Why are some urban traffic signals much less safe than others?
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An important note for the reader

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Executive summary

The development of the NZ Transport Agency's *High-risk intersections guide* revealed there was a higher risk of death and serious injury at some urban signalised intersections than at others using the same control types. The reasons why some urban signalised intersections have poorer safety records than others are not well understood. The research presented in this report compares signalised intersections with good safety performance with those that perform poorly to understand the reasons for their differences.

A literature review was conducted to gather information relating to all possible non-flow variables, whether or not they were identified to be significant. Despite the large body of literature regarding safety at intersections, only a small amount of research addresses the effect of variables other than traffic flow in contributing to crash risk at signalised intersections. Physical, operational and environmental factors identified in this review are presented in the table below.

Type	**Variable**	**Factors/considerations**
Operational	Approach speeds	
	Adaptive signal control	
	Additional advanced detectors	
	Vehicle phasing and cycle times	All-red, yellow, green or inter-green times, number of phases
	Split phasing	
	Clearance times sufficient for cyclists	
	Pedestrian and cyclist delays	Encourage crossing against signals
	Signal coordination	
	Phasing consistency	Adjacent intersections
	Degree of saturation	
	Filter turns	Including combination phases, leading, lagging
	Parking	Up/down stream presence, occupancy
	Traffic safety cameras	
Physical	Access points, service roads	
	Geometric factors	Approach angles, horizontal curves, approach gradients
	Signal displays	Number of displays, aspects on displays, mast arms
	Bus/tram bays/stops	On entrance or exit
	Clearways	
	Cycle facilities	Painted lanes (including width), storage boxes, hook turns
	Intersection depth	
	Median barrier	Presence, depth, type, width
	Number of lanes	Total, approach configurations
	Lane widths	
	Slip lanes	Radius, pedestrian facilities, acceleration lane
	Shared through/turn lanes	Through/left, through/right
	Sight distances	

Type	Variable	Factors/considerations
	Pedestrian crossing facilities	
	Right turn bay	Length, offset, channelisation
	Visibility	Intersection presence, signals, vehicles (all movements)
	Visual clutter	Traffic signage, advertising, utility poles, foliage
	Complexity of intersection	Eg pedestrians, public transport, changes in geometry or alignment
Environmental	Proximate land uses	Residential, industrial, commercial, education
	Nearby activities	Education facilities, drinking establishments
	Proximity to other intersections	
	Demographics of nearby residents	Eg elderly
	Weather	Sun glare, precipitation, ice

A broad range of intersections in Auckland, Christchurch and Dunedin were selected for qualitative analysis of coded crash factors. The crash history associated with a) sites performing better than expected, b) in line with expectations and c) worse than expected was examined. The assessment included operational, environmental and physical variables as contained within the Crash Analysis System (CAS). Using this data, the hypothesised influence of variables on safety could be confirmed or dismissed, allowing the desktop analysis and site inspections in the following stage to be more effectively targeted.

The analysis suggested that the prevalence of some crash factors (eg alcohol and drugs, failing to look for/see other vehicles that are behind when changing lane position or direction, and loss of control when turning) was inversely related to the safety performance of the intersection. These factors contribute to crashes at all intersections, but are proportionally less common at poorly performing intersections, where the actual factors that have a bearing on poor safety outcomes become more prevalent. The analysis highlighted that a number of factors identified in the literature review, which were expected to influence safety outcomes, actually had a negligible effect on performance:

- Horizontal alignment showed little difference between performance categories.
- Significantly more crashes at worse performing intersections did not involve striking an object, indicating that the presence of objects which might be struck did not worsen safety outcomes.
- More pedestrian/cyclist crashes were expected at worse performing intersections, but this was not the case. Better performing intersections did exhibit a lower rate of pedestrian/cyclist crashes, but this was not significant.

A significant finding of the analysis was that no single factor contributes overwhelmingly to poor safety performance; however, approximately 50% of crashes within each performance category can be attributed to the top 10 crash factors, with the remaining share apportioned between a further 200 factors.

The intersections analysed for coded factors were refined to a list of 40 intersections which were analysed for non-coded factors. To populate a dataset of non-coded factors, site visits were conducted at all 40 intersections and a checklist of physical, operational and environmental variables was filled out for each intersection approach. Two transportation professionals from Abley Transportation Consultants were present at each site visit. Local transport operations staff were also present for site visits. An approach-based intersection analysis provided evidence of recurring themes in crash causes with a number of key factors being present in at least half of the poorly performing approaches.

Traffic volumes are the main predictor of crash performance and this was accounted for using the traffic volume only models in the *High risk intersections guide*. There was a wide variation in the residual crash rate after accounting for the traffic flows, which strongly suggests that other factors are likely to play a key role. The flow only models permitted a sample of intersections to be selected for comparison, which had much higher and lower risk than typical. This research explored whether there were further physical operational and environmental factors involved, and investigated the differences between the poorest performing and best performing intersections that would help to further explain good or poor crash performance.

None of the factors identified were present in all of the poorly performing intersections but some were present in half or more of those approaches identified with two or more crashes for the corresponding crash type. The causes of poor safety performance differed depending on the intersection and the intersection's characteristics. In some instances, it was observed that the worst performing intersections had combinations of factors that appeared to interact to give a worse outcome than explained by the sum of the individual factors. This observation leads to the recommendation that intersections with a poor safety performance should be assessed on a case-by-case basis to identify the underlying factors and most appropriate treatment strategy.

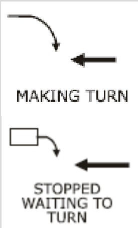
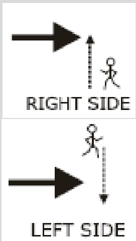
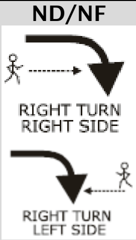
The final stage considered the crash performance of 100 different intersections to understand if any of the coded or non-coded factors identified in previous research stages were more abundant at intersection approaches with a higher rate of crossing (no turns) crashes, right turn against crashes or crashes involving pedestrians. Only crashes causing minor injury, major injury or death were included and the Welch's t-test was used to measure the statistical significance of results.

The non-coded factors were populated for each intersection approach using data from *NZ Transport Agency research report 483* 'Crash prediction models for signalised intersections – signal phasing and geometry' (Turner et al 2012), and data collected manually from Google Earth and Google Street View. The most recent crash prediction models, developed in RR483, were used to find the expected number of crashes on each intersection approach. The residual number of crashes on each intersection approach was found by subtracting the actual number of crashes from CAS. The residuals were correlated to each coded and non-coded factor to see if the presence of the factor had any effect on the value of the residual.

The table on the next page shows the factors found to be significant for each crash type studied, their effect on injury crashes and the degree of confidence for each factor. Overall, 10 factors were found to be statistically significant at greater than 95% confidence and five factors were found to be statistically significant at greater than 90% confidence. The findings that intersection approaches with larger skew or appreciable gradient had a smaller number of injury crashes were counter to expectations and further research into these factors is recommended. The results of this research stage demonstrated the value of remedial intersection treatments which modified the factors studied.

A summary table has been prepared presenting the key conclusions arising from this research alongside the findings of Turner et al (2012). The summary table included in section 6.2 of this report is intended for use by practitioners who have completed a high-level design, and are refining this to ensure crash risk is minimised. The research team found that once traffic volume is accounted for, the number of lanes and their arrangement, number of signal displays and their position, and the operational control of turning traffic are the main predictors of crash performance with other factors having minor effects on safety performance.

It is recommended the results of this research be incorporated into relevant guides for practitioners who design signalised intersections in urban areas. Further research is also recommended into re-calibrating crash prediction models to incorporate the statistically significant factors found in this research.

Crash type	Factor found to be significant	Effect on number of injury crashes	Degree of confidence
HA 	Number of signal displays less than 5	Increase	>95%
	No mast arms	Increase	>95%
LB 	Either filtering banned or part-time	Decrease	>90%
	Angle of skew less than or equal to 15º	Decrease	>90%
	Single opposed through lane	Decrease	>95%
NA/NB 	Either shared left/through or right/through lane	Increase	>90%
	Appreciable gradient on intersection approach	Decrease	>95%
	Angle of skew on intersection approach less than or equal to 5º	Increase	>95%
ND/NF 	Right-turn filtering not allowed full time	Decrease	>95%
	Right-turn filtering not allowed at all	Decrease	>95%
	No shared right/through lane	Decrease	>90%
	No right-turn red arrow	Increase	>95%
	No left-turn red arrow	Increase	>95%
	Angle of skew on intersection approach less than or equal to 5º	Increase	>95%

Abstract

Research undertaken to inform the *High risk intersections guide* showed there was a higher risk of death and serious injury at some urban signalised intersections than at other intersections using the same control types. The reasons why some urban signalised intersections are less safe than others are not well understood. The research presented in this report compares urban signalised intersections with good safety performance with those that perform poorly to understand the reasons for their differences.

The environmental, physical and operational factors identified as contributory factors to poorer safety performance are determined qualitatively in this research. The results of the research will assist practitioners by:

- identifying factors or combinations of factors that should be implemented or avoided to enhance safety outcomes
- specifying potential safety issues when designing urban signalised intersections
- providing an indication of the likely reduction in fatal and injury crashes when installing remedial treatments at urban signalised intersections.

1 Introduction

The *High-risk intersections guide* (HRIG) is a comprehensive assessment framework for evaluating safety at intersections (NZ Transport Agency 2013b). It provides transport professionals with best practice guidelines to identify, target and address key road safety issues at high-risk intersections. However, there is a knowledge gap in identifying why some urban signalised intersections have a higher risk of death and serious injury than others, and the guide does not assist transport professionals in identifying specific methods to improve the safety of urban signalised intersections. The NZ Transport Agency contracted Abley Transportation Consultants to address these knowledge gaps.

The purpose of this research project was to qualitatively analyse a number of urban signalised intersections for a range of factors that might influence safety, then disseminate the research findings to assist practitioners in selecting effective safety treatments for urban signalised intersections. Compared with existing statistical approaches for modelling crash risk, this research used a qualitative whole-system approach to identify factors that might normally be missed due, for example, to the random nature of crashes and their severity, or the process of defining variables for mathematical analysis.

The research fits with the NZ Transport Agency's *Safe System* approach by seeking to identify factors which will lead to safer roads and roadsides. Later chapters focus specifically on death and injury crashes. By researching and identifying factors correlated to these types of crashes, factors can be mitigated or removed leading to a lower risk of death or injury when driver mistakes occur.

The specific objectives of the research were:

- Identify a wide range of factors relating to increased death and serious injury risk at urban signalised intersections, from New Zealand and international literature.
- Select a sample of New Zealand urban signalised intersections that have a higher occurrence of death and serious injury crashes than would be expected, based on the type of intersection and traffic flows, for more detailed analysis. Identify a number of intersections performing in line with expectations and better than expected, to act as control group.
- Analyse the sample of intersections in detail, including desktop assessment of crash report information followed by a series of field inspections and technical analysis to qualify effects of the factors identified above upon crash performance (Land Transport NZ 2004).
- Document and disseminate the findings of the research to assist practitioners in selecting effective safety treatments for urban signalised intersections.

The research underpinning this report was undertaken during 2014–2015, starting with a literature review and concluding with the refinement and finalisation of guidance for specific factors associated with increased crash risk. This report presents both an overview of the research process as it was developed, and the outputs (including recommendations) that were generated.

1.1 Report structure

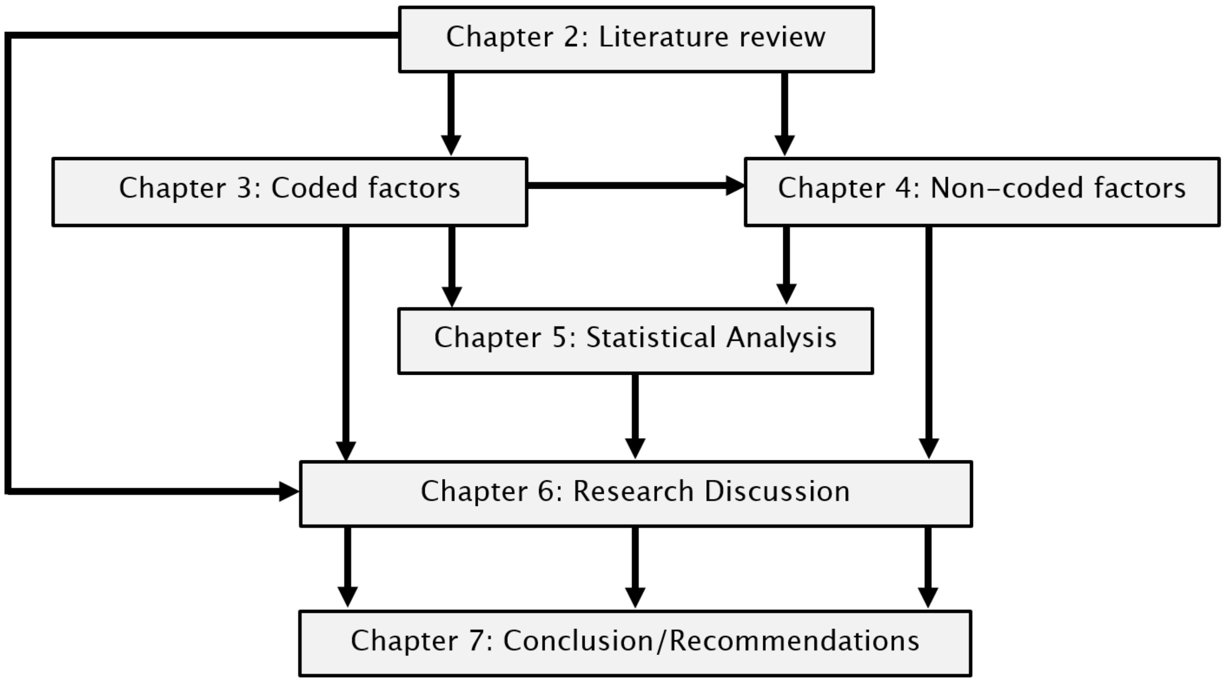
Figure 1.1 shows the overall structure of the report and how each chapter informs other chapters.

The report is organised as follows:

- Chapter 2 provides background for the research by summarising the findings of international and New Zealand literature on urban signalised intersections. Factors found to affect crash rates at urban signalised intersections are investigated further in chapters 3 and 4. The key findings from the literature review are also highlighted in the conclusions and recommendations.

- Chapter 3 describes the analysis of coded factors from CAS for injury crashes occurring at or near several thousand urban signalised intersections. The key crash types and factors influencing crash rates are investigated further in chapter 4 and carried through to the conclusions and recommendations.
- Chapter 4 describes the analysis of non-coded factors for 40 selected signalised intersections as informed by site visits. The key factors found to influence crash rates are investigated further in chapter 5 using statistical analysis and carried through to the conclusions and recommendations.
- Chapter 5 describes the statistical analysis of 100 further signalised intersections to determine if there is a statistically significant difference in crash rate between signalised intersections with and without the key factors identified in chapters 3 and 4.
- Chapter 6 presents additional discussion to conclude the technical assessment including the presentation of a useful resource for practitioners which combines the factors identified in chapter 5 with crash factors from prior research.
- Chapter 7 presents conclusions and recommendations arising from the research.

Figure 1.1 Report structure flow diagram



2 Literature review

A detailed review of national and international literature was undertaken to identify the factors influencing road safety at urban signalised intersections. This chapter is organised into four parts.

The technical background, including methods for estimating risk and measuring the safety performance of urban signalised intersections, and a brief outline of methods for the diagnosis and treatment of crash locations is presented in section 2.1.

The safety performance assessment applied in this research to identify high-risk intersections for further analysis used a conflicting flow model to equate intersections with similar characteristics. Consequently, the review aimed to identify variables other than traffic flow that might influence safety performance. There is a large body of literature in which numerical models for predicting crash rates at signalised intersections have been developed (see Kowdla 2004; Abdel-Aty et al 2006; Turner et al 2012 for thorough reviews); however, only a small selection of studies includes factors other than traffic volumes. Key literature relating non-flow factors to crash risk is reviewed in section 2.2.

A number of other studies which identify additional factors relating to increased crash risk at urban signalised intersections are discussed in section 2.3. The review aimed to identify not just factors found to be statistically significant, but all factors that could influence crash risk. Section 2.4 presents a summary of the factors identified, which are classified into physical, operational and environmental variables.

CAS crash movement and cause codes standardising the description of vehicle crash movements are presented in appendix A and appendix B respectively. Descriptions associated with literature identified in this chapter will be converted to maintain consistency with these definitions and New Zealand left-side driving.

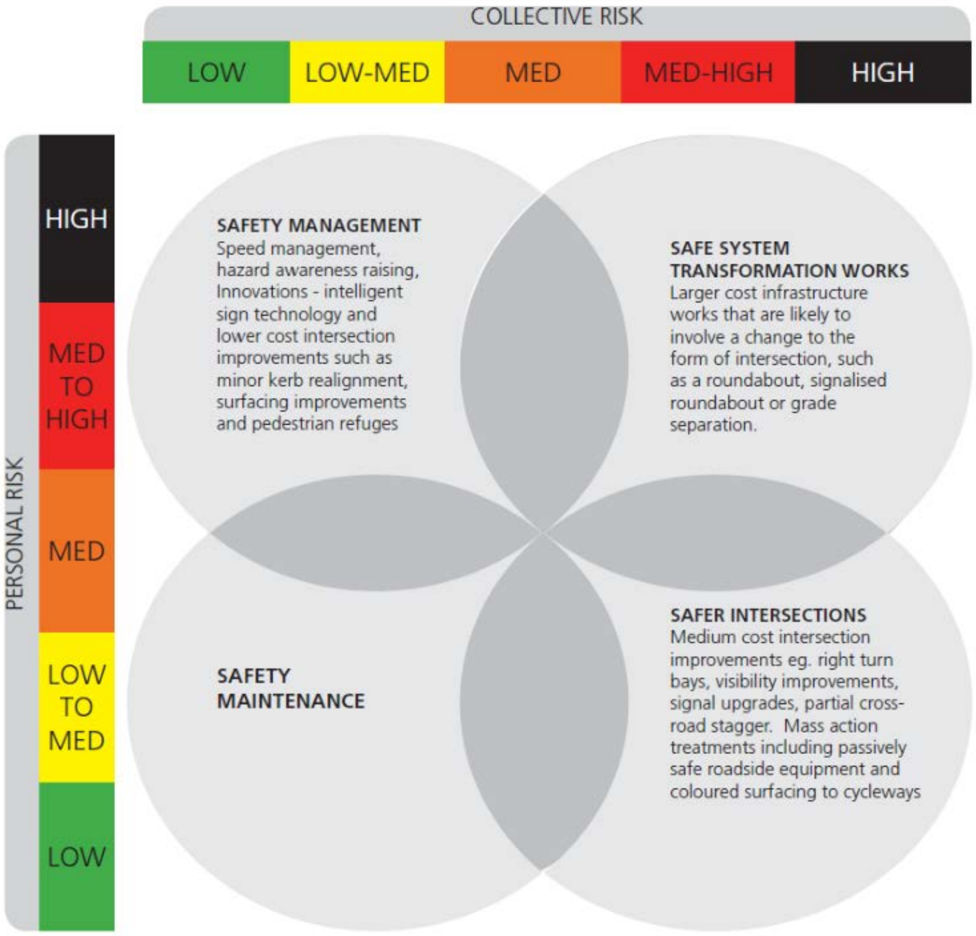
2.1 Intersection risk and safety performance

The HRIG presents two metrics quantifying crash risk (NZ Transport Agency 2013b):

- **Collective risk** is the total number of fatal and serious crashes, or death and serious injury (DSI) equivalents per intersection in a crash period.
- **Personal risk** is the risk of death or serious injury to each vehicle/person entering the intersection, calculated from the collective risk divided by a measure of flow.

Collective and personal risk metrics can reveal different aspects of the risk situation for a given intersection. The most appropriate treatment strategy for an intersection can be determined on the basis of both collective and personal risk, as shown in figure 2.1.

Figure 2.1 Intersection treatment safety improvement strategy



Source: NZ Transport Agency (2013b)

Crash risk can be assessed in a number of different ways:

- Reported risk: summary of the recent history of fatal and serious crashes.
- Estimated risk: reported injury crashes adjusted for the typical proportion of DSIs associated with each injury crash, depending upon movement type and speed environment.
- Predicted risk: models based upon the physical and operational characteristics of an intersection that are known to affect crash risk.

The following sections describe the risk assessments described above, and present the level of safety service (LoSS) method for determining the safety performance of a site relative to other sites with similar control schemes and traffic volumes. Methods for the diagnosis of safety issues and treatment of crash locations are also discussed.

2.1.1 Reported risk

An evaluation of the reported risk at an intersection assesses risk purely on the basis of crash history at the site, forming a wholly reactive approach. If all injury crashes are considered in the assessment, minor crashes can be over-emphasised, as these comprise the majority of injury crashes. Alternatively, if only fatal and severe crashes are considered, the measure places an undue weight on the often random nature of crash severity and can lead to incorrect conclusions based on small sample sizes. Consequently the reported risk does not necessarily reflect the underlying risk at the site.

2.1.2 Estimated risk

An assessment of the estimated risk at an intersection applies severity indices that represent the typical severity of crashes for a given movement and speed environment. These are used to weight each reported injury crash at a site and are summed over all crashes to produce an estimated DSI value for the site. This process increases the amount of data available for the analysis, compared with using reported fatal and serious crashes alone. The output provides a much better measure of the expected risk at a site than the reported risk.

2.1.3 Predicted risk

A number of predictive risk equations with different model forms exist, representing various intersection types and levels of complexity. Simplistic models use vehicle flows as the sole variable to represent exposure, while more complex models represent a greater number of intersection variables, but have high data requirements which can make the assessment of large numbers of existing intersections difficult. Predicted risk equations can be appropriate for assessing the potential risk during the design of new intersections, or upgrades of existing intersections, and a number of predictive risk equations are included in the NZ Transport Agency (2013a) *Economic evaluation manual.*

2.1.4 Safety performance evaluation

The purpose of safety performance evaluation is to compare sites with similar intersection configurations, speed environments and traffic flows. Intersections that perform poorly compared with expectations will often have flaws that can be readily mitigated (Cockrem et al 2013). A number of studies have developed methods for evaluating safety performance compared with expectations.

Ogden et al (1994) developed a crash prediction model for intersections on the basis of entering vehicle volumes, and used this to identify sites with more than one crash above the modelled ‘high’ risk rate, and with less than one crash below the modelled ‘low’ risk rate. The researchers performed quantitative analysis on the classified intersection groupings, and then qualitative assessment of matched pairs of intersections that were proximate and had similar flow characteristics but different safety performance. The findings are detailed in section 2.2.

Jia and Parsonson (1995) developed tables of average, and 90th and 95th percentile values for the expected number of crashes at various types of intersection for ranges of traffic flows. The tables indicated expected values for a range of crash types and severity, light and weather conditions, season, day of week and hour of day. The tables allowed practitioners to quickly identify whether a particular intersection presented more risk than others of its type, allowing greater focus on intersections with specific problems.

