The crash performance of seagull intersections and left-turn slip lanes

June 2018

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NZ Transport Agency research report 644
Contracted research organisation – MWH NZ Ltd (now Stantec New Zealand Ltd)

ISBN 978-1-98-856103-5 (electronic)
ISSN 1173-3764 (electronic)

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Turner, S, U Easwarapadcham, R Blewden, S Bosher and G Wood (2018) The crash performance of seagull intersections and left-turn slip lanes. *NZ Transport Agency research report 644.* 129pp.

MWH NZ Ltd (now Stantec NZ Ltd) was contracted by the NZ Transport Agency in 2015 to carry out this research.

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Keywords: channelised layouts, crash modifying factors, crash prediction models, left turn slip lanes, priority intersections, right turn slip lanes, safety performance functions, seagull layouts, T-intersections

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Acknowledgements

The researchers would like to acknowledge the New Zealand Transport Agency for funding this study. We also wish to thank the members of the steering group, in particular the project manager, Fergus Tate.

We would like to thank the following organisations and contacts who provided information and their time to assist with the project; Irene Tse (Auckland Transport), Tim Cheesebrough (Christchurch City Council), James Hughes, Tim Hughes, John Garvitch, Patricia Pierce (NZTA).

Finally we would like to thank the two peer reviewers, Alan Nicholson (retired Professor of University of Canterbury) and David Wanty (Wanty Transportation Consultancy Ltd).

Abbreviations and acronyms

AADT	annual average daily traffic
AIC	Akaiki information criterion
CAS	Crash Analysis System
CL	centre line
CPM	Crash Prediction Model
DS	downstream
EEM	*Economic evaluation manual*
FS	far-side
JA	right-near (crash)
LB	right-through (crash)
LTSL	left-turn slip lane
MOTSAM	*Manual of traffic signs and markings*
MRSL	main road speed limit
NS	nearside
RCA	road controlling authority
SD	sight distance
SRJA	seagull intersection, rural, JA crashes
SRLB	seagull intersection, rural, LB crashes
SUJA	seagull intersection, urban and JA crashes
TLRJA	T-intersection, LTSL, rural and JA crashes
TLRLB	T-intersection, LTSL, rural and LB crashes
Transport Agency	New Zealand Transport Agency
TRJA	T-intersection, rural and JA crashes
TUJA	T-intersection, urban and JA crashes
TULB	T-intersection, urban and LB crashes

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Executive summary

Introduction

The majority of urban and rural intersections have priority control (stop or give way) or no formal control. National Crash Analysis System data (2011 to 2015) indicates that 64% of rural and 43% of urban intersection all-injury crashes occur at three leg priority intersections. The serious injury and fatal crash proportion of rural intersections remains the same (64%), while that of urban intersections has increased to 52%. There are a limited number of studies internationally that focus on priority intersections, with more focus being on traffic signals, roundabouts and road links, especially in urban areas, due to higher rates of crash per intersection and link. This is also the case in New Zealand where there is a gap in the crash models available to the road safety industry, especially for urban areas. With a focus on the Safe System philosophy, it is important we have better tools (crash prediction models) to look at the safety of this intersection type (priority control), where over 50% of serious injuries and fatalities occur.

The challenge with priority controlled intersections is that there are so many intersections to consider for safety improvement. Generally the focus needs to be on the higher volume intersections, where high right turning volumes and high through volumes at peak times result in fewer gaps and increased risk taking. A common treatment at high-volume priority rural intersections (where the speed limit is 80 km/h or greater) is a left-turn slip lane (LTSL) to reduce rear-end crashes and remove slower moving turning traffic from the through traffic. There are concerns that some designs may increase the risk of crashes involving through and right turn out vehicles (JA crashes).

Another treatment type, which is less common, is seagull layouts, where drivers can break their right turn movement into two stages. In the first stage they cross over to a painted or solid median. In the second stage they merge with through traffic on the main road via a merge lane and taper. While in theory these layouts should be safer, the experience is that some have high numbers of JA crashes and LB (right turn out versus through or right turn versus opposing through vehicle respectively) crashes, possibly due to poor design and intersection complexity. Seagull intersections are typically priority controlled, but can also operate as traffic signals. A signal controlled seagull intersection operates with three signal phases, and allows the through movement in one direction to flow continuously. This project focused on priority controlled seagull intersections and developed crash prediction models for standard intersection layouts (with and without LTSLs) and seagull layouts.

Literature review findings

The literature review provided some information on the crash risks at priority intersections, including seagull layouts and LTSLs. The review found limited research available on seagull layouts (called channelised layouts in other parts of the world). Tang and Levett (2009) identified two major crash types (right-near JA and right-through LB) as the dominant types of crashes at seagull intersections in New South Wales, Australia. The multivariate study undertaken of potential crash-causing factors provided very little evidence on why these crashes were occurring. The study did show that young female drivers and older (≥ 67 years) male drivers were over-represented in such crashes.

Radalj et al (2006) analysed the crash data and the design of 76 seagull intersections in Perth, Western Australia. The study identified that seagull intersections, installed as per the recommended guidelines, did not result in any significant (positive or negative) change in the type or number of crashes. However, where the intersection did not conform to the recommended guidance, the crash numbers and severity, (especially the latter) increased. Both Summersgill et al (1996) and Elvik et al (2009) concluded that the safety effect of channelised passing lanes at T-intersections (seagull intersection equivalent) was to increase the crash risk. This research supports the concerns of most road safety specialists that seagull intersections are less safe, especially if poorly designed, than traditional T-intersections.

There is more extensive safety research on LTSLs. While the functions and use of left-turn lanes are reasonably well documented (to reduce rear-end crashes), the overall safety benefits and dis-benefits have recently been questioned, particularly in rural/high-speed areas. Elvik et al (2009) identified from several studies that the provision of left-turn lanes at T-intersections acted to increase the number of injury crashes by 12%. The study reasoned that left-turn lanes may create blind spots where a vehicle turning left can obscure through traffic coming from the right side of the side road. Elvik et al (2009) also added that large scale intersection channelisation can complicate the road layout and may increase driver error.

Research by Urlich (2014) looked at the safety performance of left-turn facilities at rural and grade T-intersections in New Zealand. The specific focus of this study was channelisation such as seagulls and left-turn-in lanes and the effects they had on available sight distances for side road traffic to through vehicles and how this related to the crash rates. The study provided evidence that installation or modification of left turn in lanes can increase injury crash rates. The reason identified was that left-turn vehicles were likely to mask through vehicles on a regular basis. This research indicated that careful consideration needed to be made on the design of slip lanes so they did not compromise the safety of the intersection.

Sample size and variables

A total sample set of 261 T-intersections was analysed in this study. This included 92 standard urban T-intersections and 93 standard rural T-intersections from previous studies. A further 76 intersections with LTSLs (47) and seagull layouts (29) were added to the database. For each intersection turning traffic counts (six movements) were collated, along with the speed limit (on the main road) and a large number of design variables. A total of 25, 51 and 67 design variables were collected at standard T-intersections, T-intersections with LTSL, and seagull intersections respectively. The key design variables for each intersection and key crash type (JA and LB) were combined into a design index. Crash data from 2010 to 2014 was extracted from the New Zealand Crash Analysis System.

Preliminary analysis

To explore the relationship between crashes and different variables a preliminary analysis was undertaken. This looked at the relationship between all variables and the occurrence of fatal and serious injury crashes. The key relationships were as follows:

Urban seagull intersections

- Wider right-turn bays increase JA crashes (higher-speed approach may draw attention of right-turn-out drivers more to the left rather than the right).
- Seagull intersections with wider medians have more JA crashes. (Radalj et al (2006) found that poorly designed right turn bays in wide medians – high angle – increased crashes and especially crash severity.)
- A greater nearside (same as side road) shoulder width increased JA crashes (this could be due to a greater crossing distance to the safety of the median).
- Far-side (opposite side road) upstream (left-hand side approach) features impact on JA crashes (again likely to draw the attention of drivers disproportionately to the left rather than looking both left and right). This is something to look at in future research.
- A greater number of side road traffic lanes reduces LB crashes (unclear why this is the case).

- Larger seagull islands (and typically larger intersections) increase JA crashes (most likely due to higher speeds).
- The longer the acceleration lane, the more JA crashes that are expected (unclear why this is the case).

Rural T-intersections with a LTSL

- A shorter right-turn bay increases JA crashes (this means that drivers drop into the right-turn bay later – this may draw the attention of the right-turn-out drivers to the left rather than to the right).
- A greater number of side road traffic lanes reduces LB crashes (unclear why this is the case).
- The presence and width of a side road median island increases LB crashes (may be associated with a slower right-turn movement around the median island, leaving vehicle exposed to a crash for longer).
- The absence of a top-of-the-T chevron board increases LB crashes (would expect this treatment to reduce JA crashes). This is probably a simple correlation with no significant link.
- The type of downstream median island impacts on the number of JA crashes. Wider painted and solid medians are safer. This is probably because the wider medians make through vehicles travel more slowly.
- A give way control on a LTSL appears to reduce JA crashes (this could be due to lower speeds of left-turning vehicles or due to the safer design of the LTSL – generally give ways are placed on high entry angle LTSLs).

Rural seagull intersections

- Longer right-turn bay increases LB crashes (may be surrogate for high right-turn movement and creates pressures on drivers to make the right turn into the side road).
- Seagull intersections with wider main road medians have more LB and JA crashes.
- The presence of two near-side lanes increases LB and JA crashes (this may be due to wider distance to cross to get to a safe area).
- The presence of two far-side through lanes increases LB and JA crashes (this is likely to be highly correlated to the number of near-side lanes, where the extra width is likely to increase crashes).
- Intersections with stop controls have a higher risk of JA crashes than give way control (this is likely to be due to the reduced approach sight distance at stop controlled intersections and the greater time to cross the conflict area).
- The type of LTSL treatment impacts on LB crashes (this has been found in other studies and might be due to drivers turning right into the side road expecting vehicles to turn left rather than travel straight through).
- The further back the side road limit line is from the left-turn bay lane line, the higher the number of JA and LB crashes. In the case of the former this is likely to be due to left-turning vehicles obscuring the sight distance to through vehicles for drivers on the side road if the side road limit line is set well back from the main road.

Detailed analysis

These relationships were explored further in the detailed analysis, which included the development of eight crash prediction models for the more common intersection types. The two models for standard urban T-intersections had a poor fit despite a lot of variables being identified. Further work is required to develop better fitting models for urban T-intersections.

The other six models had a moderate to excellent fit to the data, providing a high level of confidence the models could estimate crash risk based on a small set of variables. The variables identified in the preliminary analysis were combined into a design index, and appear along with speed limit and the two conflicting flows in each of the models.

An Excel toolkit (published separately as appendix J at www.nzta.govt.nz/resources/research/reports/644) was developed to assess the safest form of control for a given combination of variables. In most cases the designers have little control over the traffic volume and speed limit of the road. The crash rate does appear to be quite sensitive to the design index, as expected. Hence there is considerable scope for a designer to improve safety by improving an intersection's design.

Finally an alternative modelling approach was presented that found the LTSL design appears to impact on JA crashes at urban intersections. It indicates that shorter and high-entry angle LTSLs into side roads are safer than longer low-entry angle LTSLs. This is further evidence the LTSL can impact on the ability of vehicles pulling out of side roads to see the through vehicles they are meant to give way to.

Abstract

A number of alternative intersection layouts are used around the country to reduce traffic delays and to improve road safety. One such group of alternative intersections are termed 'priority controlled seagull intersections'. Seagull intersections are often used on roads to reduce traffic delays as they allow right-turning traffic from the side road to give way to traffic flow on the main road one direction at a time (without impeding the through traffic). However a number of seagull intersections experience high crash rates. This can be a result of design compromises (e.g. short merges) and/or due to the complexity and unfamiliarity of this intersection layout.

While there is considerable debate about the safety problems that occur at seagull intersections and left-turn slip lanes at priority intersections, there has been very little research that attempts to quantify the safety impact of different layouts. In New Zealand, crash prediction models are available for urban and rural priority controlled intersections of a standard layout. In this study, crash prediction models have been developed in an attempt to quantify the effect of various seagull intersection and left-turn slip lane designs.

1 Introduction

A number of priority intersection enhancements are used to reduce traffic delays and improve road safety. This includes various types of seagull intersection layouts and the addition of right-turn (right-turn bays) and left-turn slip lanes (LTSLs). There are safety concerns with some seagull intersections and LTSLs into side roads. The purpose of this research was to identify those features of priority intersections incorporating either seagull intersection layouts and/or LTSLs, which impact on safe intersection performance. This report outlines the safety analysis undertaken on a sample of urban and rural priority T-intersections, with and without seagull intersection treatments and LTSLs.

1.1 Research objectives

- Undertake a literature review of research on priority controlled T-intersections with a specific focus on seagull treatments and left-turn treatments.
- Build on previous data and research at urban and rural priority T-intersections to look at the safety of standard intersections like seagulls.
- Develop crash prediction models for the seagull intersections and priority intersections with LTSLs.

1.2 National data of priority controlled intersections

A high proportion of both urban (low-speed) and rural (high-speed) intersections have priority control; either stop or give-way control. Of the priority controlled intersections the majority have three legs. National Crash Analysis System (CAS) data (2011 to 2015) indicates that 64% of rural intersection and 43% of urban intersection injury crashes occur at three leg priority intersections. This shows that crashes at these intersections are a relatively large proportion of all intersection crashes, even if the number of crashes at each intersection is generally lower than at other forms of intersection control. The data also shows that 64% of rural intersection and 52% of urban intersection crashes resulting in serious injury or fatality occur at three leg priority intersections. The crash severity factors in the *New Zealand crash estimation compendium* (NZ Transport Agency 2016) also show that almost a third (32%) of crashes at rural priority T-intersections result in death or serious injury. This compares with 18% and 20% at rural roundabouts and three leg traffic signals respectively.

While the size of the road safety problem is relatively large, the high number of intersections out on the network makes targeting these crashes with safety improvement treatments difficult. Most road controlling authorities (RCAs) use standards/guidelines and warrants to manage the design and safety of these intersections. RCAs rely on a combination of markings and signage to manage safety. Only a small number of such intersections receive attention in crash reduction studies or traffic capacity upgrades, especially in rural areas. It is predominately higher volume intersections that are likely to get this attention.

1.3 Study of upgrades to priority intersections

This research looked at the priority T-intersections that have been designed or upgraded to improve capacity of the intersection and/or road safety, and considered how they perform when compared with unmodified or standard intersections. The two most common upgrades at priority three leg intersections are the installation of right-turn bays and LTSLs. In this study we focused on LTSLs at rural (high-speed) intersections. The primary benefit of these lanes is to provide room for left-turning vehicles to partially or fully decelerate when turning into a side road. Hence they are installed to reduce the likelihood of rear-end crashes, which are relatively rare compared with other crash types, and typically have a low level of crash severity (ie rarely cause a serious injury or fatal crash). LTSLs also increase efficiency by not requiring through traffic to slow behind right-turning vehicles. Of particular concern, and the reason for looking at this treatment, are situations where the design of the left-turn in facility reduces the visibility for drivers turning right out of the side (minor) road of straight-through vehicles approaching from the right. The concern here is that the crash type that involves a right turn out versus a through vehicle from the right is a more frequent crash type, and also more likely to cause death or serious injury due to the side collision with the driver's door.

1.4 Study of seagull intersections

The research also looked at the safety performance of both urban and rural channelised intersections, and specially the seagull layout. In the seagull layout the right-turn-out of the side road vehicle first crosses the right-to-left through traffic to a protected central median before merging, via an acceleration lane, with traffic travelling left to right at the intersection. While the break-down of the right-turn-out into two movements appears to have both traffic efficiency and road safety benefits compared with having to cross the two-direction main road traffic, the experience across New Zealand and Australia is that these intersections can have a poor road safety record. Some seagull intersections have had very high crash rates, most likely due to compromised design. This research examined (through the use of crash models and other analysis methods) whether well designed seagull layouts have a similar, better or worse road safety performance than other high-volume three leg priority intersections, in urban and rural areas. For those seagull intersections with a poor crash history the research attempted to isolate the design or other factors that caused this outcome.

1.5 Report structure

The first section of the report looks at the limited research available on the safety performance of seagull layouts. The safety issues associated with LTSLs are covered in chapter 2. Chapter 3 looks at the various types of three leg priority intersections, especially the various types of LTSL treatments and the various channelised intersection options that fall between a standard priority intersection with a right-turn bay, and a fully channelised (solid median) seagull intersection layout. Chapter 4 presents the sites that were selected for analysis and variables that were collected for each intersection. Chapter 5 presents the results of the preliminary analysis and chapter 6 the crash prediction modelling. There is then a discussion on these findings before the conclusions and recommendations for future research in chapter 7. An Excel spreadsheet containing a design index and unsafety calculator developed as part of the research is published separately as appendix J at www.nzta.govt.nz/resources/research/reports/644.

2 Literature review

2.1 Introduction

This literature review was conducted by the authors and focused on studies of priority controlled seagull intersections and LTSLs (particularly from a main road into a side road). The research was undertaken using online search engines. It also included more general crash modelling studies of priority intersections.

Seagull intersections get their name from the pattern that the two right-turn lanes make when viewed from above. Internationally (Europe and North America) they are also referred to as 'continuous green T-intersections', 'turbo-T intersections' or 'high-T intersections'.

The intersection form allows one direction of traffic to travel straight through without stopping, while those right turners into the side road utilise a separate lane (which forms one 'wing' of the seagull). Traffic turning right out of the side road simply crosses the intersecting carriageway and traverse along the other 'wing' of the seagull, before merging with the carriageway.

Seagull intersections are typically priority controlled, but can also operate as traffic signals. A signal controlled seagull intersection operates with three signal phases, and allows the through movement in one direction to flow continuously. This project focuses on priority controlled seagull intersections. Across New Zealand there is a variety of existing seagull intersections, as identified in figure 2.1.

LTSLs are provided at most priority (and signalised) intersections for efficiency reasons; they reduce traffic delay to through vehicles by allowing most of the deceleration of left-turning vehicles to occur in a separate (slip) lane. They are also intended to reduce rear-end crashes. Three of the four seagull intersections shown in figure 2.1 have LTSLs of varying types (both into and out of the side road). Many non-seagull intersections also have LTSLs, which come in a variety of different forms, from small painted islands to long low radius curves. This study looks at the effect of LTSLs into side roads only. Many of these do have a form of priority control, which is normally give way. Others have a merge and only a small number slip into a new lane (lane gain); a long slip lane.

Although there are a number of examples of their use, there is limited New Zealand based research in regard to the design of seagull intersections and LTSLs. Hence, to inform this study, a broad review of international literature was undertaken.

A summary of relevant research, collated from studies undertaken in the US, UK, Australia and Spain, is provided within this chapter, as a means of developing a holistic understanding of the appropriate application of seagull intersections. The chapter has been structured in a manner that outlines the suitable application of a seagull intersection and typical treatments used for channelised and left-turn lanes.

It should be noted that, for consistency and readability, references within US and Spanish-based research papers have been amended to reflect New Zealand conditions (ie left-hand-side drive).

Figure 2.1 Use of seagull intersections in New Zealand

Seagull intersection with painted island, LTSL and merge – SH1/Raumati Road, Wellington

Seagull intersection with large painted island, LTSL and merge – SH29/Cambridge Road, Tauranga

Seagull intersection with large solid island, LTSL and merge – SH2/Western Hutt Road, Wellington

Seagull intersection with small painted island, no LTSL and merge – Rossall Street/Holmwood Road, Christchurch

2.2 Seagull intersections

2.2.1 Standards

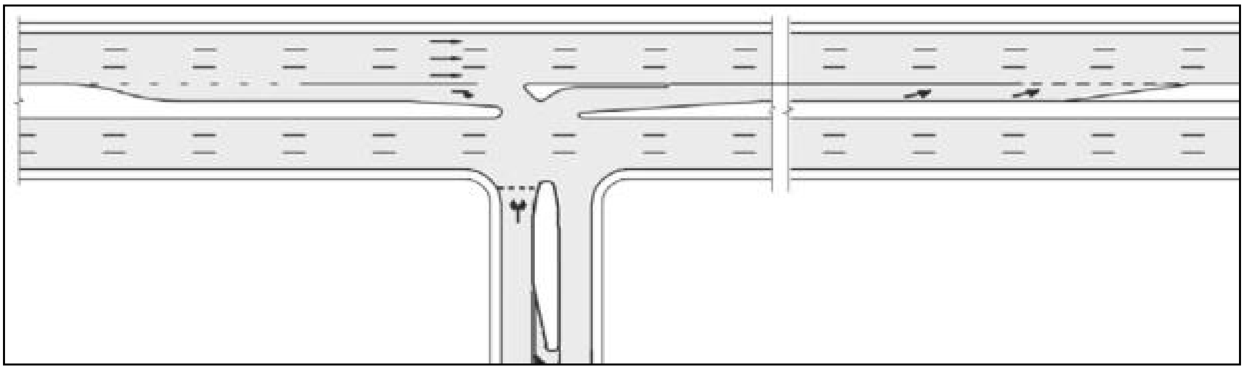
Austroads (2010) notes that seagull intersections usually work well where right-turning traffic from the side road is delayed for extended periods due to the lack of gaps in the traffic streams on the major road. The guidelines advise that detailed traffic analysis is required to demonstrate the suitability of a seagull intersection, and that the following facets should be satisfied:

- There is a substantial volume of traffic from the side road of a T-intersection making the right-turn movement.
- Right-turning traffic is presented with adequate gaps on the near-side carriageway.
- There is a low likelihood of a high demand access being introduced opposite the side road.

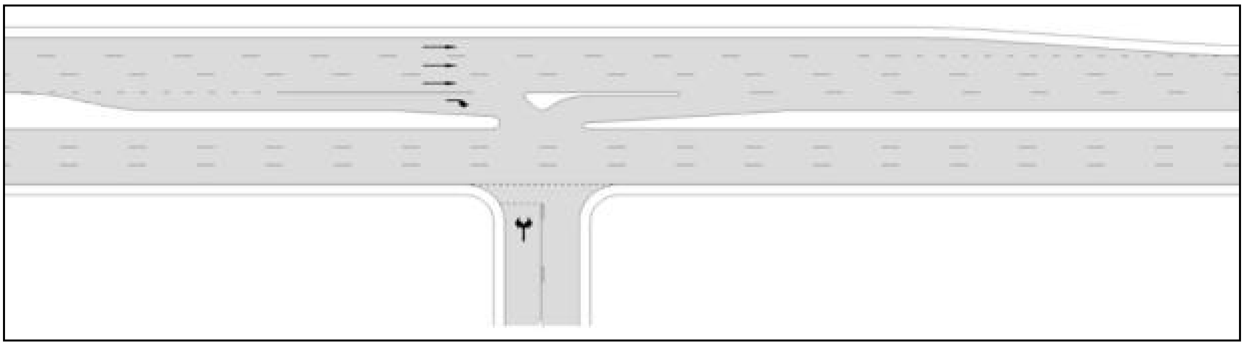
Austroads (2010) states the principles that guide the application of seagull treatments for rural locations are generally the same as those used in urban areas. However, for successful implementation of a seagull intersection in an urban environment, suitable provisions for pedestrians/cyclists, and the potential need to accommodate access to a major development opposite the side road in the future, must be considered.

Figure 2.2 presents sketches of the 'preferred' and 'alternative' seagull intersection treatments, as per the Austroads (2010) guidelines. Where the number of right-turning vehicles from the side road is high relative to the number of through vehicles with which they must merge, the 'alternative' layout is seen to be appropriate.

Figure 2.2 Seagull intersection treatments



Seagull treatment (preferred). Source: Austroads (2010).



Seagull treatment (alternative). Source: Austroads (2010

2.2.2 Safety

Tang and Levett (2009) identified that two crash types based on NZ Transport Agency's guide to coded crash reports (see appendix F); right-near (JA) and right-through (LB) were predominant in crashes at seagull intersections. The study identified no obvious reasons for this. However, a number of crashes involved either young female drivers or older (≥ 67 years old) male drivers. As such, a potential reason was considered to relate to young female drivers' ability to select appropriate gaps in traffic and to the diminishing cognitive ability of the older drivers to select appropriate gaps in the traffic.

Radalj et al (2006) also studied safety at seagull intersections through analysis of crash data and design at 76 intersections across Perth, Australia. The study identified that seagull intersections installed as per the recommended guidelines did not result in any significant change in the type or number of crashes. Where the intersection angle did not conform to the recommended sizes, crash numbers and severity increased. Based on their findings, Radalj et al (2006) recommended that seagull islands be removed from the list of possible intersection safety treatments due to the potential negative impact on crash probability if they were installed incorrectly.

Elvik et al (2009) summarised the effect of channelised passing lanes (lane bypassing the intersection ahead of the T-intersection) and they found a 26% increase in the risk of crashes. However, opinion regarding the assignment of a crash reduction factor to a seagull intersection treatment generally appears to be divided.

2.2.3 Design

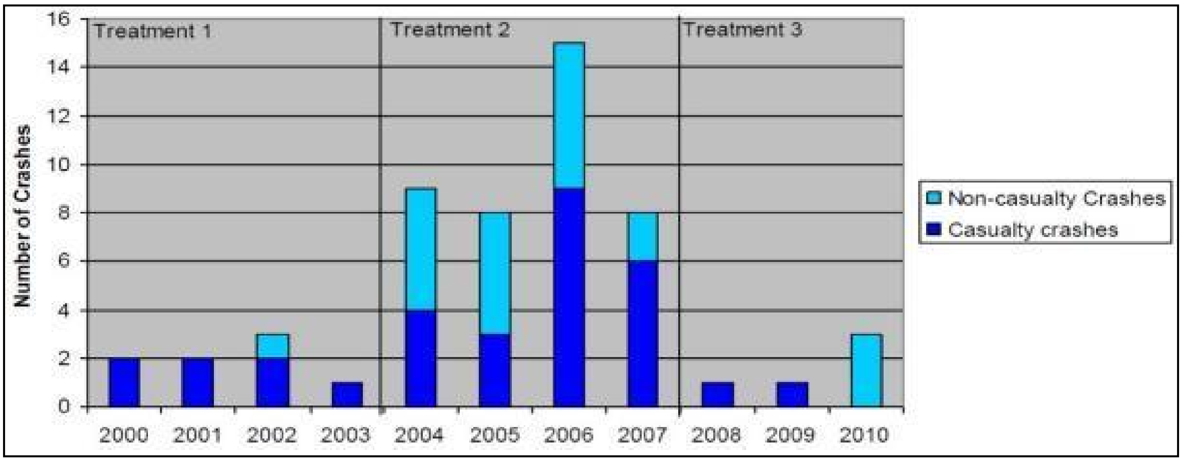
Research in regard to seagull intersection design was undertaken by Harper et al (2011), who looked at the performance of three design variations of the A1 Highway/Island Point Road intersection in New South Wales, Australia.

Harper et al (2011) identified that, upon initial instalment of the seagull intersection, a greater number of 'right near' JA type crashes began to occur. Subsequently, the intersection was modified to include a short left-turn splay that included a small raised concrete splitter island and priority control at the intersection of the left-turn deceleration lane and the side road. However, the new intersection layout did not effectively address the 'right-near' crashes, and indeed, right-through type crashes began to occur more frequently.

A third modification was then undertaken which included two features; namely, increased separation between the left-turn lane and the side road and additional separation between the left-turn deceleration lane and the straight-through lane along the major road.

Figure 2.3 presents a summary of the historical crash data at the intersection, and the explicit impact upon safety of each treatment.

Figure 2.3 Island Point Road/A1 intersection – crash history



Harper et al (2011) concluded that the main design issues related to the connection of the left-turn lane with the side road and the lack of clear sight lines for vehicles waiting to turn right into the side road. It was contended that the issues identified at the case study site might be readily transferrable to many other T-intersection right-turn arrangements, regardless of the presence of a seagull intersection treatment.

2.2.4 Gap acceptance

Llorca et al (2013) monitored gap acceptance at two separate seagull intersections which provide auxiliary right-turn lanes[1]. The focus of the study was the behaviour of drivers entering the major road from the median acceleration lane.

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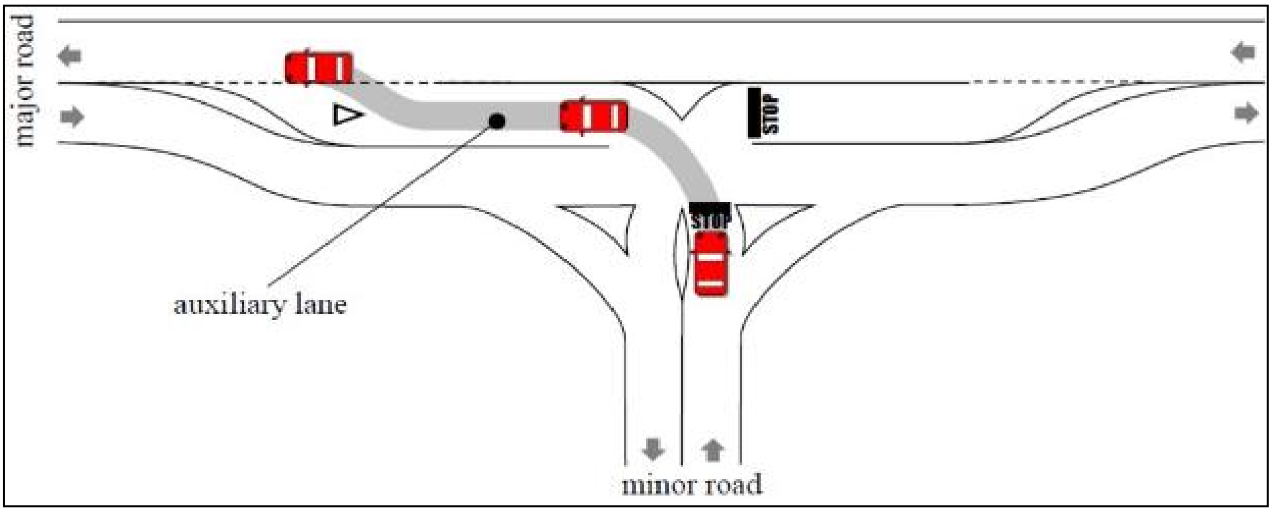
[1] Described as left-turn lanes in the paper.

The research concluded that the speed at which vehicles merged with the major road from the median acceleration lane did not depend on the length of the lane. As such the lane did not encourage acceleration, but rather was used by drivers to select an appropriate gap on the major traffic flow.

Llorca et al (2013) noted that the US and Spanish design guidelines for median acceleration lanes require the lengths to be sufficient to allow vehicles to reach 0.6 and 0.5 times the posted speed limit respectively. Llorca et al (2013) postulated that the presence of vehicles in the median acceleration lane would also have an effect upon operation speed of the major road.

Figure 2.4 provides a schematic diagram of the type of seagull intersection that was studied, noting that the diagram reflects right-hand-side (Spanish) driving conditions.

Figure 2.4 Island Point Road/A1 intersection – movement



Source: Llorca et al (2013)

2.3 Left-turn treatments

2.3.1 Standards

Channelised left-turn lanes are usually implemented at signalised intersections to reduce vehicle delay and to reduce occurrence of rear-end crashes; especially at locations with high left-turn traffic (Autey et al 2012).

The typical standards used for installation of a left-turn treatment in Australia and New Zealand are set out in Austroads (2010). Key factors include traffic volume, vehicle type, speed, site constraints and the provision for cyclists and pedestrians.

Sullivan and Arndt (2014) have recently developed warrants for a range of situations (such as brown field developments) and have made recommendations in regard to their use. Yang (2008) has also presented a methodology for establishing volume warrant conditions for free left-turn lanes[2] based on the potential occurrence of rear-end crashes.

2.3.2 Justification for treatment

The main reasons for installing left-turn channelisation, as identified by Lake (1996), are:

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[2] Described as free right-turn lanes in the paper.

- when left-turning traffic is significant (>100–200 veh/h during the peak hour)
- when the side road intersects at an acute angle and results in a large area of open pavement and an unacceptable corner radius
- if space is readily available
- when left-turn channelisation is economically viable.

Lake (1996) also noted that making a special provision for left-turning traffic is dependent upon:

- the class of the intersecting roads
- the volume and composition of the left-turning traffic
- the angle of the left turn in lane.

2.3.3 Safety

While the functions and use of left-turn lanes are reasonably well documented, the safety benefits and dis-benefits have recently been questioned. Indeed, Fitzpatrick et al (2006) noted the basis for the concerns relates to the notion that rear-end crashes may increase due to collisions resulting from stationary vehicles waiting at the intersection of the left-turn lane and the major road (for a left-turn slip out of the side road). This can occur when the second driver sees a gap and expects the first vehicle to proceed and they do not. The driver of the second vehicle is looking over their right shoulder at available gaps and may interpret a small movement in the first vehicle at the limit of their vision as acceleration into the main road. This does not affect the safety benefits of the left turn into the minor side road which is the main focus of our study.

Research undertaken by Ale et al (2013) identified that the provision of left-turn lanes[3] reduces the incidence, severity and economic costs of rear-end crashes. Overall, crashes involving left-turn movements were found to be relatively rare (8.5% of all multi-vehicle crashes) with the significant contributing crash factors found to be traffic volume, percentage of heavy vehicles, junction type and road surface condition.

