or crashes that involve drivers of a certain age group. Few existing studies have investigated the risk factors for intersection collisions across an entire road network, and none have done so within the WA road network. A unique opportunity to provide this information is available in the present study.

1.3 Aim

The aim of this study is to identify and quantify the risk factors for killed and serious injury (KSI) intersection crashes in the Perth metropolitan area from 2006 to 2015 using the Integrated Road Information System (IRIS).

2. METHODS

2.1 Study design

A retrospective population-based, longitudinal study of road crashes that occurred at intersections in the Perth metropolitan area of WA during the period 2006 to 2015 was undertaken. The likelihood of whether a metropolitan intersection crash resulted in a killed or seriously injured (KSI) crash versus a non-KSI crash was modelled, examining the following potential contributing factors: *season, day of the week, time of day, atmospheric conditions, intersection type, traffic controls, road grade and nature of the crash (single or multiple vehicle).*

2.2 Integrated Road Information System (IRIS)

Crash data was obtained from the Integrated Road Information System (IRIS) which is maintained by Main Roads, Western Australia (MRWA). It was used to identify crashes that occurred at intersections in the metropolitan area of Perth, WA during a 10 year period from 1st January, 2006 to 31st December, 2015 (hereinafter referred to as the study period).

The IRIS database contains detailed information on the characteristics of the vehicles involved in road crashes, crash circumstances, police-reported injury and road information related to the crash location.

Critical data retrieved for use in the study were:

- crash date
- crash time
- crash severity
- posted speed limit at the crash location
- traffic control (presence/absence, and whether it was operational)
- grade of road at intersection (level or otherwise)
- atmospheric condition (clear, raining, or other)
- road condition (dry or wet)
- the number of vehicles involved in the crash (single or multiple)

The study adopted an approach that utilised 10 years of crash data. Crash data used in the analysis included all fatal, hospitalisation, medical treatment and property damage only (PDO) crashes.

2.3 Operational definitions

The definition of a crash used throughout this report is the definition used in the annual publication "*Reported Road Crashes in Western Australia 2014*" (Office of Road Safety 2014). That is, a crash is "*any unpremeditated incident where in the course of the use of any vehicle on a road that was not temporarily closed off to the public, a person is injured or property is damaged. The crash must involve vehicle movement and does not include collisions that occur due to a medical condition, deliberate acts (e.g. suicide attempts) or police chases*".

The severity of a crash is derived from "*the most serious injury in a crash*". A fatal crash is "*a road crash in which at least one person was killed immediately or died within 30 days of the crash, as a result of the crash*". A hospitalisation crash is a road crash that involved at least one admission to hospital but "*no fatalities within 30 days of the crash*". A medical treatment crash (or medical attention crash) is "*a road crash in which the most serious injury resulted in a person requiring medical treatment, but without being admitted to hospital*". A PDO crash involved no/unknown injuries only.

For the purpose of this report, a killed or seriously injured (KSI) crash was defined as a road crash that resulted in at least one person being either "*killed immediately or died within 30 days of the day of the road crash as a result of the crash*" or "*admitted to hospital as a result of the road crash and who does not die from injuries sustained in the crash within 30 days of the crash*". KSI crashes include all fatal crashes, and hospitalisation crashes. Non-KSI crashes included all medical treatment and PDO crashes.

In WA, it is mandatory for the driver of a vehicle to report a traffic crash when the incident occurred on a road or any place commonly used by the public, e.g. carparks; and;

1. the incident resulted in bodily harm to any person; or
2. the total value of property damaged to all involved parties exceeds $3000; or
3. the owner or representative of any damaged property is not present.

2.4 Criteria for ascertainment of an intersection crash

A total of 179,307 road crashes that occurred between 1st January 2006 and 31st December 2015 were identified as metropolitan intersection crashes from IRIS. These crashes had the Region identified as “Metropolitan” (i.e. variable “Reg_No” = 7), and either: (a) an Intersection ID (i.e. variable “Intx” not blank), or (b) the Accident Type identified as “Intersection” (i.e. variable “Acc_Type” = 2).