Kononov and Allery (2003) developed safety performance functions for roadways, which predicted crashes per mile on the basis of traffic flows, then generated four LoSS bands on the basis of extent of deviation between the actual and modelled performance. Sites with a greater number of crashes than modelled by more than 1.5 standard deviations were classed as LOSS IV (worst). Sites with fewer crashes than modelled by more than 1.5 standard deviations were classed as LOSS I.

The technique developed by Kononov and Allery (2003) was adapted for use in the HRIG. The guide measures the safety performance of intersections by comparing crash risk to risk exposure for different types of intersection, termed a LoSS assessment (NZ Transport Agency 2013b). The LoSS assessment first categorises intersections on the basis of speed environment and intersection type, performing a separate analysis for each category. Intersections for a given category are then plotted on a scatter plot of crash risk versus traffic exposure. The HRIG used all reported injury crashes, ie reported risk, as the measure of crash risk. The daily product of flow (PoF) formula, as shown in equation 2.1, was used by the guide to represent exposure.

$$PoF = (average(Q_{major_1}, Q_{major_2}).average(Q_{minor_1}, Q_{minor_2}))^{0.4} \quad \text{(Equation 2.1)}$$

where:

- Q_{major_1} and Q_{major_2} are the two-way average annual daily traffic (AADT) volumes on each leg of the major road; the formula presumes that the entering traffic is half the two-way total.
- Q_{minor_1} and Q_{minor_2} are the two-way AADT volumes on each leg of the minor road; at a T intersection Q_{minor_1} is the side road AADT volume, and Q_{minor_2} is defined to be zero.

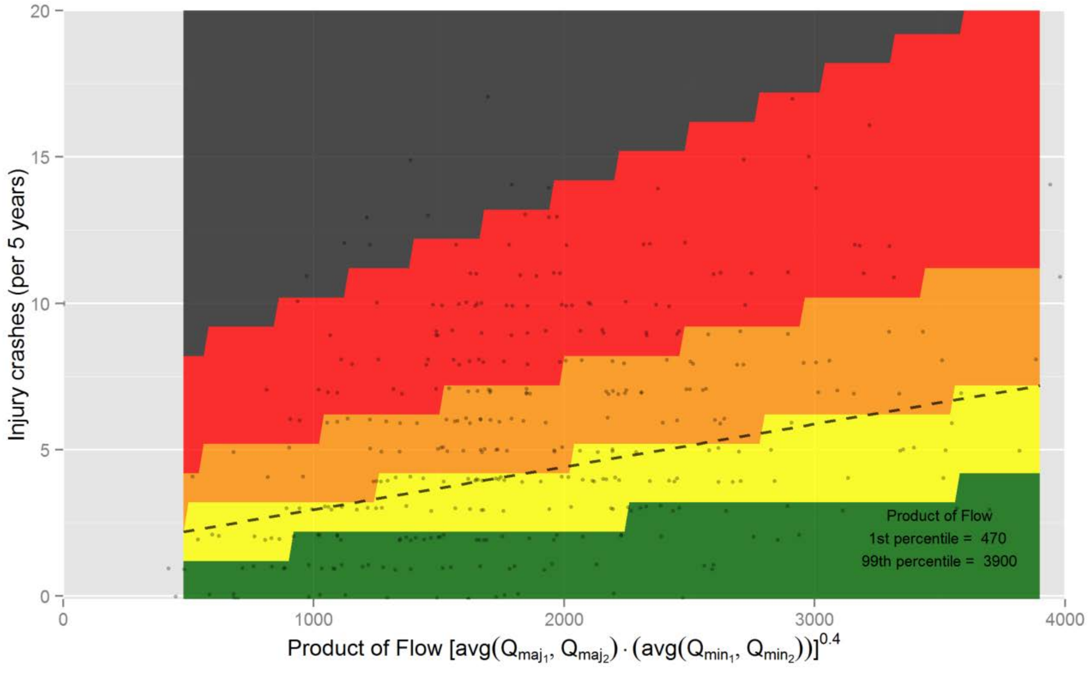
The HRIG defined five LoSS bands that classify intersections by the percentile of safety performance into which they fall, as shown in table 2.1. LoSS V, for example, indicates that the crash rate is in the worst 10% band. A LoSS chart for urban signalised crossroads indicating the spread of intersections over the five LoSS bands is shown in figure 2.2.

Table 2.1 Level of safety service band definitions

Level of safety service	Safety performance
LoSS V	90–100th percentile
LoSS IV	70–90th percentile
LoSS III	50–70th percentile
LoSS II	30–50th percentile
LoSS I	0–30th percentile

Source: NZ Transport Agency (2013b)

Figure 2.2 Example level of safety service chart for urban signalised crossroads, dashed line indicates median



Source: NZ Transport Agency (2013b)

2.1.5 Treatment of crash locations

Effective treatment of crash locations requires identifying the underlying safety issue for remediation. *A New Zealand guide to the treatment of crash locations* (Land Transport NZ 2004) indicates that specific safety problems can be diagnosed by performing a detailed assessment of crash history data, which is then further refined by site visits. The guide suggests that common factors in crashes should be identified, including crash movements, directions, time, vehicle types and traffic conditions.

The Australasian *Guide to road safety part 8: treatment of crash locations* (Austroads 2009), for which the New Zealand guide is a companion document, presents a comprehensive discussion of the components of a traffic system that can contribute to crashes, including travel speed, factors affecting road users and elements of the road environment. The guide presents diagnostic methods including the analysis of crash movements (ie by frequency histogram) and factor matrices, which combine movement codes with other information such as directions, vehicle types, weather and day of week.

Kononov and Janson (2002) present an alternative diagnostic methodology for detecting safety problems at intersections, which treats traffic crashes as random Bernoulli trials, allowing identification of crash patterns that deviate from the statistical process for a given environment. This can provide clues to causality and assist practitioners in identifying influential environmental factors.

2.2 Factors affecting crash risk at signalised intersections

The HRIG identifies that the following movement types correspond to the greatest proportions of crashes at urban signalised intersections (NZ Transport Agency 2013b):

- right turn against
- crossing (no turns)
- pedestrians crossing road.

Although the HRIG describes the types of treatment strategy that may be suitable for improving safety once a risk issue is identified, as shown in figure 2.1, it does not describe specific interventions to improve safety. Specific factors are examined that are expected to contribute to the most frequent crash types and countermeasures are suggested. These factors for urban traffic signals include (NZ Transport Agency 2013b, p54):

- visibility of:
  - the signal head
  - the intersection to approaching vehicles
  - through vehicles for right-turning vehicles
- long cycle times, short inter-green intervals or excessive approach speeds (which may encourage red light running)
- filter turns, or combinations of protected and filter turns.

As part of a larger research project into road safety, researchers from the Monash University Accident Research Centre performed a qualitative assessment of factors other than traffic volumes affecting crash patterns at signalised intersections (Ogden et al 1994). The researchers used crash prediction models, based on entering traffic volumes, to identify intersections performing as expected, and better or worse than expected (labelled ‘normal’, ‘low’ and ‘high’, respectively). The classified intersections were quantitatively assessed for number of lanes, presence of shared or exclusive right-turn lanes, slip lanes, exclusive left-turn lanes (no slip lane), lane width, median presence and width, tram/bus stop presence, signal mast arms, gradient, right-turn control, clearway presence, surrounding land use (industrial, commercial, educational, residential or other) and presence of service roads. Conclusive findings from the quantitative assessments included:

- A greater proportion of sites with exclusive right-turn lanes tended to be in the normal or low categories.
- Medians, and wider medians, were associated with safer sites.
- Industrial land uses tended to have safer intersections, while less safe intersections were associated with residential land uses.
- Mast arms were more likely to be present at intersections with higher than expected crash rates.
- There was a strong tendency for intersections with higher than expected crash rates to have fully controlled right turns.

The researchers suggested that mast arms and fully controlled right turns had possibly been added to intersections with a poor safety record but failed to address the underlying safety issues. A second round of site inspections was conducted where sites in the high category were paired with an adjacent site for which there was flow data. The research produced a number of qualitative findings:

- Sites with a poor safety record typically had one or more approaches on an up-grade.
- Increased visual clutter (including lines of utility poles or illuminated advertising signs) was observed at a number of sites classified as high.
- Sites in the high group tended to have increasingly complex decision-making environments – in addition to signals there were often trams, pedestrians, and changes in road geometry and alignment.

Turner et al (2012) quantified the effect signal phasing had on crash types for various modes at traffic signals, taking into account speed limits, intersection geometry and the land-use environment. This study forms the most comprehensive assessment of non-flow variables identified in the literature review. Data representing a large number of variables was collected for 238 low- and high-speed intersections from five cities throughout New Zealand and Melbourne, Australia. Crash prediction models were developed for the predominant vehicle-vehicle crash types (crossing (no turns), right turn against, loss of control and rear end) and pedestrian-vehicle crash types (crossing, right turning). Vehicle crash models were developed for both all-day and peak time periods. The effects of all significant parameters are summarised in table 2.2. Due to limited information cyclist crash prediction models were not developed. Variables that were either highly correlated to other variables or not found to be significant in any of the models included the number signal displays, the number of aspects on signal displays, and the presence of pedestrian crossing facilities, bus bays (on intersection exit) and cycle storage boxes.

These types of studies reach their conclusions by comparing the safety performance of different intersections. There is an essential bias in the method that means some results need to be treated with caution. One issue is correlation between variables that mask effects. Also where any of the features or parameters being measured are more likely to be implemented at higher-risk situations, the safety benefit may be underestimated. This can be to the extent that measures appear harmful, when in fact they are beneficial. So where particular features have been introduced in an attempt to address a poor crash history, the feature can be misidentified as a cause of the problem.

A before and after study of intersections with the same feature may show it was effective at reducing crash risk. But the 'before and after' method also has biases in the opposite direction, and can easily overestimate the effectiveness of a remedy applied at a site with a poor crash history (regression to the mean), and when more than one remedy is combined.

To ensure the estimated effects are reliable, in studies comparing the safety performance of different intersections it is important to take into account correlation between variables, and also assess whether some features are more likely to have been implemented at higher-risk sites or busier sites. Any conclusions drawn about variables that are more likely to be used at busier or riskier intersections should be confirmed by before and after studies of their implementation.

Table 2.2 Effect of significant intersection parameters on crashes by crash types

+	Presence of/increase in parameter increases crashes	--	Presence of/increase in parameter decreases crashes

Presence of/increase in parameter	**Vehicle- vehicle crashes**					**Pedestrian-vehicle crashes**	
	Crossing (no turns)	**Right turn against**	**Loss of control**	**Rear end**	**Other**	**Crossing**	**Right turning**
Approaching traffic volume	+		+	+	+	+	
Right-turning traffic volume		+					+
Degree of saturation		+	+				
Pedestrian volume						+	+
Intersection size (lanes, depth)	+						
Approach lanes			+	+		+	
Through lanes		+					
Approach width					+		
Cycle time	--	--	--		+	+	--
All-red time	--					+	
Yellow time							+
Inter-green + all-red time				--			
Full right-turn protection		--					--
Split phasing	--		+	+	+	--	
Mast arm	--						
Coordinated signals	+				--		+
Additional advanced detectors[1]	+				--		
Shared turns	+				+	+	
Shared right-turn/through lane		--					
Raised median/central island	--	+				--	
Right-turn bay/lane length		--		--			

[1] Turner et al (2012) qualify this result by stating: 'The sites with advanced detectors had high numbers of crashes, a counterintuitive result that should be treated with caution. Additional analysis in the form of before-and-after studies is required to assess the safety offered by these loops.'

+	Presence of/increase in parameter increases crashes	- -	Presence of/increase in parameter decreases crashes

Presence of/increase in parameter	Vehicle- vehicle crashes					Pedestrian- vehicle crashes	
	Crossing (no turns)	Right turn against	Loss of control	Rear end	Other	Crossing	Right turning
Free vehicle left turn			+	+	+		
Merge on intersection exit			+		- -		
Cycle facilities		+		- -		- -	
Upstream bus bay (within 100m)			+		+		
Upstream parking			- -		- -		
High speed limit (>= 80kph)			+	+	+		
Commercial land use					+		
Residential land use			- -				- -

Source: Turner et al (2012)

2.3 Additional factors affecting crash rates

This section identifies factors affecting risk that are additional to those found in the studies outlined in section 2.2. It does not attempt to review the large body of existing literature regarding flow-based models of crash risk at intersections.

The stops and goes of traffic signals: a traffic signal auditor's perspective (Land Transport New Zealand 2006) reviews and summarises the findings of a number of traffic signal audits from throughout New Zealand. The report identifies four safety issues that occur at signalised intersections then suggests factors that contribute to these issues, including:

- compromised visibility (geometry)
- misjudgement of speed or intentions of other vehicles
- turning on yellow
- phasing inconsistencies between adjacent intersections
- excessive delays encouraging red light running
- lack of space and conspicuity for cyclists (particularly for through movement)
- slip lanes with large radii for pedestrians.

The report then examines specific design considerations related to the above factors and describes recommended treatments for signalised intersections.

Turner et al (2006) developed a range of models predicting crash rates for cyclists and pedestrians. The following non-flow variables were identified as influencing crash rates for pedestrians and cyclists:

- proportion of pedestrians crossing against green man
- intersection depth (average crossing distance of both approaches)

- number of through lanes opposing right turners
- lane width (including cycle lane if present)
- visibility of right-turning vehicles in right-most opposing lane.

A number of studies of signalised intersection crash rates have been conducted in Singapore and identified the following additional factors (Chin and Quddus 2003; Kumara et al 2003; Kumara and Chin 2005):

- sight distances less than 100m
- presence of horizontal curves
- obtuse approach angle
- acceleration lane for slip lane
- provision of adaptive signal control
- median railings
- surveillance camera
- right-turn channelisation.

Roozenburg and Turner (2005) tested a range of non-flow variables for signalised intersection crash rates, including right-turn signal phasing and right-turn bay offset.

Turner et al (2009) assessed cyclist crashes using non-flow variables (not specifically for signalised intersections) including width of cycle lane, presence of flush median and presence and occupancy of parking around the intersection.

Abdel-Aty and Wang (2006) included analysis of signalised intersections in the context of transport corridors, and identified that presence of driveways near the intersection and the distance to other signalised intersections along the corridor might influence crash risk.

Austroads (2002) performed site investigations at 18 intersections throughout metropolitan Melbourne to investigate cyclist safety. The researchers found that clearance times (whether they were sufficient for cyclists to cross the intersection) and the ability to make hook turns might influence cyclist safety at intersections.

Mitra et al (2007) incorporated spatial data in the analysis of vehicle crash causation, assessing the relation between crash rates and local resident demographics, weather (sun glare, precipitation) and proximity to drinking establishments.

Other factors identified in the literature included the number of signal phases, the presence of a road shoulder and the presence of hazards along roadsides (Agbelie and Roshandeh 2014; Maheshwari and D'Souza 2010; Mitra and Washington 2007; Poch and Mannering 1996).

2.4 Summary

Despite the large body of literature regarding safety at intersections only a small amount of research addresses the effect of variables other than traffic flow in contributing to crash risk at signalised intersections. The purpose of this review was to gather information relating to all possible non-flow variables, whether or not they were identified to be significant. The physical, operational and environmental factors identified in this review are summarised in table 2.3.

Table 2.3 Variables influencing crash risk at urban signalised intersections

Type	Variable	Factors/considerations
Operational	Approach speeds	
	Adaptive signal control	
	Additional advanced detectors	
	Vehicle phasing and cycle times	All-red, yellow, green or inter-green times, complexity of phases
	Split phasing	
	Clearance times sufficient for cyclists	
	Pedestrian and cyclist delays	Encourage crossing against signals
	Signal coordination	
	Phasing consistency	Adjacent intersections
	Degree of saturation	
	Filter turns	Incl. combination phases, leading, lagging
	Parking	Up/down stream presence, occupancy
	Traffic safety cameras	
Physical	Access points, service roads	
	Geometric factors	Approach angles, horizontal curves, approach gradients
	Signal displays	Number of displays, aspects on displays, mast arms, visibility of displays, age/condition of displays
	Bus/tram bays/stops	On entrance or exit
	Clearways	
	Cycle facilities	Painted lanes (incl. width), storage boxes, hook turns
	Intersection depth	
	Flush median	Presence, depth, barriers
	Number of lanes	Total, approach configurations
	Lane widths	
	Slip lanes	Radius, pedestrian facilities, acceleration lane
	Shared through/turn lanes	Through/left, through/right
	Sight distances	
	Pedestrian crossing facilities	
	Right-turn bay	Length, offset, channelisation
	Visibility	Intersection presence, signals, vehicles (all movements)
	Visual clutter	Traffic signage, advertising, utility poles, foliage
	Complexity of intersection	Eg pedestrians, public transport, changes in geometry or alignment
Environmental	Proximate land uses	Residential, industrial, commercial, education
	Nearby activities	Education facilities, drinking establishments
	Proximity to other intersections	
	Demographics of nearby residents	Eg elderly
	Weather	Sun glare, precipitation, ice

3 Analysis of coded factors

The technical analysis presented in chapters 3 through 5 of this report builds incrementally upon the results of the previous chapter. Chapter 3 assesses crash factors coded in CAS for all injury crashes relating to signalised intersections in order to identify any underlying trends and common crash types. Chapter 4 refines the list of signalised intersections to 20 performing better than expected and 20 performing worse than expected. Site visits inform the analysis in chapter 4 and help to identify the factors present at poorly performing intersections for each crash type.

The analysis in chapters 3 and 4 is deliberately qualitative rather than quantitative but uses some quantitative information to inform the key findings summarising the important trends within the data. Factors found to be significant in chapter 4 are analysed in chapter 5 in an attempt to find statistically significant differences in injury crash numbers between signalised intersections with and without each factor present.

3.1 Introduction

The analysis of several thousand intersections as part of the New Zealand Road Assessment Programme (Urban KiwiRAP) provided the basis for the selection of sites to inform the research (Brodie et al 2013). Urban KiwiRAP analysis of intersections adapts the risk profiling process defined in the HRIG. The dataset of intersections from Auckland, Christchurch and Dunedin is based on crash data from 2008 to 2013. The LoSS was calculated for all urban signalised crossroads and T-intersections and the number of intersections in each LoSS band was counted as shown in table 3.1. Auckland has the greatest number of intersections and also a similar number of crossroads as T-intersections. The other two cities have a much greater proportion of crossroads than T-intersections.

Table 3.1 Number of intersections by type, city and LoSS band

	Crossroads						T- intersection					
	I	II	III	IV	V	Total	I	II	III	IV	V	Total
Auckland	117	70	55	53	17	312	119	76	73	70	39	377
Christchurch	38	32	42	38	27	177	14	11	17	16	7	65
Dunedin	8	8	11	18	9	54	2	2	1	1	2	8
Total	163	110	108	109	53	543	135	89	91	87	48	450

Outputs from CAS for all injury crashes relating to signalised intersections were analysed to identify any underlying trends. All injury crashes were used in preference to just death and serious injury crashes in order to expand the size of the dataset and increase the likelihood of finding trends within the data. The CAS outputs contain coded information for each crash regarding location, vehicles involved, the crash movement, objects struck, environmental conditions at the time of the crash and factors identifying why the crash may have occurred (NZ Transport Agency 2014). Much of this information is recorded by police officers responding to the crash or coded after consideration of involved parties' statements and police descriptions and comments.

The full list of urban signalised intersections was analysed for crashes occurring at intersections performing better than expected (LoSS I-II), in line with expectations (LoSS III) and worse than expected (LoSS IV-V). The total number of injury crashes within these categories is shown in table 3.2. Data for all three cities was merged for the analysis of the coded factors. There is a greater number of crashes in the worse category, as crash rates are part of the LoSS determination. The data shows that crossroad intersections in Dunedin and

Christchurch had a greater share of intersections that perform worse compared with Auckland. T-intersections show a similar spread across categories for all performance categories.

Table 3.2 Injury crashes within performance categories by intersection type and city

Location	Crossroads				T- intersections			
	Better	As expected	Worse	Total	Better	As expected	Worse	Total
Auckland	498	335	695	1,528	179	208	602	989
Christchurch	148	214	635	997	16	40	113	169
Dunedin	31	48	209	288	2	2	23	27
Total	597	677	1,539	2813	197	250	738	1,185

3.2 Movements

The first digit of the movement code recorded in CAS for each crash was used to identify the primary crash movement. The proportion of crashes of each type within the categories at crossroads is shown in table 3.3 and at T-intersections in table 3.4. Each table row totals 100% (although values may be rounded). The total row shows the proportion of crashes by each movement for the whole population of intersections with each form.

Table 3.3 Crash movements by performance category for crossroads

Performance category	Right turn against	Crossing (no turns)	Pedestrians crossing/ pedestrians other	Rear end	Other[2]	Crossing (vehicle turning)	Lost control	Cornering
Better	17%	17%	13%	17%	19%	7%	4%	5%
As expected	19%	16%	17%	17%	17%	4%	6%	4%
Worse	27%	18%	18%	16%	11%	3%	4%	3%
Total	23%	17%	17%	17%	14%	4%	4%	4%

Key findings for crossroads:

- Right turn against crashes form the greatest proportion of crashes (almost one quarter), followed by crossing (no turns) and pedestrian crashes, then rear end.
- Right turn against crashes formed a greater proportion of crashes at sites classed as worse than those performing as expected.
- Crash movements classed as 'Other' occurred less frequently at worse performing sites.
- Crossing (vehicle turning) occurred more frequently at 3–7%).

[2] Crash movements classed as 'Other' in tables 3.3 and 3.4 include type A, B, E, G, K, M and Q (overtaking and lane change, head on, collision with obstruction, turning versus same direction, merging, manoeuvring and miscellaneous, respectively). See appendix B for further details on crash movement types and codes.

Table 3.4 Crash movements by performance category for T- intersections

Performance category	Right turn against	Crossing (no turns)	Pedestrians crossing/ pedestrians other	Rear end	Other[1]	Crossing (vehicle turning)	Lost control	Cornering
Better	10%	3%	12%	24%	26%	10%	5.1%	10%
As expected	20%	1%	13%	16%	22%	14%	5.2%	9%
Worse	21%	1%	16%	21%	19%	11%	4.5%	7%
Total	**19%**	**2%**	**15%**	**20%**	**21%**	**12%**	**5%**	**8%**

Key findings for T-intersections:

- Other crash movements were the highest proportion.
- Rear-end crashes formed the largest specific crash movement, followed by right turn against, pedestrian crashes and crossing (vehicle turning).
- There was a lower proportion of right turn against crashes occurring at better performing sites.

3.3 Environmental factors

The CAS data contains a range of information regarding factors at the time of crash, including weather, road surface wetness, light conditions and time of day/day of week. Many of the factors showed little variation and no significant differences over the performance categories, therefore the output tables for these factors are not included in the main body of the report, but are presented in appendix C.

Of the assessed environmental factors, two warranted detailed examination: objects struck during the crash, as shown in table 3.5 and the horizontal alignment of the crash location, as shown in table 3.6. It should be noted that the horizontal alignment is recorded by the reporting police officer (NZ Transport Agency 2014) and may be prone to a degree of subjectivity.