However, Elvik et al (2009) identified that the provision of left-turn lanes into the side road at T-intersections acts to increase the number of injury crashes by 12%. Elvik et al (2009) reasoned that a left turn in lanes may create blind spots where a vehicle turning left can obscure approaching through traffic for road users who are coming from the right side of the road. An example of this type of intersection in New Zealand is the SH1– Cherry Lane T-intersection as shown in figure 2.5.

Figure 2.5 SH1 – Cherry Lane (Waikato, New Zealand)

Elvik et al (2009) also added that large-scale intersection channelisation can complicate the road layout, which may increase driver error. This is especially true for drivers used to driving on the opposite side of the road.

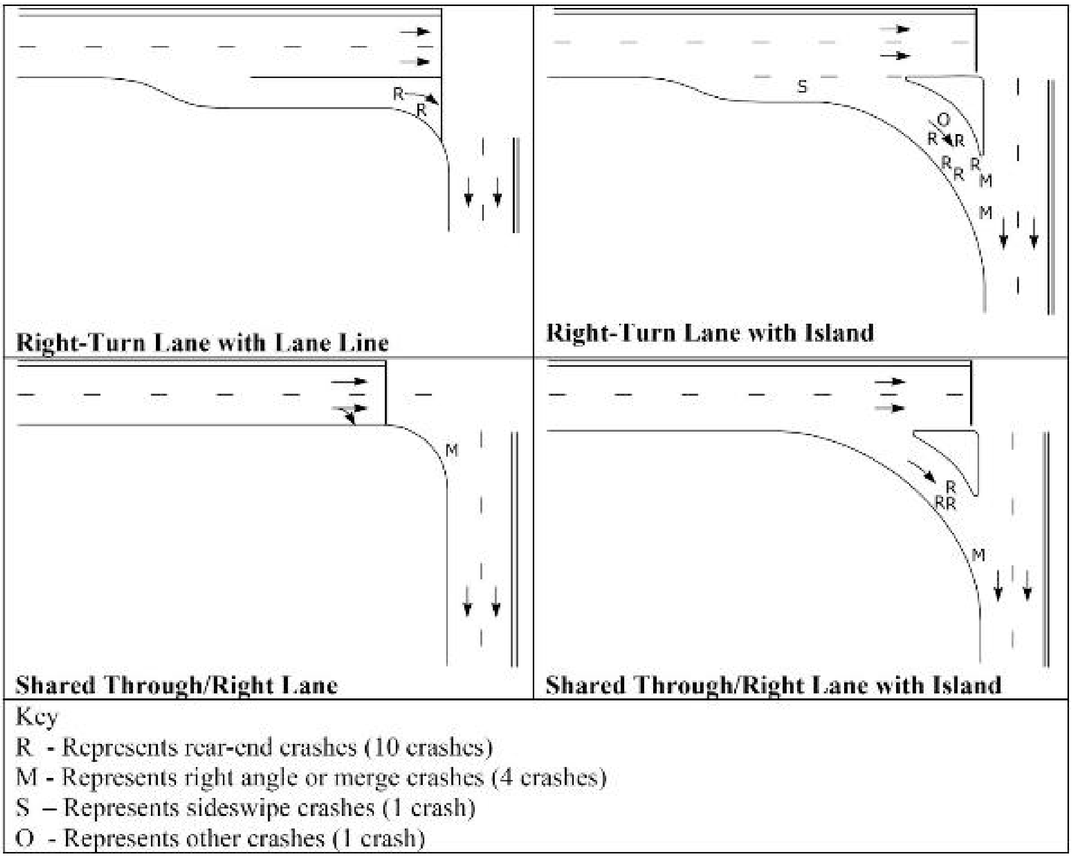
2.3.4 Design

The relationship between vehicle speed and safety for various left-turn treatments[4] was analysed by Fitzpatrick et al (2006). Several left-turn designs were explored, including lane line pavement markings, free-flowing left turns, channelisation of a free-flowing left turn and a left-turn lane with a dedicated downstream lane. One of the most serious safety concerns was that large radius curves might increase vehicle speeds, which consequently would have a negative impact upon the severity of pedestrian–vehicle crashes. Notwithstanding this, it was argued that higher vehicle speeds might result in smaller speed differentials with following vehicles and cause less severe rear-end conflicts, which are rarely severe anyway.

To understand the effect of different left-turn treatments upon crash rates, three-year crash data was analysed by Fitzpatrick et al (2006) for various intersections which provide the following left-turn treatments:

- left-turn lane with lane line
- left-turn lane with island
- shared through/left lane
- shared through/left lane with island.

Figure 2.6 Summary of crashes by left-turn treatment



Source: Fitzpatrick et al (2006)

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[4] Described as right turn in the paper.

Figure 2.6 illustrates these treatments and the location of crashes. Note that this image has been extracted from the research paper, and as such reflects right-hand side (US) driving conditions.

Fitzpatrick et al (2006) concluded that a shared through/left-turn lane resulted in the lowest number of crashes. However, the research did not consider the volume of traffic at each location. This conclusion might be a solution at lower volume sites.

Potts et al (2013) built upon the research of Fitzpatrick et al (2006) and identified that signalised intersection approaches with channelised left-turn lanes are more likely to reduce the likelihood of crashes when compared to shared left-turn lanes. Potts et al (2013) also identified that intersection approaches with channelised left turns delivered a similar pedestrian safety performance to approaches with shared through and left-turn lanes. Furthermore, intersection approaches with conventional left turn lanes had significantly more pedestrian crashes than channelised approaches.

The results from Potts et al (2013) appear to show, aside from intersection approaches with conventional left-hand lanes, other left-turn lane designs tend to have similar safety performance.

2.4 Crash prediction models

2.4.1 Turner (2001)

Turner (2001) developed crash prediction models for rural and urban intersections and links. This is inclusive of models for roundabouts, traffic signals and uncontrolled intersections such as priority T-intersections and uncontrolled T-intersections. Crash and flow data from over 1,000 sites throughout New Zealand were used in the models. The following prediction models have been produced for the different crash types. The total number of crashes can be predicted by summing the individual predictions for each crash type on each approach. The crash models for priority T-intersections and uncontrolled (no give-way, stop or signals) T-intersections are shown in tables 2.1 and 2.2 respectively.

The 'A' is the number of crashes q_1, q_3 and q_5 are the turning flows at the intersections and Q_e is the link flow.

Table 2.1 Priority T-intersection crash prediction models

Crash type	Codes	Equation (injury crashes per approach)
Right turn against	LB	$A = 3.33x10^{-4} \bullet q_5^{0.49} \bullet q_3^{0.42}$
Rear-end	FA to FD	$A = 1.45x10^{-6} \bullet Q_e^{1.18}$
Crossing (vehicles turning)	JA	$A = 3.60x10^{-5} \bullet q_5^{0.93} \bullet q_1^{0.22}$
Loss-of-control	C & D	$A = 8.22x10^{-3} \bullet Q_e^{0.30}$
Other	All others	$A = 2.49x10^{-3} \bullet Q_e^{0.51}$

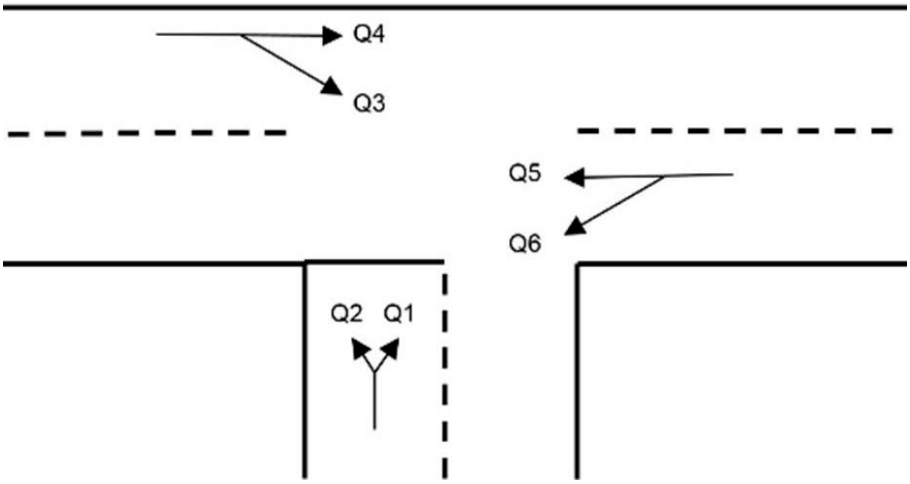
Source: Turner (2001)

Table 2.2 Uncontrolled T-intersection crash prediction models

Crash type	Codes	Equation (injury crashes per approach)
Right turn against	LB	$A = 1.63x10^{-3} \bullet q_5^{0.31} \bullet q_3^{0.41}$
Rear-end	FA to FD	$A = 8.69x10^{-8} \bullet Q_e^{1.50}$
Crossing (vehicles turning)	JA	$A = 4.11x10^{-4} \bullet q_5^{0.22} \bullet q_1^{0.79}$
Loss-of-control	C & D	$A = 2.51x10^{-3} \bullet Q_e^{0.31}$
Other	All others	$A = 6.27x10^{-3} \bullet Q_e^{0.41}$

Source: Turner (2001)

Figure 2.7 Diagram showing six turning counts



2.4.2 Turner and Roozenburg (2007)

Turner and Roozenburg (2007) developed crash prediction models for rural intersections in New Zealand. The crash prediction models were formed by factors including traffic volume, sight distance, approach speed and geometric design.

The Turner and Roozenburg (2007) crash prediction models for a T-intersection are provided in table 2.3. The typical mean-annual numbers of reported injury crashes for rural T-intersections can be calculated using turning movement counts and the crash prediction models. The total number of crashes can be predicted by summing the individual predictions for each crash type on each approach.

Table 2.3 Rural priority T-intersection crash prediction models (Turner and Roozenburg 2007)

Crash types	Equation (injury crashes per approach)	Error structure	Significant model
Crossing – vehicle turning major road approach to right of side road (JA)	$A_{RMTP1} = 5.29x10^{-6} \bullet q_1^{1.33} \bullet q_5^{0.15} \bullet (V_{RD} + V_{LD})^{0.33}$	NB (K=8.3)*	Yes
Right-turning and following vehicle on major road (GC, GD, GE)	$A_{RMTP2} = 5.29x10^{-27} \bullet q_3^{0.46} \bullet q_4^{0.67} \bullet S_L^{11.0}$	NB (K=1.4)*	Yes
Other – major road approach to right of side road (crashes of all types other than those outlined above that occur on the major road approach to the right of the side road)	$A_{RMTP3} = 1.59x10^{-5} \bullet (q_5 + q_6)^{0.91}$	NB (K=1.0)*	Yes
Other – major road approach to left of side road (crashes of all types other than those outlined above that occur on the major road approach to the left of the side road)	$A_{RMTP4} = 2.99x10^{-4} \bullet (q_3 + q_4)^{0.51}$	NB (K=3.0)*	Yes

*K is the Gamma shape parameter for the negative binomial (NB) distribution, q1 to q6 are the various turning movement around the T-intersection. VRD and VLD are the visibility deficiency to right and left and the Austroads 2010 requirements for the operating speed, SL is the approach speed.

2.4.3 Urlich (2014)

This research looks at the safety performance of left-turn facilities at rural at grade T-intersections in New Zealand. Rural intersections are more likely to have high severity crashes than urban intersections due to geometric features, traffic volumes and traffic speed. The specific focus of this study was channelisation, such as left turn in lanes and the effects they have on available sight distances for side road traffic to through vehicles, and how this related to the crash rates. The assessment process looked at 80 rural sites that have some form of left-turn facility and looked at five intersections to assess the before and after crash rates after the addition of left-turn-in lanes.

The study concluded that without taking traffic flows into account, those intersections with left-turn-in lanes had higher crash rates than those with no or small channelisation. The five case studies provided evidence that installation or modification of left-turn-in lanes could increase injury crash rates. The reason identified was that left-turn vehicles are likely to mask through vehicles on a regular basis. Therefore this research indicates that careful consideration needs to be made on the design of slip lanes so they do not compromise the safety of the intersection.

2.4.4 Ale et al (2013)

Ale et al (2013) re-examined the premise that left-turn movements[5] only led to rear-end crashes, and developed both multivariable binary and multivariable multinomial logistic regression models.

The binary models were used to estimate the probability of a crash occurring, and were also used for estimating the occurrence probability for a variety of key crash types. A multinomial crash model was also developed to estimate crash injury severity.

2.4.5 Summersgill et al (1996)

Summersgill et al (1996) investigated the frequency and character of crashes in relation to traffic flow, road features, geometric design, land use and other variables. They produced crash prediction models for various traffic movements at different junction and link types. For some of the movements the models also included the effect of channelisation.

The models relevant to the most common crash types at seagull intersections are presented in table 2.4 below:

Table 2.4 Crash prediction models

Movement		Equation	Note
JA	Right turn from minor with major right to left.	$A = 0.0179 \bullet Q_{43}^{1.037} \bullet Q_6^{0.602}$	Crash risk increased by a factor of 1.5 for junctions with painted channelisation.
LB	Right turn from major with major right to left.	$A = 0.0255 \bullet Q_2^{0.509} \bullet Q_3^{0.569}$	Crash risk was increased by a factor of 1.6 at junctions with a channelised left-turn island
KA	Left turn from minor with major right to left.	$A = 0.00528 \bullet Q_{35}^{0.093} \exp (1.098 \bullet Q_6^{0.60})$	-

Source: Summersgill et al (1996)

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[5] Described as right turn in the paper.

2.4.6 Oh et al (2003)

Following the Federal Highway Administrations sponsorship of the Interactive Highway Safety Design Model, Oh et al (2003) undertook research to independently validate its statistical models and algorithms. Both external and internal model validations were completed for five proposed types of rural intersection crash models. The internal validation results indicated crash models were potentially suffering from omitted safety-related variables, site selection and countermeasure selection bias, and poorly measured variables. The external validation indicated the inability of models to accurately predict actual crash numbers.

Oh et al (2003) made the following recommendations from their study:

- Crash models are carefully designed.
- Data standardisation and collection practices are introduced.
- Before-and-after studies are undertaken.

3 Identification and classification of enhanced priority intersection layouts

In order to simplify and quantify the unique aspects of a seagull intersection there was a need to develop standard terminology for a seagull intersection and the types of LTSLs.

3.1 Classification of seagull intersection layout

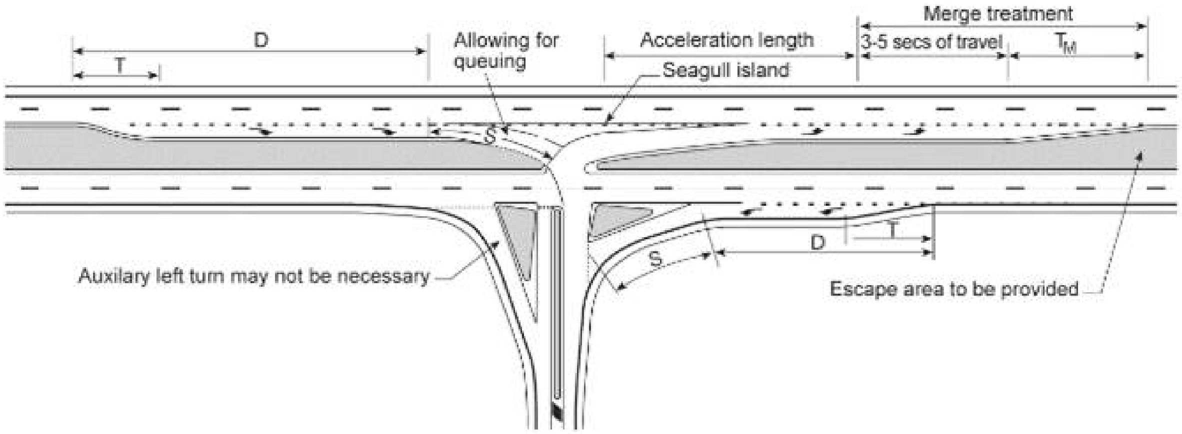
There are three diagnostic characteristics that an intersection must have to be classified as a seagull intersection:

1 Must have one seagull shaped island. The island can be painted (with or without hit posts (flexible lane marker posts)/reflective raised pavement markers) or solid (raised).

2 Must have one diverge lane and one merge lane so vehicles do not stop and wait to merge with downstream traffic.

3 Must have at least one bypass traffic lane.

Figure 3.1 Standard seagull intersection layout



In this study the focus is on priority controlled seagull intersections. Signalised seagull intersections are also used in New Zealand. At signalised seagull intersections the right-turn-in and right-turn-out movements are controlled, as is the right to left through movement. The other through movement (left to right) has a continuous flow, like a priority controlled seagull intersection. Right-turn-out traffic from side road needs to merge via an acceleration lane, as occurs with a priority controlled seagull intersection.

3.1.1 New Zealand-specific design aspects

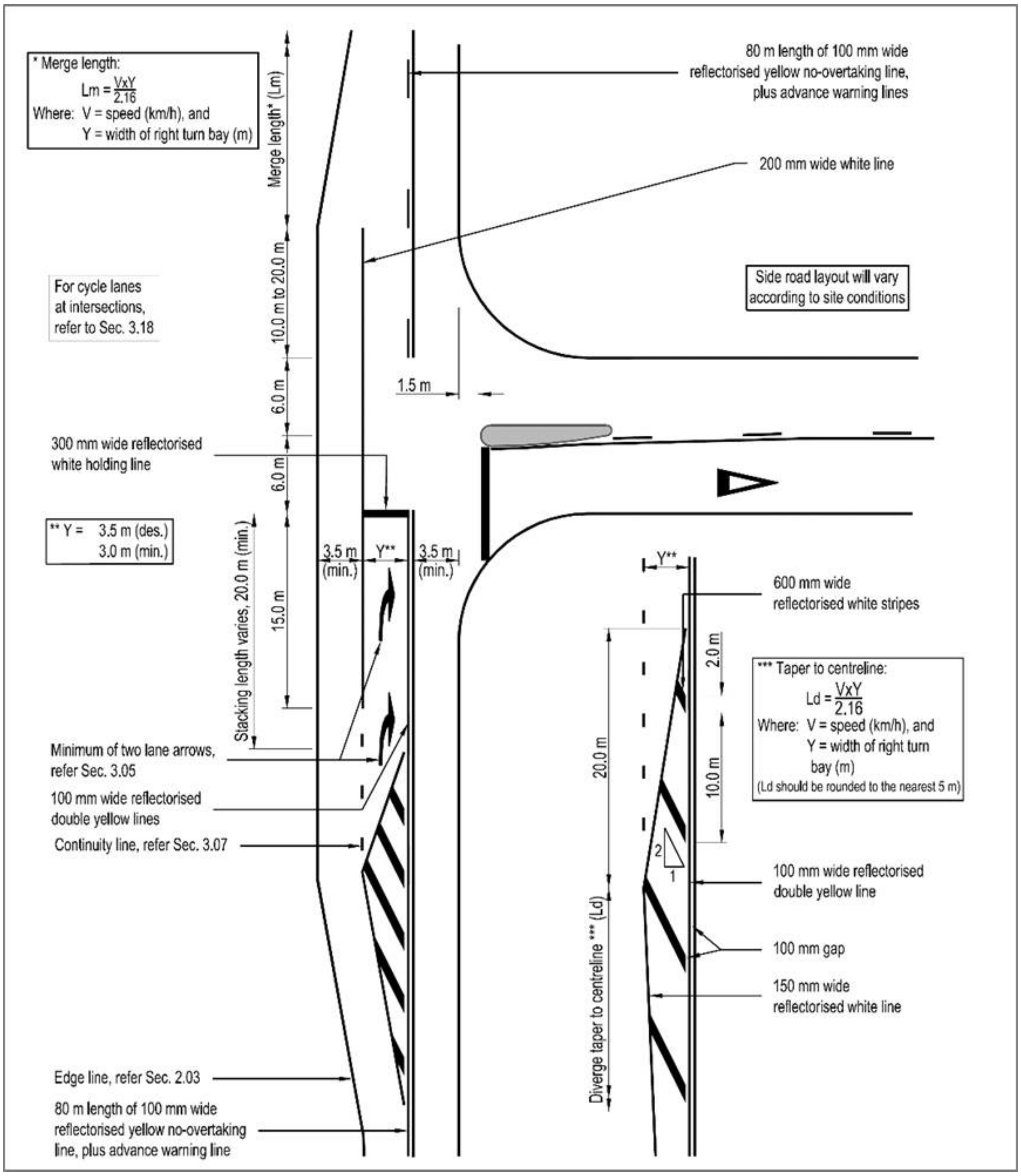
In New Zealand there are two design aspects that differ from the rest of the world, which are important to note:

1 In New Zealand it is legal to drive on a painted flush median. Therefore vehicles can technically drive over a painted seagull intersection island and along a flush median prior to an intersection. This is only if turning and only for a limited distance.

2 New Zealand's standard rural and urban intersection design for a right-turn bay (auxiliary lane) has downstream space that allows the intersection to act like a pseudo seagull intersection, with right-

turning vehicles waiting in this space. This design is from the *Manual of traffic signs and markings* (MOTSAM) (NZ Transport Agency 2011). It is important to note that this intersection design is not a seagull intersection, see figure 3.2. In some places intersections have been widened and flexible slip posts added to create a seagull intersection that looks similar to this design. A key difference is the addition of an acceleration lane and tapper.

Figure 3.2 Right-turn bay markings in rural areas



3.1.2 Seagull intersection layout definitions

To provide consistency throughout this report the following definitions for each aspect of a seagull intersection are used. Median islands separate two directions of travel, while splitter islands separate traffic travels in the same direction.

Figure 3.3 Seagull intersection definitions

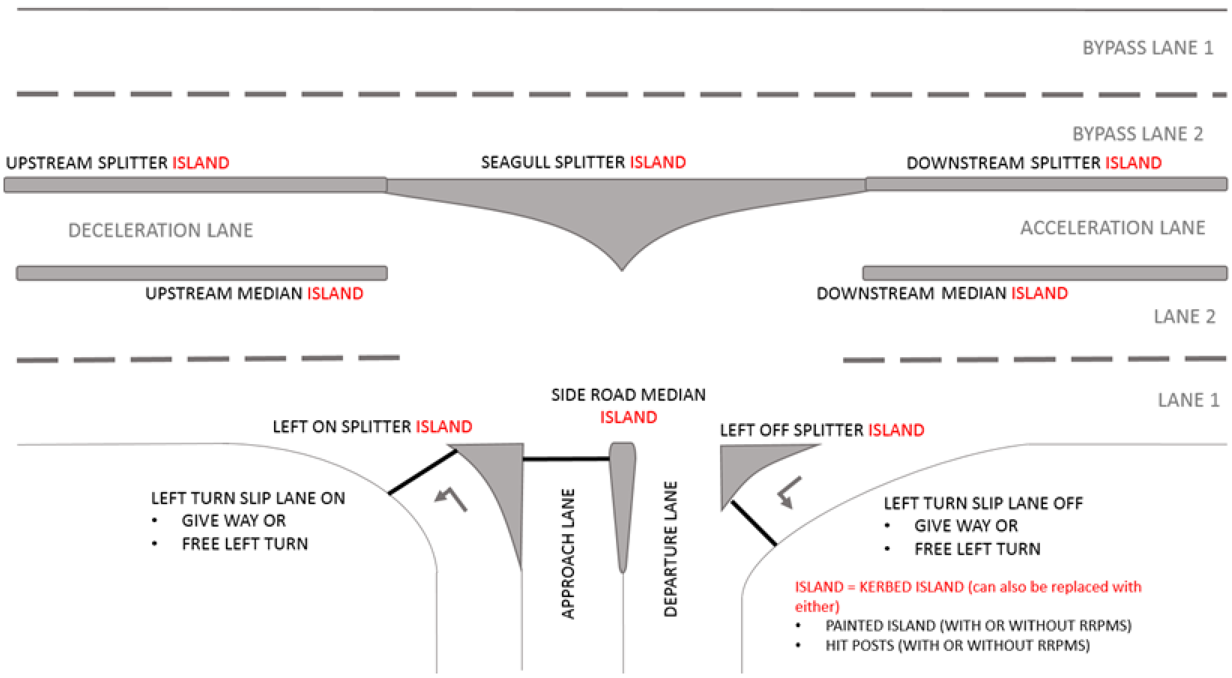


Figure 3.4 Urban seagull intersection)

Source: Google Earth

Figure 3.5 Rural seagull intersection)

Source: Google Earth

An urban seagull intersection is more likely to have a painted seagull island as shown on figure 3.4, whereas a rural seagull is more likely to have a channelised solid island as shown on figure 3.5 as it is in a high-speed environment. There is a large amount of variety in the use of painted and solid islands. Many sites have both types. In recent years hit posts have been used in place of islands. A number of these installations have been installed in Hawke's Bay, including the main highway access to the Napier Airport.

There are a number of intersections, especially those with wide medians that sit between a standard T-intersection and a full seagull intersection, which are termed intermediate layouts.

Figures 3.6 to 3.8 show some poor examples of these intermediate intersection types.

Figure 3.6 shows an intersection where the design of the islands makes it very difficult to make a right turn into the main road, as there is no safe place to stop in the centre of the road. In figure 3.7, a common layout, more aggressive drivers may move to the central area of the road before moving into the through traffic. In figure 3.8, there is a lot of room for the driver to wait in the central area of the intersection but there is a very short acceleration area when merging with through traffic. One such example is the wide median opposite the Placemakers (Hardware) store on Cranford Street in Christchurch. These intermediate intersection layouts have not been included in this study but do warrant analysis, at a later date, to determine their relative safety.

Figure 3.6 Priority T-intersection where right turn out is unlikely to be made in two steps

Figure 3.7 Priority T-intersection layout, where some aggressive drivers may use median space

Source: Google Earth

Figure 3 8 Priority T-intersection with room to wait in centre but small area for storage

Source: Google Earth

3.2 Classification of left-turn treatments

There are a number of left-turn auxiliary lanes, which are commonly known as LTSL designs, as shown in figures 3.9 to 3.13. Figures 3.9 and 3.10 are the most common LTSLs. They typically have a painted island, or a solid island within a painted island, and a short deceleration lane. The left-turn-out main road in this case is late; the turning traffic is not removed from the through traffic until right at the intersection. The combination of this and a single through lane is likely to be safer than a LTSL with a short deceleration lane as shown in figure 3.10 (especially if there is limited scope for through vehicles to overtake slowing left-turn vehicles). A short deceleration lane can lead to safety issues with dynamic queuing (and associated reduced visibility to through vehicles), especially when the side road stop/give way limit line is set back.

Figure 3.9 LTSL with island

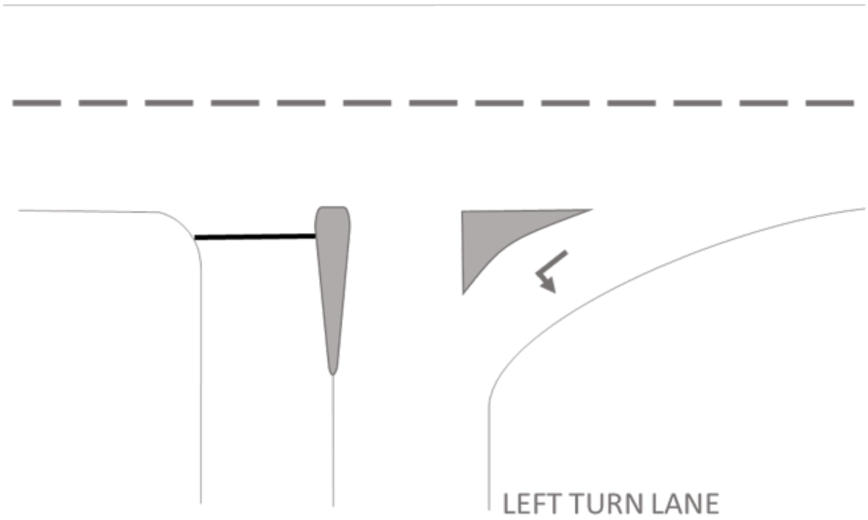
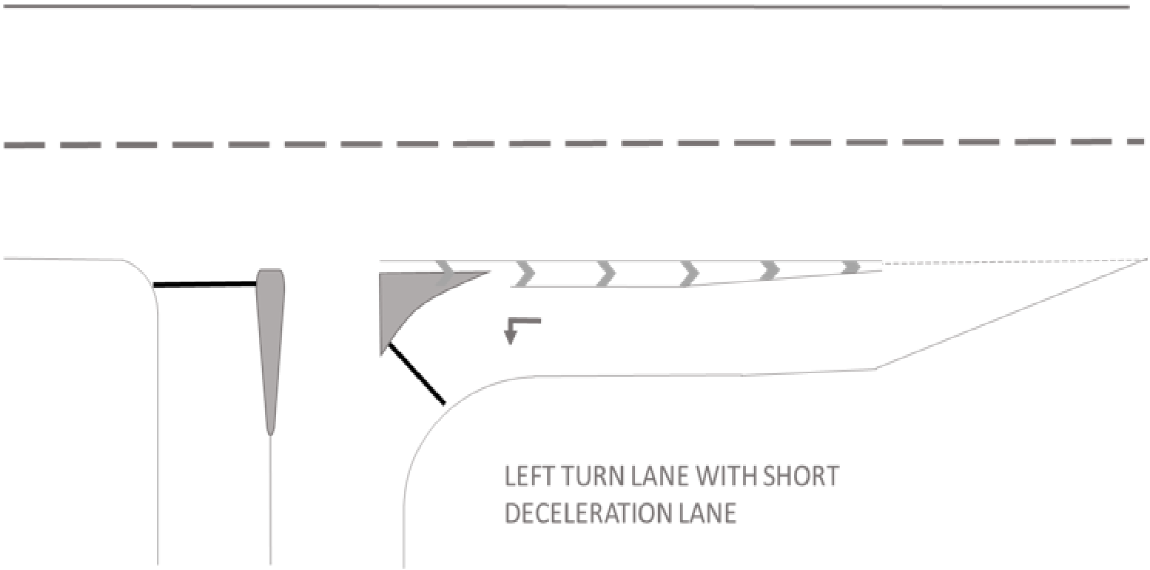


Figure 3.10 LTSL with short left-turn bay



The following figures show designs which are more common in rural or high-speed environments. Figure 3.11 (with a long deceleration lane design) improves visibility to through traffic by providing early separation of turning traffic from through traffic. A left-turn lane drop (as shown in figure 3.12) is a separate lane for left-turning traffic and it reduces the uncertainty of vehicles waiting on the side road as to whether the traffic is going straight through or turning left. However, in both cases the amount of set-back of the side road limit line is important.

Figure 3.11 LTSL with long left-turn bay

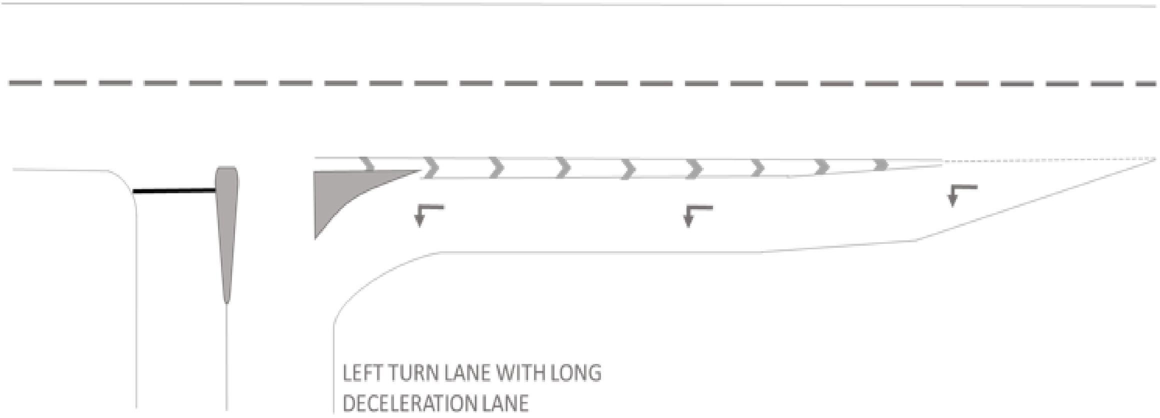


Figure 3.12 LTSL with lane drop

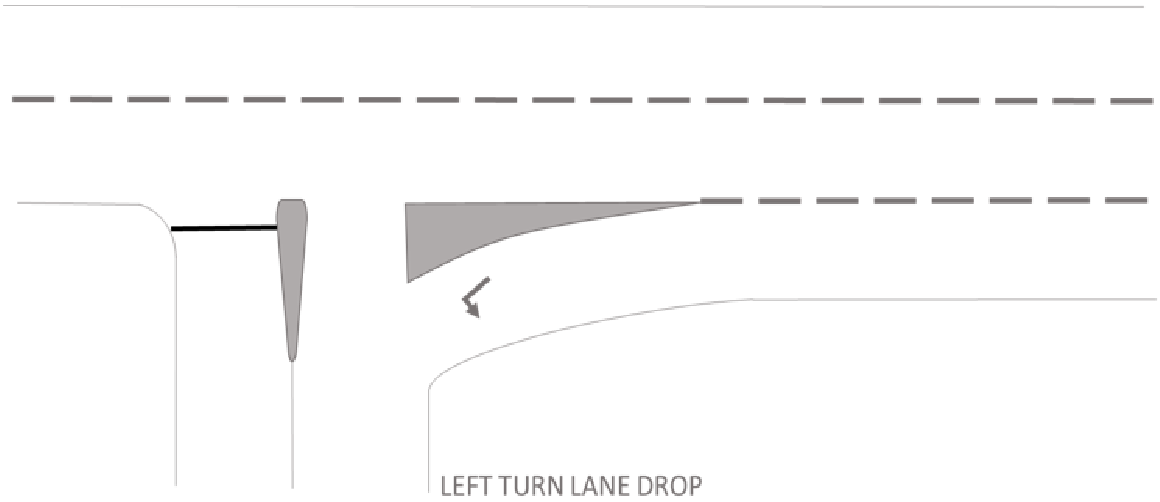


Figure 3.13 LTSL with flush median

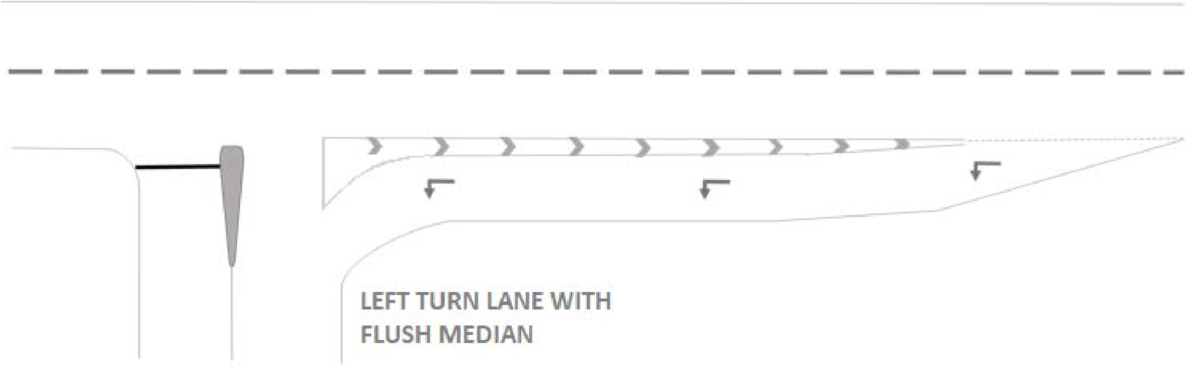


Figure 3.13 shows a LTSL with a flush median which clearly separates out the through traffic and turning traffic, and sets the latter back from the limit line on the side road. The set-back of the turning traffic from the traffic waiting on the side road is the thickness of the flush median. This is a good design for improving visibility of approaching through traffic on a main road for vehicles waiting on the side road.