Further, only crashes that occurred at either: (a) a 4-way intersection, (b) a 3-way intersection (T-junction), (c) an intersection with more than 4 legs, or (d) a roundabout, were included in the final study (n = 175804) (i.e. variable “Feature” = 1, 2, 3 or 4), with crashes that occurred at locations with less common configurations excluded (n = 3503) (i.e. variable “Feature” = 5 or greater, or blank).

2.5 Variable categorisations

Table 2.1 shows the categorisations of variables of interest utilised in the study.

Table 2.1 Variable categorisations

Variable	Categorisation
Season	Summer: December, January and February Autumn: March, April and May Winter: June, July and August Spring: September, October and November
Time Block	Block 0: 0600 - 1159 Block 1: 1200 - 1759 Block 2: 1800 - 2359 Block 3: 2400 - 0559
Speed Limit	Category 0: Low (Speed Limit ≤ 50 km/h) Category 1: Medium (Speed Limit > 50 km/h and < 80 km/h) Category 2: High (Speed Limit ≥ 80 km/h)
Intersection Type	Type 0: Roundabout Type 1: 3-way Intersection (T-junction) Type 2: Intersection with 4 legs or more
Traffic Control	Assumed "None" if variable "Traf_Ctrl" = 10 (No Sign Or Control) or blank, or if variable "Traf_Ctrl" = number other than 10, but variable "TC_Func" = N. 0: None 1: Non-signalised Traffic Control 2: Signalised Traffic Control
Road Grade	Assumed "Level" if variable "Grade" = 1 or blank. Assumed "Not Level" if variable "Grade" = 2 or 3.
Atmospheric Condition	Assumed "Clear" if variable "Atmos" = 1 or blank. Assumed "Raining" if variable "Atmos" = 2. Assumed "Other" if variable "Atmos" = 3, 4, 5 or 6.

2.6 Traffic volume

Traffic volume is another factor that would change over the course of a week. For example, if a crash was to occur on a weekday morning, the crash location could experience a higher traffic volume than a crash that occurred on a weekend at night. It would be ideal to adjust for traffic volume experienced by the crash location at the time of the crash, or include the traffic volume as a covariate in any modelling. While MRWA holds figures of annual average daily traffic (AADT) for major locations, figures specific to the different times of the day are not available.

Therefore, the time block during which the crash occurred together with whether the crash occurred on a weekday or weekend are the closest proxy.

2.7 Statistical analysis

Univariate odds ratios were undertaken to examine the association between the severity of a metropolitan intersection crash (whether killed or serious injury (KSI) or not), and variables of interest that were identified as having the potential to influence the outcome of a crash.

Multivariate logistic regression modelling was then undertaken to analyse the likelihood of a metropolitan intersection crash being a KSI crash, when all potential contributing factors examined in the univariate analysis were considered together:

$$logit(P) = ln\left(\frac{P}{1-P}\right) = \beta_0 + \beta_1 x_1 + \cdots + \beta_i x_i$$

where P is the probability of a crash being KSI, and each x_i is an independent explanatory variable (risk factor), and each associated β_i is a model coefficient determined from the logistic regression modelling.

Multivariate logistic regression analysis provides a convenient way to determine the likelihood of a KSI crash outcome through the determination of the modelling coefficients (the β_is). If one independent variable x_i is increased by one unit, and all other variables held constant, then the likelihood of a KSI crash outcome will increase by a factor of $\exp(x_i)$. Hence, Odds Ratios can be determined for each independent variable, defined as such.

$$OR_i = exp(\beta_i)$$

By calculating the Odds Ratio for each independent variable, each significant potential risk factor, and the values it can attain, can be conveniently ranked. The independent variables included in the analysis were both continuous and discrete variables.

3. RESULTS

3.1 Univariate analysis

A total of 175,804 crashes were included in the study, 7181 KSI crashes and 168,623 non-KSI crashes. Table 3.1 shows the univariate associations between the severity of a metropolitan intersection crash (whether KSI or not) and each of the various potential temporal and weather contributing factors, namely: season, day of the week (weekday/weekend), time of day and atmospheric conditions.