Table 3.5 Object struck during crash by performance category

Performance category	None	Fence, letterbox, hoarding, etc.	Traffic island or median strip	Parked motor vehicle	Utility pole incl. lighting column	Broken down vehicle, workmen's vehicle, taxis picking up, etc.	Traffic signs or signal bollards	Other[(a)]
Better	85.5%	1.9%	0.8%	1.8%	3.0%	2.3%	1.0%	3.7%
As expected	85.5%	0.7%	1.8%	2.4%	1.9%	2.7%	1.5%	3.5%
Worse	89.3%	0.9%	1.2%	2.0%	1.8%	1.5%	1.1%	2.2%
Total	87.6%	1.1%	1.2%	2.0%	2.1%	1.9%	1.2%	2.8%

[(a)] Other objects include bridge, cliff, bank or retaining wall, barriers and rails, buildings, public furniture, kerb (when contributing to crash), landslide/floodwater, train, trees or other objects.

Key findings:

- The greatest proportion of crashes involved no object, followed by other objects, and then utility poles and vehicles (parked, broken down, workmen's vehicle or taxi).
- A greater proportion of crashes in the worse category involved no object. This indicated that objects were not contributing to the worse performance of these sites (ie factors other than objects were influencing the crash performance).

Table 3.6 Horizontal alignment at crash location by performance category

Performance category	Straight road	Easy curve	Moderate curve	Severe curve
Better	83.9%	10.9%	4.3%	0.9%
As expected	85.0%	10.2%	4.1%	0.7%
Worse	87.8%	7.7%	3.6%	0.8%
Total	86.4%	8.9%	3.9%	0.8%

Key findings:

- The greatest proportion of crashes occurred on straight roads, followed by easy then moderate curves.
- There were no significant differences in the crash rates for alignment between the performance categories, indicating that alignment was not contributing to the worse performance of these sites.

3.4 Road users and vehicles

The proportion of vehicles by vehicle type involved in crashes (as a percent of all vehicles involved in crashes) within each performance category at crossroads is shown in table 3.7 and at T-intersections in table 3.8. The proportion of crashes involving active road users (pedestrians or cyclists) by intersection type is shown in table 3.9.

Table 3.7 Vehicles involved in crash by performance category at crossroads

Performance category	Car	Van, ute	Taxi or taxi van	Bus	SUV or 4X4	Truck	Motor-cycle/ moped	Bicycle	Other/ unknown
Better	67.9%	7.1%	1.5%	1.8%	8.4%	4.0%	5.3%	4.0%	0.0%
Average	70.6%	5.1%	1.9%	2.0%	7.4%	2.8%	5.7%	4.6%	0.1%
Worse	72.2%	6.4%	1.3%	1.7%	7.0%	2.6%	4.4%	4.3%	0.1%
Total	70.8%	6.3%	1.5%	1.8%	7.4%	3.0%	4.9%	4.3%	0.1%

Table 3.8 Vehicles involved in crash by performance category at T- intersections

Performance category	Car	Van, ute	Taxi or taxi van	Bus	SUV or 4X4	Truck	Motor-cycle/ moped	Bicycle	Other/ unknown
Better	74.9%	4.7%	0.5%	1.0%	6.3%	3.4%	4.7%	4.5%	0.0%
Average	70.9%	5.6%	0.2%	0.6%	5.2%	3.4%	6.3%	7.5%	0.2%
Worse	72.7%	5.8%	0.4%	1.1%	6.4%	3.1%	5.6%	4.8%	0.0%
Total	72.7%	5.6%	0.4%	1.0%	6.1%	3.2%	5.6%	5.3%	0.0%

Table 3.9 Proportion of crashes involving pedestrians or cyclists by intersection type and performance category

Performance category	Crossroads	T- intersection
Better	21%	21%
Average	26%	26%
Worse	26%	25%
Total	25%	24%

Key findings:

- At both intersection types, cars were involved in the largest proportion of crashes, followed by SUVs/4X4s, vans/utes, motorcycles/mopeds and bicycles.
- The proportion of cars involved in crashes at crossroad intersections performing worse than expected was higher, but this trend did not extend to T-intersections.
- Fewer crashes at intersections performing better than expected involved pedestrians or cyclists, but the difference was not significant.

3.5 Factors and roles

The CAS data contains a number of reasons why each crash occurred and these are coded after consideration of the involved parties' statements and police descriptions/comments. As a crash may have multiple contributing factors there can be a number of causes listed. This analysis assigns no weighting to different factors, counting each assigned factor for a crash equally at an intersection, and summing all factors for all crashes to generate a value for each intersection. The roles of various parties in contributing to the crash are not examined. The full list of factors used in CAS is shown in appendix B.

Generalised crash factors (ie first digit of factor code) are broken down into finer categories for vehicle conflict and driver control, which are the most prevalent factors, as shown in table 3.10 for crossroads and in table 3.11 for T-intersections.

Table 3.10 Generalised crash factors for all injury crashes by performance category at crossroads

Performance category	Vehicle conflicts					Driver control								
	Failed to give way	Did not stop	Inattentive: failed to notice	Did not see or look for another party until too late	Other	Alcohol or drugs	In line of traffic	Other	Pedestrians	General driver	General person	Road	Vehicles	Miscellaneous
Better	11%	15%	9%	10%	8%	8%	5%	12%	7%	4%	3%	2%	2%	4%
As expected	12%	13%	11%	9%	9%	8%	7%	10%	7%	5%	2%	2%	1%	4%
Worse	16%	13%	11%	9%	8%	6%	6%	9%	8%	4%	2%	2%	1%	3%
Total	14%	14%	11%	9%	8%	7%	6%	10%	8%	4%	2%	2%	1%	4%

Table 3.11 Generalised crash factors for all injury crashes by performance category at T- intersections

Performance category	Vehicle conflicts					Driver control								
	Failed to give way	Did not stop	Inattentive: failed to notice	Did not see or look for another party until too late	Other	Alcohol or drugs	In line of traffic	Other	Pedestrians	General driver	General person	Road	Vehicles	Miscellaneous
Better	7%	9%	9%	10%	7%	9%	7%	16%	7%	7%	3%	3%	1%	7%
As expected	13%	10%	5%	13%	8%	8%	6%	14%	6%	4%	3%	2%	0%	8%
Worse	12%	10%	9%	10%	9%	8%	6%	12%	7%	4%	3%	2%	1%	7%
Total	12%	10%	8%	11%	8%	8%	6%	13%	7%	5%	3%	2%	1%	7%

Key findings:

- Failure to give way/stop, see or notice were the most common factors resulting in a crash at both types of intersection, followed by various driver control factors and pedestrians.
- At crossroads, failure to give way was more prevalent at intersections performing worse than expected, compared with those performing as expected.
- At T-intersections failure to give way was less prevalent at sites performing better than expected.

The data included 225 individual crash factors (ie all three digits of the factor code) that featured in one or more crashes. The most commonly occurring individual crash factors were isolated.

The top 10 high-level factors are assessed for crossroads in table 3.12 and T-intersections in table 3.13. Only those factors which make up a large proportion of each high-level factor are shown, for example, there are 16 factors within the failed to give way (300), category but most of the factors contribute only a small amount to the total. Differences at the high-level factor code level (first two digits) are highlighted, but testing was not conducted for the individual crash codes.

Table 3.12 Major factors within top 10 high- level factors at crossroads

Factor code	Better	Average	Worse	Total	Factor group/detail
Sum of 300	11.5%	11.8%	15.6%	13.8%	Failed to give way
303	7.4%	7.8%	11.4%		When turning to non-turning traffic
Sum of 320	14.6%	13.4%	13.4%	13.7%	Did not stop
322	12.5%	10.9%	11.1%		At steady red light
Sum of 330	9.4%	10.6%	11.3%	10.7%	Inattentive: failed to notice
331	4.5%	3.8%	4.2%		Vehicle slowing, stopping or stationary in front
334	3.4%	4.7%	5.3%		Traffic lights
Sum of 370	10.3%	9.0%	9.2%	9.4%	Did not see or look for another party until too late
372	3.5%	2.4%	1.4%		Behind when changing lanes position or direction (incl. U-turns)
375	4.1%	2.9%	5.1%		When required to give way to traffic from another direction

Factor code	Better	Average	Worse	Total	Factor group/detail
Sum of 100	8.5%	7.9%	6.4%	7.2%	Alcohol or drugs
103	5.1%	4.5%	3.4%		Alcohol test above limit or test refused
Sum of 710	6.6%	6.0%	7.3%	6.9%	Pedestrians crossing road
711	1.7%	2.1%	2.4%		Walking heedless of traffic
712	1.4%	0.7%	1.1%		Stepping out from behind vehicles
713	2.2%	1.8%	2.1%		Running heedless of traffic
Sum of 180	5.3%	7.4%	5.6%	5.9%	In line of traffic
181	4.9%	7.0%	5.5%		Following too closely
Sum of 350	5.5%	6.5%	5.4%	5.6%	Attention diverted by
351	1.0%	0.7%	0.9%		Passengers
353	1.4%	1.5%	1.1%		Other traffic
Sum of 130	3.7%	2.9%	2.1%	2.6%	Lost control
131	2.1%	1.3%	1.0%		When turning
Sum of 400	2.0%	3.0%	2.5%	2.5%	Driver inexperience
402	1.5%	1.7%	1.4%		New driver showed inexperience

Key findings for crossroads:

- Increased failure to give way when turning into non-turning traffic at worse performing sites confirmed right turn against crash movement trends noted in section 3.1.
- There was an increase in failure to notice traffic lights at worse performing sites, potentially as a result of poor visibility of signal hardware or distractions present in the vicinity of the intersection.
- Pedestrians walking across the road heedless of traffic were more prevalent at worse performing sites.
- A number of factors decreased in occurrence at worse performing sites, including: failure to see/look behind when changing lanes/position, alcohol or drugs and lost control when turning.

Table 3.13 Major factors within top 10 high- level factors at T- intersections

Factor code	Better	Average	Worse	Total	Factor group/detail
Sum of 300	6.6%	13.4%	12.3%	11.7%	Failed to give way
303	2.8%	7.7%	8.2%		When turning to non-turning traffic
Sum of 370	10.2%	13.2%	10.1%	10.8%	Did not see or look for another party until too late
372	4.2%	3.1%	1.9%		Behind when changing lanes position or direction (incl. U-turns)
375	3.3%	4.6%	4.3%		When required to give way to traffic from another direction
377	0.6%	2.3%	1.7%		When visibility obstructed by other vehicles
Sum of 320	8.9%	9.8%	9.6%	9.5%	Did not stop
322	7.2%	7.1%	7.2%		At steady red light
Sum of 330	9.4%	5.2%	8.7%	8.1%	Inattentive: failed to notice
331	5.3%	2.7%	4.8%		Vehicle slowing, stopping or stationary in front
334	2.8%	1.9%	1.9%		Traffic lights

Factor code	Better	Average	Worse	Total	Factor group/detail
Sum of 100	8.9%	7.7%	7.6%	7.9%	Alcohol or drugs
103	4.2%	5.2%	4.7%		Alcohol test above limit or test refused
Sum of 180	6.6%	6.5%	6.2%	6.3%	In line of traffic
181	6.6%	6.5%	5.9%		Following too closely
Sum of 350	5.8%	5.4%	6.2%	6.0%	Attention diverted by
353	1.1%	1.0%	1.5%		Other traffic
Sum of 710	5.8%	4.4%	5.9%	5.6%	Pedestrians crossing road
711	1.1%	1.5%	1.7%		Walking heedless of traffic
713	2.5%	1.3%	2.3%		Running heedless of traffic
Sum of 920	5.3%	6.5%	5.1%	5.4%	Entering or leaving land use
927	0.3%	2.1%	1.2%		Other commercial land use
929	2.8%	1.5%	1.0%		Private house/farm
Sum of 110	4.2%	4.0%	3.8%	3.9%	Too fast for conditions
111	2.8%	2.7%	1.8%		Cornering

Key findings for T-intersections:

- Better performing sites had fewer crashes where vehicles failed to give way when turning into non-turning traffic. This was consistent with the s right turn against crash movement trends from section 3.1.
- In contrast to crossroads, failure to notice traffic lights was not a safety issue.
- Pedestrians walking across the road heedless of traffic were more prevalent at worse performing sites.
- A number of factors decreased in occurrence at worse performing sites, including: failure to see/look behind when changing lanes/position and alcohol or drugs.

3.6 Summary

The intention of this chapter was to investigate the crash history associated with sites performing better than expected, in line with expectations, and worse than expected. The assessment included operational, environmental and physical variables as contained within the CAS data. Using this data the hypothesised influence of variables on safety could be confirmed or dismissed, allowing the desktop analysis and site inspections in the following chapter to be more effectively targeted.

The analysis suggested that the prevalence of some crash factors was inversely related to the safety performance of the intersection. These factors include *alcohol and drugs*, *failing to look for/see other vehicles that are behind when changing lane position or direction*, and *loss of control when turning*. These factors contributed to crashes at all intersections, but were proportionally less common at poorly performing intersections, where the actual factors that had a bearing on poor safety outcomes became more prevalent.

The analysis highlighted a number of coded factors identified in the literature review that were expected to influence safety outcomes, but had a negligible effect on performance:

- Horizontal alignment showed little difference between performance categories.

- More crashes at worse performing intersections involved striking no object, indicating that the presence of objects which might be struck did not worsen safety outcomes.
- Increasing proportions of pedestrian/cyclist crashes were expected at worse performing intersections, which was generally found to be the case. The differences were small, however, and there was substantial variation within the coded factors for pedestrian and cyclist crashes.

A significant finding of the analysis was that there is no ‘silver bullet’ (single factor that contributes overwhelmingly to poor safety performance); however, approximately 50% of crashes within each performance category could be attributed to the top 10 crash factors, with the remaining share apportioned between a further 200 factors.

4 Analysis of non- coded factors

4.1 Site selection

A site selection process using both personal DSI and LoSS as selection parameters reduced the number of intersections in the dataset from chapter 3. Intersections performing worse than expected had high personal risk and LoSS IV-V. Intersections performing better than expected were those with low personal risk and LoSS I-II.

Aerial/satellite imagery was used to inspect each intersection selected in this manner, and intersections with the following characteristics were removed:

- one-way approach, exit or through lane on one or more approaches
- more than four legs
- bus lanes running up to the stop line on one or more approaches
- located in the Christchurch CBD (possibly subject to earthquake effects).

The intersection list was narrowed down to a list of 40 intersections for identification of non-coded factors. Intersections were removed to provide a more even geographical spread between the three cities and the finalised list is included in appendix D. Road controlling authorities in each area were consulted to remove those intersections with significant changes over the crash period and those that met the above conditions.

4.2 Analysis method

The site inspections were undertaken by two experienced road safety auditors from the research team who were accompanied by representatives from the local road controlling authority in Auckland (Auckland Transport and Auckland Transport Operating Centre) and Dunedin (Dunedin City Council). The Christchurch Transport Operations Centre was unable to assist in attending the site inspections; however, a representative from the local NZ Transport Agency office was available for some sites. All site inspections were undertaken during weekday working hours in early to mid-February 2015. Care was taken that traffic patterns were representative of 'typical' operating conditions as far as possible and were unaffected by any local events occurring at the time (eg 2015 Cricket World Cup matches).

The site inspection checklist is also included in appendix D.

The desktop analysis consisted of reviewing CAS for details of injury crashes at each of the 40 intersections, coupled with measurements and observations from Google Earth and Google Street View.

The desktop assessment focused on those sites with a poor safety performance and more than three crashes for a given crash movement (over the 2008–2013 crash period to be consistent with the site selection process). The analysis included a thorough assessment of crashes, site inspection sheets, aerial imagery and Google Street View.

This process was used to identify the key factors relating to safety performance of urban signalised intersections, and was coupled with key themes and site-specific observations from the site inspections.

This chapter describes the key observations from the site inspections and an assessment of factors affecting safety, establishing the most likely non-coded factors for further consideration in the subsequent technical analysis. The assessment is qualitative and intends to explore possible crash risk factors rather than reach statistically significant conclusions.

4.2.1 Assessment of crash types

Crash causes by movement type from CAS were assessed to identify common factors. CAS movement and cause codes can be found in appendices A and B respectively.

The process of coding crashes is open to some interpretation and multiple codes may, in some cases, duplicate the same root cause. Care was taken by the research team in this regard when analysing the CAS data. The most commonly occurring factors by movement code are summarised in table 4.1 which presents the number of crashes corresponding to those movement code/cause code combinations at the 40 selected intersections. A limitation of this coded data is that the assessment is carried out by Police officers who focus on legal breaches rather than system failures.

Table 4.1 Common crash causes by movement type – number of crashes

	In line of traffic: following too closely	Failed to give way: when turning into non- turning traffic	Failed to give way: when turning at signals to pedestrians	Did not stop: at steady red light	Did not stop: at steady amber light	Inattentive: failed to notice: vehicle slowing, stopping or stationary in front	Inattentive: failed to notice: Traffic lights	Did not see or look for another party until too late: When required to give way to traffic from another direction	Did not see or look for another party until too late: When required to give way to pedestrians	Misjudged: intentions of another party	Pedestrians crossing road: walking heedless of traffic	Pedestrians crossing road: stepping out from behind vehicles	Pedestrians crossing road: running heedless of traffic	Pedestrians crossing road: not complying with traffic signals or school patrols
Crossing (no turns)				15			7							
Pedestrians crossing road			4	5	1		2		4		14	5	5	5
Rear end	12					11				2				
Right-turn against		41		4	6		3	13		4				
Grand total	12	41	4	24	7	11	12	13	4	6	14	5	5	5

4.3 Intersection level analysis of non-coded factors

The research team facilitated a workshop where the transportation engineers attending the site inspections used the detailed assessment notes included in appendix E, site inspection forms and photos of each intersection to isolate the key factors to be carried forward into the subsequent stages of the research. Care was taken to determine factors relevant at a number of the sites rather than focusing on variables that might have an isolated impact.

Factors specified in the literature review and stages of the coded factors were also discussed in the workshop as a prompt to include any additional factors that could be supported through the site inspections.

The two most significant themes arising from the site inspections were that poorly performing intersections are typically characterised by higher vehicle speeds and poor inter-visibility between all road users (including pedestrians).

A total of 15 factors were isolated and categorised as physical, operational and environmental factors. They are presented in sections 4.3.1, 4.3.2 and 4.3.3 respectively. These factors were assessed at an intersection level, so if, for example, an approach to an intersection was identified as having one of the factors the intersection was classified accordingly. This was a limitation of the analysis and measures to report at a finer level of detail are discussed in section 4.4. The specific metrics used in determining each factor are also described below.

4.3.1 Physical factors

- Large intersection: Intersections with a greater number of lanes are wider, and are typically associated with higher vehicle speeds, longer exposure times for pedestrians crossing and longer clearance times for cyclists. *Measure: limit line number of lanes (excluding slip) + downstream number of lanes > 4.*
- Poor visibility of signal hardware: Obstructions (permanent or temporary) can limit signal display visibility (for through and turning movements). Lamp types, LED or halogen, affect visibility in poor light conditions. *Measure: Halogen lamps or conspicuity, visibility or obstruction issue identified.*
- Large radius of turning movements: Intersections that were wide, skewed or otherwise had large radii for left- or right-turning traffic, which resulted in higher vehicle speeds. *Measure: large left/right turning movement radii.*
- Right-turn bays offset: A lack of visibility of through traffic for right turners is possible where right-turn bays are offset. *Measure: offset right-turn bays.*
- Small pedestrian waiting area or poor kerb quality: Narrow waiting areas and poor quality kerbs encourage pedestrian non-compliance, particularly in high pedestrian demand locations. *Measure: pedestrian markings or kerb noted as being of poor quality.*
- Cyclist infrastructure missing or insufficient width: Few intersections had significant numbers of crashes involving cyclists. Since the quantity of cyclists was unknown this made it difficult to discern if cycling provisions were improving safety or not. A high proportion of the intersections inspected in Auckland had no cycle facilities, which may have deterred cyclists for safety reasons and hence generated a low crash rate for cyclists. *Measure: missing cycle lanes or insufficient width of lanes.*

4.3.2 Operational factors

- High-speed environment: Vehicle speed affects control through turning movements and the time available for drivers to react. Speed in the intersection was not directly measured, but posted speed and side friction both affect negotiation speeds through intersections. *Measure: posted speed > 50km/h or no on-street parking upstream of the intersection.*
- Right turn filtering allowed: Right-turn filtering at intersections, which involves turning across oncoming vehicles, may result in increased right turn against crashes. *Measure: right-turn filtering permitted.*

- Pedestrian protection missing or insufficient: The existence of pedestrian protection (and whether it is partial or full protection) may influence the number of crashes involving pedestrians. *Measure: pedestrian protection not present or clearance times for pedestrians insufficient.*
- Split phasing: Split phasing removes the conflict between pedestrians and vehicles, possibly leading to less pedestrian crashes. *Measure: split phasing present.*

4.3.3 Environmental factors

- Approach gradients: Downhill approaches can result in higher vehicle speeds and increase the frequency of red light running, while uphill approaches are associated with reduced forward visibility. *Measure: gradient on approach.*
- Geometric complexity: Skewed or offset intersections typically have greater radii for some movements, resulting in higher speeds, and can increase driver workload and confusion. *Measure: skewed or offset approaches.*
- Curvature on approach to intersection: A bend on an intersection approach can cause visibility issues for approaching vehicles (ability to see signal displays), right turners (ability to see oncoming vehicles) and pedestrians (ability to see vehicles). *Measure: horizontal curvature on approach sufficient to limit visibility.*
- Nearby signalised intersections: Downstream signal displays may be visible if there are signalised intersections nearby downstream of an intersection. Particularly if these displays are operating on a different phase there is potential for driver confusion and red light running. *Measure: signalised intersection within 200 metres.*
- High pedestrian generators: Facilities such as railway stations, schools and shops near intersections can result in higher pedestrian volumes, which increase the potential for pedestrian-vehicle interactions. *Measure: proximate land uses or activities indicate high levels of pedestrian activity.*

4.3.4 Analysis

The site inspection sheets for each of the 40 intersections were assessed for the above criteria, with the results presented in appendix D. Table 4.2 lists the non-coded factors and the performance of the intersections where these factors were present. Performance is split into better than expected and worse than expected based on crash prediction modelling. Note there are 20 intersections within each performance category.

Table 4.2 Non- coded factors – count of intersections with factor by performance

	Better than expected	Worse than expected
Large intersection	11	10
Poor visibility of signal hardware	16	17
Large radius of turning movements	8	8
Right turn bays offset	6	7
Small pedestrian waiting area or poor kerb quality	7	8
Cyclist infrastructure missing or insufficient width	17	18
High-speed environment	19	18
Right turn filtering allowed	15	16
No or partial pedestrian protection	6	10
Split phasing	9	9
Approach gradients	6	6
Geometric complexity	10	12
Curvature on approach to intersection	7	9
Nearby signalised intersections	7	5
High pedestrian generators	6	8

Table 4.2 shows that the difference between the number of intersections performing better or worse than expected was very small for all but one factor – no or partial pedestrian protection – which was observed more often for poorly performing intersections. These differences were most likely due to chance and/or traffic exposure.