4 Site identification, variables and data collection

4.1 Site selection process

Data has previously been collected for standard three-arm urban and rural priority T-intersections (Turner 2001; Turner and Roozenberg 2007). In both studies data was collected for more than 90 T-intersections. This data has been included in the current research, as it allows comparisons to be made between standard T-intersections and those with a LTSL and seagull intersection layout. Additional layout data was collected for the intersections in the two old datasets. Appendix B shows the number of intersections by location that were used in these two studies. Roundabout T-intersections were excluded from the study.

In this research the focus was on adding urban and rural priority seagull intersections and rural priority T-intersections with LTSLs to the previous datasets. About 50 sites were selected across both islands of New Zealand, in multiple cities and rural areas. Given it is a relatively rare intersection type, most of the seagull intersections for which turning volume data was already available, or could easily be collected nationally, were included in the dataset. Rural intersections with LTSLs were selected mainly in the Canterbury and Wellington regions. Turning traffic volumes and layout data was collected for all intersections. Table 4.1 shows the sample size of the number of urban and rural seagull intersections and priority T-intersections with a LTSL. Approximately 20 sites from each of the old urban and rural datasets were chosen to obtain traffic and crash data for 2010–2014, to allow comparisons to be made with the traffic and crash data collected for the new intersections. The total number of sites where 2012 volumes and 2010–2014 crashes have been used is given in appendix C**.**

Table 4.1 -Sample size of seagull intersections and T-intersections with LTSL sites

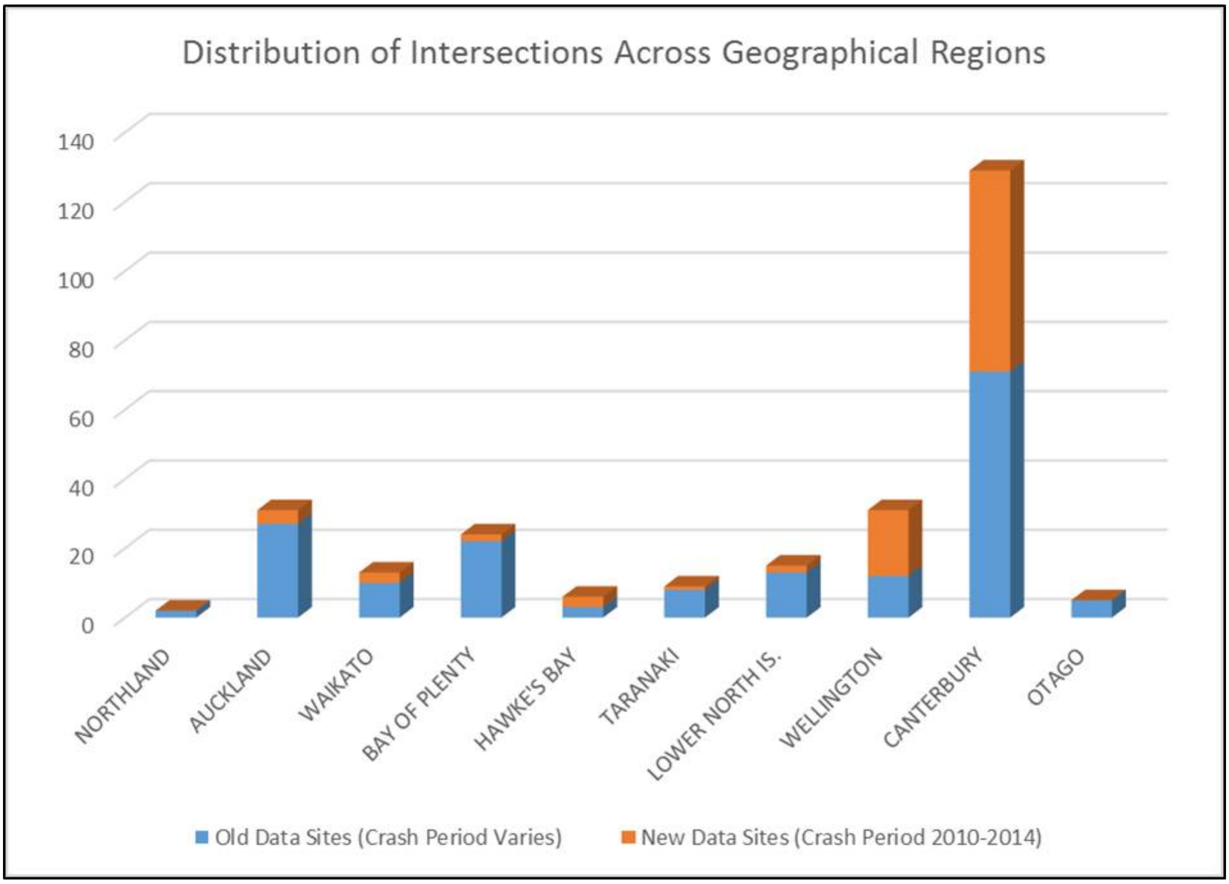
Intersection type	Urban	Rural
Seagull intersections	16	14
T-intersections with LTSL	4	34

Table 4.2 Distribution across ‘rural’ and ‘urban’ of the sampled intersection types

Intersection type	Urban	Rural	Total
T-intersection	92	93	185
T-intersection with LTSL	10	37	47
Seagull intersection	17	12	29
Total	119	142	261

As shown in figure 4.1 approximately half the sites are in the South Island (mainly in Canterbury and Christchurch City) and the other half are spread around a number of North Island cities (urban) and regions (rural). All urban and rural T-intersections and a proportion of urban and rural T-intersections with LTSLs are the ‘old’ sites from Turner (2001) and Turner and Roozenberg (2007).

Figure 4.1 Distribution of intersections across geographical regions



We note that the 261 intersections described are necessarily a convenience sample, a mix of previously sampled and more recently obtained sites. The data has been collected from all around New Zealand with many of the data sites being from the Canterbury region as the researchers involved were based in Canterbury. The effect of the Canterbury earthquakes and the change to the give way rules (on 25 March 2012) have been ignored, with all sites combined for analysis on a national basis. The 'lower North Island' region is made up of the data collected from regions such as Whanganui, Manawatu and Horowhenua.

The following results should be seen as descriptive of these intersections and not the entire set of intersections of the given types (T, T with LTSLs and seagull intersections) in New Zealand. No full sampling frame (listing all intersections of a given type) exists, necessitating the approach that has been taken.

4.2 Data collection and variables

4.2.1 Data collection process

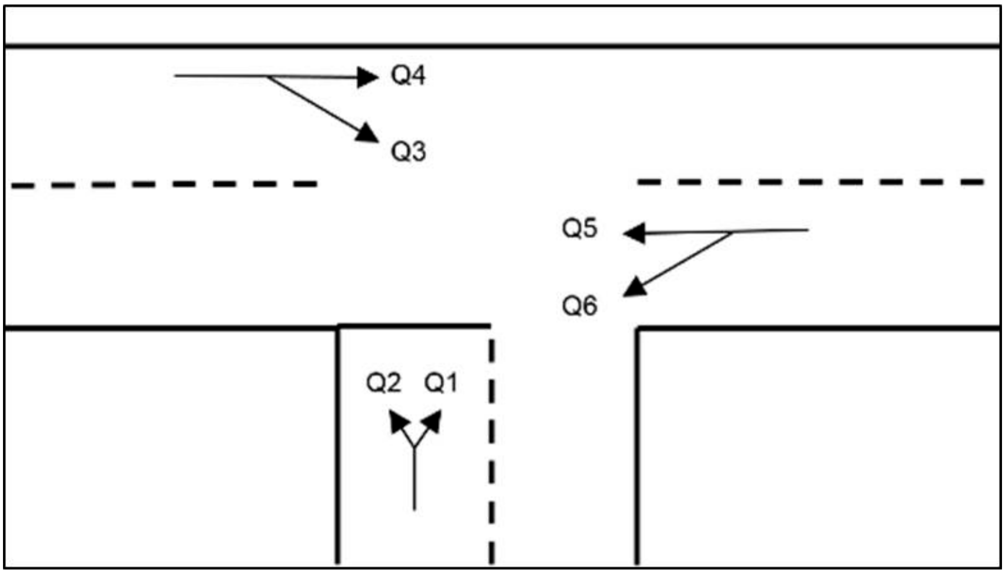
A database was set-up to store data for all 261 intersections. Where relevant, data from previous studies was extracted and imported into the database. Layout data was collected from Google maps and street-view. Data included 1) turning traffic volumes, 2) crash data, 3) speed limit (on through road) and 4) layout data. For standard T-intersections there were 25 variables. For intersections with LTSL this increased to 51 variables, while for seagull intersections 67 variables were entered into the database.

4.2.2 Traffic volumes, crashes and speed limits

For the new sites, typical daily turning traffic volumes (six turning counts per intersection – see figure 4.2), crash data by conflict type (eg LB and JA crashes) and speed limit was collected.

The turning counts (figure 4.2) were typically morning and evening peak periods (one hour each). The two hours of counts were averaged for each movement and then scaled up or down by a growth rate to get the annual average daily traffic (AADT) for year 2012 (middle year of crash record). The counts were then factored using a daily factor and monthly factor to incorporate daily and seasonal variations respectively. See appendix G for an example of how the traffic volumes were calculated for one of the sites.

Figure 4.2 Diagram showing six turning counts



Crash data was extracted from New Zealand Crash Analysis System (CAS). A 50m square 'radius' was applied to each intersection for extracting the crash data. This system includes all crashes reported by the Police. Only injury (minor and serious) and fatal crashes were included in the modelling. Non-injury or property damage only crashes were excluded due to highly variable reporting rates of this crash type across New Zealand. For approximately 20 sites from each of the rural and urban standard T-intersection datasets (from previous research), the crash data was collected for the same time period as the new intersections. A five-year crash period of 2010–2014 was used for each intersection.

The speed limit was extracted from the crash listings for each intersection. For intersections with zero crashes (only in old datasets) the speed limit was extracted from these datasets. If neither of these approaches produced speed limits then a Google Earth search was done to check the speed limit signs leading up to the intersection. Urban speed limits ranged from 50 km/h to 70 km/h, with the majority being 50 km/h. Rural speed limits ranged from 80 km/h to 100 km/h, with the majority of sites having a speed limit of 100km/h. There were some sites with 'rural' (high) speed limits within urban areas.

Previous research on rural intersections by Turner and Roozenburg (2007) shows that the actual approach speed on the main road was a better variable than the speed limit for the prediction model. Unlike on urban roads, the operating speed can be different from the speed limit because of the surrounding terrain and road alignment. In the models both operating speed and speed limit were modelled for rural roads, whereas only the latter was modelled for urban roads.

4.2.3 Intersection layout data

Data was collected on a large number of layout variables for each of the 261 intersections in the dataset. The layout data included the general geometry of the intersections (eg whether on curve or grade), the layout of lanes (width and length), the island/median types (solid, painted and hit posts) and sizes, the number of traffic lanes, and the distance and type of the nearest upstream and downstream features (eg another side road, parking, bus bay). A summary of the layout variables collected is listed in table 4.3 below, with the full set of variables collected listed in appendix D, along with diagrams in appendix E.

Table 4.3 Intersection layout variables

Category	Layout variables
General	Road category, intersection types and region
Right turn off main road	Right-turn bay, right-turn bay width, right-turn bay length and right-turn bay stacking
Main road media	Length and width
Near side	Number of lanes and shoulder width
Features	Near side upstream and downstream, far side upstream and downstream (refer to appendix D and E)
Far side	Number of lanes and shoulder width
Side road	Number of lanes, median island and median island width
Curvature of main road	No curvature, moderate or sharp
Gradient	Side road, main road left approach and main road right approach
Street furniture	Lighting, chevron sign, side road signs, main road speed limit sign and side road speed limit sign
Left-turn slip lane on main road	Type, profile, control and pedestrian crossing
Left-turn slip lane off main road	Type, profile, control, pedestrian crossing, offset distances from side road and main road
Splitter and median islands	Upstream splitter, upstream median, downstream splitter, downstream median
Acceleration lane	Type, length and width

5 Preliminary data analysis

This chapter starts with a discussion on the likely causes of crashes at urban and rural priority intersections with a LTSL and seagull layout. This discussion draws on the findings of the literature review, a workshop involving three designers/safety auditors and also the two steering group meetings. It then looks at the type of crashes that occur at priority T-intersections, with and without LTSLs and seagull layouts. It concludes with a preliminary analysis of the relationship between key crash predictor variables and crashes.

5.1 Crash causal factors

This section discusses some of the key crash causal factors that researchers and expert practitioners have identified at enhanced priority T-intersections. Enhanced intersections are those with auxiliary turning lanes and various levels of channelisation. In terms of auxiliary turning lanes there are right-turn bays and LTSLs (both into and out of the side road).

5.1.1 Enhanced priority controlled intersections

The literature review reveals that right-turn bays have a positive effect on road safety by reducing the likelihood of through vehicles rear-ending right-turn vehicles waiting to turn into the side road. The research by Turner and Roozenburg (2007) and Sullivan and Arndt (2014) shows the crash reduction for right-turn bays in terms of this crash type is high (between 75% and 90%). Some benefits can also be gained by using localised widening so that through vehicles can ‘undertake’ right-turning vehicles. Given the benefits, which seem to be achieved in almost all cases, this treatment type needed no further study.

Regarding the second type of auxiliary lane, LTSLs into and out of side roads, the main concern seems to be the LTSLs into the side road. The main reason for these treatments appears to be 1) to reduce rear-end crashes between left-turning and through vehicles and 2) to improve the capacity of the intersection. There is a relatively low number of crashes of this type and crash severity also tends to be low. The main concern with these LTSLs is that the left-turning vehicles may block the visibility of through vehicles for drivers turning right out of the side road, and cause the more severe JA crashes. Given this safety concern the research studied LTSLs.

In terms of channelisation there are a number of different layouts, but the most common one used to ‘improve safety’ in New Zealand and Australia has been the seagull treatment. In theory an improvement in safety is expected at these intersections due to drivers turning right on a busy through road being able to break their movement into two parts: 1) from side road to median and 2) from median, via an acceleration lane, into the second through-flow movement. This is considered less hazardous than turning right in one movement on both two-lane and four-lane roads. However the experience is that some seagull intersections have high crash rates and high crash severity.

What is not well understood about seagull intersections is whether the poor crash performance at some sites is influenced by the design or just a result of having high traffic volumes. Generally high-volume priority T-intersections are upgraded to signals, roundabouts or restricted to left in and left out (either due to physical barriers or due to traffic conditions where urban traffic is re-routed to other intersections). A seagull intersection is an alternative to these treatments, where full access is required but the sites are not suitable for traffic signals or roundabouts. When movements can be banned, often the right turn in or out is banned, to reduce the conflict points and improve safety.

Figure 5.1 **Seagull intersection with LTSL with give way sign, solid splitter islands and painted seagull island**

Figure 5.2 **Seagull intersection with LTSL, solid seagull island and solid splitter island**

Figure 5.3 **Seagull intersection with LTSL and give way sign, hit posts and painted seagull island**

5.1.2 Crash causal factors identified by safety experts

A workshop involving experienced safety auditors and designers was held to discuss the key causal factors that they believe, based on their experience, impact on the safety of intersections with seagull layouts and LTSLs. These findings were also discussed and then updated at the first steering group meeting. The concerns raised (in no particular order) include:

- **Visibility to the end of the merge.** If the merge lane is too long for traffic turning right from the side road then it can appear as a separate traffic lane further upstream of the intersection. If it is too short or on a curve then vehicles may be cautious about entering the through lane.
- **Length of the upstream splitter island.** By making the upstream splitter island longer, drivers waiting in the side road to turn right will be able to determine whether vehicles approaching from the left are in the bypass lane or are moving into the right-turn bay (and hence have priority). The main concern here is that the drivers are having to focus too much on the left and not enough on vehicles approaching from the right.
- **The seagull intersection island.** Drivers in the side road need to be able to identify that there is a seagull intersection island in front of them and hence a seagull layout intersection. If the seagull intersection island is painted, too low or over a crest in the road, motorists may not be able to judge that they can turn right without giving way to bypass traffic, causing driver frustration in vehicles behind them.
- **Main road curvature.** When intersections are located at a curve in the main road, there can be issues with reliably assessing which lane drivers are in. They may for example appear to be in the bypass lane but instead are coming into the right-turn bay. The same can occur in terms of judging if a vehicle is turning into a LTSL or going straight through.
- **Speed environment (speed limit and operating speed).** The speed of approaching vehicles can be difficult to judge when the speed limit is high. Higher speeds are also more likely to cause injury and fatal crashes than lower-speed intersections. High speed in combination with a poorly designed intersection or one on a curve or crest, can create black spots as these affect available sight distances.
- **Length of the acceleration lane**. Seagull intersections with a deficient taper can catch drivers out when they are merging with traffic. In addition merging from the right is a fairly uncommon movement as most merges are from the left (eg at most motorway on-ramps) and can confuse some drivers.
- **Presence of central medians and splitter islands**. In rural areas median and splitter islands can come as a surprise to drivers when they occur over only a short section of roadway. Some drivers can also become confused about how to negotiate the intersection islands when turning in and out of side roads. This distraction can be enough to take the focus off giving way to traffic. The research by Harper (2011) also indicates that drivers struggle with low angle (less than 70 degrees) right-turn bays in wide medians.
- **Double or single lane**. Having two rather than one lane for through traffic can impact on speeds and also increase the distance to the safety of the median or side road.
- **Available sight distance**. Sight distance is important if drivers are to avoid collision with vehicles they must give way to. The lack of readability of an intersection layout can lead to indecision and driver error. At seagull intersections and priority intersections with LTSLs, insufficient sight distance can be due to 1) the alignment and topography or 2) changing length of the left turn in queuing via a LTSL. The former indicates a design compromise or can be due to the growth of vegetation or placement of

man-made objects (like signs) in the sight lines. Dynamic queuing in a LTSL can temporarily restrict visibility of through traffic when turning right out of the side road.

- P**resence of a left turn off a main road slip lane (with or without a give way**). The design of the LTSL (and how many vehicles are turning left) will have an impact on how safe it is. At busy intersections drivers turning right from the side road may not see a through vehicle that is masked by the vehicles turning left. This can occur even if there is a parking bay or extra widening and through vehicles can overtake left-turning vehicles. In addition the LTSL may confuse vehicles turning right onto the main road. They may think someone is turning left when they are actually going straight through.

Where possible these factors have been considered in the modelling by the selection of various layout variables. A key issue with some of the factors is that they only occur at a small number of intersections and hence can be difficult to examine using the sample sizes available for crash prediction models. Safety auditing of new installations should address such issues.

5.2 Crash analysis

This section presents national and sample crash data graphs for urban and rural priority T-intersections. Some data is also provided comparing standard intersections with those with a LTSL and also seagull intersection layouts (note that sample sizes are fairly small for some of the datasets). The main focus is to identify the key crash types at these intersections and also how they may change based on design.

Figures 5.4 and 5.5 show the two vehicle crash types that might be expected at standard intersections with LTSLs and seagull layouts. These diagrams only show typical crash movements and do not show all crash movements that could occur. Many of the crash types are fairly uncommon and make up the 'other' category. Information on the 'other' category can be found in the crash codes in appendix F.

Figure 5.4 Typical T-intersections with LTSL crash types

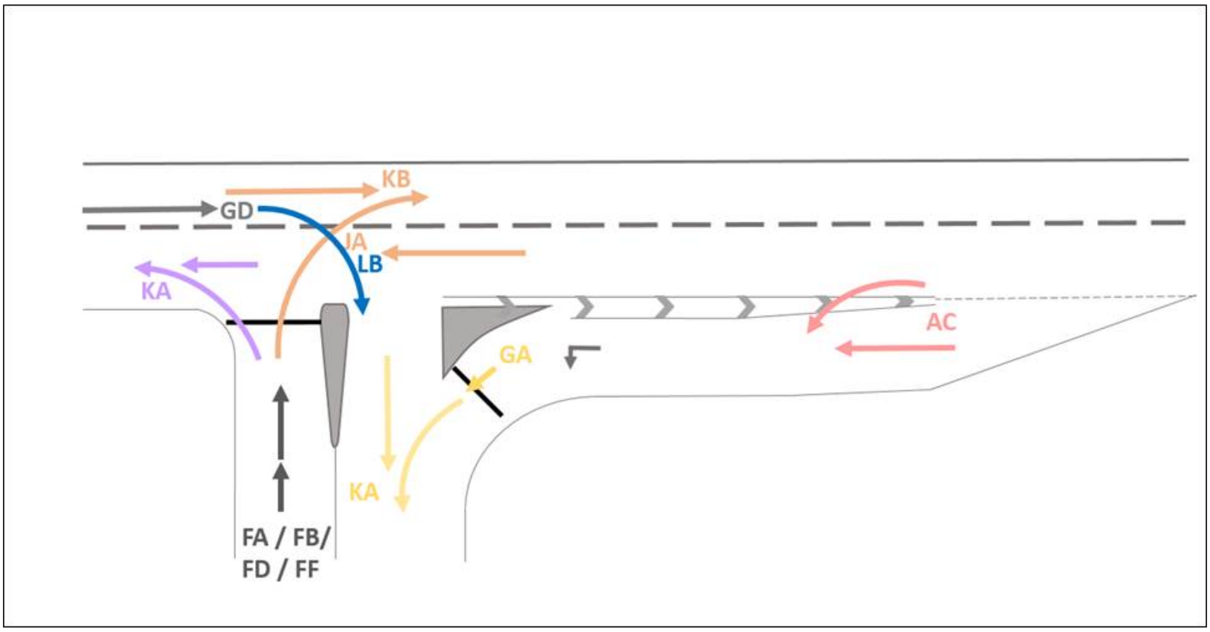
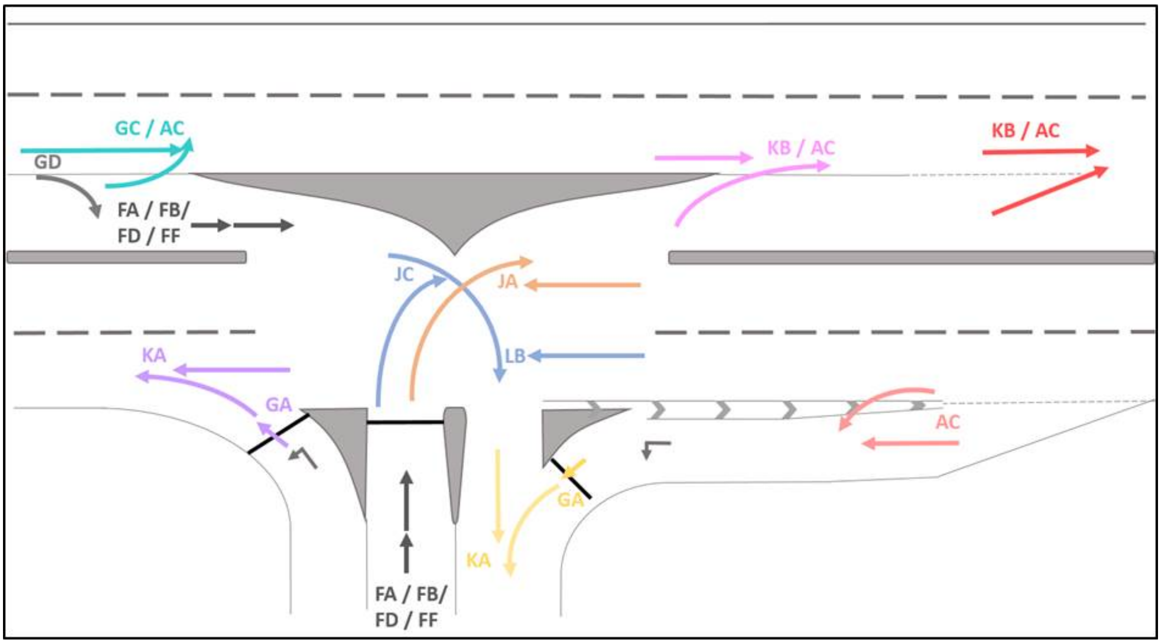


Figure 5.5 Seagull intersection injury crash types



5.2.1 National crash trends

This following graphs show the national crash data extracted from CAS for all crashes at urban and rural priority T-intersections in New Zealand for the period 2010–2014 inclusive. Refer to appendix F for code explanations. This data includes standard T-intersections, T-intersections with LTSLs and seagull intersections. The CAS extraction does not separate the priority T-intersections into ones that contain LTSLs and ones that are seagull intersections. Figures 5.6 and 5.7 show the level of crash severity, ie the number of fatal, serious injury, minor injury and non-injury crashes that have been reported. Figures 5.8 and 5.9 show the general trend in crash types observed in urban and rural areas.

Figure 5.6 National urban T-intersections

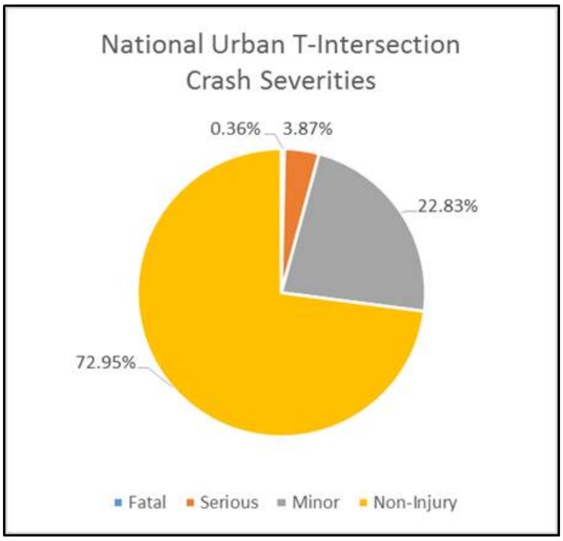
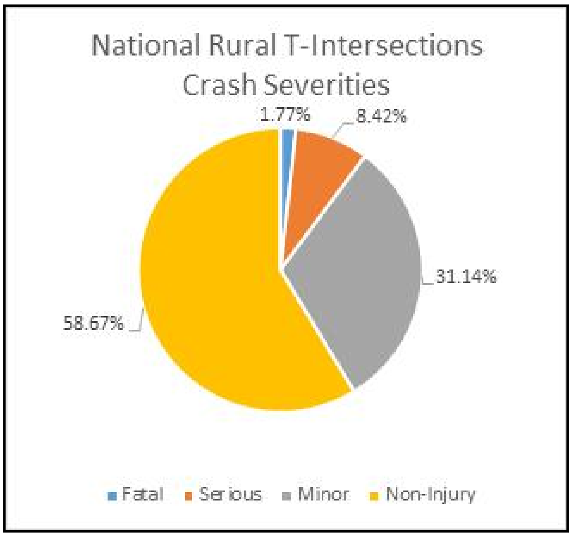


Figure 5.7 National rural T-intersections



It can be seen from figures 5.6 and 5.7 that rural intersections have a larger proportion of fatal and serious crashes than urban intersections. This is most likely due to the rural intersections being in a higher-speed environment than urban intersections. The crashes will be more severe and result in serious injuries and fatalities.

The two pie graphs in figures 5.8 and 5.9 show that LB and JA crashes are the most common at urban and rural T-intersections. Right-turn rear-end (where a through vehicle hits a waiting right-turning vehicle – a GD crash) is also fairly common at rural intersections. Right-turn bays are often used to reduce this crash risk. The graphs also show there are a large number (similar proportion) of other crash types occurring at urban and rural T-intersections.

Figure 5.8 National urban T-intersections crash types

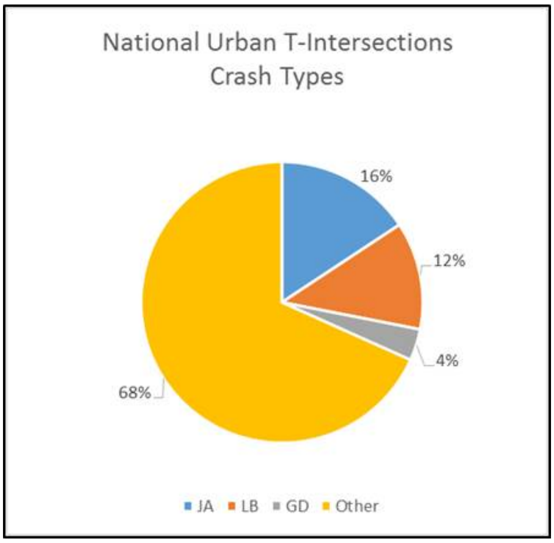
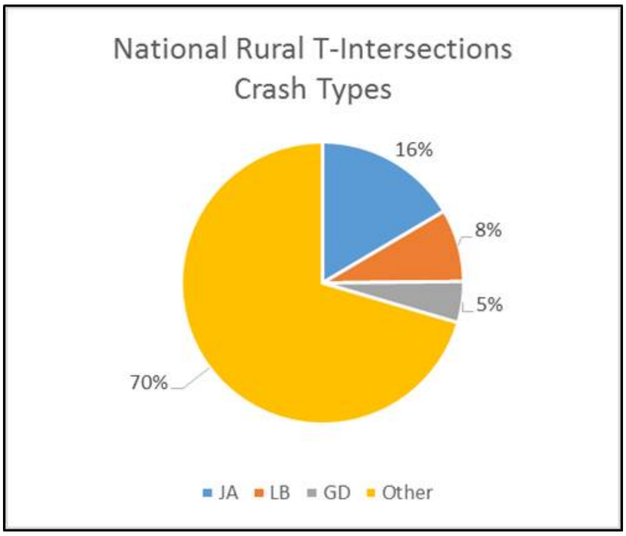


Figure 5.9 National rural T-intersections crash types



5.2.2 Sample rural T-intersections

Figure 5.10 shows the proportion of crashes by type at the standard T-intersections in the sample set. It is noticeable at these 93 intersections there are very few LB crashes. The number of JA crashes is fairly high at 28%, compared with 16% nationally. As for the national data there are more other crashes of many types compared with the sample data percentage of 59%.