When season was considered as the only factor, the odds ratio analysis showed a varied but significant association with the severity of the crash. Winter crashes were at slightly lower odds of being a KSI crash (OR=0.928), compared with summer crashes (p-value = 0.028).

When day of the week (weekday versus weekend) was considered as the only factor, the odds of a weekend crash being a KSI crash was 1.305 times that of weekday crashes (p-value < 0.001).

When time of the day was considered as the only factor, night time crashes (1800 – 2359) and early morning (dark) crashes (0000 – 0559) were 1.564 and 1.965 times more likely to be a KSI crash (p-values < 0.001), compared with morning crashes (0600-1159).

When atmospheric or weather conditions were considered as the only factor, a crash that occurred during rainy conditions was less likely (OR=0.750) to be a KSI crash than a crash that occurred during clear conditions (p-value < 0.001). All other atmospheric conditions (such as overcast, fog, smoke, dust or mist), were combined as one group and there was no significant difference in the odds of a crash being a KSI crash when compared with crashes that occurred in clear conditions (p-value = 0.560).

Table 3.1 Frequency distribution and associations between the severity of a metropolitan intersection crash and temporal and weather factors

	KSI Crash								
	No		Yes		Total		Odds		
	n	%	n	%	n	%	Ratio	95% C.I.	p-value
Season									
Summer^	38416	95.8	1704	4.2	40120	100	1.000		
Autumn	44558	95.9	1927	4.1	46485	100	0.980	0.917 - 1.047	0.541
Winter	44611	96.1	1825	3.9	46436	100	0.928	0.868 - 0.992	0.028
Spring	41038	96.0	1725	4.0	42763	100	0.945	0.883 - 1.011	0.101
All	**168623**	**95.9**	**7181**	**4.1**	**175804**	**100**			
^Reference Group; *Model: χ^2 = 6.01, df = 3, p-value = 0.111									
Weekday / Weekend									
Weekday^	134318	96.1	5390	3.9	139708	100	1.000		
Weekend	34305	95.0	1791	5.0	36096	100	1.305	1.236 - 1.378	< 0.001
All	**168623**	**95.9**	**7181**	**4.1**	**175804**	**100**			
^Reference Group; *Model: χ^2 = 88.79.01, df= 1, p-value < 0.001									
Time Block									
0600-1159^	54577	96.3	2085	3.7	56662	100	1.000		
1200-1759	78640	96.5	2844	3.5	81484	100	0.949	0.897 - 1.005	0.075
1800-2359	28434	94.4	1698	5.6	30132	100	1.564	1.466 - 1.670	< 0.001
0000-0559	6308	93.0	476	7.0	6784	100	1.965	1.774 - 2.176	< 0.001
All	**167959**	**95.9**	**7103**	**4.1**	**175062**	**100**			
^Reference Group; *Model: χ^2 = 392.59, df= 3, p-value < 0.001; **n = 742 with missing information									
Atmospheric Condition									
Clear^	139700	95.8	6099	4.2	145799	100	1.000		
Raining	17201	96.8	561	3.2	17762	100	0.750	0.688 - 0.819	< 0.001
Other	11722	95.7	521	4.3	12243	100	1.027	0.938 - 1.124	0.560
All	**168623**	**95.9**	**7181**	**4.1**	**175804**	**100**			
^Reference Group; *Model: χ^2 = 46.40, df= 2, p-value < 0.001									

Table 3.2 shows the frequency distribution and univariate association between the severity of a metropolitan intersection crash (whether KSI or not) and each of the various potential road and crash factors, namely: posted speed limit category, intersection type, traffic control, road grade, and whether the crash involved multiple vehicles.

In relation to the posted speed limit at the location of the crash, this information was missing nearly one in two target crashes (n = 81932, 47%). Analysing only those crashes that had the speed limit reported, intersection crashes on roads with speed limits greater than 50km/hour and less than 80 km/hour, and, 80 km/h or above were 1.087 and 1.630 times respectively more likely to be a KSI crash (p-value = 0.017; p-value < 0.001, respectively), compared with crashes at intersections with lower speed limits (50 km/hour or below).