4.4 Approach level analysis of non-coded factors

Overall, the intersection level analysis of the previous sections did not isolate factors strongly correlated to intersection performance. For example, there was no difference in the number of intersections with approaches on a gradient that performed well compared with those that performed poorly. This suggests that these factors in isolation are not sufficient to explain the variation in safety performance at an intersection. An approach-level analysis was used to investigate factors at a finer level of detail.

4.4.1 Identifying poorly performing approaches

A similar process was applied to approaches as for intersections: identifying a consistent trend within the crash record with regard to typically severe crash movements. Initially a requirement of three or more crashes relating to vehicles on an approach was used as the criterion for a consistent trend. This was later reduced to two or more crashes to increase the number of approaches with poor safety records in the assessment and subsequently identify crash trends. The approaches identified in this manner focused on the most commonly occurring crash types being 'H' (crossing (no turns)), 'L' (right turn against) and 'N' (crashes involving pedestrians) and are listed in table 4.3.

Table 4.3 Number of crashes by approach for poorly performing intersections

City	Intersection	Movement type	Approach – number of crashes by approach (of at- fault vehicle)			
			S	W	N	E
Auckland	Albert, Victoria Street West	H	0	1	1	2
Christchurch	Milton Strickland	H	0	1	2	1
Dunedin	Stuart London, Dunedin	H	2	1	2	1
Auckland	Aviemore, Pakuranga, Bucklands Beach	L	0	3	0	1
Auckland	Neilson, Onehunga	L	0	0	1	2
Auckland	Orakei, Remuera, Ascot	L	0	0	1	2
Christchurch	Blenheim, Clarence	L	2	0	0	1
Auckland	Great North, Pt Chevalier, Carrington	L	0	4	0	0
Christchurch	Blenheim, Matipo	L	0	4	0	2
Christchurch	Grahams, Wairakei	L	1	1	1	0
Auckland	Donnell, Walmsley, Mahunga	L	0	2	1	6
Christchurch	Hills Innes	L	1	2	0	1
Christchurch	Riccarton Middleton	L	0	0	4	3
Auckland	Massey Hospital	L	1	3		0
Auckland	Weymouth Russell	L	0	0	0	4
Christchurch	Whiteleigh Troup	L	2	0	0	0
Auckland	Aviemore, Pakuranga, Bucklands Beach	N	0	1p-0v	0	1p-0v
Auckland	Mt Albert, New North, Carrington	N	1p-0v	0p-1v		0p-1v
Auckland	Albert, Victoria Street West	N			2p-1v	1p-1v
Auckland	Great North, Pt Chevalier, Carrington	N		1p-1v		1p-0v
Auckland	Queen Street, Karangahape Road	N	2p-0v	1p-1v	1p-0v	0p-1v
Christchurch	Grahams, Wairakei	N		0p-1v		1p-2v
Auckland	Ash, Rosebank	N		0p-1v	0p-1v	1p-1v
Christchurch	Riccarton Middleton	N	2p-0v	0p-1v		

Note: H = crossing (no turns) crashes, L = right turn against crashes, N = pedestrian crashes, p = pedestrian, v = vehicle.

4.4.2 Detailed assessment of approaches

A detailed approach-specific list of factors was developed for each of the crash types assessed:

- Crossing (no turns):
  - posted speed
  - number of displays
  - mast arms/signals on median
  - aspect visibility and conspicuity
  - visibility of downstream signals
  - geometric factors of approach
- Right turn against:

- filter turning allowed and phasing on approach
- lanes and shared lanes on approach and opposing approach
- geometric factors of approach and opposing approach

- Pedestrian (using a basis of approach that vehicle was travelling prior to hitting pedestrian):
  - aspect visibility
  - right-turn filtering permitted
  - shared through/turn lanes present
  - left/right-turn red arrow presence
  - geometric factors of approach
  - non-compliant pedestrians seen during site visit
  - pedestrian facility presence
  - pedestrian protection presence
  - pedestrian phase – no separate phase
  - quality of kerb or pedestrian markings
  - presence of tactile paving
  - clearance time sufficient.

The results for approaches with two or more crossing (no turns) crashes are shown in table 4.4, where ‘Y’ indicates the presence of a presumed negative factor.

Table 4.1 Approaches with two or more crossing (no turns) movement type crashes

Intersection	Approach	Number of crashes by type	Posted approach speed (> 50km/h)	Number of displays (< 5)	No mast arms	No signals on edian	Lack of contrast	Aspect visibility limited (permanent obstructions)	Aspect visibility limited (vehicle obstructions)	Visibility of downstream signals	Gradient (> 2 or < - 2)	Curve	Skewed	Crashes involving red/amber light running	Crashes involving failing to notice traffic signals
Albert Street, Victoria Street West	Victoria Street – E	2		Y		Y				Y	Y				Y
Milton Street, Strickland Street	Strickland Street – N	2		Y	Y	Y								Y	Y
Stuart Street, London Street	Stuart Street – S	2		Y				Y		Y	Y			Y	Y
Stuart Street, London Street	Stuart Street –N	2		Y	Y						Y	Y		Y	Y

The following factors were found to be present in at least half of the approaches with two or more crossing (no turns) crashes:

- number of displays (<5)
- no mast arms
- no signals on median
- visibility of downstream signals
- gradient (>2 or <-2)
- crashes involving red/amber light running
- crashes involving failing to notice traffic signals.

Given the very low sample sizes involved in the approach-based assessment it was unlikely that any statistical inferences could be made around the significance of these factors. These seven factors were carried forward into the more comprehensive analysis in the next stage which included a statistical component.

The results for approaches with two or more right turn against crashes are shown in table 4.5, where ‘Y’ indicates the presence of a presumed negative factor.

Table 4.2 Approaches with two or more right turn against crashes

Intersection	Approach	Number of crashes by type	Crashes involving red/amber arrow running	Crashes involving failing to notice traffic signals	Approach right turns						Approach configuration				Opposing configuration					Approach geometry			Opposing geometry		
					Filter allowed	Only filter	Partial filter lead	Partial filter lag	Lead arrow	Lag arrow	Total lanes	Shared L/T	Shared R/T	> 1 R (or R/T) lane	Total lanes	Multiple through lanes	Shared L/T	Shared R/T	> 1 R (or R/T) lane	Skewed	Curve	Gradient	Skewed	Curve	Gradient
Aviemore, Pakuranga, Bucklands Beach	Pakuranga – W	3							Y		3				3	Y							Y	Y	
Great North, Pt Chevalier, Carrington	GNR – W	4							Y		3				3	Y	Y			Y	Y		Y		
Blenheim, Matipo	Blen – W	4		Y	Y		Y				3				3	Y									
Donnell, Walmsley, Mahunga	Walmsley – E	6	Y	Y					Y		2	Y			2			Y							
Riccarton Middleton	Ilam – N	4			Y	Y					1		Y		1			Y		Y			Y		
Riccarton Middleton	Riccarton – E	3			Y	Y					2	Y			3										
Massey Hospital	Massey – W	3		Y	Y		Y				2		Y		2							Y			Y
Weymouth Russell	Weymouth – E	4							Y		2		Y		2	Y									
Neilson, Onehunga	Neilson – E	2									2	Y			3	y	Y			Y					
Orakei, Remuera, Ascot	Remuera – E	2	Y		Y		Y		Y		3	Y			3	Y	Y					Y			Y
Blenheim, Clarence, Whiteleigh	Clarence – S	2			Y	Y					3	Y			3	Y	Y				Y			Y	
Blenheim, Matipo	Blenheim – E	2		Y	Y		Y				3				3	Y									
Donnell, Walmsley, Mahunga	Walmsley – W	2			Y	Y					2	Y	Y		2	Y	Y								
Hills Innes	Innes – W	2			Y	Y					2	Y			3										
Whiteleigh Troup	Whiteleigh – S	2			Y		Y			Y	2				2						Y				

The following factors were found to be present in at least half of the approaches with two or more right turn against crashes:

- filtering allowed on right-turning approach
- shared left/through and/or right-through lane on right-turning approach
- shared left/through and/or right-through lane on opposing movement approach
- skewed or curved approach or a gradient on the right-turning approach
- multiple opposing through lanes.

Given the very modest sample sizes involved in the approach-based assessment the value of statistical testing was likely to be marginal. These five factors were carried forward into the more comprehensive analysis in the next stage where a considerably larger sample size was available and included a statistical component.

The results for approaches with more than two pedestrian crashes (where the vehicle was travelling on this approach prior to the crash) are shown in table 4.6, where ‘Y’ indicates the presence of a presumed negative factor. The number of crashes is shown by the party at fault, but not by turning movement of the crash.

Table 4.2 Approaches with two or more pedestrian crashes (where vehicle was travelling on the approach prior to the crash)

Intersection	Approach	Pedestrian/vehicle fault, number of crashes (movement not shown)	On approach											Other approaches					
			Aspect visibility (permanent obstructions)	Aspect visibility (vehicle obstructions)	Right turn filtering permitted?	Through/right lane present	Right turn red arrow not present	Gradient	Skewed	Curved	Through/left lane present	Left turn red arrow not present	Non- compliant pedestrians crossing during site inspection	Crash occurred where Ped. Crossing facilities not present (vehicle or pedestrian fault)	Crash occurred where pedestrian phase not fully protected (veh. fault)	Crash occurred where pedestrian phase has no lead (veh. fault)	Crash occurred where condition of pedestrian markings and kerb are (> 2) (veh or ped. fault)	Crash occurred where tactile paving not present (vehicle or pedestrian fault)	Crash occurred where there was insufficient pedestrian clearance time (veh. fault)
Albert, Victoria Street West	Albert Street – S	2p–1v	Y										Y		Y		Y	Y	Y
Queen Street, Karangahape Road	Upper Queen Street –N	2p–0v						Y			Y		Y						
Grahams, Wairakei	Wairakei Road – W	1p–2v	Y		Y	Y	Y		Y		Y	Y			Y	Y	Y	Y	Y
Riccarton Middleton	Ilam Road – N	2p–0v			Y	Y	Y		Y	Y			Y		Y	Y		Y	Y

A large number of factors were found to be present in at least half of the approaches with two or more pedestrian crashes:

- aspect visibility (permanent obstructions)
- right-turn filtering permitted?
- through/right lane present
- right-turn red arrow not present
- gradient
- skewed
- through/left lane present
- left-turn red arrow not present
- non-compliant pedestrians crossing during site inspection
- crash occurred where pedestrian phase not fully protected (ie no lead or partial protection)
- crash occurred where pedestrian phase has no lead
- crash occurred where condition of pedestrian markings and kerb are poor (>2)
- crash occurred where tactile paving not present
- crash occurred where there was insufficient pedestrian clearance time.

Given the small sample size involved in the approach-based assessment it was very unlikely that statistical inferences could be made. The range of factors above were carried forward perhaps with some consolidation into the more comprehensive analysis in the next stage where a considerably larger sample size was available and included a statistical component.

4.4.3 Additional discussion

A number of additional observations were made relating to specific intersections included in the non-coded factors analysis.

The intersection of Ilam Road, Riccarton Road and Middleton Road has a skewed alignment with a large intersection width for some crossing movements. There is anecdotal evidence that cars take advantage of the wide intersection by filter turning right when the signal first turns green rather than waiting for oncoming traffic to clear the intersection first. There was an abundance of crashes at this intersection caused by right-turning vehicles failing to give way to oncoming traffic but no specific mention in police reports that this related to cars filtering before oncoming through traffic immediately following a green light. Some police crash reports noted the primary cause as obstruction of view to oncoming traffic caused by a car waiting in the middle of the intersection to turn right.

Right-turn filtering was banned at the intersection of Great North Road/Point Chevalier Road/Carrington Road due to safety concerns in February 2010. Crash records showed a cluster of crashes caused by right filter turning traffic failing to give way to oncoming traffic prior to the ban. No such crashes occurred after the change was made within the period for which CAS data was extracted. Because all right turn against crashes occurred prior to the ban on filter right turns, the intersection was classified as having right-turn filtering allowed for the purposes of analysis.

A ban on filter turns at the intersection of Donnell Avenue/Walmsley Road/Mahunga Drive was implemented in June 2013. Because CAS records used for this research only extended to the end of 2013, there is insufficient data to conclude whether there was a reduction in crashes caused by right-turning traffic failing to give way to oncoming traffic. Site inspections showed that as of February 2015, right-turn filtering was permitted on at least one of the intersection approaches. Based on this evidence, the intersection was classified as having right-turn filtering allowed. If filtering was in fact banned in June 2013 then the effects on results would be minor since the period of time affected only constitutes one tenth of the period for which CAS data was extracted.

4.5 Summary

The intention of this chapter was to select and analyse 40 signalised intersections, 20 performing better than expected, and 20 performing worse than expected with the intention of finding reasons for the differences in performance. The site visits included noting down the operational, environmental and physical variables found to be important in chapter 3 as well as noting any other reasons for poor safety performance. Using this data, factors which were more prevalent at poorly performing intersections could be isolated.

Factors were first assessed at an intersection level, so if, for example, any intersection approach was identified as having one of the factors the intersection was classified as having the factor. The key factors identified included:

Table 4.4 Summary of findings from intersection level analysis

Physical factors	• Large intersection • Poor visibility of signal hardware • Large radius of turning movements • Right-turn bays offset • Small pedestrian waiting area or poor kerb quality • Cyclist infrastructure missing or insufficient width
Operational factors	• High-speed environment • Right-turn filtering allowed • Pedestrian phase has no lead or only partial protection. • Split phasing
Environmental factors	• Approach gradients • Geometric complexity • Curvature on approach to intersection • Nearby signalised intersections • High pedestrian generators

Overall, the intersection level analysis of the previous sections did not isolate factors strongly correlated to intersection performance so the intersections were analysed at an approach level. The following factors were found to be present in at least half of the approaches with each crash type.

Table 4.5 Summary of findings from approach level analysis

Crossing (no turns)	• Number of displays (<5) • No mast arms • No signals on median • Visibility of downstream signals • Gradient (>2 or <-2) • Crashes involving red/amber light running • Crashes involving failing to notice traffic signals
Right-turn against	• Filtering allowed on right-turning approach • Shared left/through and/or right through lane on right-turning approach • Shared left/through and/or right through lane on opposing movement approach • Skewed or curved approach or a gradient on the right-turning approach • Multiple opposing through lanes
Pedestrian crashes	• Aspect visibility (permanent obstructions) • Right turn filtering permitted? • Through/right lane present • Right-turn red arrow not present • Gradient • Skewed • Through/left lane present • Left-turn red arrow not present • Non-compliant pedestrians crossing during site inspection • Crash occurred where pedestrian phase not fully protected (ie no lead or partial protection) • Crash occurred where pedestrian phase has no lead • Crash occurred where condition of pedestrian markings and kerb are poor (>2) • Crash occurred where tactile paving not present • Crash occurred where there was insufficient pedestrian clearance time

The two most significant themes arising from the site inspections were that poorly performing intersections are typically characterised by higher vehicle speeds and poor inter-visibility between road users (which is particularly important for vehicles turning and giving way or giving way to pedestrians). The factors found to be significant in this chapter have been carried forward to chapter 5 where they are analysed statistically.

5 Statistical analysis of factors

An entirely new dataset of 100 signalised intersections was analysed to identify factors which had a statistically significant effect on intersection safety performance. Factors tested were taken directly from the approach level analysis in chapter 4. The intersections tested consisted of a mix of T-intersections and X-intersections located in Auckland, Hamilton, Wellington, Christchurch and Dunedin. The analysis was conducted by intersection approach since intersection level analysis in the previous chapter yielded few significant findings.

This chapter describes the origins of the data, the analysis method used and the key findings from the analysis.

5.1 Data collection

A dataset compiled as part of *NZ Transport Agency research report 483* 'Crash prediction models for signalised intersections' (Turner et al 2012) was obtained from Beca Group Limited. The following paragraphs summarise how the dataset was compiled and the derivation of crash prediction models.

> *A total of 238 low- and high-speed signalised intersections from Auckland, Wellington, Hamilton, Christchurch, Dunedin and Melbourne were selected for this study. These included both three-arm and four-arm intersections. These included both three-arm and four-arm intersections. Data collection on a wide range of physical and operational characteristics of signalised intersections was collected for these sites. This included intersection layout and geometry, signal phasing and coordination, road user counts (motor vehicles, pedestrians and cyclists), signal displays and crashes, among others. Automated methods that allowed analysis of the large amount of SCATS® data were also developed to determine signal operation parameters, including type of phasing, degree of saturation, frequency of pedestrian phase activation, signal cycle times, and green, yellow and all-red phase times. Data was collected prior to the changes to the New Zealand give-way rules that were implemented on 25 March 2012.*
>
> *The degree of saturation and pedestrian usage at each intersection was also estimated. Degree of saturation for the selected approaches was calculated using adjusted SCATS® traffic volumes and SCATS® signal-timing information, in conjunction with number of lanes and an assumed lane capacity. Pedestrian usage at the selected intersections was estimated through categorisation into five 'bins' (namely low, medium-low, medium, medium-high and high), using data available from SCATS® regarding the occurrence of pedestrian phases.*
>
> *Crash prediction models were developed for the main crash types involving motor vehicles and pedestrians. For motor vehicles, these included rear-end (Type F), right-turn-against (Type LB), right-angle (Type HA) and loss-of-control crashes (Types C and D). For pedestrians, these were right-angle (Type NA and NB) and right-turning crashes (Type ND and NF) involving a motor vehicle colliding with a pedestrian* (Turner et al 2012).

The crash prediction models predict the number of injury crashes at an intersection approach over a five-year period (2004 to 2008) for several different crash types. Note that injury crashes refer to crashes causing minor injuries, serious injuries or death. In this chapter, crashes refer to injury crashes only.

The intersection dataset used for this stage of work was preferred since:

- it was consistent with the dataset used for modelling in Turner et al (2012)

- it had been confirmed as having no major changes to intersection operation during the analysis period
- Sydney Coordinated Adaptive Traffic System (SCATS) data was available for all intersections being analysed
- the dataset had previously been peer reviewed and approved
- effects of the 2010–2011 Christchurch earthquakes are avoided.

5.1.1 Dataset filtering

Intersection approaches in the dataset from Turner et al (2012) were removed if they were located in Melbourne, had a one-way approach or were analysed in chapter 4. A stratified random sample of intersections was taken from this filtered dataset based on the number of intersections in the list from each city. In total, 48 intersections from Auckland, 11 intersections from Hamilton, 7 intersections from Wellington, 30 intersections from Christchurch and 4 intersections from Dunedin were selected. The selected list of intersections was examined to check that both T-intersections and X-intersections from each city were included where possible.

This filtered list of 100 intersections will henceforth be referred to as 'the Dataset'.

5.1.2 Manual collection of data

Google Earth and Google Street View were used to populate values for each of the factors identified as significant from chapter 4. All factors populated were obtained through the Dataset, Google Earth, Google Street View or CAS. Google Street View images dated 2004 to 2008 were used if available so that intersection conditions reflected those of the time period for which CAS data was collected. On a small number of intersection approaches, images from this time period were unavailable and the oldest post-2008 imagery was used.

5.1.3 Removal of factors

Pedestrian compliance was removed from the list of factors to be populated as it would have required comprehensive surveys at each of the intersections. Tactile paving was not populated as a separate factor. The condition of tactile paving was taken into account when rating the condition of pedestrian markings and kerbs. Gradient on right-turning bays was not assessed separately as a factor since its value was identical to the populated value for gradient on most intersection approaches.

5.2 Analysis method

The crash prediction models presented in Turner et al (2012) were used to calculate the expected number of crashes over a five-year period at each intersection approach. For pedestrian crashes (type N), two models were devised in Turner et al (2012). Both of these crash prediction models were tested to see if the factors identified in chapter 4 for pedestrian crashes had any correlation. For crossing (no turns) crashes (type HA) and right turn against (type LB) crashes, only one crash prediction model was presented in Turner et al (2012) for each crash type. For pedestrian crashes (type N) there were two models presented in Turner et al (2012), one for type NA/NB crashes and one for type ND/NF crashes. The corresponding crash prediction model equations for types HA, LB, NA/NB and ND/NF from Turner et al (2012) are included as equations 5.1, 5.2, 5.3 and 5.4 respectively.

$$A_{HA} = B_0 \times q_2^{0.311} \times (q_5 + q_{11})^{0.362} \times exp(0.356 \times \text{Number of approaching lanes}) \times (\text{Intersection depth})^{0.602} \times (\text{Cycle time})^{0.037} \times (\text{All-red time})^{0.636} \times F_{\text{Split Phasing}} \times F_{\text{Mast arm}} \times F_{\text{Coordinated}} \times F_{\text{Adv detector}} \times F_{\text{Shared turns}} \times F_{\text{Med Island}}$$ (Equation 5.1)

Table 5.1 Model variables for type HA crash model equation

Factor	Value	Description
$B_{0(Auckland)}$	4.27E-05	Constant for Auckland
$B_{0(Wellington)}$	2.08E-05	Constant for Wellington
$B_{0(Christchurch)}$	8.69E-05	Constant for Christchurch
$B_{0(Hamilton)}$	1.13E-04	Constant for Hamilton
$B_{0(Dunedin)}$	1.54E-04	Constant for Dunedin
$F_{Split\ Phasing}$	0.69	Split phasing on approach
$F_{Mast\ arm}$	0.74	Presence of signal mast arm
$F_{Coordinated}$	1.31	Signal coordination with upstream intersection
$F_{Adv\ Detector}$	2.06	Presence of advanced detector on approach
$F_{Shared\ turns}$	1.19	Lanes with shared movements (eg left-turn/through or right-turn/through) present on approach
$F_{Med\ Island}$	0.67	Presence of raised median/central island on approach

where:

A_{HA} = number of predicted HA injury crashes in five years

q_2 = daily volume of through vehicles going straight through on approach

q_5 = daily volume of through traffic coming from left-side approach

q_{11} = daily volume of through traffic coming from right-side approach

$$A_{LB} = B_0 \times q_7^{0.155} \times (1 + \text{Length of RT Bay or Lane})^{-0.124} \times \exp(0.352 \times \text{Number of through lanes}) \times (\text{Degree of saturation})^{0.397} \times (\text{Cycle time})^{-0.683} \times F_{Full\ RT\ Protection} \times F_{Shared\ RT} \times F_{Med\ Island} \times F_{Cycle\ Facilities} \qquad \text{(Equation 5.2)}$$

Table 5.2 Model variables for type LB crash model equation

Factor	Value	Description
$B_{0(Auckland)}$	3.83	Constant for Auckland
$B_{0(Wellington)}$	4.10	Constant for Wellington
$B_{0(Christchurch)}$	4.41	Constant for Christchurch
$B_{0(Hamilton)}$	2.27	Constant for Hamilton
$B_{0(Dunedin)}$	4.16	Constant for Dunedin
$F_{Full\ RT\ Protection}$	0.71	Fully protected right-turn phasing
$F_{Shared\ RT}$	0.72	Shared right-turn/through lane present on approach
$F_{Med\ Island}$	1.22	Presence of raised median/central island on approach
$F_{Cycle\ Facilities}$	1.35	Presence of cycle facilities (cycle lanes or storage) on approach

where:

A_{LB} = number of predicted LB injury crashes in five years

q_7 = daily volume of right-turning vehicles turning right from approach

$$A_{NA,NB} = B_0 \times q^{0.314} \times p^{0.364} \times \exp(0.16 \times \text{Number of approaching lanes}) \times (\text{All-red time})^{0.61} \times (\text{Cycle time})^{0.810} \times F_{Cycle\ Facilities} \times F_{Shared\ Turns} \times F_{Split\ Phasing} \times F_{Med\ Island} \qquad \text{(Equation 5.3)}$$

Table 5.3 Model variables for type NA/NB crash model equation

Factor	Value	Description
$B_{0(Auckland)}$	3.84E-05	Constant for Auckland
$B_{0(Wellington)}$	1.28E-05	Constant for Wellington
$B_{0(Christchurch)}$	5.30E-05	Constant for Christchurch
$B_{0(Hamilton)}$	5.94E-05	Constant for Hamilton
$B_{0(Dunedin)}$	8.90E-05	Constant for Dunedin
$F_{Cycle\ Facilities}$	0.513	Presence of facilities for cyclists (eg cycle lanes and/or storage boxes)
$F_{Shared\ Turns}$	1.321	Presence of lanes with shared turning movements (eg left-turn/through, right-turn/through, or both)
$F_{Split\ Phasing}$	0.741	Signal coordination with upstream intersection
$F_{Med\ Island}$	0.767	Presence of raised median/central island on approach with pedestrian movement

where:

$A_{NA,NB}$ = number of predicted NA and NB injury crashes in five years

q = total daily traffic volume entering the intersection from the approach

p = pedestrian volume bin on the approach (on a scale of 1–5, with 1 being low and 5 being high).

$$A_{ND,NF} = B_0 \times q_1^{0.093} \times p^{0.172} \times (Cycle\ time)^{0.579} \times (Yellow\ time)^{0.837} \times F_{Full\ RT\ Protection} \times F_{Residential} \times F_{Coordinated} \times F_{Med\ island} \quad \text{(Equation 5.4)}$$

Table 5.4 Model variables for type ND/NF crash model equation

Factor	Value	Description
$B_{0(Auckland)}$	3.10E-02	Constant for Auckland
$B_{0(Wellington)}$	1.03E-01	Constant for Wellington
$B_{0(Christchurch)}$	1.09E-01	Constant for Christchurch
$B_{0(Hamilton)}$	1.93E-02	Constant for Hamilton
$B_{0(Dunedin)}$	2.24E-01	Constant for Dunedin
$F_{Full\ RT\ Protection}$	0.63	Fully protected right-turn phasing
$F_{Residential}$	0.57	Residential land use
$F_{Coordinated}$	1.24	Signal coordination with upstream intersection
$F_{Med\ Island}$	0.99	Presence of raised median/central island on approach with pedestrian movement

where:

$A_{ND,NF}$ = number of predicted type ND and NF crashes in five years

q_1 = daily volume of right-turning vehicles from left approach

p = pedestrian volume bin on the side road (on a scale of 1-5, with 1 being low and 5 being high).