Figure 5.10 Sample rural T-intersections

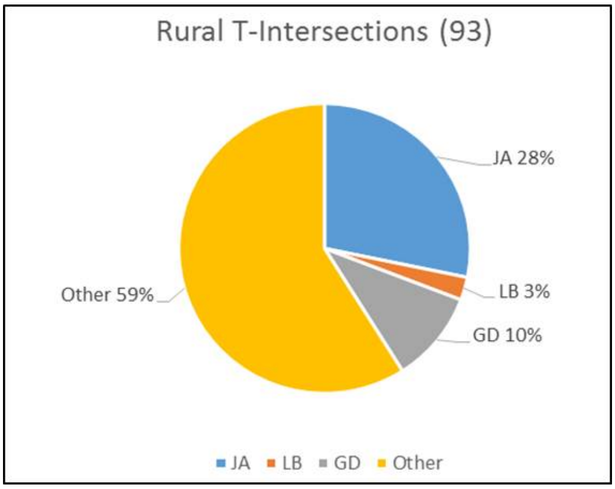


Figure 5.11 Sample rural T-intersections with LTSL

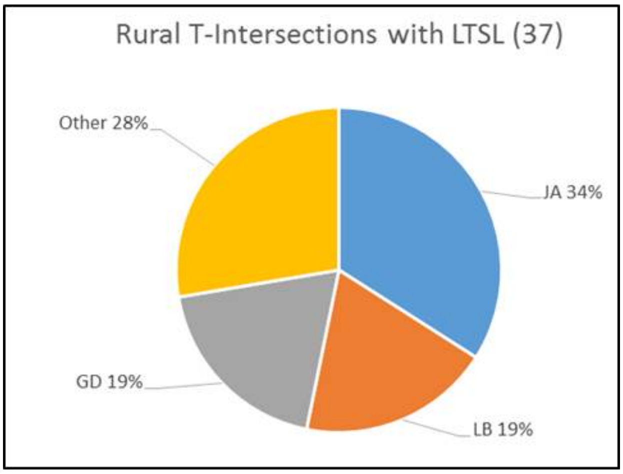
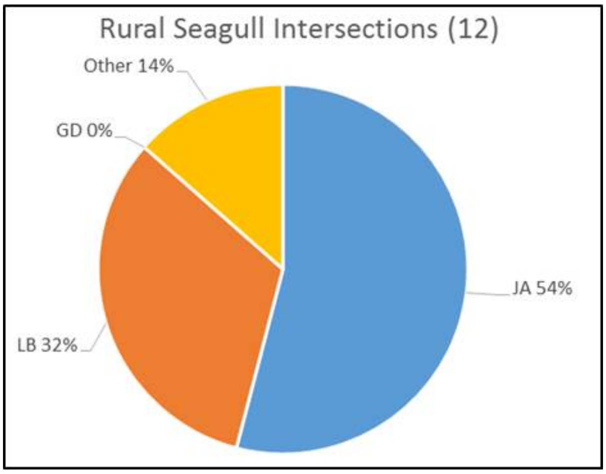


Figure 5.12 Sample rural seagull intersections

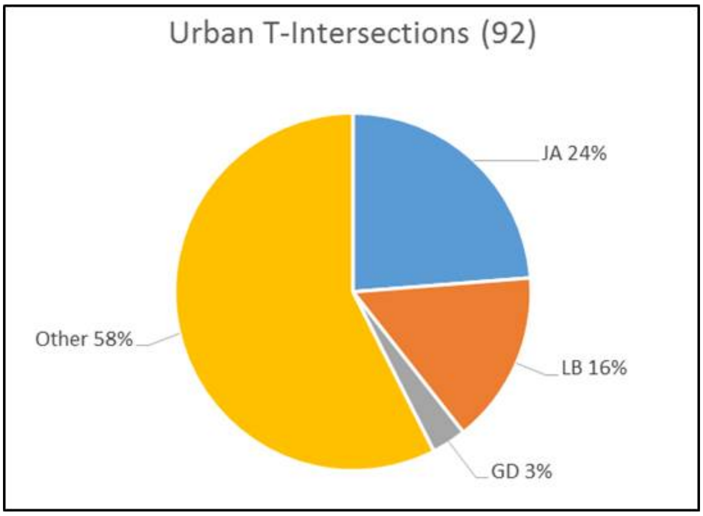


At the generally higher-volume intersections there is typically a higher proportion of JA and LB crashes, especially at seagull intersections. At lower-volume intersections there is a wider distribution of crash types. The increased percentage of side-on crashes is most likely due to reduced gap times available for turning vehicles to safely cross the through traffic.

5.2.3 Sample urban T-intersections

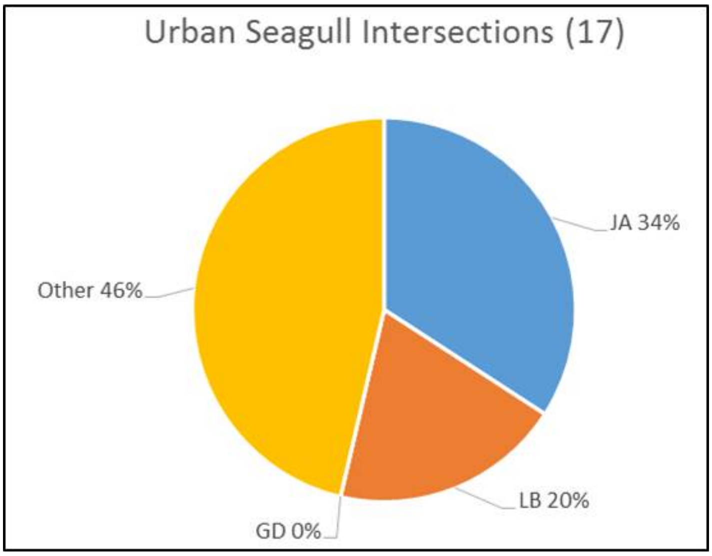
Figures 5.13 and 5.14 show the proportion of crashes by type at the standard urban T-intersections in the sample set. The percentage of other, JA and LB crashes is 58%, 24% and 16% respectively. The national data in comparison has 68% other crashes, 16% JA and 12% LB.

Figure 5.13 Sample urban T-intersection



Again the JA (and LB) crashes in the sample set are higher than the national data.

Figure 5.14 Sample urban seagull intersections



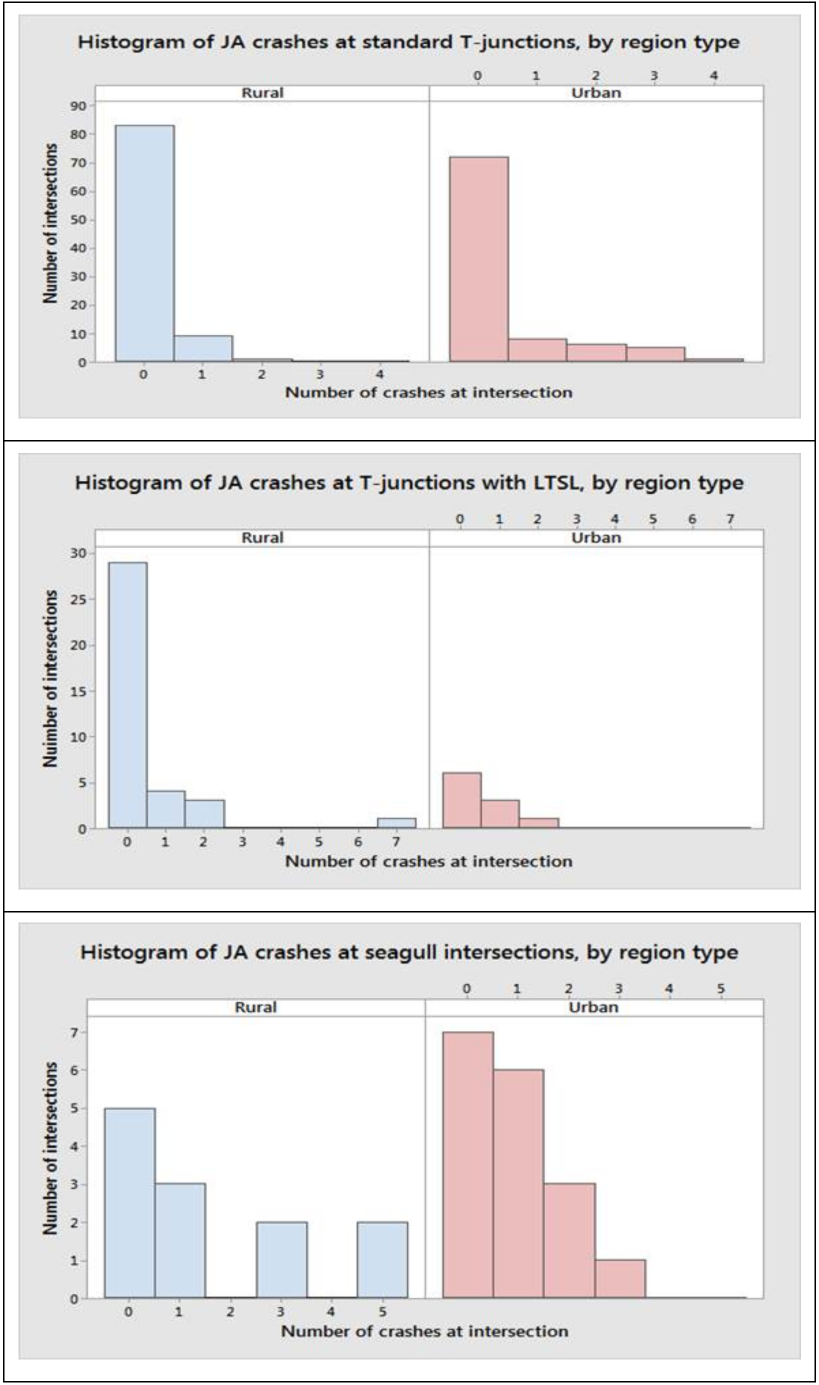
The proportion of JA and LB crashes is again greater for seagull layouts than for standard T-intersections, most likely because seagull intersection layouts are more common at higher volume intersections, where these crash types are more frequent. Compared with the rural situation there is still a high proportion of ‘other’ crashes (46% compared with 14% at rural seagull intersections)

5.2.4 Where the crashes are occurring – by intersection type

Figures 5.15 and 5.16 show the number of intersections that have zero, one and multiple JA and LB injury crashes by intersection type and region (environment type-rural or urban).

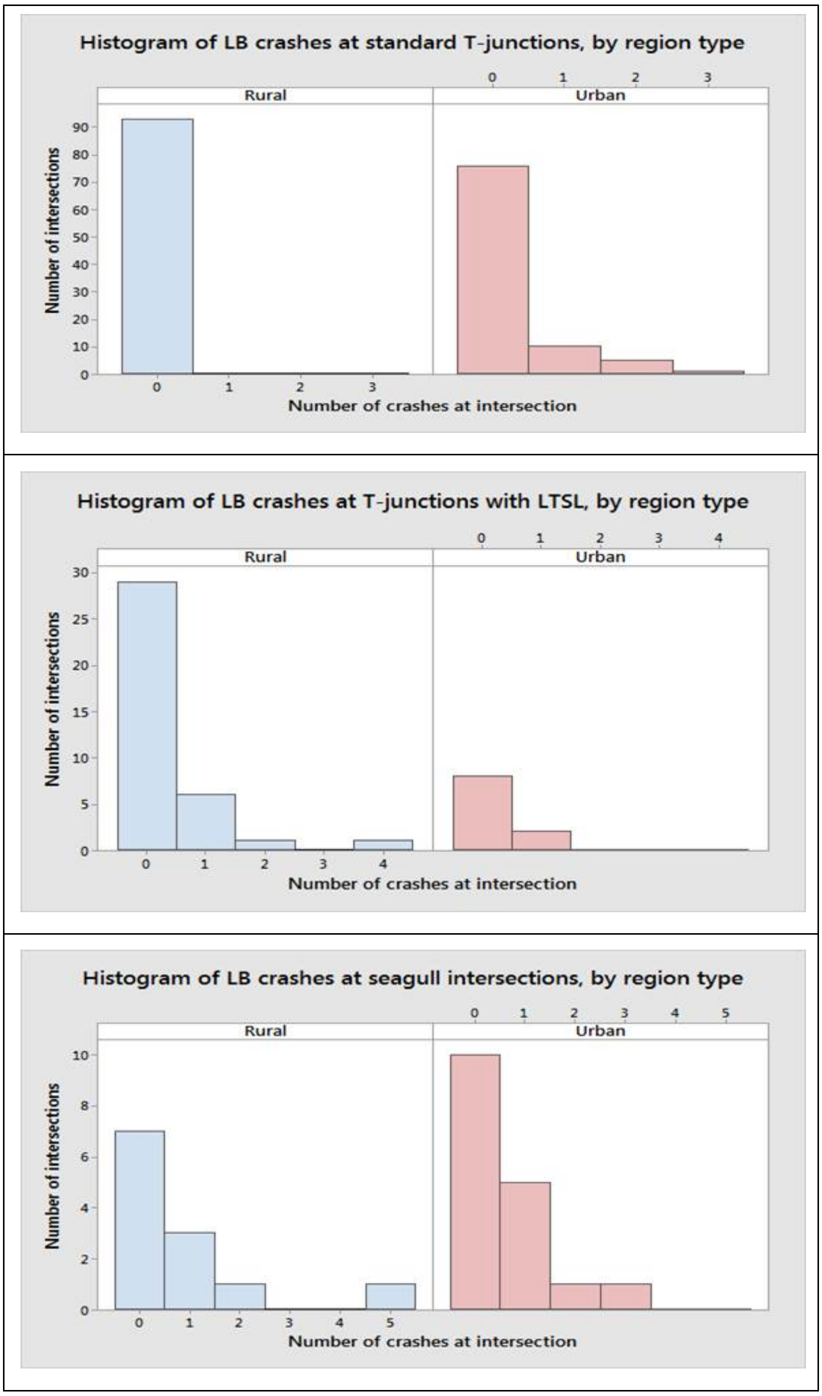
5.2.4.1 JA crashes

Figure 5.15 JA crashes at intersection types, by region (rural or urban)



5.2.4.2 LB crashes

Figure 5.16 LB crashes at intersection types, by region (rural or urban)



It is evident in figure 5.15 that multiple JA crashes are much more common at seagull intersections than at standard T-intersections. This is to be expected given the higher traffic volumes at such intersections. Figure 5.16 also shows that multiple LB crashes are more common at T-intersections with LTSLs and seagull intersections, particularly in rural regions.

5.3 Preliminary analysis of predictor variables

Figure 5.17 and the graphs in appendix I show the relationship between crashes and each of the key predictor variables. This preliminary analysis was carried out in order to help select the key variables to include in the crash prediction models. While this was undertaken for all 67 variables, only those with a strong relationship are shown here and in appendix I, with the remaining analysis variables located in appendix L. For each variable, the left-hand graph in each panel in appendix I summarises the distribution of the variable while the right-hand graph shows the relationship with fatal and serious crashes. The data points in the right-hand graphs are jittered (that is, moved slightly to show each point) where this is helpful. The contexts in which the variable enters the crash model design index are indicated (eg if the variable is a component of the design index for seagull intersections, urban, JA crashes then SUJA in red is listed). A list of the eight crash models produced follows (for the remaining four combinations there was insufficient data to produce a model fit).

Table 5.1 Crash models produced

TRJA	T-intersection, rural and JA crashes
TUJA	T-intersection, urban and JA crashes
TULB	T-intersection, urban and LB crashes
TLRJA	T-intersection, LTSL, rural and JA crashes
TLRLB	T-intersection, LTSL, rural and LB crashes
SRJA	Seagull intersection, rural, JA crashes
SRLB	Seagull intersection, rural, LB crashes
SUJA	Seagull intersection, urban and JA crashes

An explanation of the role of the design index is provided in chapter 6 of this report. Each graph shown is for all data; the relationship described in the '[ ]' annotation is only for the scenarios where the predictor is significant, so the relationship may sometimes not be evident in the overall scatterplot. The bracketed numbers before each variable description are the original numberings of the 63 variables.

Significant variables assessed in this section are grouped as follows:

1 Right-turn bay on main road

2 Main road, near-side lanes

3 Main road, far-side lanes

4 Side road (side road)

5 Curvature and gradient

6 Lighting and signage

7 Speed

8 LTSL

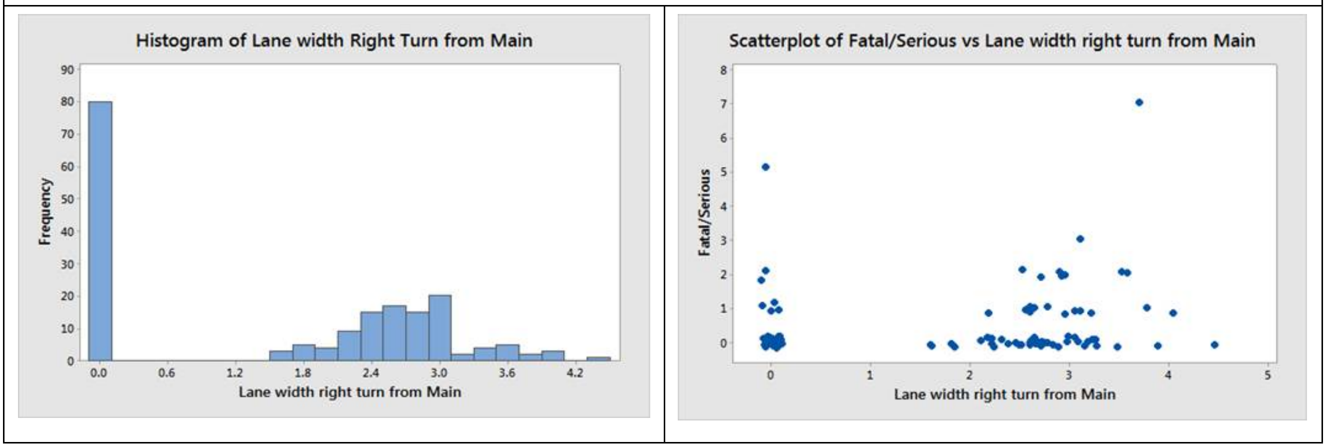
9 Islands.

The first variable in the first group (lane width, right turn from main road) is discussed in detail here. All other pairs of graphs, created according to this pattern, appear in appendix I.

5.3.1.1 Right-turn bay on a main road

Figure 5.17 Right-turn bay lane width

(2) Lane-width right turn from main road (m) – TLRLB, SUJA
(outlier at zero width is Whakatiki/SH2)
[The wider the lane, the less safe for both TLRLB and SUJA situations.]



Notes assisting the interpretation of these graphs:

- The first line of text above the graphs provides the bracketed number of the variable in the master list (see appendix D), the name of the variable and then (in red) the abbreviations of the fitted models in which this predictor variable appears in the design index (for a description of the design index, see appendix H).
- The left-hand graph is a histogram showing the distribution of lane widths of the right-turning lane from the main road. Here 80 intersections have no right-turning lane, so they are recorded as having zero width. The remainder range from widths of 1.6 m to 4.4 m, with modal width 3.0 m.
- The right-hand graph explores this distribution in more detail, showing the number of fatal or serious crashes (notated fatal/serious on the vertical axis) at the intersections with the given widths. This reveals that one intersection with no right-turn lane (Whakatiki/SH2) has five fatal and serious crashes. This data has been 'jittered' (very slightly moved both horizontally and vertically) in order to show each point.
- The comment in square brackets in the header summarises the relationship between expected number of crashes and the predictor variable, for each of the models in which this predictor variable occurs.
- The other predictor variables used are discussed in similar fashion in appendix I. Note, the name of the 'x' variable in the graphs is sometimes given in the graph title (for example, for variable (13) the horizontal 'x' scale is 'number of far-side through lanes').

6 Crash prediction modelling

6.1 Summary of models developed

Crash prediction models have been built for all combinations of region (rural and urban), intersection type (T-intersection, T-intersection with LTSLs and seagull intersections) and major crash type (JA and LB) for which adequate data is available. These cases are summarised in table 6.1.

Table 6.1 Crash summary models developed

T-intersection			T-intersection with LTSL			Seagull		
	JA	LB		JA	LB		JA	LB
Rural (93)	TRJA	X	Rural (37)	TLRJA	TLRLB	Rural (12)	SRJA	SRLB
Urban (92)	TUJA	TULB	Urban (10)	X	X	Urban (17)	SUJA	X

There were insufficient intersections or crashes for four of the combinations (those marked 'X'); in these cases models could not be fitted. The number of intersections in each row of each sub-table is shown (for example, there are 93 rural T-intersections). For each of the remaining eight datasets a design index was developed, built using the geometric variables found to influence the safety of the combination (see section 5.3). The key variables change from case to case. The design index runs from low values when the intersection is safe to high values when it is unsafe.

Crash counts for each combination were then related to the conflicting flows influencing the crash type, the main road speed limit and the design index, using standard generalised linear model methods (McCullagh and Nelder 1989) These eight models, listed in table 6.1, are presented in this section. For each case we list the model (with predictor or explanatory variables of flows, main road speed limit and design index), the formula for the design index and then show scatterplots of the crashes against each of the explanatory variables. The models express the crash rate as a product of powers of the flows, the speed limit and the design index. (The fitted model itself is not influenced by the order of entry of predictor variables.)

A summary tool was developed in Excel and is published separately as appendix J at www.nzta.govt.nz/resources/research/reports/644. This tool is described further in section 6.6. It allows the user to examine the effects on expected crash rate (a quantity often expressed more tersely as 'unsafety' in the remainder of this report) of flow, speed and design changes, for both single scenarios and comparisons of two scenarios.

6.2 Model variables – design index

Conflicting flows, raised to a power, are present in all models in the usual multiplicative way. Main road speed limit (MRSL) is also included where it significantly increases the explanatory power of the model. The other critical component in all models is an intersection design index. The research experimented with an 'expert' driven design index but found a data-driven one able to explain more. The data-driven design index captures the way aspects of the geometry of the intersection influence safety, using the specific data gathered about each intersection. This was developed for each intersection type/region/crash type case (eg seagull, urban, JA crashes). A partial model incorporating the conflicting flows and speed limit was fitted and the crash residuals examined – these are the variations in the crash rate not explained by the partial model. These residuals were plotted against all 63 intersection factors and those factors explaining some variation in the residual crash rate were noted. These were given equal weight and combined into a single design index. The variables used in at least one design index were shown graphically in chapter 5; the intersection type/region/crash type situation where they are used was shown in red, as noted earlier. For example, the factor ‘distance to far-side upstream feature’ is used in the design index for the models built in each of the three cases TRJA and TUJA and SUJA.

6.2.1 Akaiki information criterion (AIC)

This has been used to select the most appropriate model. It is defined as

$$AIC = 2k - 2\ln(L) \quad \text{(Equation 6.1)}$$

where k is the number of parameters to be estimated and L is the likelihood of the model fitted. It balances the number of parameters used against the likelihood of the model, using information theory.

The data-driven design index in all cases considerably improves the model, reducing the AIC, the goodness of fit criterion, where a lower figure indicates a better fit. The AIC measures the relative quality of models; the model with the lowest AIC might still not be of much value so therefore this can be used as a guide only for intersection improvement (see description in section 6.3).

6.3 Rural and urban crash prediction models by intersection type and crash type

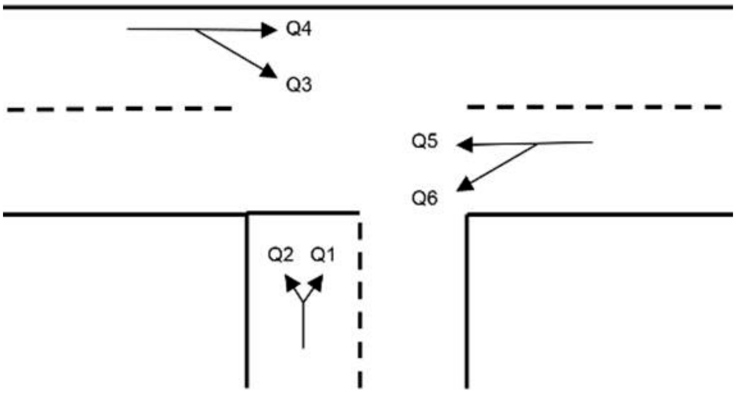
This section presents the eight crash prediction models that were developed as part of the NZ Transport Agency’s (2016) *Crash estimation compendium*. The models are described, together with the makeup of their separate design indices. In all fitted models, Y is the expected total number of reported injury and fatal crashes, of the given type, over a five-year period. The number of each predictor variable used in the design index is listed in brackets after the brief text description of the variable. A description of the design index can be found in appendix H.

Scatterplots of crashes against each of the variables (conflicting flows, speed limit and the design index) in the model are then presented, using log transformed values of the variables. The log transformation is used for ease of ‘eyeing’ the relationship – for an increasing relationship in the model, the points will follow an upward straight line while for a decreasing relationship in the model, the points will follow a downward straight line. In most graphs, log transformed crashes follow an increasing straight line. For example, for the first model, for context TRJA, log transformed crashes are seen to increase with the logarithms of Q1 and Q5, as expected. Transformed crashes also increase with increasing log transformed main road approach speed (MRAS) and the design index. Coefficients in the models have been rounded appropriately.

The most common crashes at T-intersections are type JA and LB, and only these are modelled. We caution that the effect on other crash types of intersection changes made to reduce JA and LB crashes (based on the models) has not been investigated.

Goodness of fit (the acceptable accuracy of the representation or ‘validity’) of the models is discussed in section 6.4.

Figure 6.1 Diagram showing six turning counts



As shown in figure 6.1, Q1 is the right-turn-out of the side road flow and Q5 is the through traffic flow from right to left. Q3 is the right-turn-out from the main road flow. Q1 and Q5 are the conflicting flow movements for JA crashes. Q3 and Q5 are the conflicting flow movements for LB crashes. All crashes (Y) are fatal and serious for a five-year period and flows (Q) are in vehicles/day AADT for the middle year of the five-year period.

6.3.1 T-intersections, rural, JA crashes (TRJA)

The revised fitted model is

$$Y(T\text{-}intersection, rural, JA) = exp(-30.37)*Q1^{0.51}Q5^{0.27}\ MRAS^{3.97}\ TRJADI^{1.58}$$

where the design index is

$$TRJADI = ((6-2*V1)/0.029+(2*V2-3)/0.011+5*V3/7/0.032+(4-2*V4)/0.05+(3+V5)/0.022$$
$$+(17/3-4*V6/300)/0.087)/6$$

with

V1: Right-turn bay (1)
V2: Lane width right turn from main road (2)
V3: Right-turn bay stacking (4)
V4: Main road median width (6)
V5: Near-side upstream feature (11)
V6: Right approach visibility two metres from limit line (65)

Scatterplots of ln(JA+1) crashes against the four predictors (flows, approach speed and design index) follow.

Figure 6.2 ln (JA+1) vs ln (Q1)

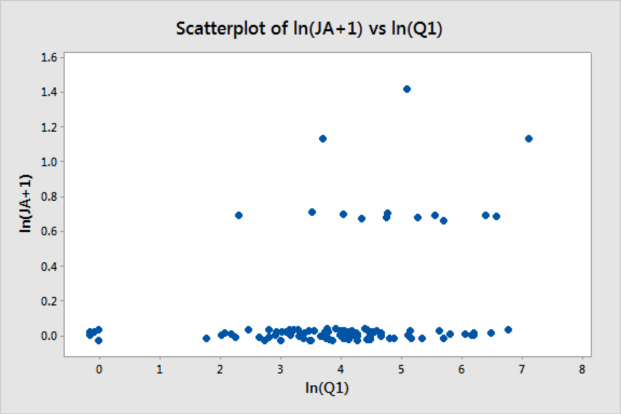


Figure 6.3 ln (JA+1) vs ln (Q5)

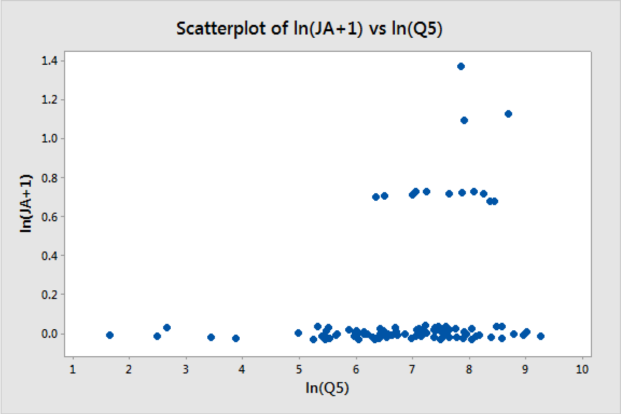


Figure 6.4 ln (JA+1) vs ln (MRAS)

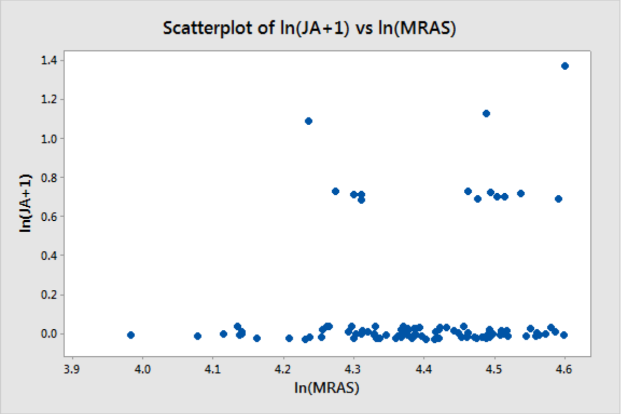
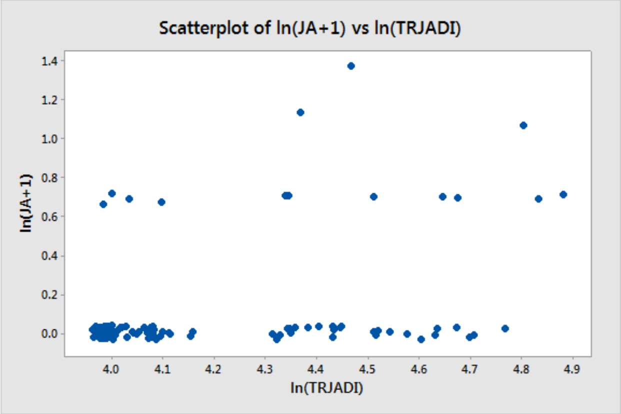


Figure 6.5 ln (JA+1) vs ln (TRJADI)



6.3.2 T-intersections, urban, JA crashes (TUJA)

The fitted model is:

$$Y(T\text{-}intersection,\ urban,\ JA) = \exp(-38.47)Q1^{0.025}Q5^{0.13}MRSL^{3.8}TUJADI^{5.8}$$

where the design index is

$$TUJADI = (V1/30/0.038+(6-V2)/0.154+2V3/0.112+(19-4V4)/3/0.222+(7-2V5)/0.033 +(4V6+1)/5/0.142+(2V7-1)/0.130+(6-V8)/0.054+(19-4V9)/3/0.218+(19-4V10)/3/0.155)/10$$

with

V1: Right-turn bay taper length (3)
V2: Main road median width (6)
V3: Near side number of through lanes (7)
V4: Distance of far side upstream feature (16)
V5: Side road number of lanes (19)
V6: Side road median width (revised) (21)
V7: Gradient of main road, right side (25)
V8: Upstream median island – type (49)
V9: Width of acceleration lane (63)
V10: Car parking (66)

Scatterplots of ln(JA+1) crashes against the four predictors (flows, speed and design index) follow.

Figure 6.6 **ln (JA+1) vs ln (Q1)**

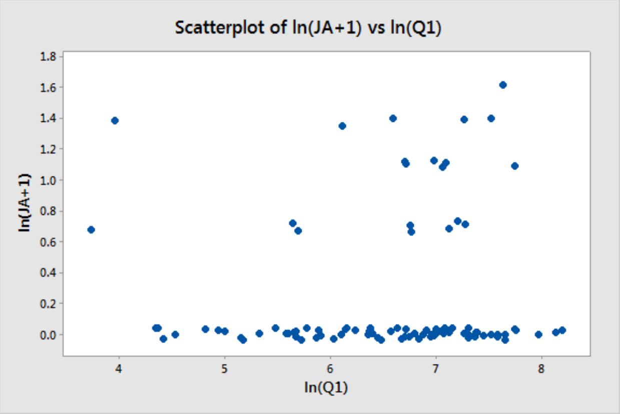


Figure 6.7 **ln (JA+1) vs ln (Q5)**

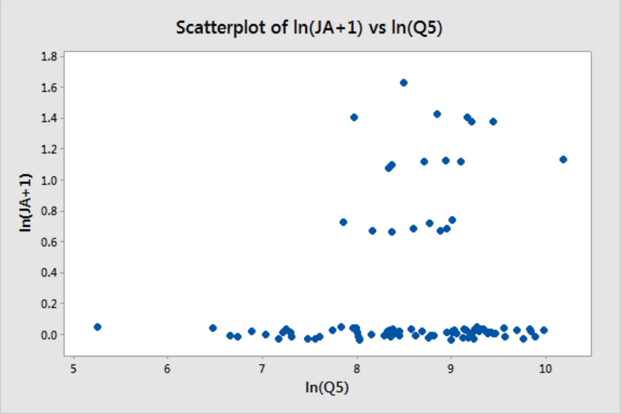


Figure 6.8 **ln (JA+1) vs ln (MRSL)**

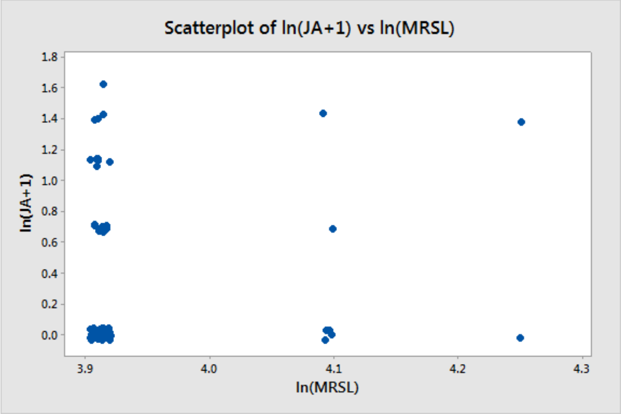
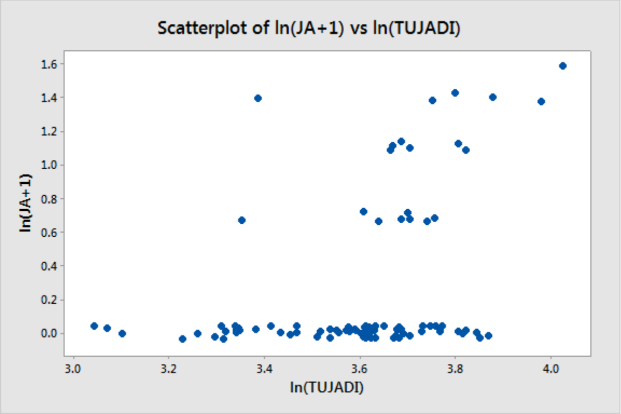


Figure 6.9 **ln (JA+1) vs ln (TUJADI)**



6.3.3 T-intersections, urban, LB crashes (TULB)

The fitted model is

$$Y(T\text{-}intersection, urban, LB) = exp(1.21)*Q3^{0.40}\ Q5^{0.21} MRSL^{-4.53}\ TULBDI^{3.07}$$

where the design index is

$$TULBDI = ((4*V1+1)/5+2*V2+(19-4*V3)/3+2*V4+(6-V5))/5$$

with

$$TULBDI = ((4V1-1)/3/0.158+2(3-V2)/0.167+V3/0.063+(4V4-1)/3/0.156$$
$$+2V5/0.081+(4V6-1)/3/0.037+V7/0.117+V8/5/0.228)/8$$

with

V1= Distance of near side upstream feature (12)
V2= Side road median island (20)
V3= Side road median width (recoded) (21)
V4= Street lighting (26)
V5= Top of T chevron board (28)
V6= Upstream median island width (51)
V7= Wider distraction (64)
V8= Total main road width (W2) (67)

Scatterplots of ln(LB+1) crashes against the four predictors (flows, speed and design index) follow.