Table 3.2 Associations between the severity of a metropolitan intersection crash, and road and crash factors

	KSI Crash								
	No		Yes		Total		Odds		
	n	%	n	%	n	%	Ratio	95% C.I.	p-value
Speed Limit Category									
50 km/h or below^	23447	95.4	1143	4.6	24590	100	1.000		
>50 and < 80 km/h	57463	94.9	3060	5.1	60523	100	1.087	1.015 - 1.165	0.017
80 km/h or above	8109	92.6	650	7.4	8759	100	1.630	1.477 - 1.799	< 0.001
All	**89019**	**94.8**	**4853**	**5.2**	**93872**	**100**			

^Reference Group; Model: $X^2 = 94.60$, df = 2, p-value < 0.001; **n = 81932 with missing information

	n	%	n	%	n	%	Odds Ratio	95% C.I.	p-value
Intersection Type									
Roundabout^	17506	96.8	587	3.2	18093	100	1.000		
3-way Intersection (T-junction)	70737	95.2	3537	4.8	74274	100	1.491	1.364 - 1.630	< 0.001
Intersection with 4 legs or more	80380	96.3	3057	3.7	83437	100	1.134	1.037 - 1.241	0.006
All	**168623**	**95.9**	**7181**	**4.1**	**175804**	**100**			

^Reference Group; Model: $X^2 = 156.77$, df = 2, p-value < 0.001

	n	%	n	%	n	%	Odds Ratio	95% C.I.	p-value
Traffic Control									
None^	32610	94.1	2030	5.9	34640	100	1.000		
Non-signalised*	52196	95.6	2405	4.4	54601	100	0.761	0.717 - 0.808	< 0.001
Signalised	83817	96.8	2746	3.2	86563	100	0.542	0.512 - 0.575	< 0.001
All	**168623**	**95.9**	**7181**	**4.1**	**175804**	**100**			

^Reference Group; Model: $X^2 = 432.58$, df = 2, p-value < 0.001; *(Stop Sign, Give Way Sign, etc.)

	n	%	n	%	n	%	Odds Ratio	95% C.I.	p-value
Road Grade									
Level^	140741	96.1	5753	3.9	146494	100	1.000		
Not Level	27882	95.1	1428	4.9	29310	100	1.252	1.181 - 1.328	< 0.001
All	**168623**	**95.9**	**7181**	**4.1**	**175804**	**100**			

^Reference Group; Model: $X^2 = 53.80$, df = 1, p-value < 0.001

	n	%	n	%	n	%	Odds Ratio	95% C.I.	p-value
Multi-vehicle Crash									
Single Vehicle Crash^	10748	89.4	1271	10.6	12019	100	1.000		
Multi-vehicle Crash	157875	96.4	5910	3.6	163785	100	0.316	0.296 - 0.336	< 0.001
All	**168623**	**95.9**	**7181**	**4.1**	**175804**	**100**			

^Reference Group; Model: $X^2 = 1047.75$, df = 1, p-value < 0.001

When the type of the intersection was considered, roundabouts were the safest type of intersection, with crashes at 3-way intersections (T-junctions) being 1.491 times more likely to be a KSI crash (p-value < 0.001), and crashes at intersections with 4 or more legs being 1.134 times more likely to be a KSI crash, than those at roundabouts (p-value = 0.006).

When the traffic control at the intersection was considered as the only factor, crashes at intersections with non-signalised traffic controls (i.e., stop sign, give way sign) were at decreased odds of being a KSI crash (OR=0.761) compared with crashes at intersections with no traffic control of any kind (p-value < 0.001). Furthermore, an intersection with a signalised traffic control had 46% lower odds (OR=0.542) for a KSI crash compared with no traffic control (p-value < 0.001).

When road grade was considered as the only factor, intersection crashes that occurred on non-level ground were 1.252 times more likely to be a KSI crash compared with those occurring on level ground (p-value < 0.001).

When whether the crash involved multiple vehicles was considered as the only factor, intersection crashes that involved multiple vehicles were at a decreased odds of being a KSI crash (OR=0.316) compared with those involving single vehicles (p-value < 0.001).