The actual number of crashes between 2004 and 2008 was obtained through CAS for each intersection approach and each crash type. This was subtracted from the predicted number of crashes to obtain the residual number of crashes per five years (RNC/5 years) for each crash type at each intersection approach. This definition for residual crashes implies that a positive number means less crashes were recorded on an intersection approach than predicted (ie an intersection approach performed better than expected). The RNC/5 years for each crash type was tested against each relevant factor identified earlier in the research to see if the presence of the factor had any effect on the RNC/5 years on an approach.

Only X-intersection approaches were used to test type HA factors as no turning movements are involved in this type of crash. For type LB, NA/NB, and ND/NF factors, restrictions on the approaches used for testing were also enforced. For example, where filter turning was being investigated, approaches with a right-turn ban or no right leg were excluded.

Scatterplots were created for each combination of factor and residual being tested. Binary variables were found to give the best trend line fit for all factors tested. Appropriate thresholds were established for factors that were not already binary (for example the number of signal displays) to find the threshold with the best trend line fit. The slope of the fitted trend line and the R^2 coefficient were used to decide if the combination should be tested further. Tables 5.5 and 5.6 show the slope and R^2 coefficient for each combination tested. The combinations brought forward for further testing are highlighted in grey.

Coded crash factors (such as crashes involving red/amber light running) were found to correlate very well to the number of crashes in most cases. These factors were not tested further since they are outcomes for intersection performance rather than input design factors for an intersection.

Table 5.5 Slope and correlation coefficient for RNC/5 years vs various factors – type HA and LB

Crash type	Factor	Slope of trend line	R^2 coefficient
HA	Number of signal displays > 4	0.17	0.015
	Presence of mast arms	0.22	0.026
	Signals on median	0.0074	0.0005
	Visibility of downstream signals	-0.13	0.0028
	Appreciable gradient	0.034	0.0002
	Crashes involving red/amber light running	-0.64	0.17
	Crashes involving failing to notice traffic signals	-0.49	0.054
LB	Right turn filtering full-time	-0.16	0.0098
	Shared left/through and/or right/through lane on approach	-0.022	0.0002
	Shared left/through and/or right/through lane on opposing approach	0.098	0.0034
	Angle of skew > 15º	-0.32	0.018
	Curved approach	-0.25	0.0057
	Signals on median	-0.34	0.023
	Multiple opposed through lanes	-0.2	0.014

Table 5.6 Slope and correlation coefficient for RNC/5 years vs various factors – type NA/NB and ND/NF

Crash type	Factor	Slope of trend line	R^2 coefficient
NA/NB	Permanent obstructions blocking visibility of signal display(s)	-0.16	0.013
	Right turn filtering full-time	-0.015	0.0002
	Through/right lane on approach	-0.021	0.0004
	Right turn red arrow	0.018	0.0003
	Appreciable gradient	0.16	0.012
	Angle of skew > 5º	0.14	0.016
	Through/left lane on approach	-0.049	0.0026
	Shared left/through and/or right/through lane on approach	-0.083	0.007

Crash type	Factor	Slope of trend line	R^2 coefficient
	Left-turn red arrow	-0.088	0.0048
	Pedestrian phase fully protected	-0.079	0.0027
	Crash occurred where pedestrian phase not fully protected (ie partial protection or no lead)	-0.53	0.17
	Crash occurred where pedestrian phase had no lead	-0.5	0.12
	Crash occurred where pedestrian markings/kerb are in poor condition	-1.2	0.096
ND/NF	Permanent obstructions blocking visibility of signal display(s)	-0.014	0.0004
	Right-turn filtering full-time	-0.08	0.026
	Right-turn filtering allowed either part-time or full-time	-0.056	0.013
	Through/right lane on approach	-0.05	0.0093
	Right-turn red arrow	0.078	0.025
	Appreciable gradient	-0.036	0.0021
	Angle of skew > 5º	0.066	0.013
	Through/left lane on approach	0.016	0.001
	Left turn red arrow	0.064	0.009
	Pedestrian phase fully protected	-0.053	0.0037
	Crash occurred where pedestrian phase not fully protected (ie no lead or partial protection)	-0.07	0.011
	Crash occurred where pedestrian phase had no lead	-0.2	0.077
	Crash occurred where pedestrian markings/kerb are in poor condition	-0.2	0.0075

5.2.1 Welch's t-test

The factors brought through for further testing were analysed using Welch's t-test, which tests the null hypothesis of two populations having the same means. It is adapted from the student's t-test but is more reliable for samples with unequal variances and sample sizes, which is the case for many of the relationships investigated in this research. A Welch's t-test value of 1.96 indicates that the null hypothesis (population mean A not equal to population mean B) is true with 95% confidence. A Welch's t-test value of 1.645 indicates that the null hypothesis (population mean A not equal to population mean B) is true with 90% confidence.

Welch's t-test may show there is a difference between means at a 95% level of significance when the difference is very small. This occurs when there is a large number of samples in each population. It reduces the uncertainty in the mean for each population so the difference can be small yet still statistically significant. Conversely, Welch's t-test may show there is no difference between means at a 95% level of significance when the difference is large. This occurs when there is a low number of samples in one or both of the populations. It increases the uncertainty in the mean for one or both of the populations so the difference can be large yet not statistically significant.

Welch's t-test is appropriate to test the relationships investigated in this research because the distribution of the underlying data (the RNC/5 years) approximates a normal distribution. Welch's t-test can be used to test populations with different variances, which is the case for the Dataset.

In most cases, factors were binary so there is a population without the factor present (eg with four or fewer signal heads) and with the factor present (eg more than four signal heads).

The expression used for Welch's t-test is shown as equation 5.5 (StatsDirect Limited 2015).

$$t = X_1 - X_2 / \sqrt{(s_1^2/N_1)/(s_2^2/N_2)} \qquad \text{(Equation 5.5)}$$

where:

t = Welch's t value

X_1 = mean value of population A

X_2 = mean value of population B

S_1 = standard deviation of population A

S_2 = standard deviation of population B

N_1 = number of values in population A

N_2 = number of values in population B.

5.2.2 Methodology for determining statistical inferences

Based on the results of Welch's t-test, the difference between the mean RNC/5 years at intersection approaches with and without the factor present were judged at both a 90% and 95% level of confidence using the Welch's t value. The difference in RNC/5 years for each population was also calculated.

Data was checked for normality by plotting histograms of the RNC/5 years. To check for correlation between factors, correlation matrices were created for factors which showed either 90% or 95% statistical significance.

Factors which were not shown to be statistically significant using Welch's t-test were combined with other factors to check if intersection approaches with a combination of factors present (for example skew and gradient) had a higher RNC/5 years compared with intersection approaches that did not have the same combination of factors. This testing was also intended to test for factors that are not mutually exclusive, for example, where a non-filter right turn existed which mitigated the number of approach lanes as a safety hazard.

Factor combinations with the highest residuals were tested using Welch's t-test but no statistically significant results were found for any crash type. Combinations of three factors were also trialled but no statistically significant results were found for any crash type.

5.2.3 Type HA results

The outcomes of the statistical testing of the dataset for type HA crashes are included in table 5.7. The difference between actual and predicted crash performance is explained by two factors with a greater number of crashes occurring on approaches with:

- four or less signal displays
- no mast arms.

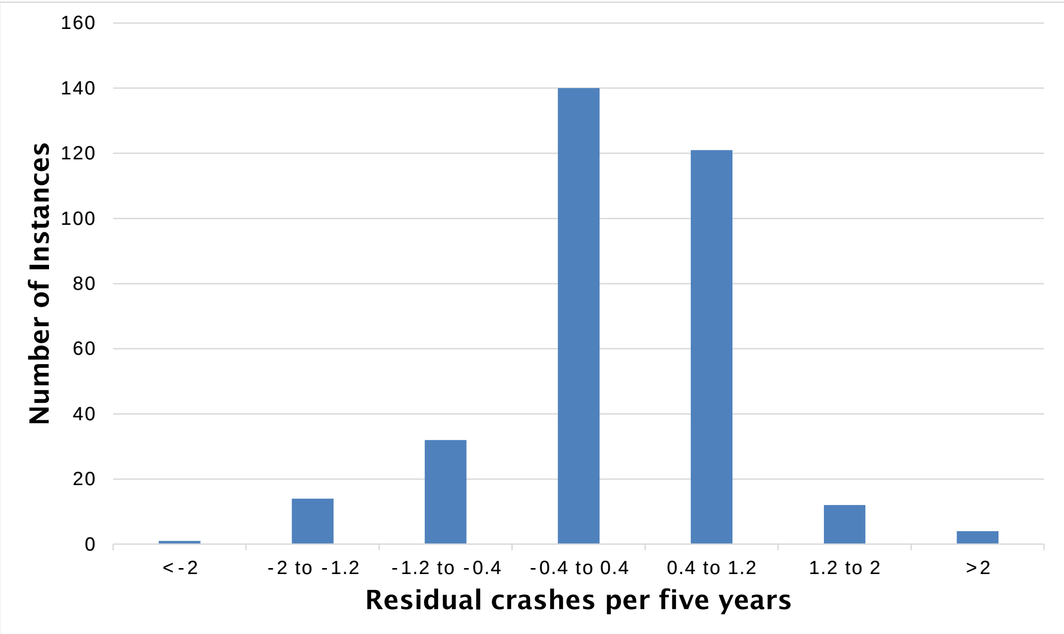
The presence of mast arms is included in the underlying equations from Turner et al (2012) but the analysis indicates it should have more weighting based on the sample population (which is smaller than that tested in Turner et al 2012).

Table 5.7 Statistical significance of factors – type HA crashes

Population A vs population B	T- statistic	Difference between means	Difference between means at 95% confidence?	Difference between means at 90% confidence?
Number of signal displays ≤4 vs >4	-2.46	0.18	Y	Y
No visibility of downstream signals vs visibility of downstream signals	0.81	-0.13	N	N
No mast arms on approach vs mast arms on approach	-2.92	0.22	Y	Y
No appreciable gradient vs appreciable gradient	-0.36	0.03	N	N

Figure 5.1 shows that the data is approximately normally distributed so Welch's t-test is appropriate.

Figure 5.1 Histogram of residual crashes per five years – type HA crashes



There is a strong correlation (0.74) between the presence of mast arms on an approach and the number of signal displays being greater than four. This makes sense given that mast arms are normally only installed on major intersection approaches with many signal displays to ensure visibility to all drivers in an approach queue. This finding should be considered if further research is conducted which attempts to use the data to refine crash prediction models.

5.2.4 Type LB results

The outcomes of the statistical testing of the dataset for type LB crashes are included in table 5.8. The difference between actual and predicted crash performance is explained by four factors with a greater number of crashes occurring on approaches:

- with more than one opposed through lane
- where right-turn filtering is full-time compared with either part-time or banned
- with an angle of skew of 15º or more
- with median signal displays.

This final finding may be due to bias in the intersection dataset. A large number of the approaches with median signal displays were on Fitzgerald Avenue in Christchurch where all right turns require drivers to filter across three lanes of traffic. Table 5.8 shows a correlation between the number of through lanes and median signal displays. On this basis, this result has not been carried forward into the conclusions.

Table 5.8 Statistical significance of factors – type LB crashes

Population A vs population B	T- statistic	Difference between means	Difference at 95% confidence?	Difference at 90% confidence?
Right-turn filtering banned or part-time vs right turn filtering full-time	1.81	-0.16	N	Y
Angle of skew ≤15º vs >15º	1.87	-0.31	N	Y
Approach not curved vs approach curved	0.83	-0.25	N	N
One opposed through lane vs multiple opposed through lanes	2.18	-0.19	Y	Y
No signals on median vs signals on median	1.83	-0.34	N	Y

Figure 5.2 shows that the data is approximately normally distributed so Welch's t-test is appropriate.

Figure 5.2 Histogram of residual crashes per five years – type LB crashes

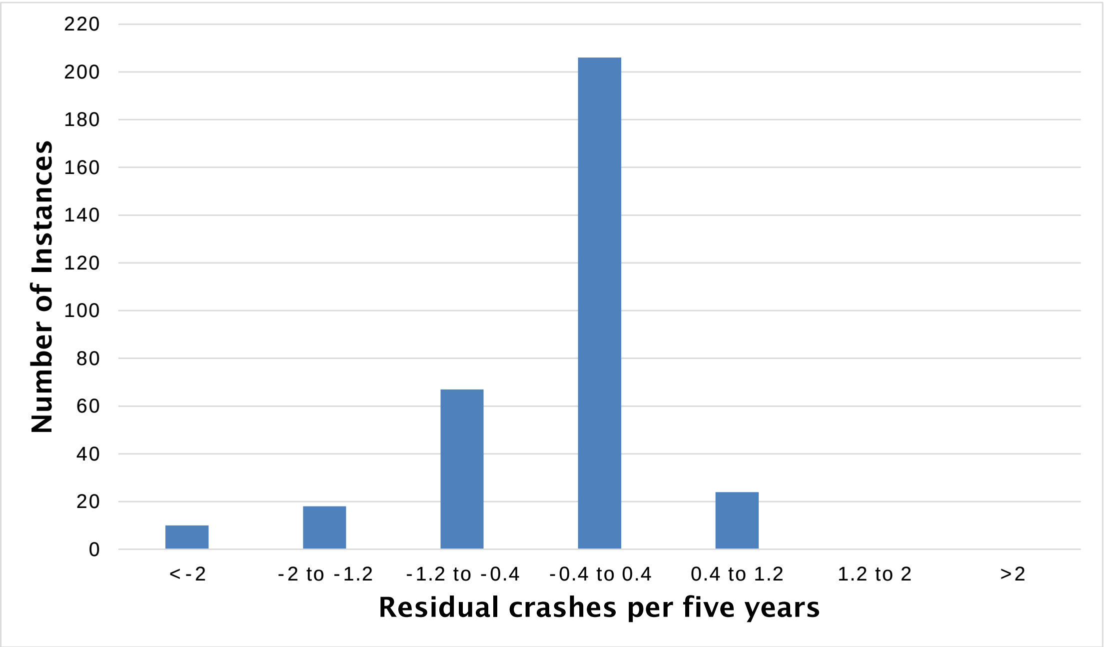


Table 5.9 shows there are no strong correlations between factors with a difference between population means at either a 90% or 95% significance level.

Table 5.9 Correlation matrix – type LB crashes

	Right turn filtering full- time	Angle of skew > 15°	Curved approach	Multiple opposed through lanes	Signals on median
Right turn filtering full-time	1.00				
Angle of skew >15º	-0.15	1.00			
Curved approach	-0.18	0.15	1.00		
Multiple opposed through lanes	-0.34	0.12	0.19	1.00	
Signals on median	0.07	0.05	0.02	0.29	1.00

5.2.5 Type NA/NB results

The outcomes of the statistical testing of the dataset for type NA/NB crashes are included in table 5.10. The difference between actual and predicted crash performance is explained by three factors with a greater number of crashes occurring on approaches with:

- no appreciable gradient
- an angle of skew of 5º or less
- shared turning lanes.

The findings that approaches with no appreciable gradient or a skew less than or equal to 5º have a greater RNC/5 years are notable. Observations during site visits at the 40 intersections investigated in chapter 4 noted that drivers generally slowed down when faced with complex intersection approaches. This gives drivers more time to notice pedestrians crossing. Intersection approaches that are skewed may give drivers a better view of pedestrians waiting to cross because of the direction they face when approaching the intersection.

Table 5.10 Statistical significance of factors – type NA/NB crashes

Population A vs population B	T- statistic	Difference between means	Difference at 95% confidence?	Difference at 90% confidence?
No permanent obstructions blocking visibility of signal display(s) vs permanent obstructions blocking visibility of signal display(s)	-0.74	0.06	N	N
Neither shared left/through and/or right/through lane on approach vs either shared left/through and/or right/through lane on approach	1.75	-0.08	N	Y
No left-turn red arrow on approach vs left-turn red arrow on approach	1.02	-0.09	N	N
No appreciable gradient vs appreciable gradient	-3.59	0.16	Y	Y
Angle of skew ≤ 5º vs >5º	-3.48	0.14	Y	Y
Pedestrian phase not fully protected (ie partial protection or no lead) vs pedestrian phase fully protected	0.82	-0.08	N	N

Figure 5.3 shows the data is approximately normally distributed so Welch's t-test is appropriate.

Figure 5.3 Histogram of residual crashes per five years – type NA/NB crashes

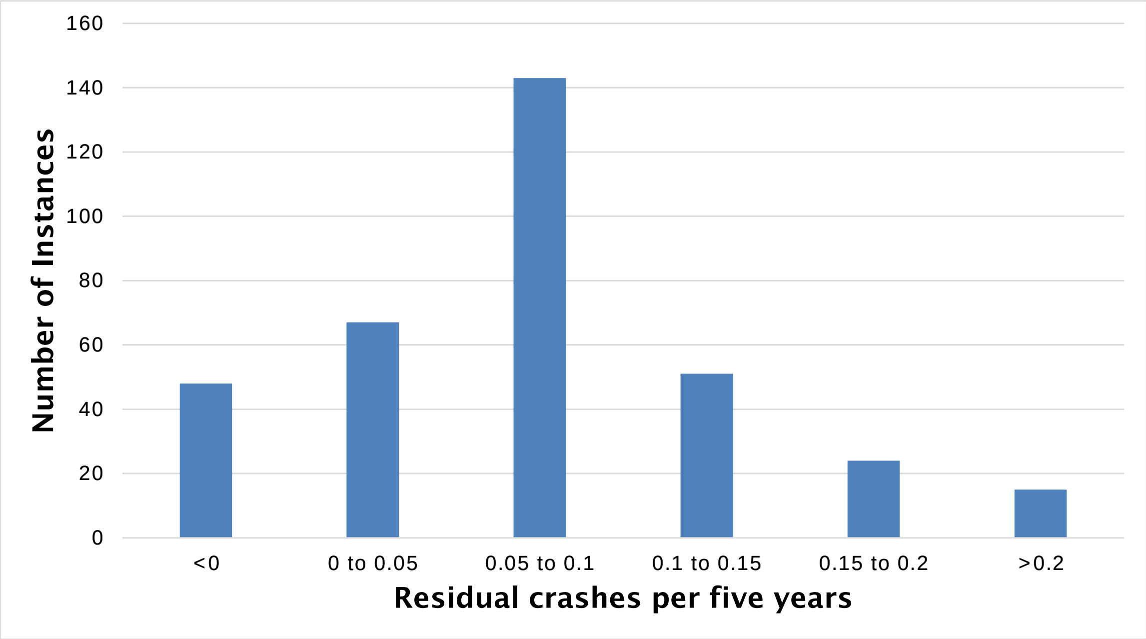


Table 5.11 shows there are no strong correlations between factors with a difference between means at either a 90% or 95% significance level.

Table 5.11 Correlation matrix – type NA/NB crashes

	Either shared left/through or right/through lane	Appreciable gradient	Angle of skew > 5°
Either shared left/through or right/through lane	1.00		
Appreciable gradient	-0.06	1.00	
Angle of skew >5°	-0.15	0.15	1.00

5.2.6 Type ND/NF results

The outcomes of the statistical testing of the dataset for type ND/NF crashes are included in table 5.12. The difference between actual and predicted crash performance is explained by six factors with a greater number of crashes occurring on approaches:

- where filtering is allowed full-time compared with being part-time or banned
- where filtering is allowed either full-time or part-time compared to being banned
- with a shared right/through lane
- without a right-turn red arrow
- without a right-turn green arrow
- with a skew less than or equal to 5°.

The finding that approaches with a skew less than or equal to 5º have a greater RNCs/5 years is notable. Observations during site visits at the 40 intersections investigated in chapter 4 noted that drivers generally slowed down when faced with complex intersection approaches, giving them more time to notice pedestrians crossing. Intersection approaches that are skewed may give drivers a better view of pedestrians waiting to cross because of the direction they face when approaching the intersection.