Figure 6.10 ln(LB + 1) vs ln(Q3)

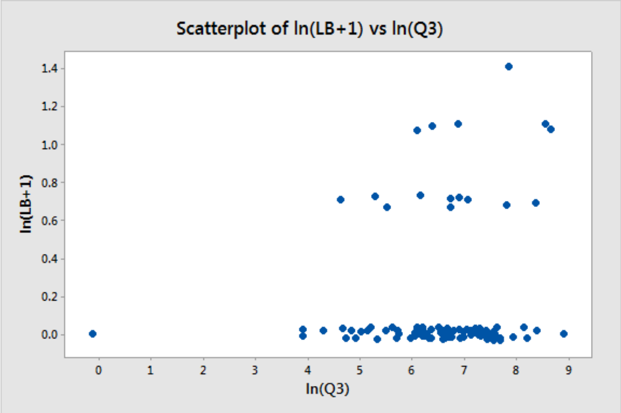


Figure 6.11 ln(LB+1) vs ln(Q5)

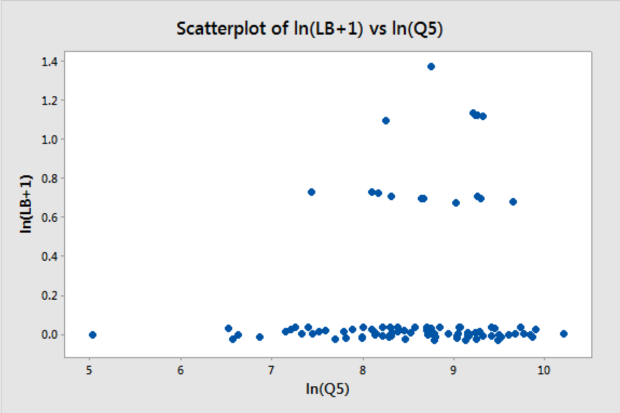


Figure 6.12 ln(LB+1 vs ln(MRSL)

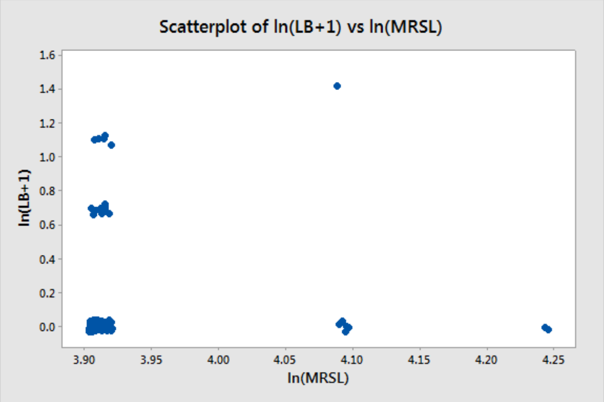
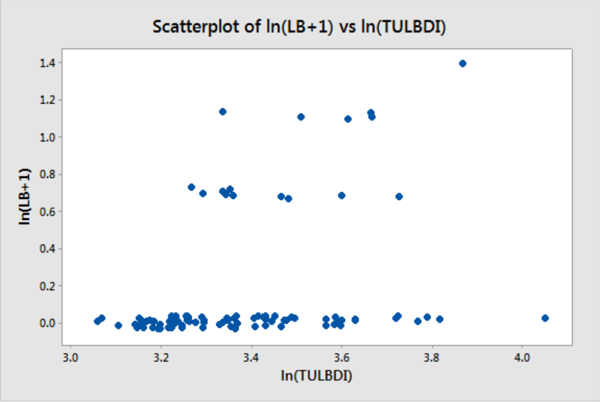


Figure 6.13 ln(LB+1) vs ln(TULBDI)



6.3.4 T-intersections with LTSL, rural, JA crashes (TLRJA)

The fitted model is

$$Y(T\text{-}intersection+LTSL,\ rural,\ JA) = \exp(-26.13)*Q1^{0.92}Q5^{0.42}MRSL^{2.24}TLRJADI^{5.26}$$

where the design index is

$$TLRJADI = ((11-V1)/2+(5-V2/10)+(5-V3)+(6-V4)-10)/2$$

with

- V1: Right-turn bay stacking (4)
- V2: Length from limit line (41)
- V3: LTSL off main road control (43)
- V4: Downstream median island type (58)

Scatterplots of JA crashes against the four predictors (flows, speed, and design index) follow.

Figure 6.14 ln(JA + 1) vs ln(Q1)

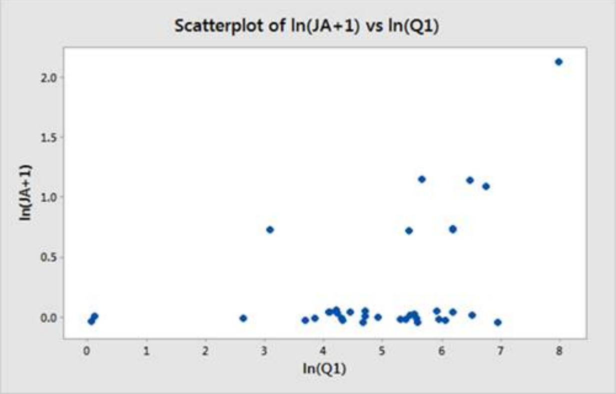


Figure 6.15 ln(JA+1) vs ln(Q5)

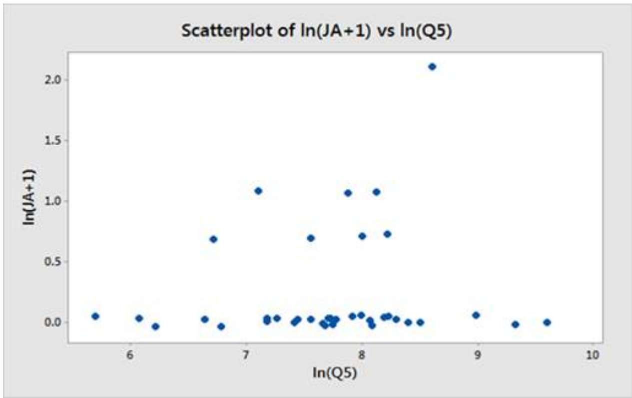


Figure 6.16 ln(JA+1) vs ln(MRSL)

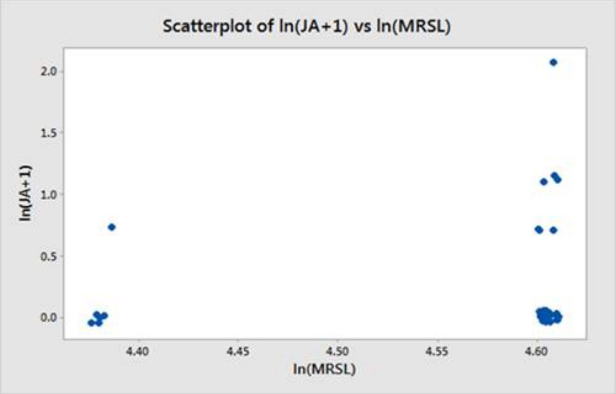
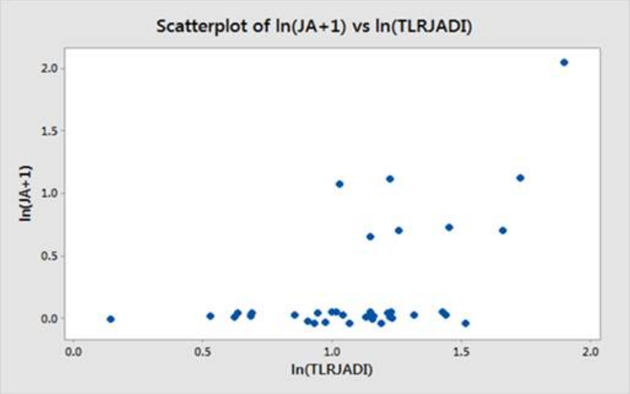


Figure 6.17 ln(JA+1) vs ln(TLRJADI)



6.3.5 T-intersections with LTSL, rural, LB crashes (TLRLB)

The fitted model is

$$Y(T\text{-}intersection+LTSL,\ rural,\ LB) = exp(-21.17)*Q3^{-0.034}\,Q5^{0.35}MRSL^{2.36}TLRLBDI^{4.77}$$

where the design index is

$$TLRLBDI = (V1+(5-V2)+V3+2*V4+2*V5-8)/2$$

with

- V1: Lane width right turn from main road (2)
- V2: Side road, number of lanes (19)
- V3: Side road median width (21)
- V4: Top of T chevron board (28)
- V5: LTSL off of main road angle type (37)

Scatterplots of LB crashes against the four predictors (flows, speed and design index) follow.

Figure 6.18 ln(LB+1) vs ln(Q3)

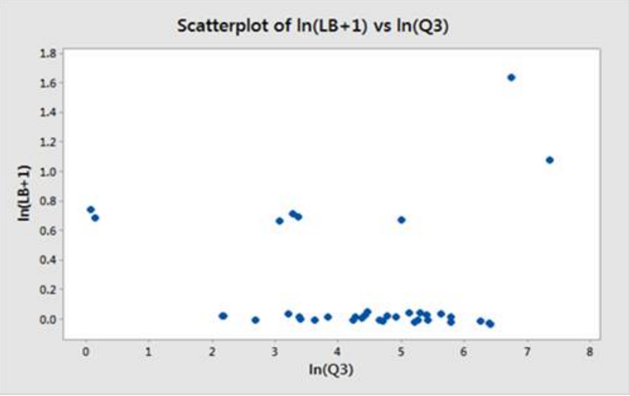


Figure 6.19 ln(LB+1) vs ln(Q5)

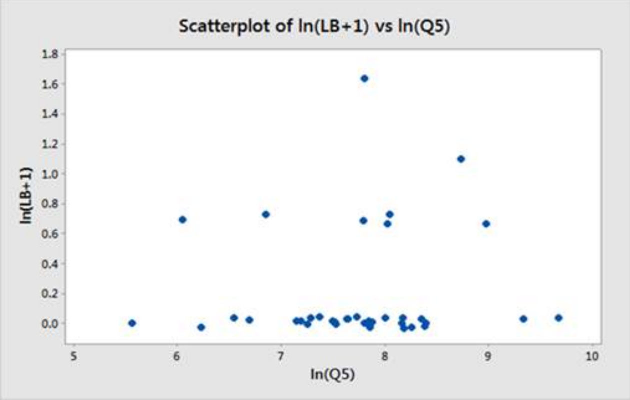


Figure 6.20 ln(LB+1) vs ln(MRSL)

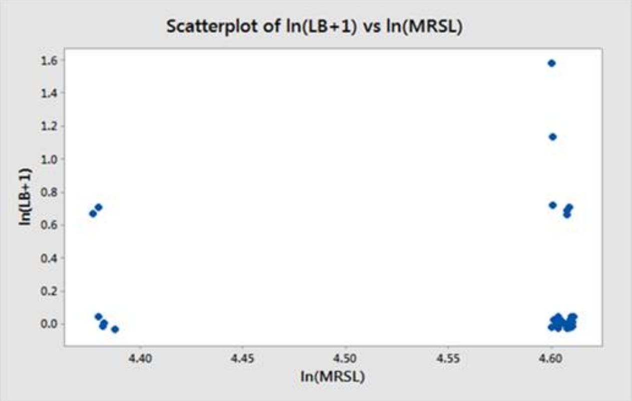
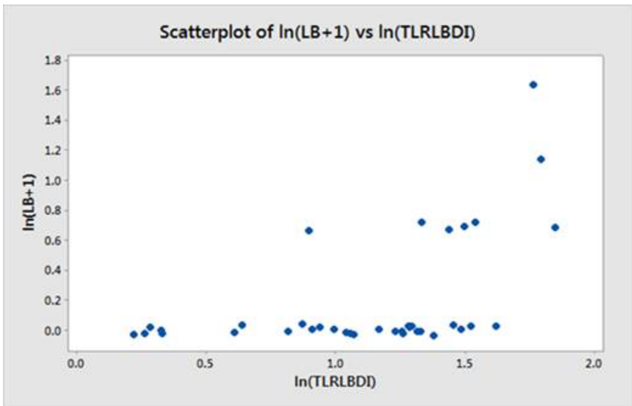


Figure 6.21 ln(LB+1) vs ln(TLRLBDI)



6.3.6 Seagull intersections, rural, JA crashes (SRJA)

The fitted model is

$$Y(seagull, rural, JA) = exp(-21.00)*Q1^{1.11}\, Q5^{0.23} MRSL^{1.85}\, SRJADI^{2.81}$$

where the design index is

$$SRJADI = (V1+2*V2+2*V3+V4+(5-V5)+(6+2*V6)+V7-15)/3$$

with

V1: Main road median width (6)
V2: Near side, number of lanes (7)
V3: Far side, number of lanes (13)
V4: Side road sign (27)
V5: Width LTSL off main road flush median (42)
V6: LTSL off main road offset from limit line of side road (44)
V7: Downstream median island type (58)

Scatterplots of JA crashes against the four predictors (flows, speed, and design index) follow.

Figure 6.22 ln(JA+1) vs ln(Q1)

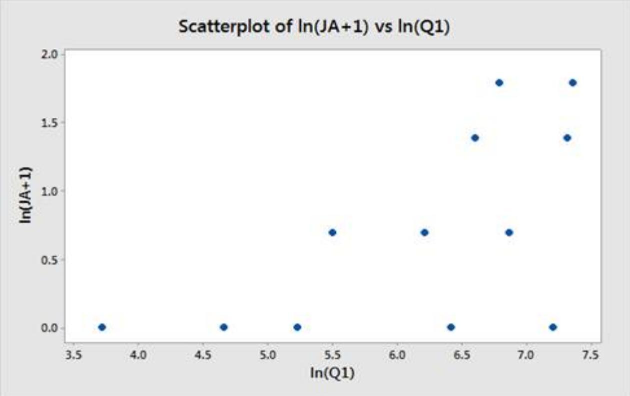


Figure 6.23 ln(JA+1) vs ln(Q5)

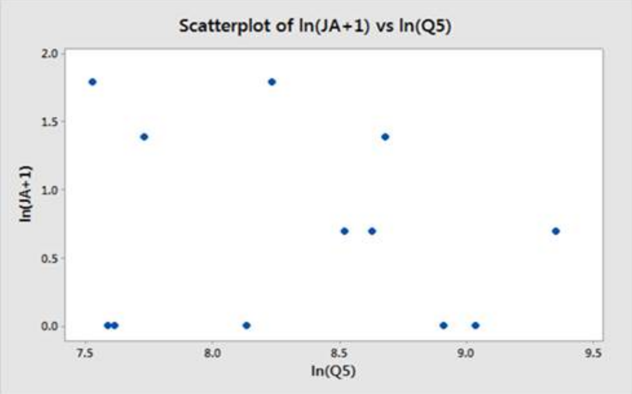


Figure 6.24 ln(JA+1) vs ln(MRSL)

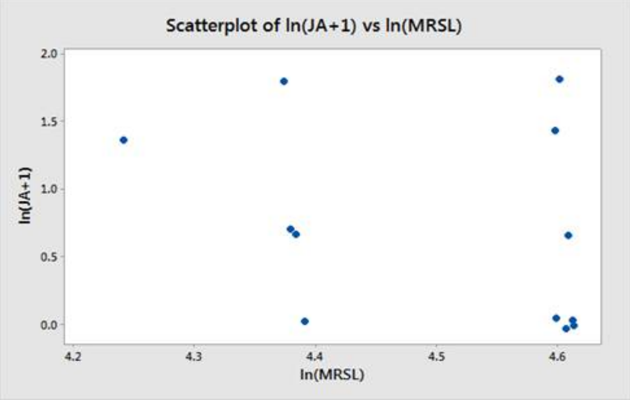
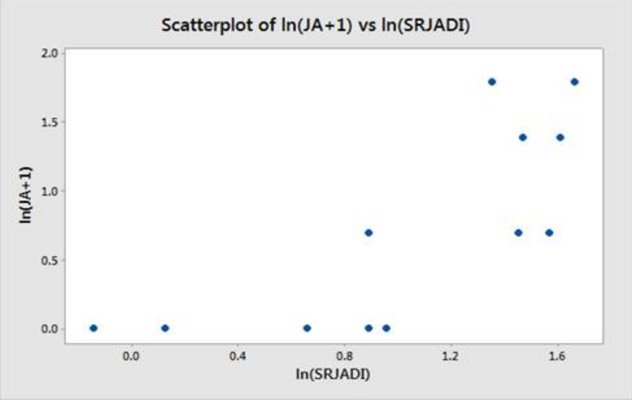


Figure 6.25 ln(JA+1) vs ln(SRJADI)



6.3.7 Seagull intersections, rural, LB crashes (SRLB)

The fitted model is

$$Y(seagull,\ rural,\ LB) = exp(-8.50)*Q3^{1.0}\ SRLBDI^{1.46}$$

where the design index is

$$SRLBDI = (V1/5+V2+2*V3+2*V4+2*V5+2*V6-1)/3$$

with

V1: Right-turn bay stacking (4)
V2: Main road median width (6)
V3: Near side, number of lanes (7)
V4: Far side, number of lanes (13)
V5: LTSL off main road – profile (38)
V6: LTSL off main road offset from limit line of side road (44)

Scatterplots of LB crashes against the four predictors (flows, speed and design index) follow.

Figure 6.26 ln(LB+1) vs ln(Q3)

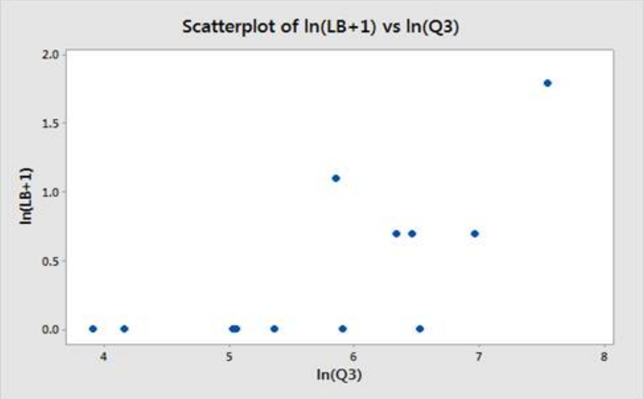


Figure 6.27 ln(LB+1) vs ln(Q5)

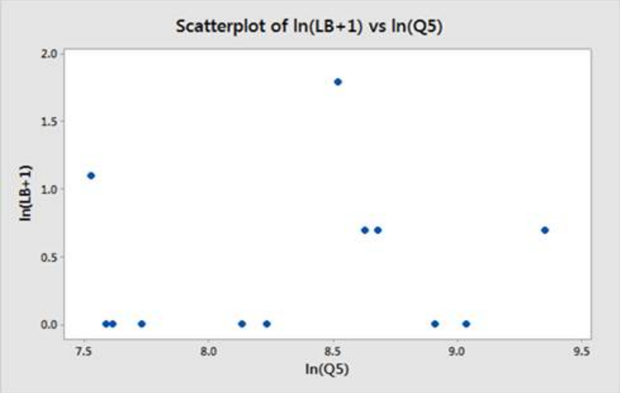


Figure 6.28 ln(LB+1) vs ln(MRSL)

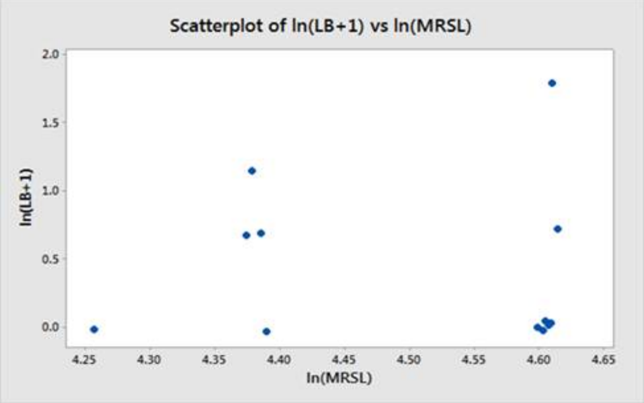
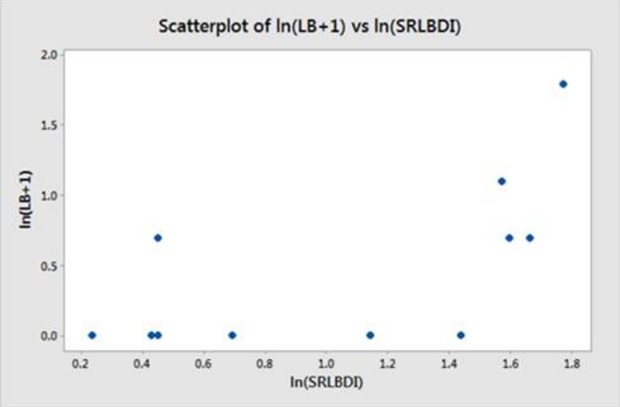


Figure 6.29 ln(LB+1) vs ln(SRLBDI)



6.3.8 Seagull intersections, urban, JA crashes (SUJA)

The fitted model is

$$Y(seagull,\ urban,\ JA) = exp(-13.42)Q1^{1.04}Q5^{0.25}SUJADI^{3.58.}$$

where the design index is

$$SUJADI=(V1+(4*V2-1)/3+(2*V3-1)+V4+(6-2*V5)+(2*V6)+V7+V8/5+V9/10)/9$$

- V1: Lane width right turn from main road (2)
- V2: Main road median width (6)
- V3: Near-side shoulder width (8)
- V4: Distance to far-side upstream feature (16)
- V5: LTSL into main road (31)
- V6: LTSL into main road angle type (32)
- V7: Upstream median island type (46)
- V8: Seagull splitter island length (53)
- V9: Length of acceleration lane (62)

Note the very different exponent of the Q1 flow in this model, compared with T-intersections; seagull intersections become less safe more rapidly with increasing Q1 compared with T-intersections. Scatterplots of JA crashes against the three predictors (flows and design index) follow. MRSL is not significant enough to be required in this model. The AIC with MRSL increased above the model presented.

Figure 6.30 ln(JA + 1) vs ln(Q1)

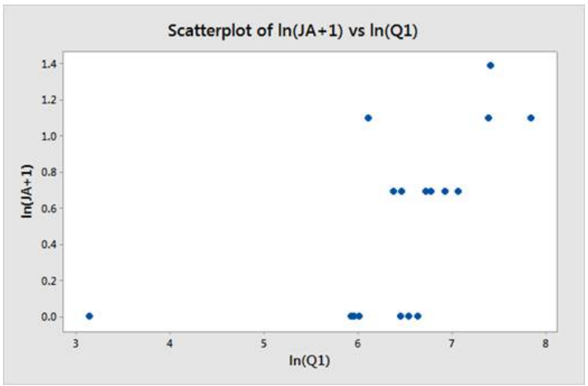


Figure 6.31 ln(JA+1) vs ln(Q5)

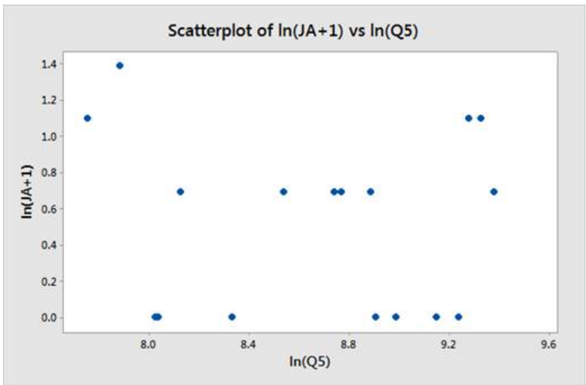
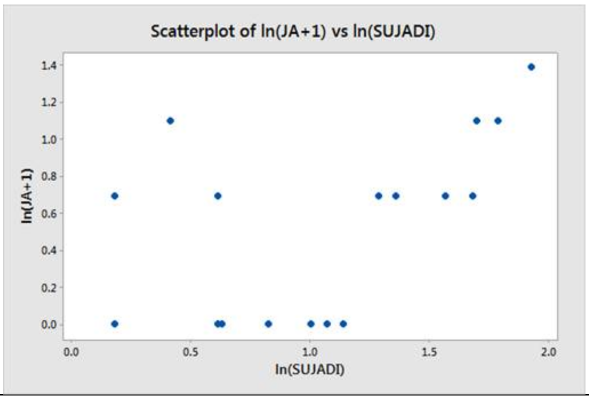
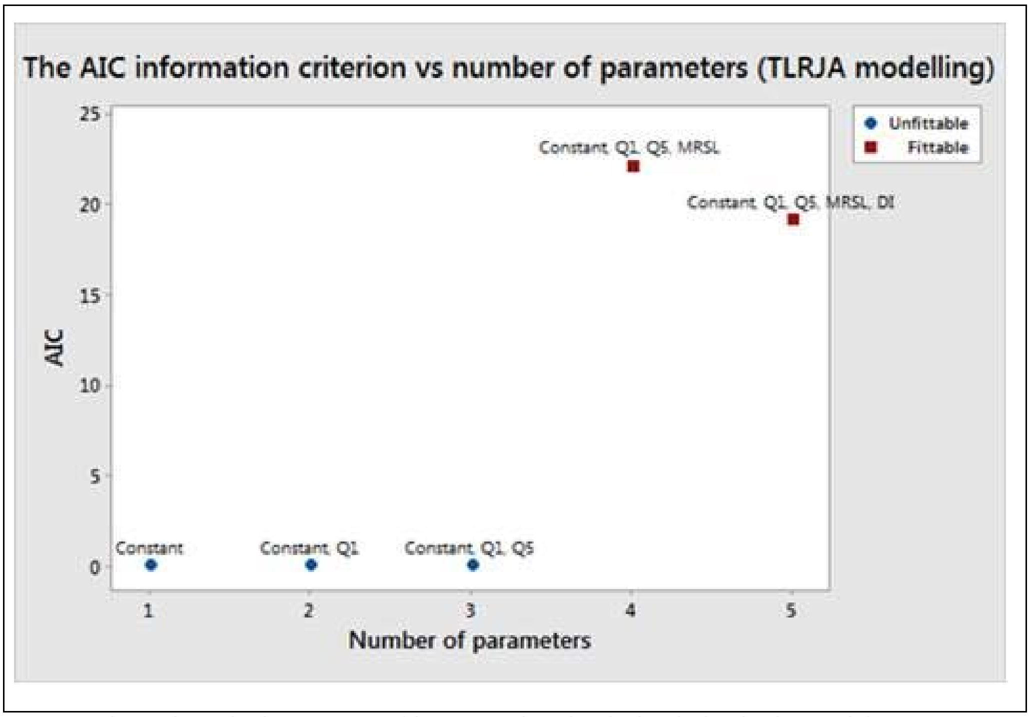


Figure 6.32 ln(JA+1) vs ln(SUJADI)



6.4 Importance of incorporating design index

Figure 6.33 AIC vs number of parameters



An example to show the importance of incorporating the design index in the models

For TLRJA, the model including a constant term, flows Q1 and Q5, MRSL and the TLRJADI design index provides an excellent fit (see section 6.3.4 for the model and section 6.5 for the goodness-of-fit testing). The model with only constant term, or constant term with Q1, or constant term with both Q1 and Q5 fails to fit (the fitting algorithm does not converge). When MRSL is included as a fourth variable the model does fit, with AIC value of 22.14. When, in addition, the TLRJA design index TLRJADI is included, the model is improved, with a lower AIC value of 19.11 (the lower the AIC value, the better the fit). These models and their AIC values are summarised in figure 6.34.

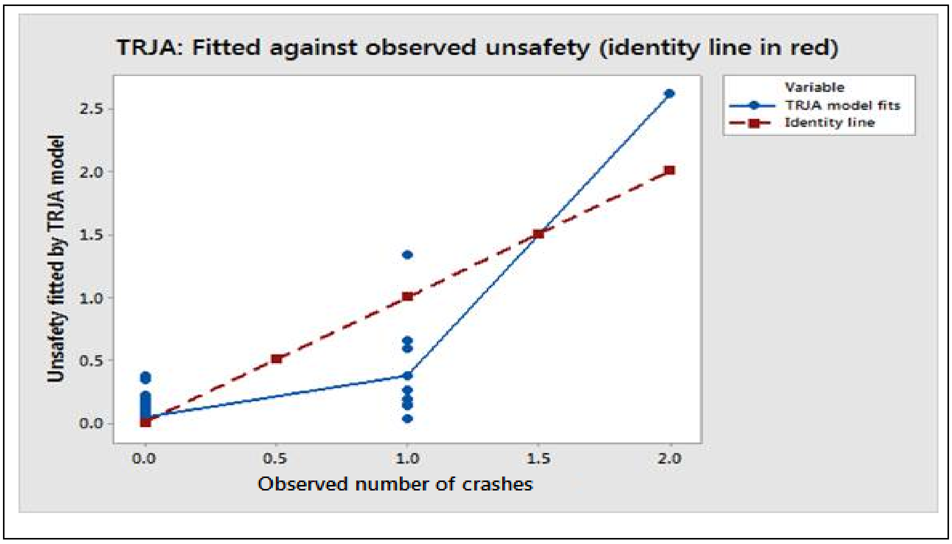
6.5 Goodness-of-fit testing

The models were tested for goodness of fit using a grouping technique developed by Wood (2002). We have low mean values so intersections must be grouped and a G^2 statistic formed.

When the model fits, G^2 follows a chi-square distribution with degrees of freedom approximately the number of groups minus the number of parameters in the model. If the model does not fit, the test indicates intersections with exceptional performance, either highly unsafe or highly safe.

The results for each of the models are summarised below, each with explanatory text and a graph that fits against observed values. The ‘fits’ are the expected number of crashes determined by the model. The observed number of crashes only relates to the number of injury crashes in the five-year analysis period. The red ‘45 degree’ line in each graph indicates exact fit; the greater the departure of the blue line (a piecewise straight line smoothing the fitted values) from the red, the worse the fit. Intersections above the blue line are safer than expected and intersections below are less safe than expected.

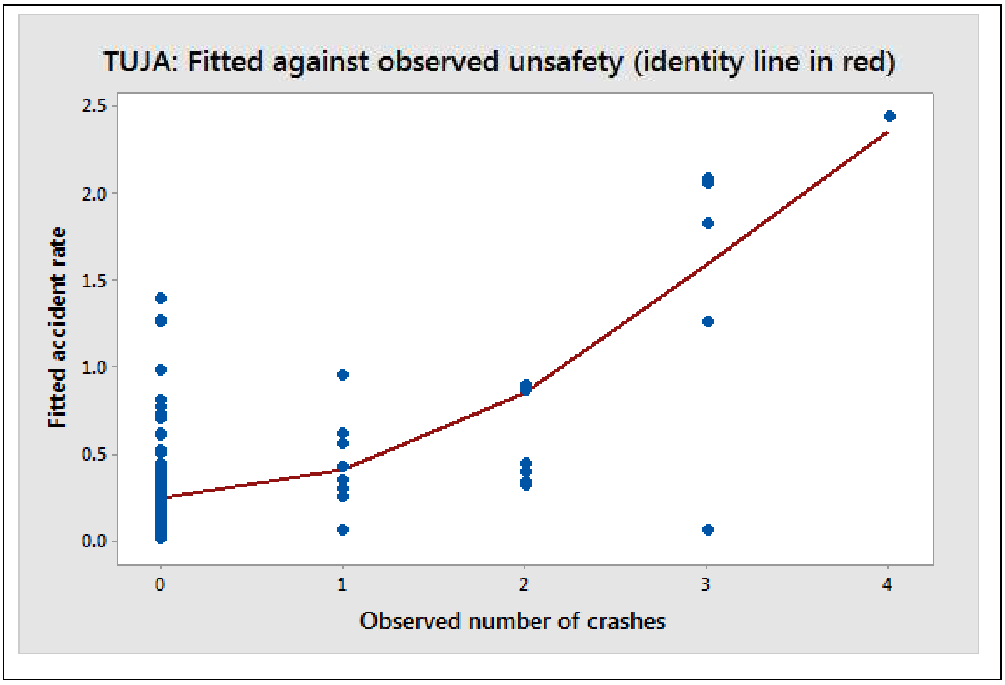
Figure 6.34 TRJA model against identity line



TRJA: $G^2 = 2.33$, 5 groups, 5 parameters, but $X^2_1(0.95) = 3.84$, so evidence of reasonable fit.