3.2 Multivariate analysis

Based on results from the univariate analysis, a decision was made to include all factors in the multivariate modelling, except for speed limit because of the high proportion of crashes with missing speed limit values (n = 81932, 47%). In addition, the year of the crash was included in the multivariate model to reflect any annual increase or decrease in KSI crashes. Although not a significant factor in the univariate analysis, season was still included along with the significant temporal factors - day of the week and time of day.

Table 3.3 shows the results from the multivariate logistic regression modelling of the likelihood of a metropolitan intersection crash being a KSI crash, when all potential contributing factors examined in the univariate analysis were considered together.

In terms of year, there was a decline in the odds of a metropolitan intersection crash being a KSI crash, with the odds at 0.970 for each year when compared to the previous year (p-value < 0.001).

For day of the week, the multivariate results also showed that a weekend crash was 1.149 times more likely to be a KSI crash than a weekday crash (p-value < 0.001). For time of day, afternoon crashes (1200 – 1759) were less likely (OR=0.938) to be KSI crashes when compared to daytime morning crashes (0600 – 1159) (p-value = 0.029). Night time crashes (1800 – 2359) and early morning (dark) crashes (0000 – 0559) however, were 1.381 and 1.310 times more likely to be KSI crashes (p-values < 0.001), when compared to daytime morning crashes.

In terms of atmospheric conditions, a crash that occurred during rainy conditions was less likely (OR=0.686) to be a KSI crash (p-value < 0.001), than a crash that occurred when conditions were clear. All other atmospheric conditions (such as overcast, fog, smoke, dust or mist) were combined as one group and were not significantly associated with the odds of a crash being a KSI one, when compared with crashes that occurred during clear conditions (p-value = 0.562).

Season was not significantly associated with the odds of a crash being a KSI crash, with the odds of a KSI crash in autumn, winter and spring not being significantly different to summer (p-value = 0.813; p-value = 0.229; p-value = 0.368, respectively).

In terms of intersection type, crashes occurring at 3-way intersections (T-junctions) were 1.902 times more likely to be KSI crashes (p-value < 0.001), and crashes at intersections with 4 or more legs were 2.017 times more likely than those occurring at roundabouts (p-value < 0.001).

In terms of traffic control at the intersection, there was no significant difference in odds of a KSI crash at intersections with non-signalised traffic controls (stop sign, give way sign etc.) and intersections with no traffic control of any kind (p-value = 0.672). Signalised traffic controls however, had significantly lower odds (OR=0.610) of a crash being a KSI crash, when compared to having no traffic control (p-value < 0.001).

When the intersection was located at a road section that was not level (either a crest of hill or a slope) then the odds for a crash to be a KSI was 1.173 times that of a level intersection (p-value < 0.001).

In terms of the number of vehicles involved in a crash, crashes that involved multiple vehicles were less likely (OR= 0.364) to be a KSI crash, compared to single vehicle crashes (p-value < 0.001).

Table 3.3 Results from multivariate logistic regression on the odds of a metropolitan intersection crash being a killed or seriously injured (KSI) crash

	Odds Ratio	95% C.I.	p-value
Year	0.970	0.961 - 0.978	< 0.001
Season			
Summer^	1.000		
Autumn	0.992	0.927 - 1.061	0.813
Winter	0.958	0.893 - 1.027	0.229
Spring	0.969	0.904 - 1.038	0.368
Weekday/Weekend^			
Weekday	1.000		
Weekend	1.149	1.086 - 1.216	< 0.001
Time^			
0600 - 1159	1.000		
1200 - 1759	0.938	0.885 - 0.993	0.029
1600 - 2359	1.381	1.291 - 1.478	< 0.001
0000 - 0559	1.310	1.173 - 1.463	< 0.001
Atmospheric Condition^			
Clear	1.000		
Raining	0.686	0.627 - 0.752	< 0.001
Other	1.028	0.936 - 1.129	0.562
Intersection Type^			
Roundabout	1.000		
3-way Intersection (T-junction)	1.902	1.722 - 2.101	< 0.001
Intersection with 4 legs or more	2.017	1.815 - 2.241	< 0.001
Traffic Control^			
None	1.000		
Non-signalised (Stop Sign, Give Way Sign etc.)	1.015	0.948 - 1.086	0.672
Signalised	0.610	0.569 - 0.655	< 0.001
Road Grade^			
Level	1.000		
Not Level	1.173	1.104 - 1.246	< 0.001
Nature of Crash^			
Single Vehicle	1.000		
Multiple Vehicle	0.364	0.339 - 0.392	< 0.001