Table 5.12 Statistical significance of factors – type ND/NF crashes

Population A vs population B	T- statistic	Difference between means	Difference at 95% confidence?	Difference at 90% confidence?
Right-turn filtering banned or part-time vs right turn filtering full-time	2.74	-0.08	Y	Y
Right-turn filtering banned vs right turn filtering part-time or full-time	2.22	-0.06	Y	Y
No shared right/through lane on approach vs shared right/through lane on approach	1.73	-0.06	N	Y
No right-turn red arrow on approach vs right turn red arrow on approach	-3.50	0.08	Y	Y
No left-turn red arrow on approach vs left turn red arrow on approach	-2.24	0.06	Y	Y
No appreciable gradient vs appreciable gradient	0.57	-0.04	N	N
Angle of skew ≤5º vs >5º	-3.73	0.07	Y	Y
Pedestrian phase not fully protected (ie partial protection or no lead) vs pedestrian phase fully protected	0.92	-0.05	N	N

Figure 5.4 shows the data is approximately normally distributed so Welch's t-test is appropriate.

Figure 5.4 Histogram of residual crashes per five years – type ND/NF crashes

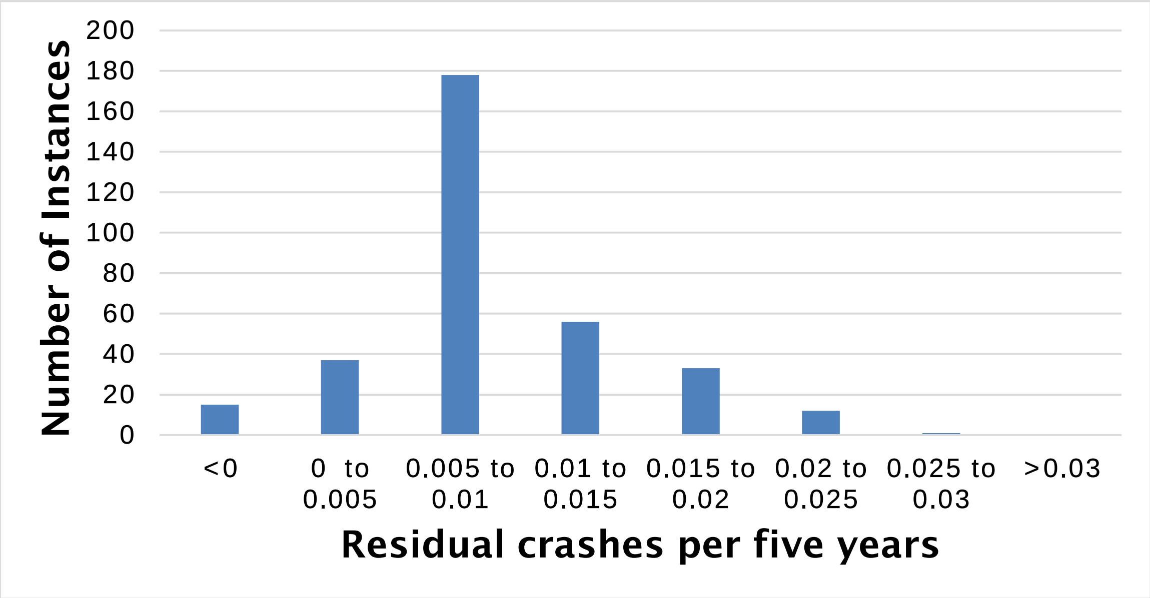


Table 5.13 shows there is a strong correlation between the two right-turn filtering factors which is expected. There is a moderate correlation between the presence of a right-turn red arrow and either full-time filtering or the presence of a shared right/through lane. There is a moderate correlation between the presence of a left-turn red arrow and either full-time/part-time filtering or full-time filtering. Neither of these correlations is unexpected since intersections with these combinations of factors are very common. These findings should be considered if further research is conducted which attempts to use the data to refine crash prediction models.

Table 5.13 Correlation matrix – type ND/NF crashes

	Right- turn filtering full- time	Right- turn filtering part-time or full-time	Shared right/through lane on approach	Right-turn red arrow	Left- turn red arrow	Angle of skew > 5º
Right-turn filtering full-time	1.00					
Right-turn filtering part-time or full-time	0.81	1.00				
Shared right/through lane on approach	0.23	0.33	1.00			
Right-turn red arrow	-0.45	-0.68	-0.56	1.00		
Left-turn red arrow	-0.54	-0.51	-0.09	0.31	1.00	
Angle of skew > 5º	-0.23	-0.23	-0.11	0.16	0.25	1.00

5.2.7 Summary

The results of this stage of the research are presented in table 5.14.

Table 5.14 Summary of results from statistical analysis

Crash type	Factor	Increase in RNC/5 years when factor present	Degree of confidence
HA	Number of signal displays less than 5	0.18	>95%
	No mast arms	0.22	>95%
LB	Either filtering banned or part-time	-0.16	>90%
	Angle of skew less than or equal to 15º	-0.31	>90%
	One opposed through lane	-0.19	>95%
NA/NB	Either shared left/through or right/through lane	0.08	>90%
	Appreciable gradient on intersection approach	-0.16	>95%
	Angle of skew on intersection approach less than or equal to 5º	0.14	>95%
ND/NF	Right-turn filtering not allowed full time	-0.08	>95%
	Right-turn filtering banned	-0.06	>95%
	No shared right/through lane	-0.06	>90%
	No right-turn red arrow	0.08	>95%
	No left turn red arrow	0.06	>95%
	Angle of skew on intersection approach less than or equal to 5º	0.07	>95%

The average recorded number of crashes per five years (ARNC/5 years) over all intersection approaches in the dataset were 0.31, 0.44, 0.18 and 0.05 for crash types HA, LB, NA/NB and ND/NF respectively. This demonstrates the potential crash reductions presented in table 5.14 of remedial treatments on an intersection approach. The difference in RNC/5 years for some factors is higher than the ARNC/5 years. This is because the recorded number of crashes per five years is higher on approaches with that particular factor.

Overall, 10 factors were found to be statistically significant at greater than 95% confidence and a further four factors were found to be statistically significant at greater than 90% confidence. The factors have been presented in appendix F in a similar style to that used in *Stops and goes of traffic signals* (Land Transport NZ 2006). This provides clear and targeted guidance to practitioners when designing urban signalised intersections. The results of this research stage demonstrate the value of remedial intersection treatments which modify the factors studied, and are discussed further in chapter 6.

6 Research discussion

The purpose of this chapter is to provide useful resources to assist practitioners in interpreting the key research findings. Section 6.1 presents a summary of the findings from the site visits, which were undertaken to inform the research. A selection of high- and low-risk intersections has been included to help illustrate the main findings from the site visits. Section 6.2 combines the statistical findings from chapter 5 alongside those from previously published research by Turner et al (2012) and presents a look-up table of a broader range of factors which increase or decrease crash risk.

6.1 Comparison of high- and low-risk intersections

The intersection safety inspections undertaken to inform this research found many of the poorly performing intersections had one or more features that appeared to contribute substantially to the safety performance of an approach or intersection. The statistical analysis in chapter 5 showed that the presence of some non-coded factors could be correlated to safety performance. When multiple non-coded factors on an intersection approach were analysed as a combination, the effect on crash numbers was often exacerbated beyond what might be expected for each factor individually. The sample size was not large enough however to draw statistically significant conclusions. Despite this, crash savings at specific intersections could be made through the implementation of remedial measures to remove or mitigate specific site features or combinations of features.

Examples 1 to 5 on the following pages are drawn from the inspections which identified multiple factors contributing to the worse than expected safety performance of the intersection. Examples 6 to 8 show intersections that performed better than expected.

Table 6.1 shows the list of 15 non-coded factors compiled from section 4.3 including references to each of the eight example(s) where the factor is present. The examples of better and worse performing intersections are included to demonstrate the extent to which a combination of factors often contributes to the overall safety performance of the intersection.

Table 6.1 List of non-coded factors from section 4.3

Non-coded factor	Example(s)
Intersection size: Intersections with a greater number of lanes are wider and are typically associated with higher vehicle speeds, longer exposure times for pedestrians crossing and longer clearance times for cyclists.	3,5
Visibility of signal hardware: Obstructions (permanent or temporary) can limit signal display visibility (for through and turning movements). Lamp types, LED or Halogen, affect visibility in poor light conditions.	4,6
Radius of turning movements: Intersections that were wide, skewed or otherwise had large radii for left- or right-turning traffic resulted in higher vehicle speeds.	3,8
Right-turn bay offset: A lack of visibility of through traffic for right turners is possible where right-turn bays are offset.	1
Size of pedestrian waiting area and kerb quality: Narrow waiting areas and poor quality kerbs encourage pedestrian non-compliance, particularly in high pedestrian demand locations.	5,7
Provision and width of cyclist infrastructure: Few intersections had significant numbers of crashes involving cyclists. Since the quantity of cyclists was unknown this made it difficult to discern if cycling provisions were improving safety or not. A high proportion of the intersections inspected in Auckland had no cycle facilities, which may have deterred cyclists for safety reasons and hence generated a low crash rate for cyclists.	3,7
Speed environment: Both posted speed and side friction affect negotiation speeds through intersections.	2,8

Non- coded factor	Example(s)
Higher vehicle speeds reduce the time available for drivers to react, increasing the risk of collisions between road users giving way to each other. Higher vehicle speeds also increase the risk of loss-of-control crashes.	
Right-turn filtering: Right-turn filtering at intersections, which involves turning across oncoming vehicles, may result in increased right turn against crashes.	1
Provision of pedestrian protection: The provision of a protected phase for pedestrians may reduce the number of crashes involving pedestrians by removing the conflict between road users. Similarly, if the length of such as phase is increased, the number of crashes involving pedestrians may decrease.	3,5,7
Split phasing: Split phasing may increase pedestrian confusion and delays, possibly leading to non-compliance.	3
Approach gradients: Downhill approaches can result in higher vehicle speeds, and increase the frequency of red light running, while uphill approaches are associated with reduced forward visibility.	2,6
Geometric complexity: Skewed or offset intersections typically have greater radii for some movements, resulting in higher speeds, and can increase driver workload and confusion.	1,3,6
Curvature on approach to intersection: A bend on an intersection approach can cause visibility issues for approaching vehicles (ability to see signal displays), right turners (ability to see oncoming vehicles) and pedestrians (ability to see vehicles).	1
Nearby signalised intersections: Downstream signal displays may be visible if there are signalised intersections near the downstream of an intersection. Particularly if these displays are operating on a different phase there is potential for driver confusion and red-light running.	2
Nearby pedestrian generators: Facilities such as railway stations, schools and shops near intersections can result in higher pedestrian volumes, which increase the potential for pedestrian-vehicle interactions.	4,6

6.1.1 Example 1: Intersection of Riccarton Road, Middleton Road and Ilam Road, Christchurch (LoSS V)

Figures 6.1 and 6.2 show a poorly performing intersection in Christchurch, assessed LoSS V.

Figure 6.1 Aerial image of Riccarton Road, Middleton Road and Ilam Road intersection, Christchurch

Figure 6.2 Northern leg of Riccarton Road, Middleton Road and Ilam Road intersection, Christchurch

6.1.1.1 Notable features:

- Geometric complexity: The unusual alignment of this intersection causes multiple operational issues including a lack of visibility for right-turning vehicles as shown in figure 6.1. In total, 20 crashes were recorded at this intersection between 2008 and 2013.
- Curvature on approach to intersection: Both the northern and southern legs of this intersection have significant curvature leading to visibility issues for vehicles filter-turning right.
- Right-turn bay offset: On the northern approach to this intersection (shown in figure 6.2) vehicles filter-turning right have very little view of oncoming traffic when a vehicle is filter-turning on the opposing approach. Four right turn against crashes were recorded between 2008 and 2013 on the northern leg of this intersection which was higher than expected for this intersection. While a similar problem exists on the southern leg of this intersection, right turners on the northern approach prevent traffic from driving straight through so collisions between straight-through traffic and right turners from the southern leg are mainly prevented.
- Right-turn filtering: Filter-turning is allowed on all four approaches to this intersection. In total, 12 crashes involving filter-turning were recorded at this intersection between 2008 and 2013.

6.1.2 Example 2: Intersection of Stuart Street, London Street and Arthur Street, Dunedin (LoSS V)

Figures 6.3 and 6.4 show a poorly performing intersection in Dunedin, assessed LoSS V.

Figure 6.3 Aerial image of Stuart Street, London Street and Arthur Street intersection, Dunedin

Figure 6.4 Southern leg of Stuart Street, London Street and Arthur Street intersection, Dunedin

Figure 6.5 Northern leg of Stuart Street, London Street and Arthur Street intersection, Dunedin

6.1.2.1 Notable features:

- Nearby signalised intersections: Drivers approaching this intersection (shown in figure 6.3) from the leg shown in figure 6.4 may be distracted by the downstream signals. Three right-angle crashes were recorded on this approach between 2008 and 2013.
- Approach gradients: The steep gradient on Stuart Street means that vehicles travelling downhill have a greater braking distance. Two right-angle crashes were recorded on the approach shown in figure 6.5 between 2008 and 2013.
- Speed environment: The approaches shown in figure 6.4 and 6.5 both have wide lanes and low side-friction. This encourages high vehicle speeds which lower the time available for drivers to react.

6.1.3 Example 3: Intersection of Rosebank Road and Ash Street, Auckland (LoSS V)

Figures 6.6 to 6.8 show a poorly performing intersection in Auckland, assessed LoSS V.

Figure 6.6 Aerial image of Rosebank Road and Ash Street intersection, Auckland

Figure 6.7 South- western leg of Rosebank Road and Ash Street intersection, Auckland

Figure 6.8 North- eastern leg of Rosebank Road and Ash Street intersection, Auckland

6.1.3.1 Notable features:

- Intersection size: Pedestrians and cyclists must cross long distances in order to traverse this intersection. Five crashes involving pedestrians and three involving cyclists were recorded at this intersection between 2008 and 2013.
- Geometric complexity: This intersection is heavily skewed (as shown in figure 6.6) meaning that some left and right turns have very large turning radii leading to faster speeds and less time for drivers to react to hazards.
- Radius of turning movements: Both the left turns from the south-eastern and north-western approaches and the right turns from the south-western and north-eastern approaches have very large turning radii.
- Provision of pedestrian protection: No pedestrian crossing infrastructure is provided on the western slip lane and both slip lanes have large turning radii for vehicles. The eastern slip lane has a zebra crossing; however, for vehicles approaching from the northeast it is largely obscured. Pedestrian crashes were recorded between 2008 and 2013 on both the approaches shown in figures 6.7 and 6.8.
- Split phasing: Split phasing exists on some intersection approaches which may be causing confusion to pedestrians.
- Provision and width of cyclist infrastructure: No cyclist facilities are provided at this intersection and lane widths are narrow. Crashes involving cyclists were recorded at this intersection between 2008 and 2013.

6.1.4 Example 4: Intersection of Mount Albert Road, Carrington Road and New North Road, Auckland (LoSS IV)

Figures 6.9 to 6.11 show a poorly performing intersection in Auckland, assessed LoSS IV.

Figure 6.9 North- western leg of Mount Albert Road, Carrington Road and New North Road intersection, Auckland

Figure 6.10 North- eastern leg of Mount Albert Road, Carrington Road and New North Road intersection, Auckland

Figure 6.11 Aerial image of Mount Albert Road, Carrington Road and New North Road intersection, Auckland

6.1.4.1 Notable features

- Visibility of signal hardware: On the approach shown in figure 6.9, an overbridge immediately before this intersection blocks view of the signals for incoming vehicles. On the approach shown in figure 6.10, the bus stop just before this intersection impedes the view of the signals. Vegetation growing on the left-hand side of the road also makes the signals less conspicuous and will block view of the signals if not cut back regularly.
- Nearby pedestrian generators: A railway station exists just west of this intersection (shown in figure 6.11) which attracts a large volume of pedestrians. In total, six accidents involving pedestrians were recorded at this intersection between 2008 and 2013.

6.1.5 Example 5: Intersection of Bucklands Beach Rd, Aviemore Dr. and Pakuranga Rd, Auckland (LoSS V)

Figure 6.12 shows a poorly performing intersection in Auckland, assessed LoSS V.

Figure 6.12 Aerial image of Bucklands Beach Road, Aviemore Drive and Pakuranga Road intersection, Auckland

6.1.5.1 Notable features:

- Provision of pedestrian protection: No pedestrian provisions exist on the four slip lanes as shown in figure 6.12. Six pedestrian crashes were recorded at this intersection between 2008 and 2013.
- Size of pedestrian waiting area and kerb quality: The pedestrian waiting areas are small on the south-western and south-eastern corners of this intersection. The slip lanes also have a high entry angle and no crossing platforms to slow down traffic.
- Size of intersection: Pedestrians and cyclists must cross long distances in order to traverse this intersection. Higher vehicle speeds are also likely given the size of the road.
- Right-turn filtering: Filtering on the eastern approach was banned in 2010. Between 2008 and 2010, there were four right turn against crashes on this approach.
- Geometric complexity: The curvature on the western leg of this intersection limits the view of oncoming traffic for vehicles filter-right turning from the eastern approach. Between 2008 and 2010, there were four right turn against crashes on this approach.

6.1.6 Example 6: Intersection of Khyber Pass Road, Grafton Road and Nugent Street, Auckland (LoSS II)

Figures 6.13 and 6.14 show an Auckland intersection with a good safety performance, assessed LoSS II.

Figure 6.13 Aerial image of Khyber Pass Road, Grafton Road and Nugent Street intersection, Auckland

Figure 6.14 Western leg of Khyber Pass Road, Grafton Road and Nugent Street intersection, Auckland

6.1.6.1 Notable features:

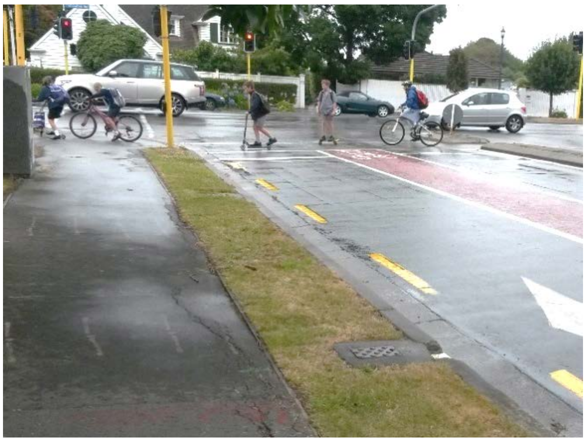
- Geometric complexity: Intersection legs meet at approximately right angles as shown in figure 6.13. This limits the distance which pedestrians and cyclists must traverse. Right turns are also banned on two of the intersection approaches. Two crashes involving pedestrians were recorded at this intersection between 2008 and 2013, which is relatively low considering the large traffic volumes traversing this intersection and high pedestrian activity. No cyclist crashes were recorded during this period.
- Visibility of signal hardware: Mast arms exist on all approaches to this intersection. Vegetation and shop awnings do not obscure signal faces on any approach. Three right-angle crashes were recorded between 2008 and 2013, which is relatively low considering the large traffic volumes traversing this intersection.
- Approach gradients: Despite the rolling terrain in the environs, this intersection and all approaches are relatively flat as shown in figure 6.14.
- Nearby pedestrian generators: Pedestrian volumes at this intersection are relatively high due to nearby retail activity and railway stations. Despite this, only two crashes involving pedestrians were recorded between 2008 and 2013, which is relatively low considering the high pedestrian activity and large traffic volumes traversing this intersection.

6.1.7 Example 7: Intersection of Fendalton Road and Glandovey Road, Christchurch (LoSS II)

Figures 6.15 and 6.16 show a Christchurch intersection with a good safety performance, assessed LoSS II.

Figure 6.15 Aerial image of Fendalton Road and Glandovey Road intersection, Christchurch

Figure 6.16 Northern leg of Fendalton Road and Glandovey Road intersection, Christchurch



6.1.7.1 Notable features

- Provision and width of cyclist infrastructure: Cyclist infrastructure exists on all intersection legs with advanced stop lines on all approaches as shown in figure 6.15. Cycle lanes are on the right side of left-turning traffic on two of the three intersection approaches with the remaining right turn mainly unused because of the off-road cycleway 1km east of this intersection. Cycle lanes are all 1.5m wide. Only one cyclist crash was recorded at this intersection between 2008 and 2013.
- Size of pedestrian waiting area and kerb quality: Pedestrian waiting areas are wide and high quality as shown in figure 6.16. No pedestrian crashes were recorded at this intersection between 2008 and 2013.
- Provision of pedestrian protection: Pedestrians are given a head-start on both crossings which provide good visibility for turning vehicles.

6.1.8 Example 8: Intersection of Gordon Road, Factory Road and Bush Road, Mosgiel (LoSS II)

Figures 6.17 and 6.18 show a Mosgiel intersection with a good safety performance, assessed LoSS II.

Figure 6.17 Southern leg of Gordon Road, Factory Road and Bush Road intersection, Mosgiel

Figure 6.18 Aerial image of Gordon Road, Factory Road and Bush Road intersection, Mosgiel

6.1.8.1 Notable features

- Speed environment: Roadside parking and retail outlets create side friction near this intersection as shown in figure 6.17. Vehicle speeds are therefore slow and the time available to react to conflicts is greater. No right angle or right turn against crashes were recorded at this intersection between 2008 and 2013.
- Radius of turning movements: Turning radii are small on all but one approach as shown in figure 6.18 meaning vehicles are forced to slow down before turning. No right angle or right turn against crashes were recorded at this intersection between 2008 and 2013.

6.2 Combining with crash factors identified in previous research

The factors identified in this research have been combined with crash factors identified in previous research. The resulting aggregated set of factors is presented as guidance for practitioners in table 6.3 with legend included in table 6.2. This gives the key statistical findings from chapter 5 alongside the findings of Turner et al (2012)[3]. In addition, the reader should refer to Austroads (2011) for cycle design guidance at signalised intersections and NZ Transport Agency (2008) for pedestrian design guidance at signalised intersections.

The summary table is intended for use by practitioners who have completed a high-level design and are refining this to ensure crash risk is minimised. The research team found that once traffic volume is accounted for, the number of lanes and their arrangement, number of signal displays and their position, and the operational control of turning traffic are the main predictors of crash performance with other factors having minor effects on safety performance.

The two most significant themes arising from the site inspections were that poorly performing intersections are typically characterised by higher vehicle speeds and poor inter-visibility between road users giving way to traffic or pedestrians. This should be considered when selecting the project stage where the summary table guidance is applied.

Table 6.2 Legend for guidance table to minimise crash risk

Legend	
Largest crash increase	↑
Moderate crash increase	↑
Slight crash increase	↑
Negligible	
Slight crash reduction	↓
Moderate crash reduction	↓
Largest crash reduction	↓

The classifications in table 6.2 were defined by comparing the relative change in crashes for each factor when each factor was changed by an amount likely as the result of remedial works. For binary factors (eg right-turn filtering) a comparison between findings was straightforward. For non-binary factors (eg cycle time), a range of changes likely to be implemented in practice was considered before a classification was made. The thresholds for largest, moderate and slight changes in crash reduction were generally:

- negligible where the factor contributed to less than 5% change in number of crashes
- slight where the factor contributed to a 5–20% increase or reduction in crashes
- moderate where the factor contributed to a 20–50% increase or reduction in crashes
- largest where the factor contributed to a 50% or more increase or reduction in crashes.