While not an excellent fit to the data, the rural T-intersection model for JA crashes has a reasonable fit. The upward trend is clear in the early part of the data. (Here, with the number of parameters equal to the number of groups, we have had to use the smallest number of degrees of freedom for a chi-square distribution. Since the G^2 value is considerably less than this, and it relies on a grouping technique, we can conclude there is a reasonable fit.)

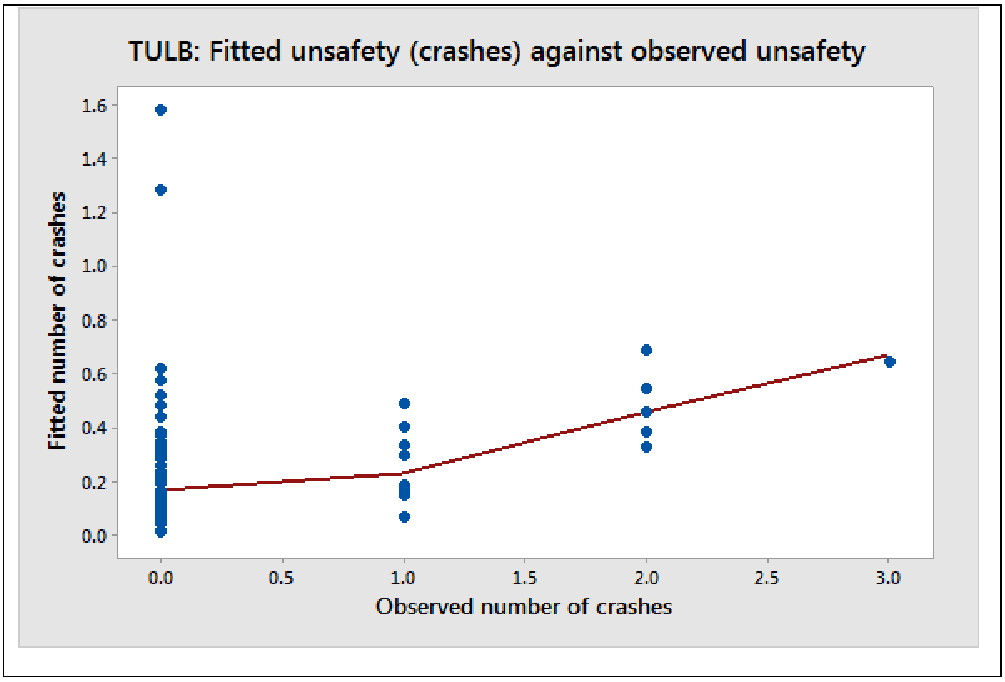
Figure 6.35 TUJA model against identity line



TUJA: $G^2 = 40.79$, 22 groups, 5 parameters. Poor fit. Examples of exceptions are Papanui/Mays (top left, safe) and Halswell/Tankerville (bottom right, unsafe)

This model for JA crashes at standard T-intersections has one of the worst fits of all the models, despite the large sample size.

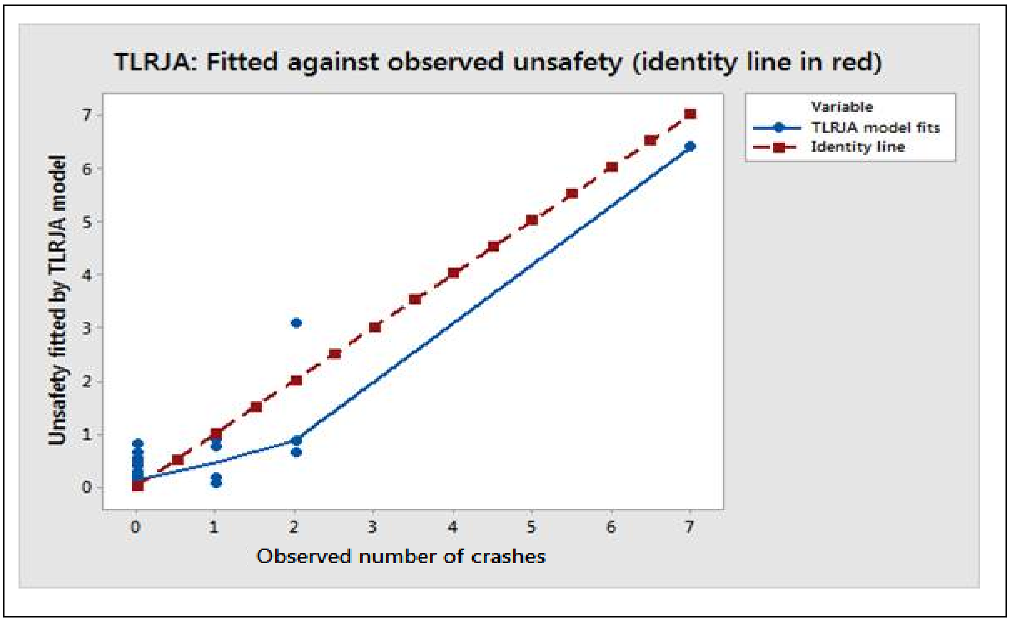
Figure 6.36 TULB model against identity line



TULB: $G^2 = 17.31$, 7 groups, 5 parameters, so a very poor fit. There are three groups with G^2 component over 20.

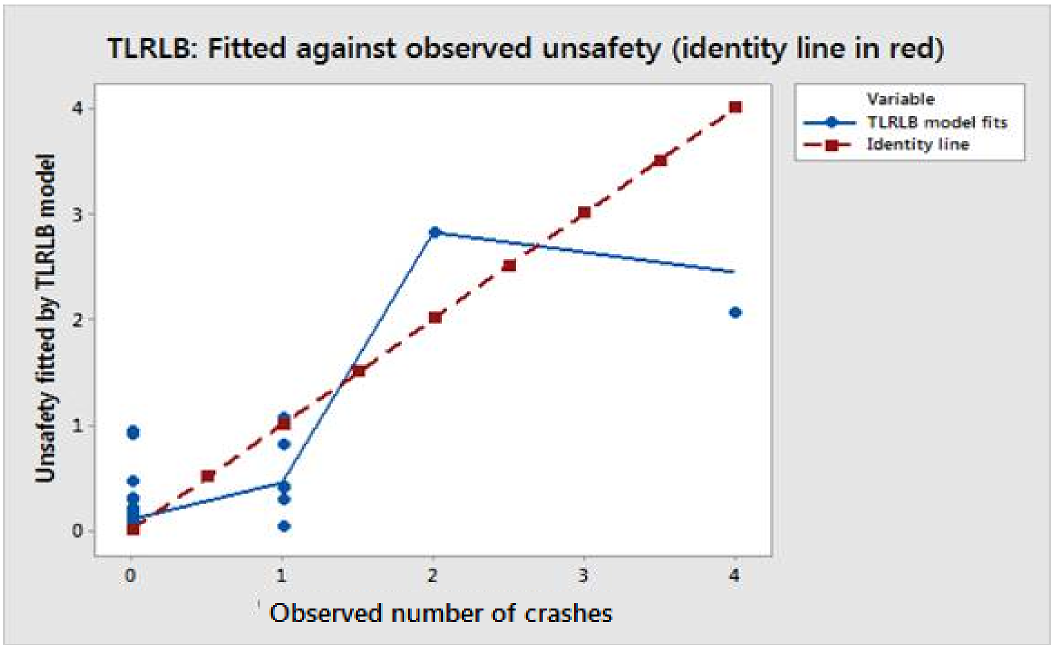
The model for LB crashes at urban T-intersections has a poor fit.

Figure 6.37 TLRJA model against identity line



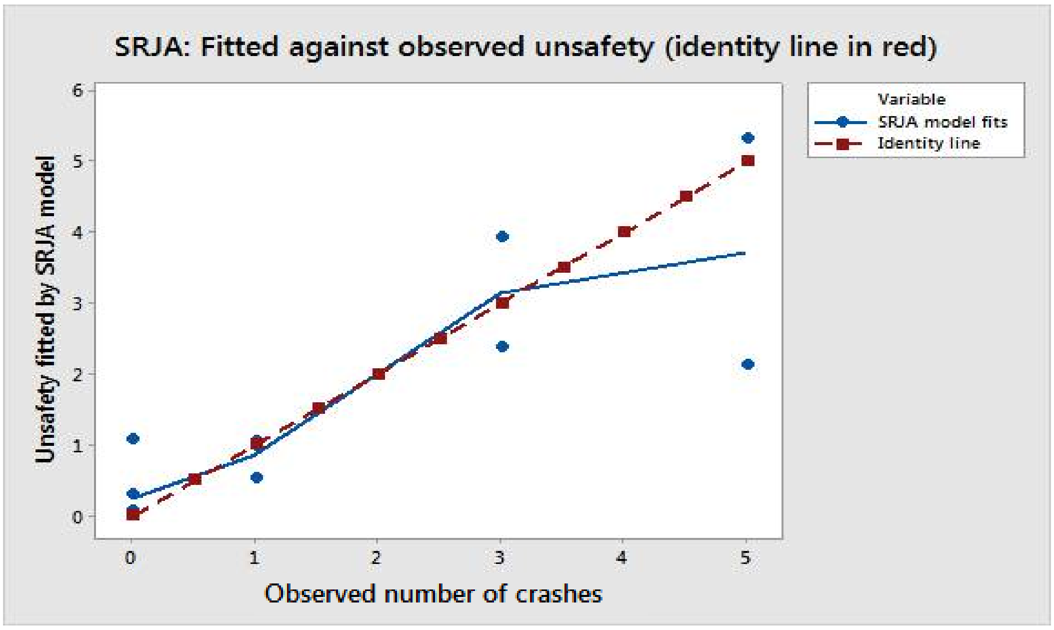
The model for JA crashes at T-intersections with a LTSL has an excellent fit.

Figure 6.38 TLRLB model against identity line



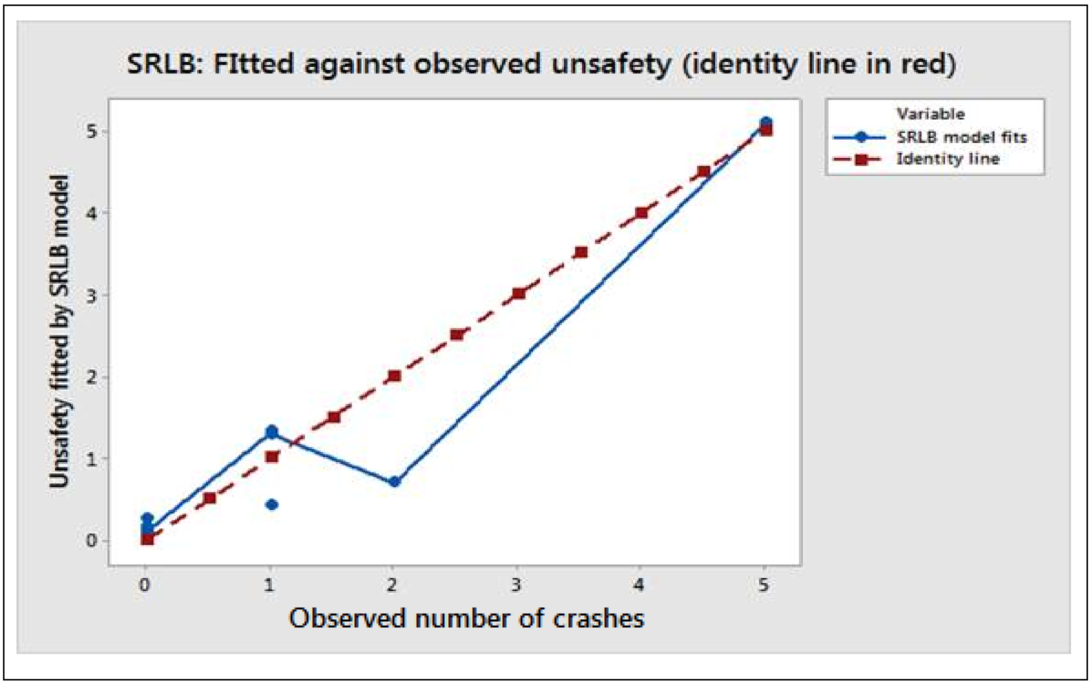
TLRLB: $G^2 = 2.27$, 6 groups, 5 parameters, $X^2_1(0.95) = 3.84$, so an excellent fit (we have an extra degree of freedom here compared to TRJA, hence the stronger conclusion)

Figure 6.39 SRJA model against identity line



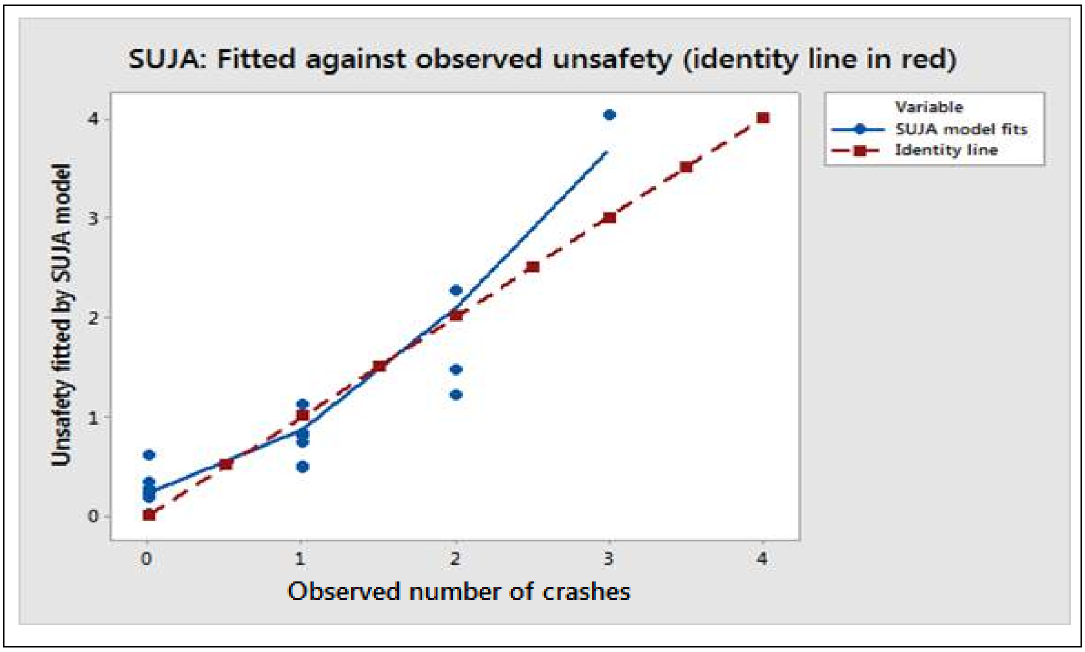
SRJA: $G^2 = 3.96$, 6 groups, 5 parameters, $X^2_1(0.96) = 4.22$, so a moderate fit. SH1/Williams St an unsafe outlier (lower right point).

Figure 6.40 SRLB model against identity line



SRLB: G^2 =1.93, 4 groups, 3 parameters, $X^2_1(0.95)$ =3.84, so an excellent fit.

Figure 6.41 SUJA model against identity line



SUJA: G^2 =1.18, 8 groups, 4 parameters, $X^2_4(0.95)$=9.49, so an excellent fit.

The model for LB crashes at T-intersections with LTSLs and the three models for seagull intersections all have an excellent fit.

The overall outcome of the modelling is well fitting models for the T-intersections with LTSLs and with a seagull layout, which are the key subjects of this research. Further work is required for the standard urban T-intersections, where both the LB and JA model have a poor fit. This is not surprising given the complexity of the urban road environment. The data for many of the urban intersections is also fairly old (based on an older study). Hence a new study should ideally look at pulling together a new dataset that should also look at other variables like adjoining land use.

6.6 Using the models in practice

6.6.1 The Excel unsafety (expected crash rate) tool

A tool was built using Excel to 'bring to life' the fitted models described in section 6.3. The tool is named the 'Design index and unsafety calculator.xlsx' and accompanies this report at www.nzta.govt.nz/resources/research/reports/644. It allows the user to vary the parameters within a single context (such as TRJA) to reduce the expected crash rate. It also allows two contexts (such as an upgrading of TRJA to SRJA), to be compared at a glance.

This section now provides an overview of the way in which the crash prediction models can be applied to real world examples using this Excel unsafety tool (). It can be used to:

1. Examine the effect of changes of flow, speed and design on the unsafety of a single intersection (e.g. the effect on JA crashes of changes to the main road median at an urban T-intersection).
2. Compare the unsafety of two types of intersection design (eg the effect on JA crashes of upgrading from a rural T-intersection to a rural seagull intersection).

The Excel file contains nine spreadsheets. It should be noted that two of the models (for JA and LB crashes at standard urban T-intersections) did not have a good fit and should be used with caution. It is recommended the guidelines that follow be read with the Excel system open alongside.

6.6.2 Expected crash rate at a single intersection (spreadsheets 1 to 8)

Spreadsheets 1–8 (in order, dealing with scenarios TRJA, TUJA, TULB, TLRJA, TLRLB, SRJA, SRLB and SUJA) allow the user to enter flow, speed and design values and receive as an output the crash unsafety (or expected crash rate). In this way the user can 'ring the changes' and examine the effect on unsafety of movements in the predictor variables.

6.6.2.1 An example

For JA crashes at a seagull intersection in an urban setting (model SUJA) changing the angle of entry of the LTSL into the side road from a low angle to a high angle reduces the expected JA crash rate from 0.47 injury crashes/year to 0.36 injury crashes/year, as shown in the following screenshots:

Figure 6.42 Effect of low angle LTSL off main road

Unsafety with low angle LTSL off main road

SUJA unsafety calculator (seagull intersection, urban, JA crashes)	
Q1	500
Q5	5000
MRSL	50
Design index	3.11
Design index calculator	**Value**
Lane width right turn from main road	3
Main road median width	2.5
Near-side shoulder width	3
Distance to far-side upstream feature, (0 m to 49 m=1, 50 m to 99 m=2, 100 m to 199 m=3, 200 m plus=4)	3
LTSL into main road (Y=1, N=2)	2
LTSL into main road (low entry angle=1, high entry angle=2)	1
Far-side upstream median island type (painted line=1, hit posts=2, solid barrier=3, painted island=4, solid island=5)	1
Seagull splitter island length (m)	30
Length of seagull acceleration lane (m)	10
Unsafety – expected injury crashes/year	**0.47**

Figure 6.43 Effect of high angle LTSL off main road

Unsafety with high angle LTSL off main road

SUJA unsafety calculator (seagull intersection, urban, JA crashes)	
Q1	500
Q5	5000
MRSL	50
Design index	3.11
Design index calculator	**Value**
Lane width right turn from main road	3
Main road median width	2.5
Near-side shoulder width	3
Distance to far-side upstream feature, (0 m to 49 m=1, 50 m to 99 m=2, 100 m to 199 m=3, 200 m plus=4)	3
LTSL into main road (Y=1, N=2)	2
LTSL into main road (low entry angle=1, high entry angle=2)	2
Far-side upstream median island type (painted line=1, hit posts=2, solid barrier=3, painted island=4, solid island=5)	1
Seagull splitter island length (m)	30
Length of seagull acceleration lane (m)	10
Unsafety – expected injury crashes/year	**0.36**

6.6.3 Intersection comparisons (spreadsheet 9)

Spreadsheet 9 (named 'Contour of comparison') provides a comparison of two intersection scenarios. We now describe the method and follow it with a worked example, with screenshots from the Excel tool.

We can compare the expected crash rate of any two intersection types by taking a ratio of their unsafety. For example, we can compare the JA crashes between various combinations of traffic flows at urban seagull intersections and a standard T-intersection by taking a ratio of their expected crash rates, namely:

$$\text{Ratio} = Y(\text{seagull, urban, JA})/Y(\text{T-intersection, urban, JA}) \qquad \text{(Equation 6.2)}$$

This can be done for any two scenarios. The default spreadsheet 9 provides a graphical contour plot summary, showing the (Q1, Q5) pairs for which the first JA crash scenario above is safer than the second.

6.6.3.1 An example

Suppose we are considering JA crashes at a rural T-intersections with a LTSL and Q1=500, Q5=5000, MRSL=100 and design index (TLRJADI) =3.75. Then the unsafety (expected number of injury JA crashes per year) is (see section 6.3.4 for the model description):

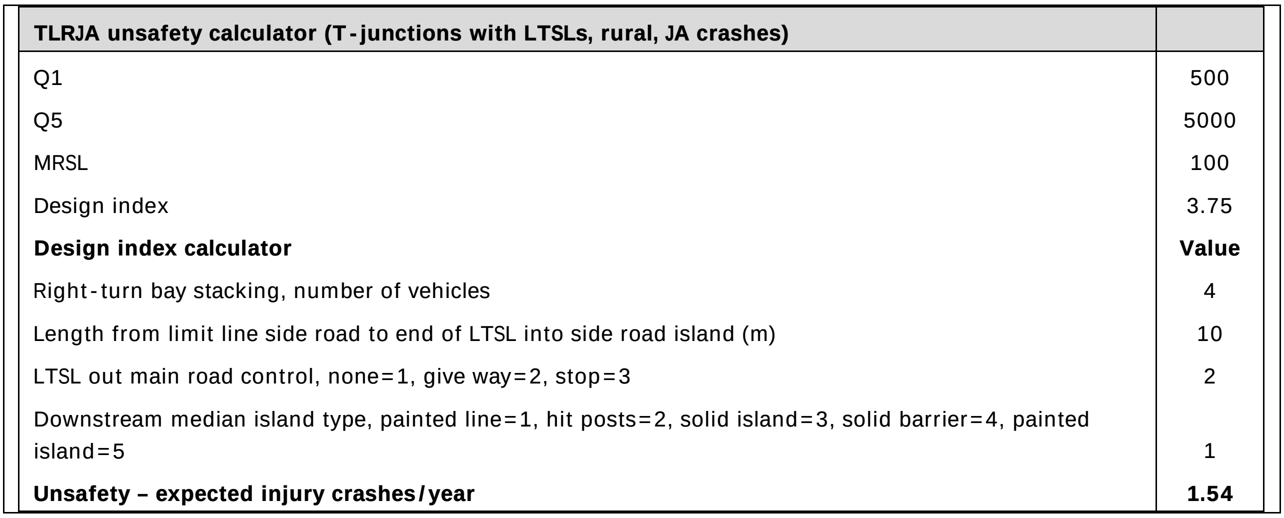
$$\begin{aligned} \text{Expected crash rate/year} &= \exp(-26.13)\, Q1^{0.92}\, Q5^{0.42}\, MRSL^{2.24}\, TLRJADI^{5.26} \qquad \text{(Equation 6.3)} \\ &= \exp(-26.13)\, 500^{0.92}\, 5000^{0.42}\, 100^{2.24}\, 3.75^{5.26} \\ &= 1.54 \end{aligned}$$

This expected crash rate can be reduced to a value of 0.73 by either:

1. Improving (by lowering) the T-intersection with LTSL design index to 3.25 (by attention to the factors involved in the design index, such as changing the give way control on the side road to a stop control), or
2. Converting to a seagull intersection (scenario SRJA) with design index of 3.25 (note, it is a coincidence here that the needed design indices are the same).

To run this, first enter relevant flow, speed and design information into the two scenarios chosen from spreadsheets 1–8 (here spreadsheet 4, TLRJA and spreadsheet 6, SRJA). Screenshots showing these two approaches achieve the same reduced expected crash rate are presented in figures 6.44 and 6.45.

Figure 6.44 TLRJA spreadsheet with design index value of 3.75



TLRJA unsafety calculator (T-junctions with LTSLs, rural, JA crashes)	
Q1	500
Q5	5000
MRSL	100
Design index	3.75
Design index calculator	**Value**
Right-turn bay stacking, number of vehicles	4
Length from limit line side road to end of LTSL into side road island (m)	10
LTSL out main road control, none=1, give way=2, stop=3	2
Downstream median island type, painted line=1, hit posts=2, solid island=3, solid barrier=4, painted island=5	1
Unsafety – expected injury crashes/year	**1.54**

Figure 6.45 SRJA spreadsheet with design index value of 3.25

SRJA unsafety calculator (seagull intersection, rural, JA crashes)	
Q1	500
Q5	5000
MRSL	100
Design index	3.25
Design index calculator	**Value**
Main road median width (m)	0.75
Near-side number of through lanes	1
Far-side number of through lanes	2
Side road signage (none=1, give way=2, stop=3, signal=4)	2
Width LTSL out main road flush median or painted line (painted line(<0.1m)=1, 0.1-3.0m=2, >3.0m=3)	2
LTSL out main road offset from limit line of side road (m) (positive if LTSL behind limit line)	2
Downstream median island type (painted line=1, hit posts=2, solid island=3, solid barrier=4, painted island=5)	3
Unsafety-- expected injury crashes/year	**0.73**

In order to assess how these configurations will compare as traffic flows change (in this way, exploring the future, when flows will change but the design indices and the MRSL remain constant), nominate these setups in cells F3 and F4 (by entering spreadsheet numbers '4' and '6' respectively) of spreadsheet 9. A contour plot comparing the unsafety of these two scenarios, as the two flows change (here Q1 and Q5), is as shown in figure 6.47. If the ratio is less than one the first (TLRJA) scenario is safer than the second (SRJA) scenario. This does not occur for any of the flow combinations in this case. Hence a seagull intersection layout is safer than a T-intersection with a LTSL across the full range of these traffic flows for a given design index. This may change if the design of the seagull intersection is poor.

Figure 6.46 Chosen scenarios TLRJA vs SRJA

Scenario	Code		First chosen scenario		4
TRJA	1		Second chosen scenario		6
TUJA	2				
TULB	3				
TLRJA	4				
TLRLB	5				
SRJA	6				
SRLB	7				
SUJA	8				
The orientation of the contour plot is the same as that in the table of ratios beneath the graph.					
Thus 'Series 1' is Q5=1000 etc. and 1 on the horizontal axis is Q1 (or Q3) =100.					
(Excel contour plots allow no control over the labels on the rows and columns.)					
Flow combinations with values under one indicate that the first scenario is safer.					

Figure 6.47 Contour of comparison for TLRJA vs SRJA

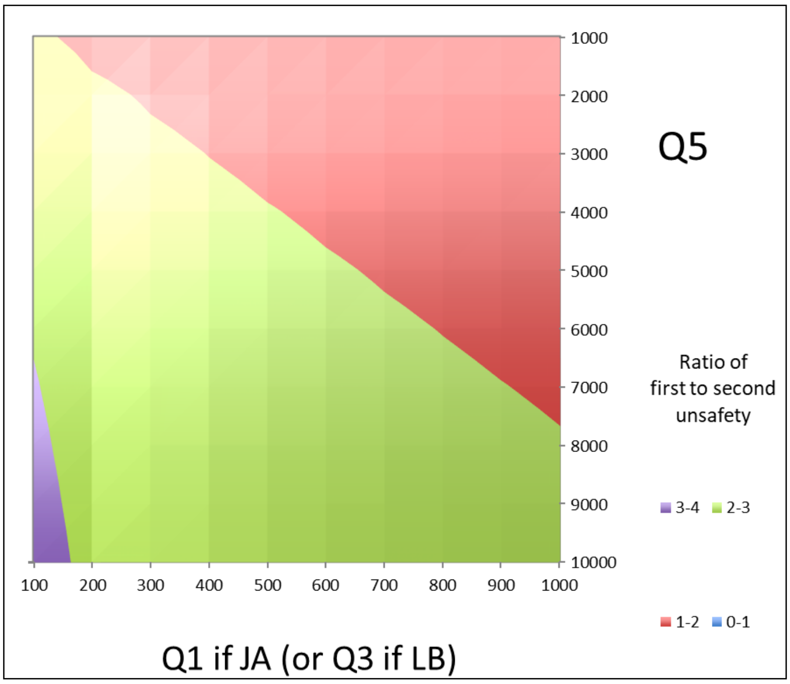


Figure 6.47 shows that the second scenario is safer than the first as there are no cases when the ratio is less than one.

A caution: this software is only as good as the underlying models. At present the models are based on relatively noisy data; as better data becomes available, the current system could be modified and so provide more accurate predictions. Spreadsheet tabs for the models in the Excel unsafety tool are coloured (red is very poor running through to blue for excellent), indicating the quality of the associated models.

What is not evident in the example is the typical value of the design index for each of the intersection types. It may be a lot more difficult to score a low design index value for seagull intersections than for T-intersections with LTSLs. Hence one might see that T-intersections with LTSLs being safer than seagull intersections for the typical design index values.

7 Conclusions and future research topics

7.1 Conclusions

The previous research in this area, and an analysis of national crash data and crashes at the study intersections, identified there were three main crash types at high-volume priority T-intersections: JA (right-turn crossing), LB (right turn against) and GD (right turn rear-end). Right-turn bays have been shown to significantly reduce the 'GD type' crashes and are applied fairly consistently to higher-volume T-intersections across New Zealand to address this issue. The lower cost treatments that are available for JA and LB crashes are less effective and hence these crash types, especially JA crashes, are still relatively common at T-intersections.

Of particular interest in this study has been the impact of LTSLs and seagull layouts, at priority T-intersections, on JA and LB crashes. As detailed in the literature review, road safety professionals are concerned that in some situations LTSLs may be increasing the risk of JA crashes. There are also concerns that seagull layouts, especially poorly designed ones, also increase the crash risk. The impact of various design and layout variables on crash occurrence is also significant. Other important variables include the conflicting traffic volumes and speed.

To explore the relationship between crashes and different variables a preliminary analysis was undertaken. This looked at the relationship between all variables and the occurrence of fatal and serious injury crashes. Sections 7.1.1 to 7.1.3 highlight the key relationships.

7.1.1 Urban seagull intersections

- Wider right-turn bays for turning into the side road increase JA crashes (higher-speed entry may draw attention of right-turn-out drivers more to the left rather than to the right).
- Seagull intersection layouts with wider medians have more JA crashes (Radalj et al 2006 found that poorly designed right-turn bays in wide medians – high angle – increased crashes and especially crash severity).
- A greater nearside shoulder width increased JA crashes (this could be due to a greater crossing distance to the safety of the median).
- Far-side upstream features impact on JA crashes (these are likely to draw the attention of drivers turning right into the main road to the left, rather than the right where they should be primarily focused).
- A greater number of side road traffic lanes reduces LB crashes (unclear why this is the case).
- Larger seagull islands (and typically larger intersections) increase JA crashes (most likely due to higher speeds).
- The longer the acceleration lane is for drivers turning into the main road the more JA crashes are expected (it is unclear why this is the case).

7.1.2 Rural T-intersections with LTSLs

- A shorter right-turn bay for turning into the side road increases JA crashes (this means that drivers drop into the right-turn bay later – this may draw the attention of the right-turn-out drivers to the left rather than to the right).

- A greater number of side road traffic lanes reduces LB crashes (unclear why this is the case).
- The presence and a greater width of a side road median island increases LB crashes (may be associated with a slower right-turn movement around the median island, leaving the right turning vehicle exposed to a crash for longer).
- The absence of a top-of-the-T chevron board increases LB crashes (would expect this treatment to reduce JA crashes – unclear why this is the case).
- The type of downstream median island impacts on the number of JA crashes. Wider painted and solid medians are safer (unclear why this is the case).
- A give way control on a LTSL appears to reduce JA crashes (this could be due to lower speeds of left-turning vehicles or due to the safer design of the LTSL – generally give ways are placed on a high entry angle LTSL).

7.1.3 Rural seagull intersections

- Longer right-turn bay increases LB crashes (may be surrogate for high right-turn movement and create pressures on drivers to make the right turn into side road).
- Seagull intersections with wider main road medians have more LB and JA crashes.
- The presence of two near-side lanes increases LB and JA crashes (this may be due to wider distance to cross to get to a safe area).
- The presence of two far-side through lanes increases LB and JA crashes (This is likely to be highly correlated to the number of near-side lanes, where the extra width is likely to increase crashes).
- Intersections with stop controls have a higher risk of JA crashes than give way control (this is likely to be due to the reduced approach sight distance at stop controlled intersections).
- The type of LTSL treatment impacts on LB crashes (this has been found in other studies – might be that right-turn-out of side road drivers are expecting vehicles to turn left rather than travel straight through).
- The more positive the offset between the side road limit line and the left-turn bay lane line, the higher the number of JA crashes. This is likely to be due to left-turning vehicles obscuring sight distance to through vehicles for drivers on the side road if the side road limit line is well set back from the main road.

These relationships were explored further in the detailed analysis, which included the development of eight crash prediction models for the more common intersection types. The two models for standard urban T-intersections had a poor fit despite a lot of variables being identified. Further work is required to develop better fitting models.