^Reference Group; *Model: χ^2 = 1815.66, df = 16, p-value < 0.001

4. DISCUSSION

This investigation used the Integrated Road Information System (IRIS) to identify risk factors for KSI intersection crashes in the Perth metropolitan area from 2006 to 2015. Several risk factors for an increased risk of a KSI crash were identified from the multivariate analysis and are discussed below.

4.1 Temporal and Weather-Related Factors

Firstly, results of the multivariate analysis found that weekend crashes were more likely to be KSI crashes compared with weekday crashes. This is possibly due to increased risk of alcohol intoxication and alcohol related crashes on weekends (NHTSA, 2015) and well as increased speeds due to low levels of traffic congestion.

In addition, compared with morning daylight crashes (0600-1159), night time (1800-2359) and early morning dark (0000-0559) crashes were more likely to be KSI crashes. Afternoon crashes (1200-1759) showed a slightly lower risk of being KSI crashes than morning daylight crashes. These findings confirm those of previous studies examining crash risk at intersections which highlighted the increased risk of more severe crashes during the evening and night time (Chen et al., 2012; Hassan & Al-Faleh, 2013; Huang et al., 2008, Miller et al., 2011). Night and early morning crashes are more likely to be severe for several reasons including increased risk of speeding (Ministry of Transport New Zealand, 2013), alcohol intoxication (NHTSA, 2015), driver fatigue (Dobbie, 2002) and poorer visibility during these hours. In addition, lower traffic volumes during these hours compared to peak times may substantially increase vehicle speeds, resulting in higher crash severity. (Chen et al., 2012; Huang et al. 2008; Martiniuk et al. 2013).

Interestingly, rainy conditions significantly reduced the likelihood of a crash being a KSI crash at intersections in the current study. While a meta-analysis of 29 studies concluded that precipitation was associated with a considerable increase in crash rate, the association with fatal crash rate was not so definitive (Qiu & Nixon 2008). Previous studies in Saudi Arabia and Canada reported an increase in the severity of collisions in wet weather (Hassan & Al-Faleh, 2013; Zhang et al., 2000). It is possible that rain reduced the likelihood of a crash being a KSI crash in this WA study due to lack of snow or severe weather conditions in WA and drivers possibly exercising more caution when raining. When combined into one variable, other atmospheric conditions including overcast, fog, smoke, dust or mist were not significantly associated with the risk of a KSI crash. This may be due to these conditions being relatively uncommon or mild in WA.

Season of the year was not significantly associated with risk of KSI crashes in the multivariate model. This is likely due to the relatively mild changes in climate in WA throughout the year.

4.2 Intersection Type

Compared with roundabouts, crashes at T-intersections were 1.9 times more likely to be a KSI crash and crashes at 4-way intersections were 2 times more likely to be a KSI crash in the multivariate model. This is consistent with previous research which indicates that roundabouts are effective for reducing crash severity (Flannery & Datta, 1996, Hydén & Várhelyi, 2000). T- intersections and 4 way intersections have been associated with more severe crashes due to a higher frequency of 90 degree angle crashes occurring at these intersection types (Candappa et al., 2015, Flannery and Datta, 1996). Roundabouts, on the other hand reduce the angles of possible conflict points, thus reducing crash severity.