Each of the resultant classifications was revisited and in some instances refined as informed by the learnings from the site inspections, previous research and wider industry knowledge. This introduced an element of engineering judgement into the classifications. The results are not directly comparable but have been included in this table to provide indicative guidance to the relative influence of each factor on crash performance by crash type.

The researchers were not in a position to fully assess the relativity of each risk factor identified in prior research in combination with factors identified in this research. Some of these will have a greater influence

[3] Readers are directed to the commentary in section 2.2 of this report regarding the methods employed in these types of studies and any corresponding assumptions and limitations arising from the technical analysis.

on risk than others. There is some likelihood that a small number of the factors identified will explain most of the variability in crash performance with the remaining factors explaining only a relatively small component. As it is important to make this distinction regarding the relative importance of the crash factors, a more comprehensive assessment combining the findings of this research with prior work is recommended.

Table 6.3 Guidance table to minimise crash risk

	Parameter	Effect on crash type			
		Crossing (no- turns)	Right- turn against	Left turn against pedestrian	Right turn against pedestrian
Operational	Coordinated signals	↑			↑
	Full right-turn protection		↓		↓
	Higher pedestrian volume			↑	↑
	Increased approaching traffic volume	↑		↑	
	Increased degree of saturation		↑		
	Increased right-turning traffic volume		↑		↑
	Longer all-red time	↓		↑	
	Longer cycle time		↓	↑	↓
	Longer yellow time				
	Split phasing	↓		↓	
	Right-turn filtering allowed		↑		↑
Physical	Cycle facilities		↑	↓	
	Install left-turn red arrow				↓
	Install right-turn red arrow				↓
	Larger intersection size	↑			
	Longer right-turn bay/lane		↓		
	Mast arms	↓			
	More approach lanes	↑		↑	
	More through lanes		↑		
	Number of signal displays >4	↓			
	Raised median/central island	↓	↑		
	Removal of intersection skew		↓	↑	↑
	Shared right-turn/through lane		↓		↑
	Shared turns	↑		↑	
Environmental	Residential land use				↓

7 Conclusions and recommendations

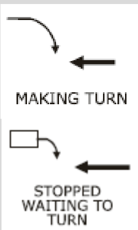
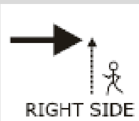
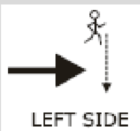
7.1 Conclusions

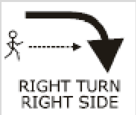
The research team found that once traffic volume is accounted for, the number of lanes and their arrangement, number of signal displays and their position, and the operational control of turning traffic are the main predictors of crash performance.

The findings show that at times, the safety performance of an intersection cannot be predicted or explained accurately simply on the basis of its form, design features and operating characteristics. There may be no individual set of treatments to reduce crashes at every intersection approach. For this reason, specific site studies and safety audits remain a useful technique at intersections exhibiting poor safety performance, to help identify site-specific problems and appropriate remedial measures.

Table 7.1 shows the factors found to be significant for each crash type studied, the effect each has on injury crashes and the degree of confidence for each factor. Overall, 10 factors were found to be statistically significant at greater than 95% confidence and five factors were found to be statistically significant at greater than 90% confidence. The findings that intersection approaches with a larger skew or appreciable gradient had a smaller number of injury crashes were counter to expectations and further research into these factors is recommended. The results of this research demonstrate the value of remedial intersection treatments to modify the factors studied.

Table 7.1 Summary of significant factors

Crash type	Factor found to be significant	Effect on number of injury crashes	Degree of confidence
HA 	Number of signal displays less than 5	Increase	>95%
	No mast arms	Increase	>95%
LB 	Either filtering banned or part-time	Decrease	>90%
	Angle of skew less than or equal to 15º	Decrease	>90%
	Single opposed through lane	Decrease	>95%
NA/NB  	Either shared left/through or right/through lane	Increase	>90%
	Appreciable gradient on intersection approach	Decrease	>95%
	Angle of skew on intersection approach less than or equal to 5º	Increase	>95%

ND/NF	Right-turn filtering not allowed full time	Decrease	>95%
	Right-turn filtering not allowed at all	Decrease	>95%
	No shared right/through lane	Decrease	>90%
	No right-turn red arrow	Increase	>95%
	No left-turn red arrow	Increase	>95%
	Angle of skew on intersection approach less than or equal to 5º	Increase	>95%

7.2 Recommendations

The recommendations relate first to future work to build on the findings of the research, and second to where the findings of this research could be incorporated to provide practitioners with guidance on safe intersection design. The intersections in the dataset used in this report are all located in New Zealand; however, the findings and recommendations of the research are potentially applicable in other countries.

To build on the findings of the research, it is recommended that the NZ Transport Agency considers re-calibrating the crash prediction models in Turner et al (2012) to incorporate the significant factors identified in the research. By doing this, the accuracy of the crash prediction models should improve as well as allowing the percentage reduction in crashes of each type to be estimated for specific remedial treatments (for example the installation of mast arms). This assessment would be particularly useful to ensure practitioners understand the relative importance of both the factors identified in the research and those from prior work, in terms of the extent to which they explain any variation in the crash performance of intersections.

A larger study looking at a greater number of signalised intersections would also be advantageous to build on the dataset compiled during the research project and reduce the variation in population means. This would allow the findings from the research to be confirmed with a greater degree of certainty and may reduce the variation in population means enough for some factors to become statistically significant. This may also shed more light on the counter-intuitive findings for intersections that were skewed or had an appreciable gradient. The analysis conducted in chapters 3 to 5 could also be repeated using just death and serious injury crashes.

It is recommended that the findings of the research are incorporated in publications which provide guidance to practitioners who design new or upgraded signalised intersections in urban areas. Sections 4 to 8 of *Stops and goes of traffic signals* (Land Transport NZ 2006) should be updated to include the conclusions of this research. The update should ideally include findings from parallel road safety projects for traffic signal design and operation, including work towards cycle safety at urban signalised intersections.

Section 3 of the HRIG (NZ Transport Agency 2013b) should be updated to include the findings in section 4 for non-coded factors. The research findings relating to coded factors should also be incorporated into section 3 of the HRIG to complement the existing findings for coded factors. By incorporating these changes into relevant guidance documents, the goals of the New Zealand Government's *Safer Journeys* strategy (Ministry of Transport 2013) will be facilitated through the provision of safer roads and roadsides that are predictable, promote safe behaviour and are forgiving of human error.

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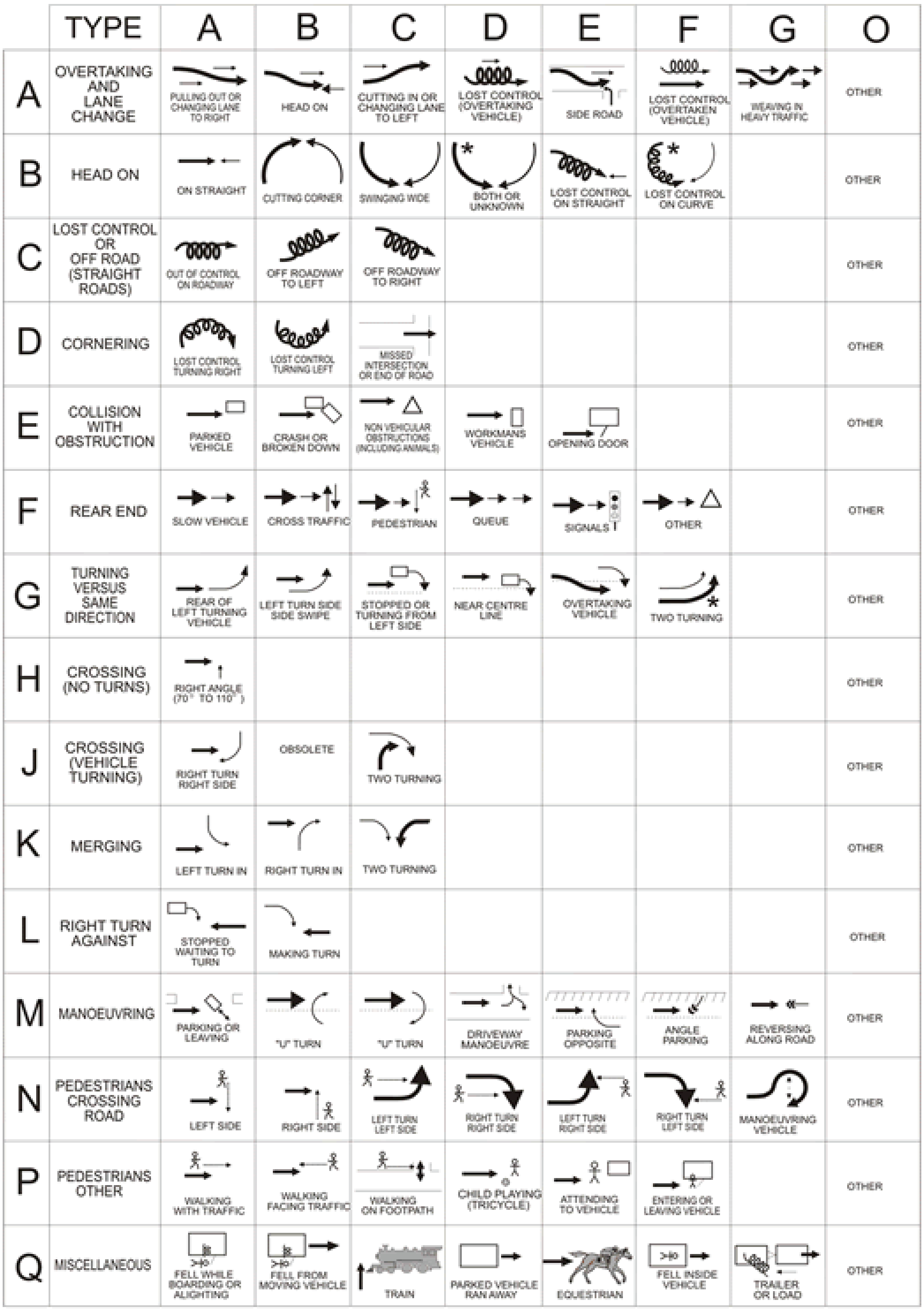
Appendix A: CAS crash movement codes



	TYPE	A	B	C	D	E	F	G	O
A	OVERTAKING AND LANE CHANGE	PULLING OUT OR CHANGING LANE TO RIGHT	HEAD ON	CUTTING IN OR CHANGING LANE TO LEFT	LOST CONTROL (OVERTAKING VEHICLE)	SIDE ROAD	LOST CONTROL (OVERTAKEN VEHICLE)	WEAVING IN HEAVY TRAFFIC	OTHER
B	HEAD ON	ON STRAIGHT	CUTTING CORNER	SWINGING WIDE	* BOTH OR UNKNOWN	LOST CONTROL ON STRAIGHT	* LOST CONTROL ON CURVE		OTHER
C	LOST CONTROL OR OFF ROAD (STRAIGHT ROADS)	OUT OF CONTROL ON ROADWAY	OFF ROADWAY TO LEFT	OFF ROADWAY TO RIGHT					OTHER
D	CORNERING	LOST CONTROL TURNING RIGHT	LOST CONTROL TURNING LEFT	MISSED INTERSECTION OR END OF ROAD					OTHER
E	COLLISION WITH OBSTRUCTION	PARKED VEHICLE	CRASH OR BROKEN DOWN	NON VEHICULAR OBSTRUCTIONS (INCLUDING ANIMALS)	WORKMANS VEHICLE	OPENING DOOR			OTHER
F	REAR END	SLOW VEHICLE	CROSS TRAFFIC	PEDESTRIAN	QUEUE	SIGNALS	OTHER		OTHER
G	TURNING VERSUS SAME DIRECTION	REAR OF LEFT TURNING VEHICLE	LEFT TURN SIDE SIDE SWIPE	STOPPED OR TURNING FROM LEFT SIDE	NEAR CENTRE LINE	OVERTAKING VEHICLE	* TWO TURNING		OTHER
H	CROSSING (NO TURNS)	RIGHT ANGLE (70° TO 110°)							OTHER
J	CROSSING (VEHICLE TURNING)	RIGHT TURN RIGHT SIDE	OBSOLETE	TWO TURNING					OTHER
K	MERGING	LEFT TURN IN	RIGHT TURN IN	TWO TURNING					OTHER
L	RIGHT TURN AGAINST	STOPPED WAITING TO TURN	MAKING TURN						OTHER
M	MANOEUVRING	PARKING OR LEAVING	"U" TURN	"U" TURN	DRIVEWAY MANOEUVRE	PARKING OPPOSITE	ANGLE PARKING	REVERSING ALONG ROAD	OTHER
N	PEDESTRIANS CROSSING ROAD	LEFT SIDE	RIGHT SIDE	LEFT TURN LEFT SIDE	RIGHT TURN RIGHT SIDE	LEFT TURN RIGHT SIDE	RIGHT TURN LEFT SIDE	MANOEUVRING VEHICLE	OTHER
P	PEDESTRIANS OTHER	WALKING WITH TRAFFIC	WALKING FACING TRAFFIC	WALKING ON FOOTPATH	CHILD PLAYING (TRICYCLE)	ATTENDING TO VEHICLE	ENTERING OR LEAVING VEHICLE		OTHER
Q	MISCELLANEOUS	FELL WHILE BOARDING OR ALIGHTING	FELL FROM MOVING VEHICLE	TRAIN	PARKED VEHICLE RAN AWAY	EQUESTRIAN	FELL INSIDE VEHICLE	TRAILER OR LOAD	OTHER

* = Movement applies for left and right hand bends, curves or turns

Source: Land Transport New Zealand (2004)

Appendix B: CAS factors probably contributing to crashes[4]

Driver control

100 Alcohol or drugs
101 Alcohol suspected
102 Alcohol test below limit
103 Alcohol test above limit or test refused
104 Alcohol test result unknown
105 Intoxicated non-driver (pedestrian / cyclist / passenger)
106 (MOT only) dead driver not suspect, tested neg
107 Drug test result unknown
108 Drugs suspected
109 Drugs proven

110 Too fast for conditions
111 Cornering
112 On straight
113 To give way at intersection
114 Approaching railway crossing
115 When passing stationary school bus
116 At temporary speed limit
117 At crash or emergency

120 Failed to keep left
121 Swung wide on bend
122 Swung wide at intersection
123 Cutting corner on bend
124 Cutting corner at intersection
125 On straight section
126 Vehicle crossed raised median
127 Driving or riding abreast (cyclists more than 2 abreast)
128 Wandering or wobbling
129 Too far left / right

130 Lost control
131 When turning
132 Under heavy braking
133 Under heavy acceleration
134 While returning to seal from unsealed shoulder
135 Due to road conditions (requires road series code)
136 Due to vehicle fault (requires vehicle series code)
137 Avoiding another vehicle, pedestrian, party or obstacle on roadway
138 On unsealed road
139 End of seal

140 Failed to signal in time
141 When moving to left, pulling over to left
142 When turning left
143 When pulling out or moving to the right
144 When turning right
145 Incorrect Signal

150 Overtaking
151 Overtaking line of traffic or queue
152 Deliberately in the face of oncoming traffic
153 Failed to notice oncoming traffic
154 Misjudged speed or distance of oncoming traffic
155 At no passing line
156 With insufficient visibility
157 At an intersection without due care
158 On left without due care
159 Cut in after overtaking
160 Vehicle signalling right turn
161 Without care at a pedestrian crossing

170 Wrong lane or turned from wrong position
171 Turned right from incorrect lane
172 Turned left from incorrect lane
173 Travelled straight ahead from turning lane or flush median
174 Turned right from left side of road
175 Turned left from near centre line
176 Turned into incorrect lane
177 Weaving or cut in on multi-lane roads
178 Moved left to avoid slow vehicle
179 Long vehicle tracked outside lane

180 In line of traffic
181 Following too closely
182 Travelling unreasonably slowly
183 Motorist crowded cyclist
184 Incorrect merging / diverging manoeuvre

190 Sudden action
191 Braked
192 Turned left
193 Turned right
194 Swerved to avoid pedestrian
195 Swerved to avoid animal
196 Swerved to avoid crash or broken down vehicle
197 Swerved to avoid vehicle
198 Swerved to avoid object or for unknown reason
199 Avoiding approaching emergency vehicle

200 Forbidden movements
201 Wrong way in one way street, motorway or roundabout
202 When turning or U turning contrary to a sign
203 Contrary to 'in' or 'out' only driveway sign
204 Driving or riding on footpath
205 On incorrect side of road, island or median
206 Contrary to 'no entry' sign
207 In Car Park
208 Motor vehicle in cycle lane
209 Bus / Transit lane
210 Cyclist riding on ped-xing / ped signals

Vehicle conflicts

300 Failed to give way
301 At Stop sign
302 At Give Way sign
303 When turning to non-turning traffic
304 When deemed turning by markings, not geometry
305 When turning left, to opposing right turning traffic (NOT for crashes occurring after 5am 25th March 2012)
306 To pedestrian on a crossing
307 When turning at signals to pedestrians
308 When entering roadway from driveway
309 To traffic approaching or crossing from the right
310 Failed to give way at one lane bridge / road
311 Failed to give way to pedestrian on footpath or verge
312 Entering roadway not from driveway or intersection
313 To emergency vehicle
314 Driver waved through
315 When turning right to opposing left turning traffic (for crashes occurring after 5am 25th March 2012)
316 To traffic approaching or crossing from the left. (for crashes occurring after 5am 25th March 2012

320 Did not stop
321 At stop sign
322 At steady red light
323 At steady red arrow
324 At steady amber light
325 At steady amber arrow
326 At flashing red lights (Rail Xing, Fire Stn etc)
327 For police or flag-person

[4] Source: NZ Transport Agency (2014)

Appendix C: Other environmental factors

Table C.1 Crash month by performance category

Performance category	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Better	7.9%	9.4%	9.5%	7.9%	10.4%	8.1%	6.8%	9.0%	7.9%	7.4%	8.1%	7.6%
As expected	6.6%	6.3%	9.1%	9.4%	8.9%	9.0%	9.0%	9.6%	9.0%	8.0%	7.7%	7.6%
Worse	6.8%	7.8%	8.7%	9.0%	9.8%	8.7%	9.2%	8.3%	8.9%	8.1%	7.2%	7.5%
Total	**7.0%**	**7.8%**	**9.0%**	**8.9%**	**9.8%**	**8.6%**	**8.6%**	**8.7%**	**8.7%**	**8.0%**	**7.5%**	**7.5%**

Table C.2 Crash day of week by performance category

Performance category	Mon	Tue	Wed	Thu	Fri	Sat	Sun
Better	13.6%	13.8%	15.7%	17.2%	17.5%	12.4%	9.8%
As expected	12.8%	13.6%	13.1%	16.5%	17.2%	14.0%	12.8%
Worse	13.4%	14.6%	15.4%	15.4%	16.1%	14.2%	10.9%
Total	**13.3%**	**14.2%**	**15.0%**	**16.0%**	**16.7%**	**13.8%**	**11.1%**

Table C.3 Crash time of day (2- hour period) by performance category

Performance category	00–02	02–04	04–06	06–08	08–10	10–12	12–14	14–16	16–18	18–20	20–22	22–24
Better	3.5%	3.2%	4.2%	7.7%	12.0%	9.0%	9.5%	12.0%	16.1%	8.9%	7.1%	6.6%
As expected	5.0%	2.6%	2.4%	6.7%	13.2%	10.2%	10.4%	13.7%	13.3%	10.7%	6.6%	5.2%
Worse	3.5%	2.1%	2.4%	7.0%	12.2%	9.0%	11.6%	12.8%	14.1%	11.0%	8.8%	5.5%
Total	**3.8%**	**2.5%**	**2.8%**	**7.1%**	**12.4%**	**9.2%**	**10.9%**	**12.8%**	**14.4%**	**10.5%**	**8.0%**	**5.7%**

Table C.4 Road surface wetness at time of crash by performance category

Performance category	Dry	Ice or snow	Wet
Better	77.1%	0.0%	22.9%
As expected	77.3%	0.1%	22.5%
Worse	77.0%	0.1%	22.9%
Total	**77.1%**	**0.1%**	**22.8%**

Table C.5 Light conditions at time of crash by performance category

Performance category	Bright sun	Overcast	Dark, streetlights:		Twilight, streetlights:		Unknown
			On	Off/not present	On	Off/not present	
Better	39.9%	25.2%	28.7%	0.2%	3.3%	2.6%	0.0%
As expected	38.8%	28.5%	28.3%	0.4%	2.1%	1.5%	0.4%
Worse	38.7%	26.6%	29.6%	0.2%	2.6%	2.1%	0.2%
Total	**39.0%**	**26.7%**	**29.2%**	**0.2%**	**2.7%**	**2.1%**	**0.2%**

Table C.6 Weather at time of crash by performance category

Performance category	Fine	Fine, frost	Fine, strong wind	Heavy rain	Heavy rain, strong wind	Light rain	Light rain, strong wind	Mist/ fog	Snow
Better	80.2%	0.0%	0.2%	3.2%	0.1%	15.3%	0.3%	0.7%	0.0%
As expected	78.3%	0.2%	0.1%	4.3%	0.0%	15.8%	0.2%	0.9%	0.1%
Worse	80.4%	0.1%	0.3%	3.5%	0.1%	14.8%	0.2%	0.4%	0.1%
Total	**79.9%**	**0.1%**	**0.3%**	**3.6%**	**0.1%**	**15.1%**	**0.2%**	**0.6%**	**0.1%**

Appendix D: Site inspection locations and checklists

D1 Signalised intersection inspection locations

Auckland	Albert Street	Victoria Street West
Auckland	Ash Street	Rosebank Road
Auckland	Aviemore Drive	Pakuranga Road
Auckland	Donnell Avenue	Walmsley Road
Auckland	East Tamaki Road	Hills Road
Auckland	Grafton Road	Khyber Pass Road
Auckland	Great North Road	Rosebank Road
Auckland	Great North Road	Carrington Road
Auckland	Jervois Road	Kelmarna Avenue
Auckland	Massey Road	Mangere Road
Auckland	Mckenzie Road	Coronation Road
Auckland	Mount Albert Road	New North Road
Auckland	Neilson Street	Onehunga Mall
Auckland	Quay Street	Gore Street
Auckland	Queen Street	Karangahape Road
Auckland	Great North Road	Great North Road
Auckland	Remuera Road	Orakei Road
Auckland	St Marys Road	Jervois Road
Auckland	West Coast Road	Glenview Road
Auckland	Weymouth Road	Russell Road
Christchurch	Whiteleigh Avenue	Troup Drive
Christchurch	Blenheim Road	Clarence Street
Christchurch	Barbadoes Street	Edgeware Road
Christchurch	Grahams Road	Wairakei Road

Christchurch	Papanui Road	Blighs Road
Christchurch	Innes Road	Hills Road
Christchurch	Blenheim Road	Matipo Street
Christchurch	Main North Road	Richill Street
Christchurch	Fendalton Road	Glandovey Road
Christchurch	Ilam Road	Middleton Road
Christchurch	Riccarton Road	Matipo Street
Dunedin	Gordon Road	Factory Road
Dunedin	Filleul Street	St Andrew Street
Dunedin	Moray Place	Stuart Street
Dunedin	Stuart Street	London Street
Dunedin	Bradshaw Street	Hillside Road
Christchurch	Halswell Road	Sparks Road
Christchurch	Aldwins Road	Ensors Road
Christchurch	Milton Street	Strickland Street
Christchurch	Curletts Road	Lunns Road