The other six models had a moderate to excellent fit to the data providing a high level of confidence the models could estimate crash risk based on a small set of variables. The variables identified in the preliminary analysis were combined into a design index, and appear along with speed limit and the two conflicting flows in each of the models.

An Excel toolkit was developed to assess the safest form of control for a given combination of variables (see appendix J, published separately at www.nzta.govt.nz/resources/research/reports/644). There is considerable scope for a designer to improve safety by improving an intersection's design. Where this is not possible the designer can look at changing to a different layout, by adding a LTSL or a seagull layout. It is likely that the benefit of this will depend on the speed limit and the conflicting traffic volumes.

Further work is required to test the toolkit and determine whether it is useful for designers to find ways of improving intersection design to provide crash reduction benefits. Hence we suggest caution in using the spreadsheet alone to change road designs. Some of the findings can be incorporated in the economic evaluation model in the EEM but further research will be needed to make more conclusive findings from the study.

Finally an alternative modelling approach was presented that found the LTSL in a main road design appeared to impact on JA crashes at urban intersections. It indicated that late and high entry angle LTSLs are safer than longer low entry angle LTSLs. This is further evidence that LTSLs can impact on the visibility between vehicles pulling out of side roads and the through vehicles they are meant to give way to.

7.2 Future research

The focus of future research should be to:

1. Examine further the impact various LTSL types and combination of left-turn and through traffic volumes and speeds have on crash rates. The number of sites may need to be doubled from the existing sample size of 37 to produce good results.
2. Explore alternative forms of the design indices that have been used for each of the eight models. This may improve the goodness of fit of the models.
3. Study the effect of upstream and downstream features like car parking, bus shelters and side roads. The research could look at the type of features and the distance to features. It is expected on some roads that such features actually restrict sight distances but do not lower traffic speeds. While on other roads the sight distances may be restricted and the feature (eg car parking) may reduce speeds to compensate this. Hence it would be useful for urban roads, in particular, to look at lane widths and speed data.
4. Develop better crash prediction models for JA and LB crashes at standard T-intersections, especially urban intersections. These models currently underestimate the number of crashes at medium and high-volume intersections. Consideration should be given to looking at other predictor variables, such as land use, (dynamic) sight distance and operating speed. It might also be useful to develop an index for intersection complexity (considering the number of conflict points and other driver distractions). The models can then be incorporated into developing star rating models as part of urban KiwiRap (in the urban KiwiRap data priority intersections are a major cause of serious injury crashes).
5. Identify and examine a number of key safety issues raised by transport professionals on the safety performance of priority T-intersections, especially in higher-speed and higher-volume areas. The alternative modelling approach presented in this report demonstrates how such problems can be examined, using the crash model relationships and other information.

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Appendix A: Minutes of meetings

Meeting 1 – Minutes

Meeting Name	Seagull Research Steering Group 1		
Meeting Venue	Kauri Room		
Date Of Meeting	15 October 2015	Time Of Meeting	10am – 12pm
Chairperson	Shane Turner	Recorder	Hollie Spain

Project Details

Client Name	NZ Transport Agency
Project Name	Seagull Intersections LTS
Project Number	

Attendees	**Initials**
Shane Turner	ST
Rachel Blewden	RB
Kyle Martin	KM
Ian Robertson	IR
Jeremy O'Neill	JO
Vicky Waddon	VW
Bob Bunch (MoT)	BB
Tim Hughes (NZ Transport Agency)	TH
Fergus Tate (NZ Transport Agency)	FT
Irene Tse (AT)	IT

Apologies	**Initials**
James Hughes	JH
Keith Wheale	KW
Tim Cheesebrough	TC
John Garvitch	JG

Project objectives and tasks

- Previous crash prediction models for Urban and Rural X & T Junctions– based on older crash data (so may be not appropriate due to increase in volumes)

- FT – Would like a small sample on X-roads

Literature review findings (Task 1)

- FT – to send ST information from Abley (by Paul Durdin) on some preliminary research on Seagull intersections
- FT – would like to see severity ratio of crashes for left hand slip lanes
- ST – to check whether LTS diagrams were priority only or included signals – in literature review
- FT – need to include Cherie Mason's work in literature review
- FT – more interested in left hand turn slip lanes in rural areas – higher speeds so rear end crashes can be more serious

Classification of Seagull intersections and Left Turn Slip lanes (Task 2)

- Left in/left out splitter island naming convention confusing – reverse on classification diagram
- TH – examples of complex intersections with high tourist crash rates (turn off to Waitomo & Tirau)

Definition of a Seagull as defined by the Safety Audit Team

- Must have a Seagull shaped island – The island can be painted with or without hit posts or solid
- Must have a merge lane with the intention that vehicles do not stop and wait to merge with downstream traffic
- Must have at least one bypass traffic lane

Fergus defined definition as

- If cars need to find gap in 2 traffic stream = Not Seagull
- If cars need to find gap in only one traffic stream = Seagull
- FT – Stick with MWH's initial definition and see how many intersections we can get for data collection

Seagull Crash Types

- Approx. 50% are JA/LB crashes
- For further crash analysis need to compare DSi vs ALL crashes
- FT – Main focus for Left Turn Slip lane research is at standard T intersections rather than Seagull intersections. However it was noted that there appears to be a link between LTSL treated type and JA crashes at Seagull intersections
- TH mentioned that larger study of rural T Junction (by Abley) indicates rural crash prediction models may need further refinement. However urban models appear to be adequate when compared to the larger datasets.
- Auckland has the largest number or urban Seagull intersections so is a focus for data collection (IT at AT has traffic count data for a number of sites). Data collection at other sites will try to focus on a short list of other cities
- TH – Suggested looking at LTSL sites in the Waikato and Queenstown (Tim to send list of Left Turn Slip lane examples)
- Ian Robertson mentioned further Seagull sites in Wellington such as (Ian to send list):

  - Otorohanga Road & SH1 (Previously)
  - Moonshine Hill Road & SH2
  - Whakatiki Street & SH2
- ST still trying to collect data at Seagull intersections from NSW and Victoria

Identification of sites (Task 3a)

Rachel went through some of the sites identified for further analysis

Colour – Google Earth	Definition
Blue	LTS
Pink	Seagull with LTS
Yellow	Seagull only
White	Pseudo Seagull

- Rosedale/Graham Collins (been in place 5 years)
  - No Island?
- Browns Bay/Beach Road
  - Unsure if Seagull – Take out as no right hand turn in
- St Lukes/Linwood
  - Seagull – Debatable as acceleration lane short
- St Lukes/Asquith
  - Seagull – substandard, slightly longer acceleration lane
- Station/O'rorke
  - Seagull with signalised level crossing
- Station/Maurice
  - Seagull with LTS
- Rockfield/MT Smart
  - Seagull with LTS
- SH30A/Pukuatua Street
  - Seagull with LTS
- SH5 – Rotorua – to find more sites
- Waimea/Bishopdale & Waimea/Boundary Road
  - Seagull?? both interact
- Waimea/Ridgeway
  - Small Island
- Nelson Port

  - Seagull with LTS
- East Coast Rd – Tavern Road (Suggestion by Irene Tse)
  - Seagull/LTS
- Hilsborough/White Swan
  - Take out as no right turn into Side Road movement
- Roscommon Road/Bolderwood
  - Neighbouring intersection recently signalised
  - Compare crashes before and after
- ST – Please send in any other examples of sites you may have or come across.

Preliminary crash analysis (Task 4a)

- Preliminary crash data for urban/rural Seagull intersections and Left Turn Slip lanes has been prepared and presented to get an idea of the proportion of crash of different types. JA crashes dominate with LB being next highest proportion of crash crashes for all site types.
- Analysis compares crash data from standard urban and rural T intersections with Seagull intersections and intersections with LTSL.

Next steps – data collection

- Email around NZ Transport Agency to see if there are any suggestions for further sites
- Discussion with AT to see if any other sites may come up to help aid in data collection – Irene to send list
- VicRoads may be interested however may not want to help fund the exercise
- Updated schedule for the milestones
- ST to send to Steering group
- Next steering group meeting – around 10th Feb (please reserve this date 10am – 12)

Meeting 2 - Minutes

Meeting Name	Crash performance of Seagull intersections and Left Turn Slip lanes		
Meeting Venue	Kauri Room		
Date Of Meeting	11 March 2016	Time Of Meeting	1 pm
Chairperson	Shane	Recorder	Katie Adams

Attendees

Rob Partridge MWH

Shane Turner MWH

Tim Cheesebrough CCC

John Garvitch NZTA

Keith Weale MWH

Fergus Tate NZTA

James Hughes NZTA

Tim Hughes NZTA

Graham Wood - Consultant

Apologies

Irene Tse AT

Patricia Pierce NZTA

Agenda Item

1. **Last Meeting background**
2. **New items, Graham’s presentation**

Crash performance of Seagull intersections and left-turn slip lanes

1 Data
  a Needs to include the severity of crash

2 Crash and flows
  a Canterbury has highest percentage of crashes
  b Need to identify the crashes that aren’t specifically Seagull intersections
  c Rural crash rate is higher that Urban crash rate

3 Comparing T-intersection and Seagull intersection
  a Seagull intersections have a higher rate of crashes than T-intersections
  b Seagull intersections crashes are higher in urban area than rural

   c T-intersections have a higher rate of serious injury in rural areas vs. urban

4 Composite

   a Probability of serious injury in T-intersections and Seagull intersections

	Rural	Urban
T-intersection	.34(84)	.14(74)
w/LTSC	.30(37)	0.0(10)
Seagull	.29(13)	.24(15)

Unsafety index

1 Length of main road acceleration lane

2 Far side downstream splitter island

3 Main road median length

4 Main road Left Turn Slip lane offset to Side Road paint line

5 Type of Left Turn Slip lane from main road control

6 Main road curvature

7 Main road speed limit.

<u>Action</u>: Change to <80 and ≥80

Relationship between unsafety

1 Speed limit

2 Far side downstream splitter island

3 Main road curvature

4 Main road median

5 Length of acceleration lane

6 Type of left turn split

7 xxx

Other factors

1 Raised vs Painted Seagull
   - a With high traffic flow, safer when painted
   - b With low traffic flow, raised is better
   - c Raised caused difficulty on an unfamiliar road with young women and older drivers.
   - d There’s not a high likelihood of crashes being fatal and serious

2 Curvature
   - a Straight is safer than curved, but in high flow traffic, there’s little difference.
   - b The longer distance before the turn, the more dangerous
   - c Higher speeds could contribute to this.
   - d The Left Turn Slip lane has not been specified in the analysis
   - e Speed needs to be considered with the length of deceleration
   - f High flows are less safe with shortened acceleration lane

- g Low flows are better with longer acceleration lane

Action: We need the number of fatal & serious crashes to be included.

Graphs

- a Include the likelihood and severity of crashes
- b Consider the number of crashes vs. severity (minor, serious, fatal)

Summary

1 Rural Seagull intersections are not worse than Urban.

- a Action:
    - revisit data based on km/h speed limit
    - compare Seagull analysis with T-intersection and T-intersection LTSC
    - build models for JA, LB, crashes, rural and urban areas for Seagull and T-intersections
    - look at models for JA and LB as they may all affect the unsafety index
    - need visibility index for all
    - factor in the speed

Further graphs and research to consider:

1 Speed – actual rather than posted

2 Type of people, i.e. young, old, tourists

3 Skid resistance

4 Road hierarchy

5 Proportion of vehicle type, if possible

6 Questions to consider

- a Is a Seagull a good idea
- b What's the speed, environment, is it rural or urban?
- c How can we manage speed?
- d Does the Seagull serve its purpose based on crashes?
- e Is the Seagull safe, considering its characteristics and variables?
- f Rural and Urban distinctions to consider
    - Speed
    - Behaviour and environmental factors
    - Operational differences
    - Urban: High volume/low speed
    - Rural: Low volume/high speed
    - At what point should the T-intersection be changed to a Seagull, if at all?
    - Seagull has higher crash rate, consider what makes it good/bad

7 Seagull vs. T-intersection: which should be installed, considering serious/fatal injury vs. minor crashes

8 At what point is a roundabout or signal a better solution?

9 Do we have any night time crash data?

10 Consider age groups, speed, lighting, markings, etc., along with crash "types".

Appendix B: Sites used from previous research

Table B.1 Sample size of standard urban T-intersections (Turner 2001)

Region	Main road	Side road	Latitude	Longitude
NORTHLAND	WOODS	COMMERCE	35°43'44.27"S	174°19'18.96"E
AUCKLAND	LADIES MILE	ABBOTTS WAY	36°53'20.16"S	174°48'41.23"E
AUCKLAND	BALMORAL	HENLEY	36°53'19.39"S	174°45'18.32"E
AUCKLAND	CAMPBELL	MOANA	36°54'23.25"S	174°47'16.25"E
AUCKLAND	MT SMART	SELWYN	36°54'47.78"S	174°46'54.65"E
AUCKLAND	LAKE	OLD LAKE	36°48'45.87"S	174°47'32.09"E
AUCKLAND	RAILSIDE	EDSEL	36°52'54.62"S	174°37'52.72"E
AUCKLAND	GREAT NORTH	McLEOD	36°52'53.69"S	174°38'22.94"E
AUCKLAND	GREAT NORTH	MONTELL	36°52'50.19"S	174°38'16.26"E
AUCKLAND	HENDERSON VALLEY	HICKORY	36°53'1.14"S	174°37'43.99"E
AUCKLAND	HENDERSON VALLEY	KEELING	36°53'11.47"S	174°37'41.78"E
AUCKLAND	SWANSON	STURGES	36°52'24.33"S	174°37'27.57"E
WAIKATO	HOROTIUA	TE RAPA (SH 1)	37°41'55.08"S	175°11'44.64"E
WAIKATO	RIVER	ONEILL	37°46'57.87"S	175°17'4.24"E
WAIKATO	RIVER	TEAROHA	37°47'3.12"S	175°17'9.46"E
BAY OF PLENTY	ARAWA	AMOHIA	38° 8'5.65"S	176°14'55.93"E
HAWKE'S BAY	TE MATA	GUTHRIE	39°39'57.03"S	176°53'22.91"E
HAWKE'S BAY	EASTBOURNE	KARAMU	39°38'36.84"S	176°50'35.46"E
HAWKE'S BAY	ST AUBYN	MARKET	39°38'20.46"S	176°50'44.32"E
LOWER NORTH IS.	BOTANICAL	FEATHERSTON	40°21'26.33"S	175°35'23.04"E
WELLINGTON	ADELAIDE	HOSPITAL	41°18'22.47"S	174°46'41.87"E
WELLINGTON	ADELAIDE	LUXFORD	41°19'11.29"S	174°46'31.16"E
WELLINGTON	BURMA	JOHN SIMS	41°14'9.53"S	174°47'53.06"E
WELLINGTON	MIDDLETON	CHURTON	41°12'48.85"S	174°48'40.72"E
WELLINGTON	KARORI	HATTON	41°16'57.52"S	174°44'41.24"E
WELLINGTON	KARORI	RAINE	41°17'3.82"S	174°44'19.01"E
WELLINGTON	LUDLAM	BELIEVUE	41°13'2.35"S	174°54'22.00"E
WELLINGTON	LAINGS	BLOOMFIELD	41°12'48.01"S	174°54'21.62"E
WELLINGTON	WESTERN HUTT	GROUNSELL	41°11'29.53"S	174°55'36.75"E
WELLINGTON	PHARAZYN	MARSDEN	41°12'28.62"S	174°53'53.64"E
WELLINGTON	HIGH	ANDREWS	41°12'35.74"S	174°54'6.38"E
WELLINGTON	KNIGHTS	CORNWALL	41°12'40.75"S	174°54'32.20"E
CANTERBURY	BREEZES	CUTHBERTS	43°31'22.33"S	172°42'30.32"E
CANTERBURY	HALSWELL	TANKERVILLE	43°33'22.73"S	172°35'25.33"E
CANTERBURY	MARINE PARADE	HAWKE	43°30'21.25"S	172°43'49.55"E
CANTERBURY	MAIN NORTH	SAWYERS ARMS	43°29'28.29"S	172°36'46.32"E

Region	Main road	Side road	Latitude	Longitude
CANTERBURY	PAPANUI	MAYS	43°30'19.95"S	172°36'56.66"E
CANTERBURY	PAPANUI	MERIVALE LN	43°30'56.81"S	172°37'27.72"E
CANTERBURY	PAPANUI	NORMANS	43°30'20.93"S	172°36'57.36"E
CANTERBURY	AVONHEAD	STAVELEY	43°31'16.57"S	172°33'42.15"E
CANTERBURY	WAIRAKEI	BREENS	43°29'32.79"S	172°34'24.55"E
CANTERBURY	CAVENDISH	VETTCH	43°28'52.90"S	172°36'23.12"E
CANTERBURY	GREERS	CLYDE	43°30'15.00"S	172°34'55.36"E
CANTERBURY	MEMORIAL	KENDAL	43°30'6.04"S	172°33'48.16"E
CANTERBURY	WAIRAKEI	KENDAL	43°29'47.61"S	172°34'42.71"E
CANTERBURY	YALDHURST	WITHELLS	43°31'28.65"S	172°32'53.57"E
CANTERBURY	ANTIGUA	FAIRFIELD	43°32'38.71"S	172°37'40.56"E
CANTERBURY	FENDALTON	GLANDOVEY	43°31'7.88"S	172°35'39.56"E
CANTERBURY	TUAM	STANMORE	43°32'7.61"S	172°39'25.43"E
CANTERBURY	STAFFORD	CANON	44°23'37.32"S	171°15'2.37"E
CANTERBURY	ROLLESTON	HEREFORD	43°31'55.37"S	172°37'39.34"E
CANTERBURY	PARK TERRACE	PETERBOROUGH	43°31'31.77"S	172°37'41.51"E
CANTERBURY	CAVENDISH	STURROCKS	43°28'29.93"S	172°36'24.72"E
CANTERBURY	SELWYN	CORONATION	43°32'57.78"S	172°37'18.43"E
CANTERBURY	BARRINGTON	ATHELSTAN	43°33'27.13"S	172°37'9.34"E
CANTERBURY	MAIN NORTH	BELFAST	43°26'56.20"S	172°37'47.56"E
CANTERBURY	EDGEWARE	CALEDONIAN	43°30'48.35"S	172°38'8.32"E
CANTERBURY	CASHMERE	THORRINGTON	43°33'58.91"S	172°37'57.05"E
CANTERBURY	COLOMBO	TENNYSON	43°33'28.75"S	172°38'12.77"E
CANTERBURY	COLOMBO	THORRINGTON	43°33'51.64"S	172°38'13.35"E
CANTERBURY	KENDAL	CRANBROOK	43°29'52.98"S	172°34'22.19"E
CANTERBURY	DYERS	MACES	43°32'35.89"S	172°41'56.62"E
CANTERBURY	VEITCHES	GRAMPIAN	43°28'52.26"S	172°36'9.59"E
CANTERBURY	GREERS	CONDELL	43°29'41.67"S	172°35'24.23"E
CANTERBURY	HILLS	NORTH AVON	43°31'3.37"S	172°39'6.09"E
CANTERBURY	WAINONI	HULVERSTONE	43°30'13.76"S	172°42'24.12"E
CANTERBURY	KERRS	WAINONI	43°31'16.36"S	172°40'53.59"E
OTAGO	SOMERVILLE	MARNE	45°53'34.80"S	170°31'44.68"E
OTAGO	BAYVIEW	KIRKCALDY	45°54'8.89"S	170°29'47.37"E
OTAGO	BAYVIEW	MOREAU	45°54'7.89"S	170°29'49.84"E
OTAGO	KAIKORAI VALLEY	DONALD	45°53'22.27"S	170°27'42.64"E
OTAGO	MASON	WARD	45°52'33.58"S	170°30'37.38"E

Table B.2 Sample size of standard rural T-intersections (Turner and Roozenburg 2007)

Region	Main Road	Side Road	Latitude	Longitude
AUCKLAND	MAHURANGI	SH1	36°29'24.99"S	174°39'33.89"E
AUCKLAND	McKINNEY	SH1	36°24'46.32"S	174°39'25.68"E
AUCKLAND	FOSTER	SH16	36°45'59.55"S	174°30'44.72"E
AUCKLAND	KANOHI	SH16	36°36'14.44"S	174°29'15.97"E
AUCKLAND	MAKARAU	SH16	36°32'55.45"S	174°28'4.77"E
AUCKLAND	TAUHOA	SH16	36°22'38.49"S	174°27'8.12"E
AUCKLAND	BAWDEN	SH17	36°40'56.15"S	174°39'11.86"E
AUCKLAND	GREEN	SH17	36°40'43.28"S	174°38'40.19"E
AUCKLAND	HORSESHOE BUSH	SH17	36°39'5.89"S	174°38'29.28"E
AUCKLAND	PINE VALLEY	SH17	36°37'38.58"S	174°39'29.13"E
AUCKLAND	MOROA	TUAHERENKAU (SH2)	41° 7'5.12"S	175°22'44.56"E
WAIKATO	BOLTON	KEREONE	37°40'13.75"S	175°32'56.78"E
WAIKATO	PAKARAU	KEREONE	37°40'53.23"S	175°38'48.60"E
WAIKATO	CEMETERY	WHATAWHATA (SH23)	37°47'38.04"S	175°10'37.72"E
WAIKATO	STOREY	TAHUNA	37°30'57.04"S	175°17'26.24"E
WAIKATO	FLETCHER	TUHIKARAMEA	37°50'47.51"S	175°12'43.44"E
BAY OF PLENTY	MAKETU	KAITUNA	37°46'20.59"S	176°26'21.58"E
BAY OF PLENTY	SH2	GULLIVER	37°48'7.46"S	176°23'53.61"E
BAY OF PLENTY	BELL	PARTON	37°43'58.39"S	176°18'21.18"E
BAY OF PLENTY	SH2	PORIPORI	37°46'54.84"S	176° 3'3.29"E
BAY OF PLENTY	MCLAREN FALLS	PEERS	37°51'21.80"S	176° 4'3.08"E
BAY OF PLENTY	WHAKAMARAMA	YOUNGSONS	37°42'22.69"S	176° 0'15.51"E
BAY OF PLENTY	BARRETT	OLD HIGHWAY	37°41'3.81"S	176° 1'18.18"E
BAY OF PLENTY	WHARERE	WAERENGA	37°47'46.02"S	176°28'53.78"E
BAY OF PLENTY	SH2	BENNER	37°49'5.46"S	176°30'23.55"E
BAY OF PLENTY	WELCOME BAY	WAITAO	37°43'6.60"S	176°13'47.92"E
BAY OF PLENTY	WELCOME BAY	REID	37°43'14.18"S	176°16'13.67"E
BAY OF PLENTY	SH2	THOMPSONS TR	37°36'2.59"S	175°55'3.29"E
BAY OF PLENTY	PYES PA	WILLIAMS	37°49'56.37"S	176° 7'19.87"E
BAY OF PLENTY	PYES PA	TAUMATA	37°50'51.85"S	176° 7'6.82"E
BAY OF PLENTY	NO3	BAYLEY	37°50'2.64"S	176°17'15.01"E
BAY OF PLENTY	NO3	NO4	37°48'16.56"S	176°17'58.38"E
TARANAKI	LEPPER (UPPER)	EGMONT	39°11'34.74"S	174° 8'38.62"E
TARANAKI	BAYLY	MAIN NORTH (SH3)	38°59'44.75"S	174°15'37.80"E
TARANAKI	KAIPIKARI (LOWER)	MAIN NORTH (SH3)	38°59'55.92"S	174°22'43.37"E
TARANAKI	KAIPIKARI (UPPER)	MAIN NORTH (SH3)	38°59'55.73"S	174°22'45.18"E
TARANAKI	WAIAU	MAIN NORTH (SH3)	38°59'51.62"S	174°20'11.07"E
TARANAKI	MANUTAHI	MOUNTAIN (SH 3A)	39° 3'48.44"S	174°11'50.78"E

Region	Main Road	Side Road	Latitude	Longitude
TARANAKI	CROYDON	OLD MOUNTAIN (SH3)	39°15'39.60"S	174°15'12.10"E
LOWER NORTH IS	SH4 (RP223/7.40)	KAIMATIRA RD	39°53'50.43"S	175° 5'23.63"E
LOWER NORTH IS	SH3 (RP415/5.93)	TURAKINA VALLEY RD	40° 2'20.77"S	175°12'43.40"E
LOWER NORTH IS	SH3 (RP415/3.74)	RATANA	40° 1'40.16"S	175°11'38.88"E
LOWER NORTH IS	No.3 Line	KAIMATIRA RD	39°54'54.33"S	175° 6'5.65"E
LOWER NORTH IS	SH3 (RP402/10.96)	WARRENGATE RD	39°59'22.69"S	175° 9'42.29"E
LOWER NORTH IS	No.2 Line	OKOIA ROAD	39°56'25.71"S	175° 7'41.12"E
LOWER NORTH IS	SH3 (RP384/9.00)	BLUESKIN RD	39°53'21.84"S	175° 0'24.46"E
LOWER NORTH IS	BRADEY RD	SH58	41° 6'50.26"S	174°55'10.80"E
LOWER NORTH IS	KUKU BEACH	MAIN (SH1)	40°40'48.82"S	175°14'23.89"E
CANTERBURY	MARSHLAND	McSAVENEYS	43°29'6.40"S	172°39'37.92"E
CANTERBURY	MARSHLAND	BELFAST	43°27'31.30"S	172°39'29.08"E
CANTERBURY	BELFAST	GUTHRIES	43°27'13.41"S	172°38'37.40"E
CANTERBURY	GUTHRIES	FACTORY	43°26'53.19"S	172°38'51.10"E
CANTERBURY	PRESTONS	QUAIDS	43°28'28.90"S	172°39'5.65"E
CANTERBURY	PRESTONS	WALTERS	43°28'29.49"S	172°38'57.02"E
CANTERBURY	SPRINGS	HODGENS	43°34'26.74"S	172°31'7.14"E
CANTERBURY	MARSHES	FOUNTAINS	43°34'37.32"S	172°32'16.10"E
CANTERBURY	HALSWELL JN	WHINCOPS	43°34'19.74"S	172°32'44.84"E
CANTERBURY	HALSWELL JN	WIGRAM	43°34'21.33"S	172°32'47.45"E
CANTERBURY	KENNEDYS BUSH	CASHMERE	43°35'45.94"S	172°34'20.50"E
CANTERBURY	CASHMERE	SUTHERLANDS	43°35'36.84"S	172°34'55.01"E
CANTERBURY	SABYS	CANDYS	43°35'34.78"S	172°33'28.27"E
CANTERBURY	RYANS	GRAYS	43°30'28.80"S	172°31'27.46"E
CANTERBURY	GARDINERS	STYX MILL	43°28'3.71"S	172°35'21.85"E
CANTERBURY	POUND	ROBERTS	43°31'39.64"S	172°30'0.37"E
CANTERBURY	McTEIQUE	HALSWELL JUNCTION	43°34'2.63"S	172°32'17.52"E
CANTERBURY	THRELKELDS	MILL	43°22'7.36"S	172°35'36.94"E
CANTERBURY	KETTLEWELL	MINERS	43°30'38.45"S	172°26'45.63"E
CANTERBURY	GOLF LINKS	RANGIORA WOODEND	43°18'2.63"S	172°36'59.83"E
CANTERBURY	GRESSONS	RANGIORA WOODEND	43°18'32.17"S	172°38'16.81"E
CANTERBURY	GRESSONS	SH1	43°17'47.96"S	172°41'2.77"E
CANTERBURY	WAIKUKU BEACH	SH1	43°17'21.97"S	172°41'6.35"E
CANTERBURY	LEADLEYS	TAITAPU (SH75)	43°36'25.50"S	172°33'32.78"E
CANTERBURY	NORTHWOOD	TRAM	43°21'8.43"S	172°25'59.88"E
CANTERBURY	BUCHANANS	OLD WEST COAST	43°30'27.80"S	172°27'59.75"E
CANTERBURY	SH75	OLD TAI TAPU	43°36'4.60"S	172°33'34.90"E
CANTERBURY	SH1	HARLESTON	43°13'39.47"S	172°43'37.09"E

Appendix C: Sites with new data (2010–2014)

Table C.1 New sites surveyed with 2012 traffic volumes and 2010–2014 crash data (urban and rural)

Region	Main road	Side road	Latitude	Longitude
WAIKATO	SH1	POIHIPI RD	38°40'23.99"S	176° 4'9.92"E
WAIKATO	SH1	SH29	37°56'35.79"S	175°40'6.36"E
WAIKATO	SH29	CAMBRIDGE RD	37°44'19.84"S	176° 5'55.65"E
BAY OF PLENTY	FAIRY SPRINGS RD	OLD QUARRY RD	38° 6'58.54"S	176°13'35.66"E
HAWKE'S BAY	PREBENSEN RD	TAMATEA DR	39°29'47.27"S	176°52'12.52"E
HAWKE'S BAY	GLOUCESTER ST	LEE RD	39°32'19.37"S	176°50'51.20"E
HAWKE'S BAY	SH2	NAPIER RD	39°37'11.27"S	176°53'34.31"E
TARANAKI	SH3	EGMONT RD	39° 2'34.30"S	174° 7'28.80"E
LOWER NORTH IS	TENNENT RD	MASSEY UNIVERSITY RD	40°22'53.22"S	175°36'56.28"E
LOWER NORTH IS	TAUPO QUAY	SOUTH HILL ST	39°56'8.82"S	175° 3'15.96"E
WELLINGTON	CALABAR RD	CALEDONIA ST	41°19'14.51"S	174°48'33.44"E
WELLINGTON	SH1	RAUMATI RD	40°55'36.05"S	174°59'56.09"E
WELLINGTON	SH1	IHAKARA ST	40°55'16.25"S	175° 0'10.95"E
WELLINGTON	SH RIVER RD	MOONSHINE HILL RD	41° 7'30.38"S	175° 1'51.34"E
WELLINGTON	SH RIVER RD	WHAKATIKI RD	41° 7'4.22"S	175° 2'48.50"E
WELLINGTON	TITAHI BAY DR	PROSSER ST	41° 7'54.63"S	174°50'12.30"E
WELLINGTON	KENEPURU DR	RAIHA ST	41° 8'56.86"S	174°49'59.73"E
WELLINGTON	SH2	EAST TARATIHI	40°58'51.37"S	175°35'7.69"E
WELLINGTON	SH1	WAITARERE BEACH RD	40°33'59.66"S	175°15'55.04"E
WELLINGTON	SH1	SH57	40°38'52.67"S	175°15'37.19"E
WELLINGTON	SH3	RALEIGH ST	39° 0'56.23"S	174°13'2.52"E
WELLINGTON	SH3	SH3A	39° 1'16.76"S	174°11'40.70"E
WELLINGTON	SH1	PEKAPEKA RD	40°50'25.96"S	175° 5'12.57"E
WELLINGTON	SH58	JOSEPH BANKS	41° 6'25.14"S	174°54'53.41"E
WELLINGTON	SH2	NORANA RD	41° 6'2.09"S	175° 6'14.73"E
WELLINGTON	SH2	TOPAZ ST	41° 5'49.48"S	175° 6'46.44"E
WELLINGTON	EASTERN HUTT RD	REYNOLDS BACH	41° 8'58.19"S	174°59'35.07"E
WELLINGTON	SH57	QUEEN ST	40°37'49.43"S	175°18'23.30"E
WELLINGTON	SH2	AKATARAWA RD	41° 6'17.70"S	175° 5'53.97"E
CANTERBURY	SH1	BELFAST RD	43°26'56.16"S	172°37'47.51"E
CANTERBURY	SH1	SELWYN LAKE RD	43°38'53.14"S	172°13'42.22"E
CANTERBURY	SH1	TELEGRAPH RD	43°38'27.72"S	172°14'47.79"E
CANTERBURY	SH1	WILLIAMS STREET	43°21'9.27"S	172°39'46.49"E
CANTERBURY	SH74	TRAVIS COUNTRY DRIVE	43°29'32.07"S	172°41'16.78"E
CANTERBURY	SH1	OLD SOUTH RD	43°41'24.57"S	172° 6'51.90"E
CANTERBURY	SH75	OLD TAI TAPU RD	43°36'4.60"S	172°33'34.90"E

Region	Main road	Side road	Latitude	Longitude
CANTERBURY	WEST COAST RD	BANGOR RD	43°29'17.37"S	172° 6'20.51"E
CANTERBURY	MAIN SOUTH RD	NORTHPARK RD	43°52'51.86"S	171°46'55.21"E
CANTERBURY	MAIN SOUTH RD	WORKS RD	43°52'14.38"S	171°47'53.93"E
CANTERBURY	MAIN NORTH RD	ENGLEFIELD RD	43°27'26.44"S	172°37'27.82"E
CANTERBURY	MAIN NORTH RD	PA RD	43°20'54.67"S	172°39'51.30"E
CANTERBURY	SH1	HARLESTON RD	43°13'39.47"S	172°43'37.09"E
CANTERBURY	SH1	TENNYSON ST	43°35'26.50"S	172°22'44.46"E
CANTERBURY	SH73	HASKETTS RD	43°30'41.06"S	172°29'54.28"E
CANTERBURY	SH1	BARTERS RD	43°33'1.17"S	172°29'12.44"E
CANTERBURY	MARSHLAND RD	MAIN NORTH RD	43°25'57.64"S	172°38'59.44"E
CANTERBURY	SH1	AVONHEAD RD	43°29'51.85"S	172°32'50.15"E
CANTERBURY	SH74	GRIMSEYS RD	43°29'8.24"S	172°37'35.27"E
CANTERBURY	NORTHCOTE RD	CAVENDISH RD	43°29'2.69"S	172°36'22.15"E
CANTERBURY	SH73	PRISON RD	43°31'1.30"S	172°27'18.95"E