4.3 Intersection Traffic Control

Consistent with the findings of previous studies (Chen et al., 2012; Montella & Mauriello, 2012; Zhang et al., 2000), this investigation found that signalised controls at intersections (i.e., traffic lights) significantly reduced the risk of a KSI crash compared with intersections with no traffic controls This is an expected outcome as with signalisation directs and regulates the safe movement of vehicles through intersections (Candappa et al. 2015) to reduce the likelihood of conflict between vehicles, particularly those travelling in opposing directions. Interestingly, there was no significant difference in the risk of KSI crashes for intersections with non-signalised traffic controls (i.e., stop sign, give way sign) compared with those with no traffic controls. Previous studies have also provided mixed results on the impact of non-signalised traffic controls on intersection safety (Chen et al., 2012; Miller et al., 2011). For example, Chen et al. (2012) also reported no significant difference in risk of fatal crashes at uncontrolled intersections and intersections with stop or give way signs. There are a number of possible explanations for the non-significant difference in the risk of a KSI crash between signed-controlled intersections and uncontrolled intersections. There most likely is that drivers exercise a higher level of caution at uncontrolled intersections and travel at lower speeds, thus resulting in lower severity crashes.

4.4 Road Grade

The analysis found that non-level road sections (crest of hill or slope) were associated with a higher risk of KSI crashes. This may be due to reduced visibility for other vehicles on these roads (i.e., when approaching the crest) or an increased speed travelling in the downhill direction. In former scenario, vehicles turning right might not detect a vehicle approaching over a crest of a hill, thus resulting in a right turn thru, side impact, collision. One way to mitigate the risk of such a crash is to install a dedicated right turn green arrow (see Chen & Meuleners, 2013).

4.5 Multiple Vehicle Involvement

Finally, intersection crashes involving multiple vehicles were less likely to be KSI crashes than single vehicle crashes. This is potentially due to the additional spreading of impact forces across involved vehicles, rather than the concentration of the force of impact on one, single vehicle. It should also be noted that single vehicle crashes were much less common than multiple vehicle crashes in this study of intersection crashes. Indeed, multiple-vehicle KSI crashes outnumbered single vehicle KSI crashes six to one, meaning that multiple vehicle crashes at intersections represent the bulk of the burden of KSI intersection crashes.

4.6 Limitations

Unfortunately, 47% of the intersection crashes were missing information on the posted speed limit, meaning this variable had to be excluded from the larger broad multivariate analysis. Secondly, we were unable to adjust the analyses for traffic volume since data relating to different times of the day are not available. However, the time of day and day of the week (weekday, weekend) were used in the model as a proxy for traffic volume.

4.7 Areas for further investigation

Speed is a commonly accepted risk factor for crash severity (Chen et al., 2012, Xu et al., 2014, Haque et al., 2010), however evidence suggests that this effect is not necessary linear. It would therefore be useful to investigate this factor in more depth and for the entire population of KSI crashes if posted speed limit information was more complete. In addition, previous research has indicated that other factors may influence the risk of KSI crashes at intersection, including the number and width of lanes on approach to intersection, presence of turning lanes, and red light/ speed cameras at intersections. While these were outside the scope of the current investigation, it would be useful to examine the impact of these variables in the WA context. At this stage, there is emerging evidence in WA (e.g., Newstead et al. 2015) to support the very strong effect on combined speed and red light cameras on KSI crashes at metropolitan intersections.

5. CONCLUSION AND RECOMMENDATIONS

Multivariate logistic regression analysis has been conducted on data for crashes at metropolitan intersections in Perth WA. The analysis has identified several risk factors for KSI crashes at intersections, namely, crashes on the weekend, at night time, at non-level intersections and at 3-way and 4 or more-way intersections versus roundabouts. Factors that reduced the risk of KSI crashes included rainy conditions, signalised traffic controls and multiple-vehicle *versus* single vehicle crash types.

Therefore the following recommendations can be made:

1. Improve the recording of posted speed limits in the crash database so that analyses of the impact of speed limits on crash severity at intersections can be more accurately estimated.
2. Consider the increased use of traffic lights at intersections where appropriate.
3. Consider the increased use of roundabouts at intersections where appropriate.
4. Conduct further investigations into the safety benefits of non-signalised traffic controls (stop signs, give way signs) versus no traffic controls at intersections.
5. Conduct further investigations into the safety issues associated with intersections located on roads that are not level.

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