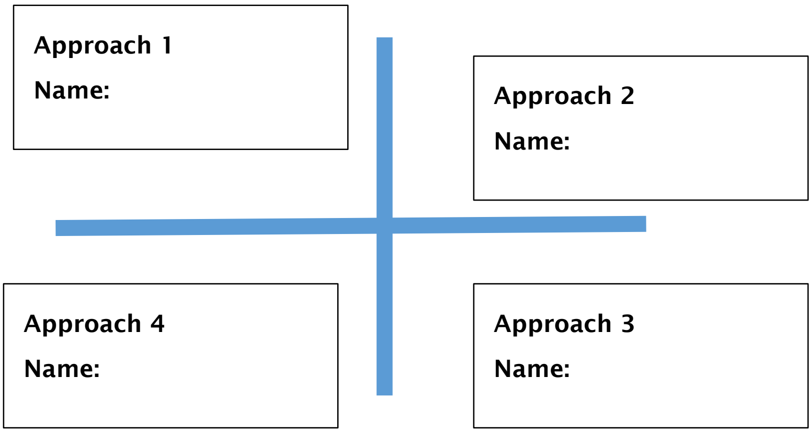
D2 Signalised intersection inspection checklist

Version 0.8

Date:	**Intersection GUID:**
Informal name:	
Surveyors:	

Notes:

- Exit, when referred to, is **beside** approach (otherwise T-junctions would be hard to assess)
- Pedestrian facilities/phases refer to pedestrians crossing approach
- Hook turn boxes are those used by cyclists from the approach
- Take a photo about 60m back from each approach
- T-junctions: skip an approach



D2.1 Overall, equipment and phasing

Lamps (**L**ED, **Ha**logen, **Ot**her):	Traffic safety camera(s) (Y/N):
Street lighting ((Y/N)/condition)?	Adaptive signal control (Y/N):

D.2.2 Environmental factors

Proximate land uses (residential, commercial, industrial, education, aged care):
Nearby activities (shopping, education facilities, drinking establishments):

D.2.3 Notes

Eg if site may be prone to adverse weather conditions (sun strike, ice, precipitation)

D2.4 Signalised intersection inspection checklist APPROACH

Approach ID: _______ Approach road name: _____________________________________

	Factor	Value	Permissible values
Overall, equipment and phasing	Posted approach speed (upstream)		<num>
	Number of displays/aspects		<num>
	Mast arms (present)		Y, N
	Signals on median		Y, N
	Aspect conspicuity (background contrast)		Y, N
	Aspect visibility (permanent obstructions)		Y, N
	Aspect visibility (vehicle obstructions)		Y, N,
	Visibility of downstream signals		Y, N
	Restricted turns		L, R, U
	Visibility of markings		Y, N
	Surface friction: visible issues?		Y, N
	Split phasing (always independent)		Y, N
	Right turn filtering permitted?		Y, N
	Right turn arrow		Lead, Lag, Combin., None
Layout/geometry	Gradient: up,down/steepness		-5 (steep down), 0 (none), +5 (steep up)
	Approach horizontal alignment		Str., Curve, Winding
	Right turn storage markings within intersection?		Y, N
	Right turn guide markings within intersection?		Y, N
	Truck/bus able to turn without overrunning?		L, R
	LHS departure roadside objects frangible		Y, N
	Presence: bus bays or stops on entrance/exit*	/	Y, N
	Pres.: business drvwy or service rd on entrance/exit*	/	0 (none) – 5 (pres & interacts)
	Upstream number of lanes		<num>
	Limit line number of lanes (excluding slip)		<num>
	Limit line lane configuration		L, LT, T, TR, R, LTR
	Slip lane present		Y, N
	Slip lane exit		Giveway, Signals, Unopposed
	Downstream number of lanes		<num>
	On-street parking present*		**Up**str, **Do**wnstr, **Bo**th, **No**ne
	Left/Right turn lane queue exceed storage capacity?		Y, N
	Median present at limit line		Flush, Raised, Barriers
Active modes	Pedestrian crossing facilities present		Y, N
	Pedestrian protected phase		Full, Head Start, None
	Pedestrian signals functioning correctly?		Y, N
	Slip lane: pedestrian provision (type)		**No**ne, **Ze**bra, **Pl**atform
	Condition of pedestrian markings and kerb		1 (good) – 5 (poor)
	Tactile paving		Y, N
	Pedestrian noncompliance at signal		Y, N
	Pedestrian jay-walking upstream?*		Y, N
	Sufficient clearance times: pedestrian		Y, N
	Cycle lanes present		**Ap**proach, **Ex**it, **Bo**th, **No**ne
	Coloured cycle lane?		Y, N
	Cycle advanced stop line		Y, N
	Cycle stop box present		Y, N
	Cycle hook turn area (for use by this approach) present		Y, N
	Condition of cycle facility markings		1 (good) – 5 (poor)
	Cycle lane of reasonable width?		Y, N
	Cyclist provision at shared lanes?		**No**ne, **La**ne, **Co**loured lane
	Cyclist provision at slip lane entry?		**No**ne, **La**ne, **Co**loured lane
	Cyclist provision at slip lane exit?		**No**ne, **La**ne, **Co**loured lane
	Sufficient clearance times: cyclist		Y, N

* within 50m of stop line

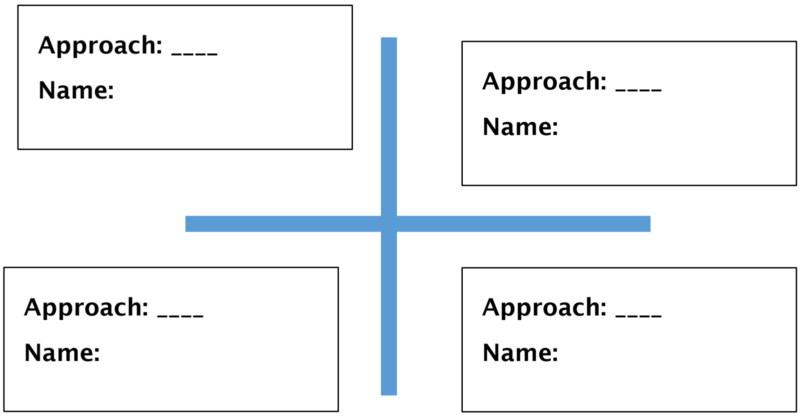
D3 Signalised intersection desktop checklist

Version 0.8

Date:	**Intersection GUID:**
Informal name:	
Surveyors:	

Notes:

- Exit, when referred to, is **beside** approach (otherwise T-junctions would be hard to assess)
- pedestrian facilities/phases refer to pedestrians crossing approach
- hook turn boxes are those used by cyclists from the approach
- refer to doc **measurement of right turn bay offset** for information on how to do this
- T-junctions: skip an approach



D3.1 Overall, equipment and phasing

Signal equipment age:	Degree of saturation:
Cycle time:	

D3.2 Environmental factors

Proximate land uses (residential, commercial, industrial, education, aged care):
Nearby activities (shopping, education facilities, drinking establishments):
Demographics of nearby residents (eg elderly; use census map):

D3.3 Notes

D3.4 Signalised intersection desktop checklist APPROACH

Approach ID: ___ Approach road name: ____________________

	Factor	Value	Permissible values
Layout/Geometry	Angle to north (to nearest 5°)		<num>, N/A
	Departure angle (180 is normal, 90 if T approach)		<num>
	Upstream distance from which signals are visible**		<num>, >200
	Proximity to nearest intersection**		<num>, >200
	Proximity to nearest signalised intersection**		<num>, >200
	Bus bays or stops on entrance/exit* (distance)		<num>, >50
	Business driveway/service road on entrance/exit* (distance)		<num>, >50
	Intersection depth (limit line to opposite entry)		<num>
	Upstream number lanes (excluding cycle lane)		<num>
	Upstream lanes total width (excluding cycle lane)		<num>
	Downstream number lanes (excluding cycle lane)		<num>
	Downstream lanes total width (excluding cycle lane)		<num>
	Limit line total width (excluding cycle lane)		<num>
	Limit line lane configuration		L, TL, T, TR, R, LTR, LR
	Right turn bay: length		<num>, N/A
	Right turn bay: offset (0 = aligned)***		<num>, N/A
	Right turn bay: channelization		Y/N, N/A
	Kerb radii at left side of approach (to nearest 0.5m)		<num>
	Left turner: clear view of footpath (no permanent obstructions, incl. slip lane if present)		Y/N
	Median: width		<num>, None
	Slip lane: acceleration lane		Y/N
	Slip lane angle to intersecting lane (to nearest 5°)		<num>
Active modes	Pedestrian crossing facilities present		Y/N
	Typical max pedestrian wait time (to cross approach)		<num>
	Cycle lanes present (entrance)		Y/N
	Cycle lanes present (exit)		Y/N
	Cycle lane width (entrance)		<num>, N/A
	Cycle lane width (exit)		<num>, N/A

* within 50m of stop line; ** within 200m of stop line; ***refer to guidance document

Appendix E: Detailed inspections

Table E.1 Detailed inspection for movement code HA – crossing (no turns)

Intersection	Desktop photos	Crash data	Inspection
Albert Street, Victoria Street West (crossroads)	From south approach (and a bit from north approach) mast arm of next intersection is prominent	All four crashes occurred early in the morning (3.15am–6.23am) [maybe quiet roads: speed?]. One crash: alcohol + road rage.	Steep upward approach, and up/downstream signals visible. Drinking establishments nearby.
Milton Street, Strickland Street (crossroads)	Mast arms (only on E and W approaches) quite far to the right	2x night crashes (red light running).	Trees obscure LHS display on E approach. Halogen lamps. Minor roads have limited numbers of displays and no mast arms.
Stuart Street, London Street (crossroads)		Four crashes 12pm–2pm weekdays, other two 7am–9am.	Some obstructions on E (utility pole)/W (tree) approaches may obscure view of one display.

Table E.2 Detailed inspection for movement code F – Rear end

Intersection	Desktop photos	Crash data	Insp.
Ash Street, Rosebank Road (crossroads)	Three on E approach, one on W. Ped Zebra on E approach, but large radius and obstructed view of pedestrians until close.	All following too closely or inattentive (vehicle slowing). No crash movements include pedestrians. One alcohol.	Skewed.
Aviemore Drive, Pakuranga Road, Bucklands Beach Road (crossroads)		All following too closely or inattentive (vehicle slowing). All crashes on E/W approach (much busier).	Advertising obscures some displays.
Donnell Ave, Walmsley Road, Mahunga Drive (Crossroads)		2/3 alcohol.	Many heavy vehicles. Trees obscure display on S (low volume) approach.
Curletts Road, Lunns Road (T-intersection)		All crashes on Curletts Rd (N/S).	
Bradshaw Street, Burns Street, Hillside Road (crossroads)		One too fast when slippery.	Mast arms installed on E/W – possibly later. Trees obstruct view on S approach.

Table E.3 Detailed inspection for movement code N – Pedestrian

Intersection	Desktop photos	Crash data	Insp.
Mount Albert Road, Carrington Road, New North Road (crossroads)		3/7 veh fail to give way; 4/7 ped cross heedless.	Near railway station. S approach: ped headstart, obstructions blocking signal vis, and non-compliant head heights. W approach: overbridge. Split phasing.
Albert Street, Victoria Street West (crossroads)		2/5 veh fail to give way; 3/5 ped cross heedless. 3/5 late night/early morning.	One ped crossing has full protection (it is unclear which one). One crossing could have a longer head start.
Great North Road, Pt Chevalier Road, Carrington Road (crossroads)	2 large radius slip lanes with no ped facilities. 3rd with Zebra.	1/3 intoxicated pedestrian. 1/3 red light running vehicle/ 1/3 ped heedless.	Near Unitec.
Queen Street, Karangahape Road (crossroads)	Queen street approaches very wide (3 lanes, + slip) and both on up-grade, with ped Zebra on slip [drivers possibly distracted looking for vehicles, not peds on Zebra]. .	2/7 ped not comply. 2/7 intox ped heedless. 1/7 veh redlight run. 1/7 veh misjudge ped. 1/7 veh not notice obstructions (?)	E/W approaches no ped protection Split phasing. Intervisibility: pedestrians/vehicles. Filtering: RTA.
Ash Street, Rosebank Road (crossroads)	Large radius slip lane Ash S approach, no ped facilities. Obscured slip lane with ped Zebra on Ash N approach.	¼ ped heedless. 2/4 veh failure to look/stop for peds on crossing. ¼ veh red light run.	Protection varies. High speeds; wide intersection means long ped exposure.
Aviemore Drive, Pakuranga Road, Bucklands Beach Road (crossroads)	4 large radius slip lanes with no ped facilities [that are visible on Sat or street view].	3/3 ped heedless.	¾ slip lanes have zebra (installed at end of 2013). Width. Split phasing.
Grahams Road, Wairakei Road (Crossroads)	Skewed; slip lanes on both small radii corners, no ped facs.	¼ veh red light run. 2/4 veh fail to give way when turning (sig). ¼ ped heedless.	No ped protected phase. Signals obscured. No pedestrian protection.
Ilam Road, Riccarton Road, Middleton Road (crossroads)	One large radii slip lane, one smaller. Offset of minor legs may mean that vehicle sight lines are more extreme than normal.	2/5 ped heedless. 1/5 ped not comply. 1/5 veh fail to give way to ped when turning sig. 1/5 ped mental illness, confused.	Clearance times sufficient. Large radii on controlled Left turns, no ped protection.

Table E.4 Detailed inspection for movement code L – Right- turn against

Intersection	Desktop photos	Crash data	Insp.
Weymouth Road, Russell Road (T-intersection)	Good visibility. < 90deg R turn from E approach [vehicles maybe faster? Possibly due to few filters in Auck, not practised]	All crashes from E approach. 1/5 run amber. 4/5 fail to filter (1 alcohol).	E: Lead RT arrow, then filter.
Great North Road, Pt Chevalier Road, Carrington Road (crossroads)	E approach vis of oncoming vehicles limited by curve [possibly].	All RTA crashes < 2010, and on E approach.	Filtering disallowed on E approach 2010.
Massey Road, Mangere Road, Hospital Road (T-intersection)	Turn is > 90deg	3/5 fail to filter (1 suspected alcohol). 1/5 red light run. 1/5 heavy rain – both vehicles failed to notice signals. [Directions are unclear for this intersection]	Combined right turn arrow + filtering. Intersection is at the top of a crest (should have good vis if stopped to filter, but poor vis on approach).
Aviemore Drive, Pakuranga Road, Bucklands Beach Road (crossroads)	N approach has R, TR + slip configuration – seems a bit confusing.	All crashes from E approach. 2/4 did not stop at steady red. 2/4 failed to filter (1 inexperience)	No filtering. 60 km/h.
Donnell Ave, Walmsley Road, Mahunga Drive (crossroads)	E approach has an R arrow, W approach does not.	All crashes from W approach. 8/9 fail to filter (1 fail to notice: dazzling sun; 1 signal ineffective/ inadequate). 1/9 red light run.	Filtering permitted from E approach.
Blenheim Road, Matipo Street (crossroads)	E/W approaches (Blen Rd) have 2 opposing through lanes, other approaches have only 1.	3/6 fail to filter. 1/6 red light run. 1/9 too fast. 1/9 turned R from incorrect lane. Crashes only in E/W directions	Filtering permitted all approaches. Side friction, speeds. Heavy vehicles. Visibility.
Grahams Road, Wairakei Road (crossroads)	Skewed. No arrows visible.	2/3 fail to filter (1 alcohol suspected). 1/3 red light run.	Filtering permitted all approaches [old survey: did not have arrows].
Whiteleigh Avenue, Troup Drive (T-intersection)	Two opposing through lanes, large offset.	3/3 fail to filter (1 failed to give way when waved through? 1 not see/look). 3/3 travelling south?	Lag right turn arrow with Filtering. Possibly crashes occurring when traffic backed up due to level crossing closures.
Ilam Road, Riccarton Road, Middleton Road (crossroads)	Offset.	All crashes from W or S approach. 7/7 failed to filter (4 failed to see/look).	Filtering permitted all approaches (no arrows). Complexity.
Innes Road, Hills Road (crossroads)	Painted R turn wait areas for E,W approaches. W approach R turn view partially limited by curve.	4/4 fail to filter (2 failed to see/look, 1 vis obstruct (vehicle), 1 misjudge speed/size).	Filtering permitted. No arrows. Speed of opposing vehicles. Improvements?

Appendix F: Design issues and remedial treatments

F1 Intersection and lane layout – intersection layout

F1.1 Safety and efficiency issues

Intersection approaches that are either curved or skewed can cause:

- problems associated with aspect conspicuity due to the angle at which drivers approach the intersection
- drivers to miss hazards at the intersection because of the angle at which they approach it.

F1.2 Recommended treatments

- Re-align the intersection approach if possible.
- Implement minor safety improvements to mitigate the skew.

Further note: While removing a curved or skewed approach improves aspect conspicuity, it inevitably causes drivers to approach the intersection at a higher speed. Appropriate pedestrian infrastructure needs to be put in place simultaneously to ensure pedestrians are not endangered by higher vehicle speeds.

F2 Intersection and lane layout – shared turning movements

Exclusive turning movement lanes should be provided whenever possible.

F2.1 Safety and efficiency issues

Shared movement lanes can lead to:

- drivers (particularly those right-turn filtering) guessing if a vehicle behind a turning vehicle is carrying on straight through or not
- drivers being hurried in their turning movement because of vehicles behind them waiting to go straight through
- pedestrian crashes caused by vehicles paying more attention to vehicles on opposing shared movement lanes than pedestrians crossing.

F2.2 Recommended treatments

- Provide dedicated turning lanes when efficiency and space limitations allow them to be separated.
- Provide dedicated turning lanes when there is a poor safety record for pedestrians.

F3 Intersection and lane layout – right-turn filtering

F3.1 Safety and efficiency issues

- Drivers struggling to find gaps in the traffic to filter turn and hence turning on red lights.

- Drivers struggling to judge appropriate gaps in traffic (particularly when there are multiple opposing through lanes).
- Drivers being pressured by large queues behind them to filter into small gaps.
- Pedestrians being endangered by drivers who focus on more on vehicles while filtering than looking out for pedestrians.

F3.2 Recommended treatments

- If the intersection capacity allows it, have right-turn filtering banned or permit only partially filtering.
- Consider banning right-turn filtering if there is more than one through lane on the opposing approach.
- Consider banning right-turn filtering if there is a poor safety record for pedestrians being hit by right tuners.

F4 Signal post and display location – post placement and signal conspicuity

F4.1 Recommended treatments

- Install mast arms on an intersection approach if aspect conspicuity exists. A few examples of situations where this may occur are:
  - covered shop frontings
  - tall trees (beware that deciduous trees may have acceptable gaps to see signal displays through in winter)
  - where large queues of vehicle form (particularly when a large percentage of heavy vehicles are present on an intersection approach)
- Ensure there are an appropriate number of signal displays on an intersection approach (five or greater is desirable) to ensure all vehicles in the likely queue length will be able to see a signal display for each turning movement.
- Align intersection approaches so the angle of skew is minimised.

F5 Phasing and operational issues – right-turn and left-turn arrow operation

F5.1 Safety and efficiency issues

- The absence of a right-turn red arrow can cause some motorists to assume they have priority when turning right, when in fact oncoming traffic or pedestrians have priority.
- The absence of a left-turn red arrow can cause a similar situation to occur for left turners when in fact pedestrians have priority.

F5.2 Recommended treatments

- Install right-turn and left-turn red arrows on all intersections with a poor safety record for turning movements or when considering an intersection upgrade.

Appendix G: Glossary

AADT	Average annual daily traffic.
CAS	The Crash Analysis System (CAS) is an integrated computer system operated by the NZ Transport Agency that provides tools to collect, map, query and report on road crashes and related data.
Coded factor	A factor recorded in CAS, which is deemed to contribute to crash rates.
Collective risk	A measure of the risk of DSI over a crash period.
DSI	Number of deaths and serious casualties. May be reported, estimated or predicted.
Estimated risk	An estimate of the risk of DSI calculated from the reported history of all injury crashes weighted by the relevant severity indices for the movement type and speed environment. Usually expressed as DSI equivalents.
Filter turns	Permitted movement of right-turning traffic to filter through gaps in the opposing traffic (as opposed to protected right turns, which provide an exclusive phase for right turning vehicles).
Full pedestrian protection	Pedestrian phases at traffic signals are long enough to allow time to cross the intersection completely.
LoSS	The level of safety service (LoSS) is an assessment technique which combines risk exposure (conflicting traffic flows) with crash history to identify intersections performing worse than might be expected, when compared to other similar intersections.
Non-coded factor	A factor deemed to contribute to crash rate which is not recorded within CAS.
Partial pedestrian protection	Pedestrian phases at traffic signals are instated but do not allow enough time for pedestrians to cross the intersection completely.
Personal risk	A measure of the risk of DSI to each vehicle/person entering the intersection, calculated from the collective risk divided by a measure of flow.
PoF	Product of flow (PoF) is a measure for determining the level of traffic risk exposure at intersections.
Predicted risk	Risk determined by prediction models based upon the physical and operational characteristics of an intersection that are known to affect crash risk. Usually expressed as DSI equivalents.
Reported risk	Summary of the recent history of fatal and serious crashes at a site.
RNC	The residual number of crashes is calculated by subtracting the actual number of crashes on an intersection approach from the predicted number of crashes on an intersection approach. In this research, the predicted number of crashes is calculated using crash prediction models formulated in previous research.

SCATS	Sydney Coordinated Adaptive Traffic System (SCATS) is used to manage the dynamic (on-line, real-time) timing of signal phases at traffic signals, meaning that it tries to find the best phasing (ie cycle times, phase splits and offsets) for the current traffic situation (for individual intersections as well as for the whole network). This is based on the automatic plan selection from a library in response to the data derived from loop detectors or other road traffic sensors[5].
Severity index	A severity index is the expected ratio of DSI casualties to all injury crashes. Tables of severity indices exist for each crash movement type, intersection type and speed environment. The indices are applied to injury crashes when deriving estimated DSI equivalents and an average value for all movement types is used to convert predicted injury crashes to predicted DSI equivalents.
Urban KiwiRAP	The New Zealand Road Assessment Programme (KiwiRAP) is a technique for assessing road safety risk. It moves away from the traditional approach of targeting locations where fatal and serious crashes have occurred in the past, to one that identifies those parts of the network that are at highest risk of a fatal or serious crash occurring in the future. Urban KiwiRAP covers all roads not captured by the original KiwiRAP work, ie all local roads (urban and rural) and the urban parts of the state highway network. It includes risk assessments for intersections and corridors[6].

[5] Transcore (2015) *Intelligent transportation systems*. Accessed 3 March 2016. www.transcore.com/intelligent-transportation-systems.

[6] Abley (2015) *What is KiwiRAP urban?*. Accessed 3 March 2016. http://nzta.abley.com/UrbanKiwiRAP/.