Table C.2 Turner and Roozenburg 2007 research sites with 2012 traffic volumes and 2010–2014 crash data (urban)

Region	Main road	Side road	Latitude	Longitude
AUCKLAND	LADIES MILE	ABBOTTS WAY(G)	36°53'20.16"S	174°48'41.23"E
AUCKLAND	BALMORAL	HENLEY(G)	36°53'19.39"S	174°45'18.32"E
AUCKLAND	CAMPBELL	MOANA	36°54'23.25"S	174°47'16.25"E
AUCKLAND	MT SMART	SELWYN	36°54'47.78"S	174°46'54.65"E
CANTERBURY	BREEZES	CUTHBERTS	43°31'22.33"S	172°42'30.32"E
CANTERBURY	HALSWELL	TANKERVILLE(G)	43°33'22.73"S	172°35'25.33"E
CANTERBURY	MARINE PARADE	HAWKE(S)	43°30'21.25"S	172°43'49.55"E
CANTERBURY	ROSSALL	HOLMWOOD(G)	43°31'10.73"S	172°36'56.71"E
CANTERBURY	MAIN NORTH	SAWYERS ARMS(G)	43°29'28.29"S	172°36'46.32"E
CANTERBURY	PAPANUI	MAYS(S)	43°30'19.95"S	172°36'56.66"E
CANTERBURY	PAPANUI	MERIVALE LN(G)	43°30'56.81"S	172°37'27.72"E
CANTERBURY	PAPANUI	NORMANS(G)	43°30'20.93"S	172°36'57.36"E
CANTERBURY	AVONHEAD	STAVELEY(G)	43°31'16.57"S	172°33'42.15"E
CANTERBURY	WAIRAKEI	BREENS(S)	43°29'32.79"S	172°34'24.55"E
CANTERBURY	CAVENDISH	VETTCH(G)	43°28'52.90"S	172°36'23.12"E
CANTERBURY	GREERS	CLYDE(S)	43°30'15.00"S	172°34'55.36"E
CANTERBURY	MEMORIAL	KENDAL(G)	43°30'6.04"S	172°33'48.16"E
CANTERBURY	WAIRAKEI	KENDAL(G)	43°29'47.61"S	172°34'42.71"E
CANTERBURY	YALDHURST	WITHELLS(G)	43°31'28.65"S	172°32'53.57"E

Table C.3 Turner and Roozenburg 2007 research sites with 2012 traffic volumes and 2010–2014 crash data (rural)

Region	Main road	Side road	Latitude	Longitude
BAY OF PLENTY	MAKETU	KAITUNA	37°46'20.59"S	176°26'21.58"E
CANTERBURY	MARSHLAND	McSAVENEYS	43°29'6.40"S	172°39'37.92"E
CANTERBURY	MARSHLAND	BELFAST	43°27'31.30"S	172°39'29.08"E
CANTERBURY	BELFAST	GUTHRIES	43°27'13.41"S	172°38'37.40"E
CANTERBURY	GUTHRIES	FACTORY	43°26'53.19"S	172°38'51.10"E
CANTERBURY	PRESTONS	QUAIDS	43°28'28.90"S	172°39'5.65"E
CANTERBURY	PRESTONS	WALTERS	43°28'29.49"S	172°38'57.02"E
CANTERBURY	SPRINGS	HODGENS	43°34'26.74"S	172°31'7.14"E
CANTERBURY	MARSHES	FOUNTAINS	43°34'37.32"S	172°32'16.10"E
CANTERBURY	HALSWELL JN	WHINCOPS	43°34'19.74"S	172°32'44.84"E
CANTERBURY	HALSWELL JN	WIGRAM	43°34'21.33"S	172°32'47.45"E
CANTERBURY	KENNEDYS BUSH	CASHMERE	43°35'45.94"S	172°34'20.50"E
CANTERBURY	CASHMERE	SUTHERLANDS	43°35'36.84"S	172°34'55.01"E
CANTERBURY	SABYS	CANDYS	43°35'34.78"S	172°33'28.27"E
CANTERBURY	RUSSLEY	RYANS	43°30'44.97"S	172°32'19.17"E
CANTERBURY	RYANS	GREYS	43°30'28.80"S	172°31'27.46"E
CANTERBURY	JOHNS	McLEANS ISLAND	43°28'30.18"S	172°33'31.32"E
CANTERBURY	McLEANS ISLAND	POUND	43°28'32.18"S	172°32'0.02"E
CANTERBURY	GARDINERS	STYX MILL	43°28'3.71"S	172°35'21.85"E
CANTERBURY	POUND	ROBERTS	43°31'39.64"S	172°30'0.37"E

Appendix D: All layout variables

Table D.1 Layout variables and their categories

Category number	Description of category	Details	Numerical classification
General	Road category	Rural	1
		Urban	2
		Rural/tidal	3
General	Intersection type	T-intersection	1
		T-intersection with LTSL	2
		T-intersection with LTSL and seagull	3
		T-intersection with seagull	4
General	Region	Northland	1
		Auckland	2
		Waikato	3
		Bay of Plenty	4
		Hawke's Bay	5
		Taranaki	6
		Lower North Island	7
		Wellington	8
		Canterbury	9
		Dunedin	10
1	Right-turn bay	Yes	1
		No	2
2	Right turn from main road lane width (m)	Distance	m
		NA	
3	Right-turn bay taper length (m)	Distance	m
		NA	
4	Right-turn bay stacking (number. of cars assuming 1 car = 6m)	NA	
5	Main road median length (m)	Distance	m
		NA	
6	Main road median width	None	
		Painted line	1
		<0.5m	2
		0.5m–1m	3
		1m–2m	4
		>2m	5
7	Near-side number of through lanes.	One lane	1
		Two lanes	2

Category number	Description of category	Details	Numerical classification
8	Near-side shoulder width	0m	1
		0m–1m	2
		>1m	3
9	Near-side downstream feature if within 200m only. Or none	Feature	Name
		None	
10	Distance of near side downstream feature	0m–49m	1
		50m–99m	2
		100m–199m	3
		200m plus	4
11	Near-side upstream feature if within 200m only. Or none	Feature	Name
		None	
12	Distance of near-side upstream feature	0m–49m	1
		50m–99m	2
		100m–199m	3
		200m plus	4
13	Far-side number of through lanes.	One lane	1
		Two lanes	2
14	Far-side shoulder width	0m	1
		0m–1m	2
		>1m	3
15	Far-side upstream feature if within 200m only. Or none	Feature	Name
		None	*
16	Distance of far-side upstream feature (m)	0m–49m	1
		50m–99m	2
		100m–199m	3
		200m plus	4
17	Far-side downstream feature if within 200m only. Or none	Feature	Name
		None	
18	Distance of far-side downstream feature (m)	0m–49m	1
		50m–99m	2
		100m–199m	3
		200m plus	4
19	Side road number of lanes	Left turn and right turn	1
		Left-right stacked (if width >5m)	2
		Combined left and right	3

Category number	Description of category	Details	Numerical classification
20	Side road median Island	Yes	1
		No	2
21	Side road median width	Painted line	1
		<0.5m	2
		0.5m–1m	3
		1m–2m	4
		>2m	5
		No centreline	6
22	Curvature of main road at CL of side road, moderate curvature > 300m radius, sharp curvature < 300m radius (inside moderate or inside sharp or outside moderate or outside sharp or no curvature)	No curvature	1
		Outside moderate	2
		Outside sharp	3
		Inside moderate	4
		Inside sharp	5
23	Gradient of side road approach, flat = 0%, moderate < 5%, steep > 5% (steep down or moderate down or flat or moderate up or steep up)	Flat	1
		Moderate down	2
		Moderate up	3
		Steep down	4
		Steep up	5
24	Gradient of main road left-side approach, flat = 0%, moderate < 5%, steep > 5%	Flat	1
		Moderate down	2
		Moderate up	3
		Steep down	4
		Steep up	5
25	Gradient of main road right-side approach, flat = 0%, moderate < 5%, steep > 5%	Flat	1
		Moderate down	2
		Moderate up	3
		Steep down	4
		Steep up	5
26	Street lighting (full or one at top of T-intersection or none)	None	1
		One at the top of T-intersection	2

Category number	Description of category	Details	Numerical classification
		One at the side of approach road	3
		Full	4
27	Side road sign	None	1
		Give way	2
		Stop	3
28	Top of T-chevron board	Yes	1
		No	2
29	Main road speed limit	Speed	Km
30	Side road speed limit	Speed	Km
31	LTSL into main road	Yes	1
		No	2
32	LTSL into main road angle type	NA	
		Low entry angle	1
		High entry angle	2
33	LTSL into main road island profile	NA	
		Painted island	1
		Solid island and painted island	2
34	LTSL into main road control sign	NA	
		None	1
		Give way	2
		Stop	3
35	LTSL into main road pedestrian crossing	NA	
		None	1
		Zebra flush	2
		Zebra raised	3
36	LTSL off main road	Yes	1
		No	2
37	LTSL off main road angle type	NA	
		Low entry angle	1
		High entry angle	2
38	LTSL off main road island profile	NA	
		Painted island	1
		Raised solid island	2
		Solid island and painted island	3
39	Centre line side road to end of solid island of LTSL off main road (m)	Distance	m
		NA	
40	Centre line side road to end of painted island of LTSL off main road (m)	Distance	m

Category number	Description of category	Details	Numerical classification
		NA	
		None	1
40a	Distance from centre line side road to start of LTSL off main road (m or NA)	Distance	m
		NA	
41	Length from limit line (LL) side road to end of LTSL into side road island (m or NA)	Distance	m
		NA	
42	Width of LTSL off main road flush median (m). Or painted line	NA	
		Painted line (<0.1m)	1
		0.1m–3m	2
		>3m	3
43	LTSL off main road control	NA	
		None	1
		Give way	2
		Stop	3
44	LTSL off main road offset from limit line (LL) side road (m). Positive if LTSL behind limit line. Negative if LTSL in front of limit line	Distance	m
		NA	
45	LTSL off main road pedestrian crossing	NA	
		None	1
		Zebra flush	2
		Zebra raised	3
46	Far side upstream splitter island type	NA	
		Painted line	1
		Hit posts	2
		Solid barrier	3
		Painted island	4
47	Far side upstream splitter island length (m)	Distance	m
		NA	
48	Far side upstream splitter island width	NA	
		Painted line	1
		<0.5m	2
		0.5m–1m	3
		1m–2m	4
		>2m	5

Category number	Description of category	Details	Numerical classification
49	Upstream median island type	NA	
		Painted line	1
		Hit posts	2
		Solid barrier	3
		Painted island	4
		Solid Island	5
50	Upstream median island length (m). If continuous, ie part of approach road then specify as 500m	Distance	m
		NA	
51	Upstream median Island width	NA	
		<0.5m	1
		0.5m–1m	2
		1m–2m	3
		>2m	4
52	Splitter island type on main road between upstream and downstream ends	NA	
		Painted line	1
		Solid	2
		Both	3
		Painted island	4
53	Splitter island length	Distance	m
		NA	
54	Splitter island maximum width	NA	*
		<0.5m	1
		0.5m–1m	2
		1m–2m	3
		>2m	4
55	Far-side downstream splitter island type	NA	
		Painted line	1
		Hit posts	2
		Solid barrier	3
		Painted island	4
56	Far-side downstream splitter island length	Distance	m
		NA	
57	Far-side downstream splitter island width	NA	
		<0.5m	1
		0.5m–1m	2
		1m–2m	3

Category number	**Description of category**	**Details**	**Numerical classification**
		>2m	4
58	Downstream median island type	NA	
		Painted line	1
		Hit posts	2
		Solid island	3
		Solid barrier	4
		Painted island	5
59	Downstream median island length. If continuous, ie part of approach road then specify as 500 (m)	Distance	m
		NA	
60	Downstream median island width	NA	
		<0.5m	1
		0.5m–1m	2
		1m–2m	3
		>2m	4
61	Acceleration lane type	NA	
		Pocket/cannot accelerate up to speed (less than 20m length)	1
		Acceleration lane	2
62	Length of acceleration lane excluding taper (m)	Distance	m
		NA	
63	Width of acceleration lane	Distance	m
		NA	
64	Wider distraction	None	2
		Distraction	4
65	Right approach visibility two metres from limit line	Distance	M
		NA	
66	Car parking	No parking	1
		One of three sides	2
		Two of three sides	3
		Three (or all) of three	4
67	Total main road width	Distance	m

Appendix E: Diagrams of typical layout variables

Figure E.1 T-intersection with typical variables

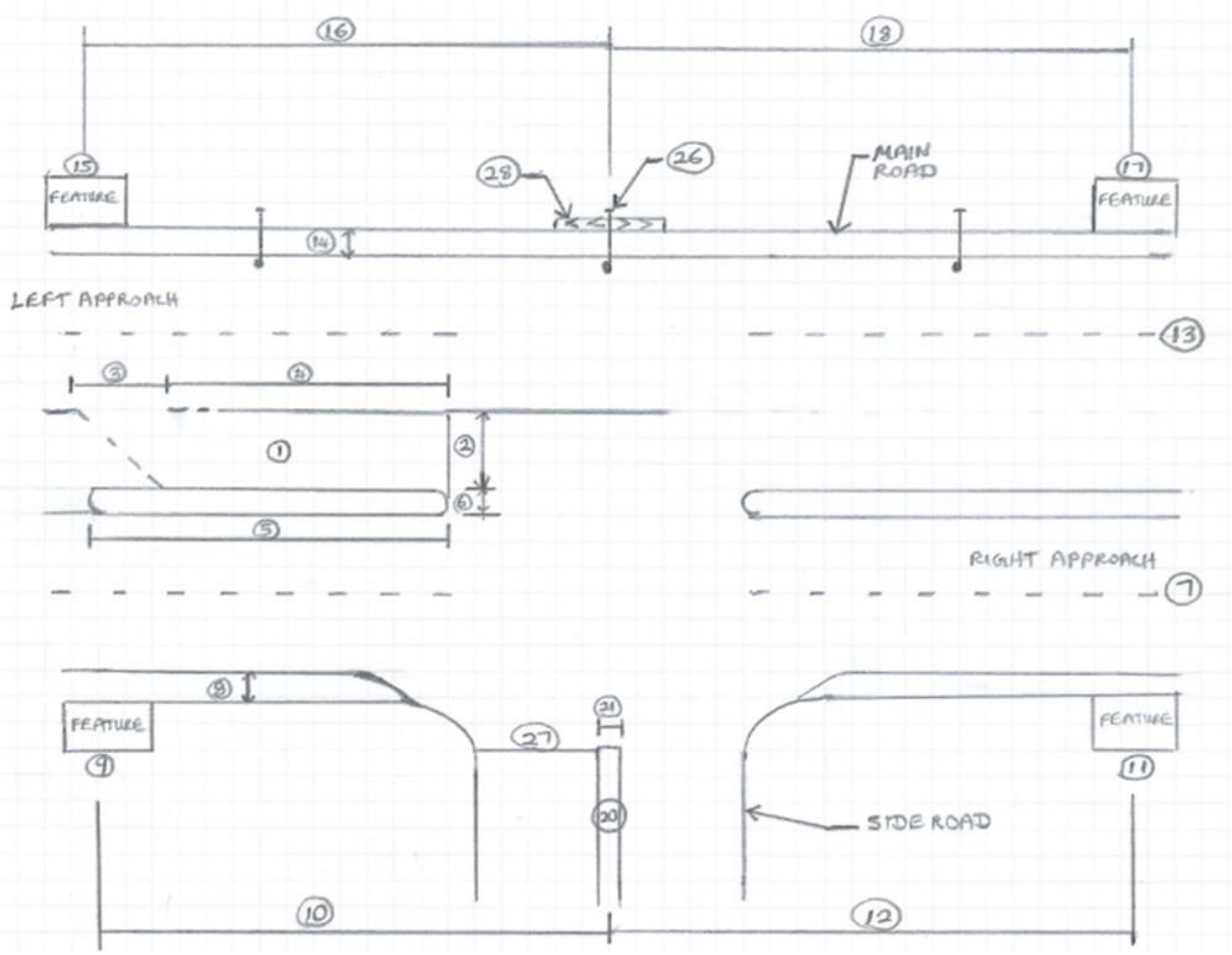


Figure E.2 T-intersection side road turning lanes

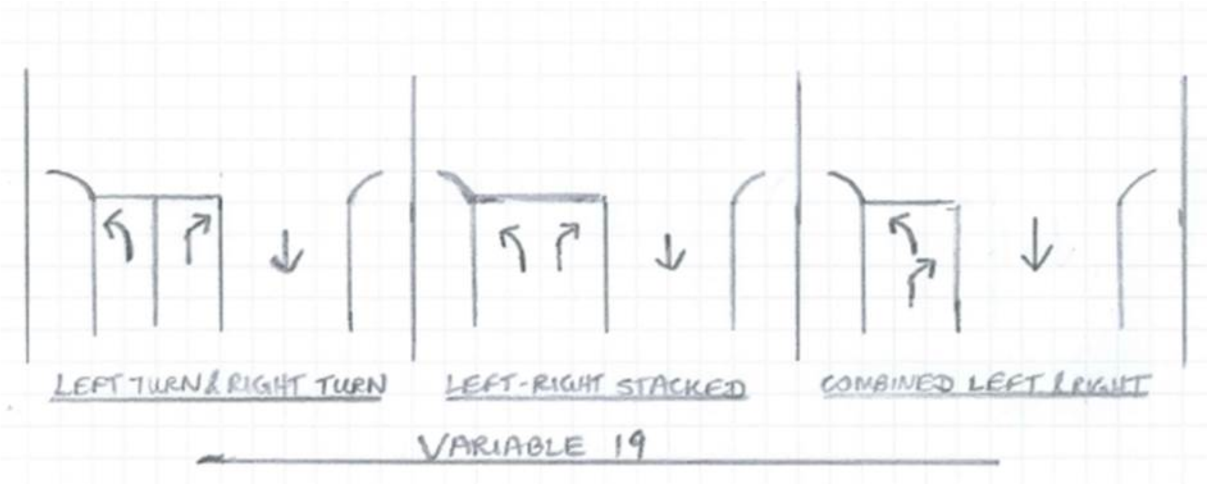


Figure E.3 T-intersection with LTSL off main road turning angles

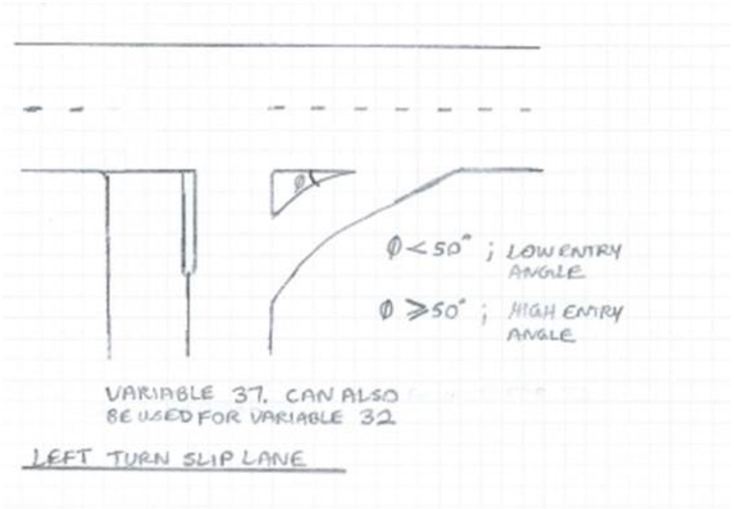
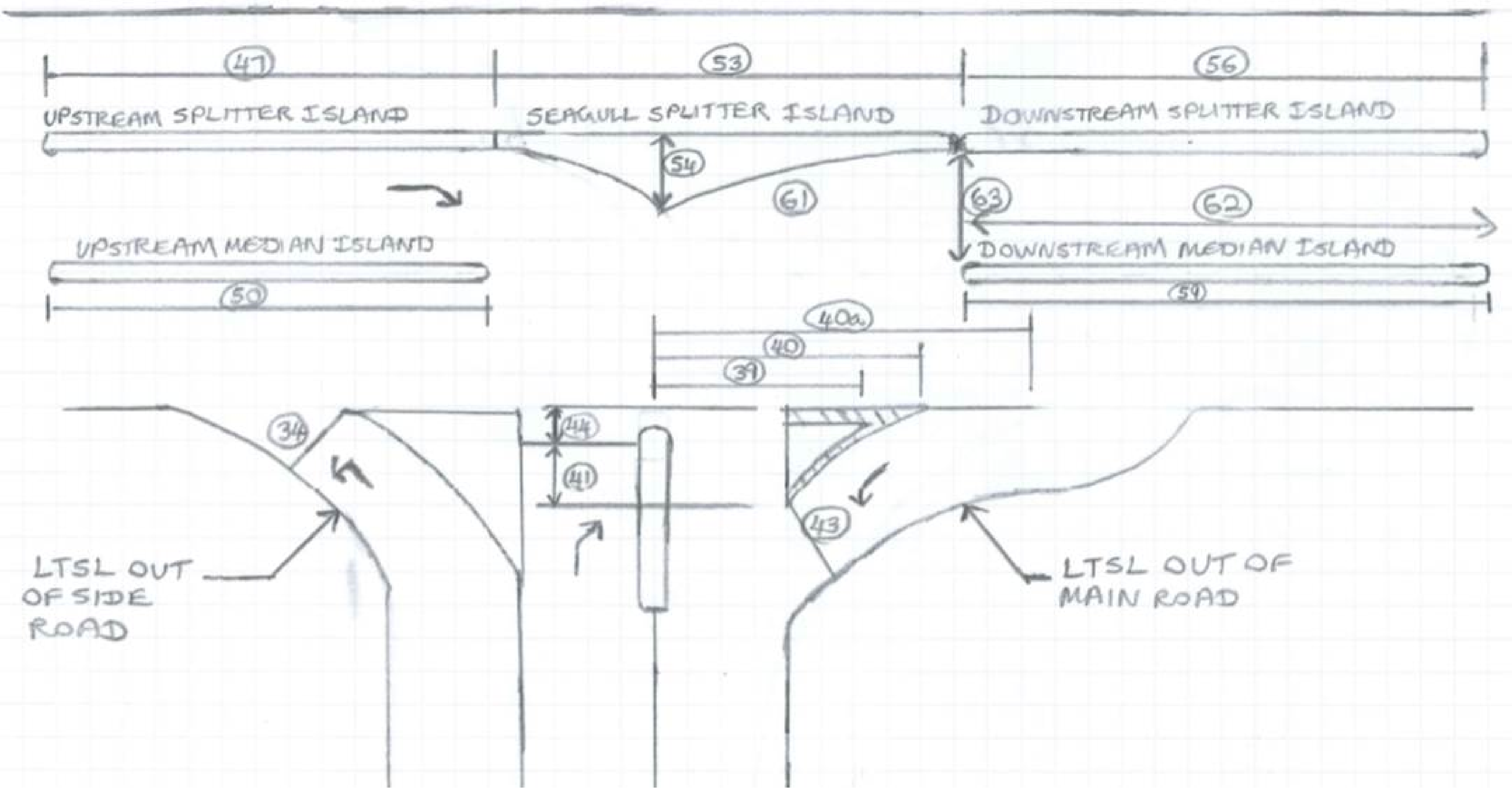
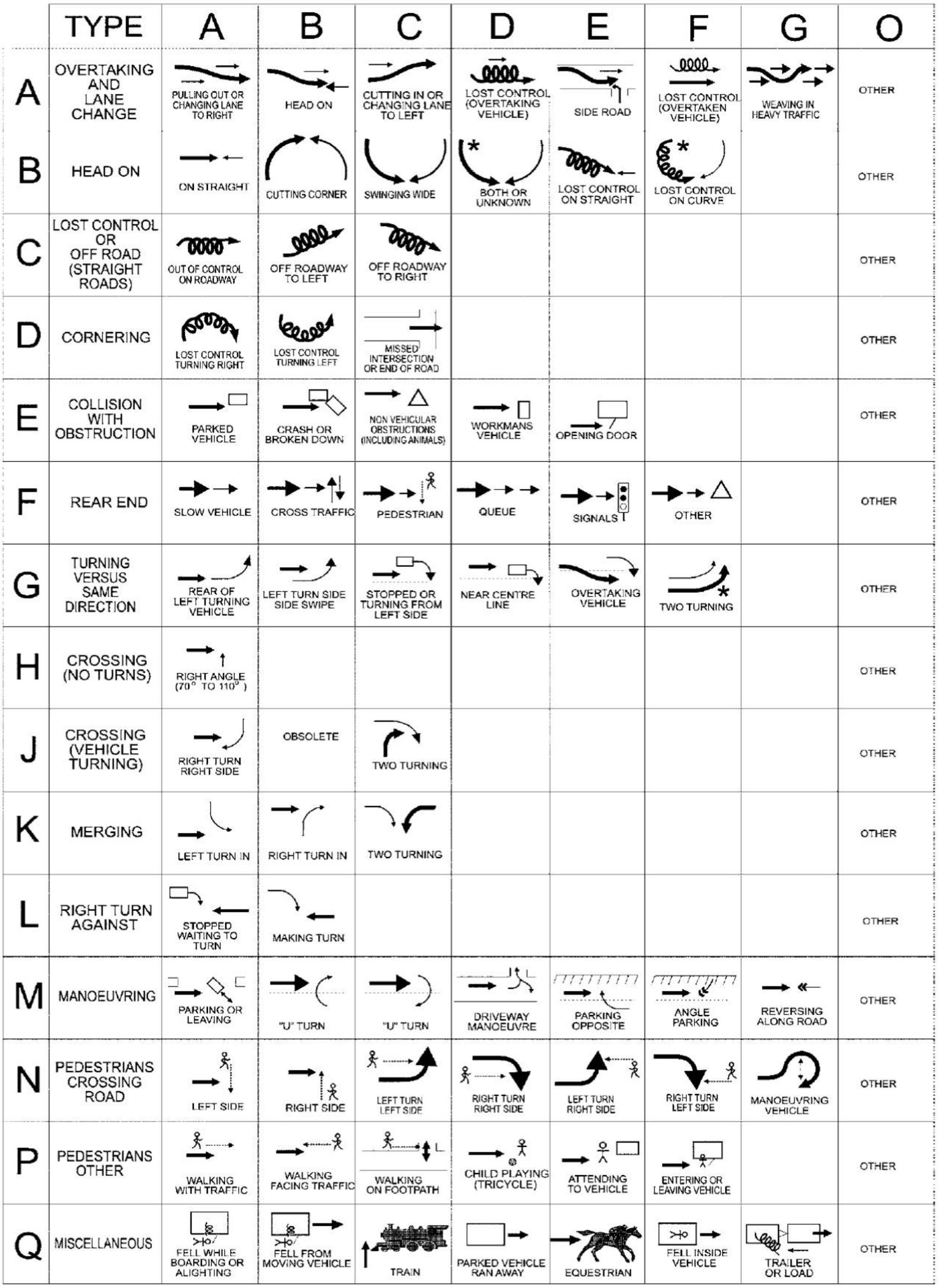


Figure E.4 Typical seagull intersection with LTSL



Appendix F: New Zealand crash coding diagram

For use with crash data from CAS (version 2.3 December 2004)



	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

Appendix G: Example of movement volume calculations

The following tables show the process undertaken to convert the 2015 movement counts to 2012 AADT counts for all movements at the Main South Road – Northpark Road intersection

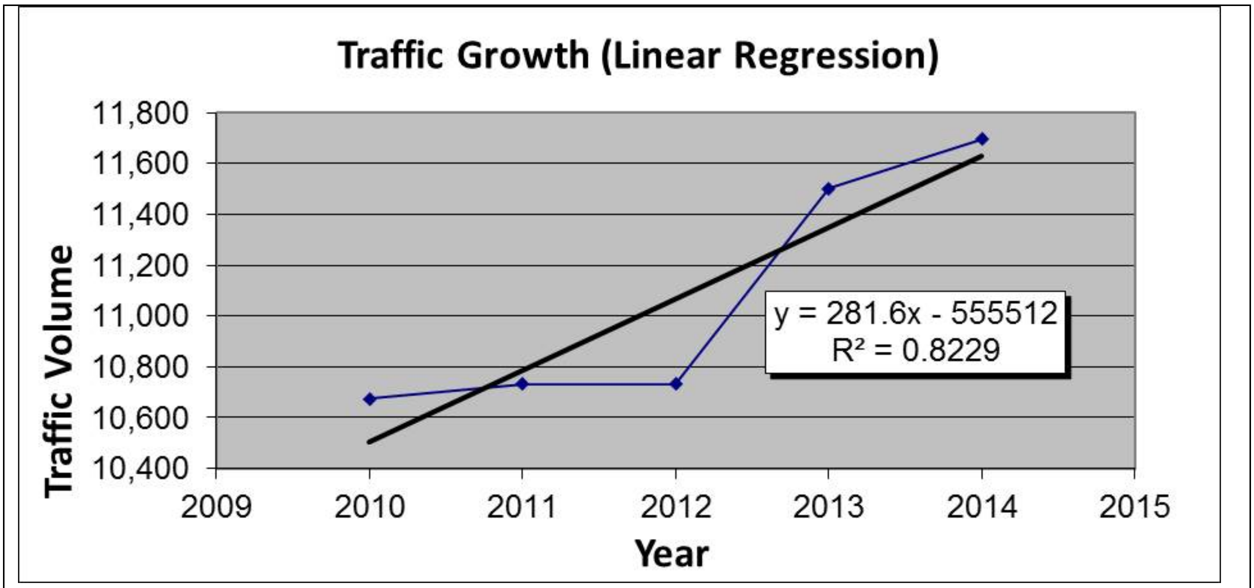
Periods		**Movement counts**					
Start	**End**	Q1 Right turn from side road to main road	Q2 Left turn from side road to main road	Q3 Right turn from main road to side road	Q4 Main road left to right looking from side road	Q5 Main road right to left looking from side road	Q6 Left turn into side road
0:00	0:15	7	4	7	89	95	5
0:15	0:30	7	4	4	102	73	2
0:30	0:45	1	11	5	96	97	6
0:45	1:00	4	7	11	102	87	3
0:00	0:15	6	11	3	96	78	2
0:15	0:30	2	11	10	78	72	4
0:30	0:45	4	8	9	82	86	5
0:45	1:00	5	7	5	85	91	2
Sum of 2-hour peak		36	63	54	730	679	29
Average peak hour		18	32	27	365	340	15

Peak hour to daily count	15	Peak hour count for a rural road is 15% of the daily flow (peak hour factor). Young et al (2003, paragraph 39).
Day of count	Wednesday	
Day factor	1.02	Turner (1995) PhD thesis
Month of count	December	
Month factor	0.92	Turner (1995) PhD thesis

2015 AADT count = (100/Peak Hour Factor) x Day Factor x Month Factor

	Q1 Right turn from side road to main road.	Q2 Left turn from side road to main road	Q3 Right turn from main road to side road	Q4 Main road left to right looking from side road	Q5 Main road right to left looking from side road	Q6 Left turn into side road
2015 AADT	113	197	169	2283	2124	91

Year	AADT volumes (Region 11, Ashburton – South of Golf Links Road), NZ Transport Agency (2017)
2010	10,673
2011	10,733
2012	10,733
2013	11,501
2014	11,697



Regression output

Constant		-555,512
X Coefficient		281.6
R squared		0.82
Time zero		2012
Time zero predicted traffic volume		11,067
Arithmetic growth rate at time zero		2.5%
Growth rate	1.025	2.5% growth rate from time zero (2012)
Year of count	2015	
Year wanted	2012	

2015 AADT Count = (2015 AADT Count)/(2015 AADT Growth Rate exp(Year of Count – Year Wanted))

	Q1 Right turn from side road to main road	Q2 Left turn from side road to main road	Q3 Right turn from main road to side road	Q4 Main road left to right looking from side road	Q5 Main road right to left looking from side road	Q6 left turn into side road
2012 AADT	105	183	157	2120	1972	84

NB: Linear method has been used to work out AADT in 2015 using peak hourly counts. Compound growth formula has been used to back calculate 2012 AADT.

Appendix H: Statistical analysis

The statistical analysis took place in three stages. First, an initial data analysis was conducted to provide an overall impression of the data. Second, models were fitted to the 'Intersection type – region – crash type' combinations with sufficient data to support model building. Third, ways in which the modelling could be used in practice were investigated. This report summarises these three phases.

A remark on the nature of this study is important. This study was not an experiment to provide confirmatory results; it was an observational study to provide indications of possible crash-explanatory variable relationships. Ideally, these would be later confirmed using 'before–after' replicated trials or a randomised controlled trial.

The second phase of the work was conducted using the following routine. For each 'Intersection type – region – crash type' combination, available data was used to construct a 'design index', a summary measure aiming to capture the unsafety of the combination. It was based on the many geometric variables measured. Crashes were then related to relevant flows, speed limit and the design index using a generalised linear model with negative binomial errors (a standard model used in these situations). The detailed steps in this second phase are described now.

1 Construction of the design index:
    a Crashes of the given type were log transformed and regressed against the log transformed two relevant flows and the speed limit (since this is the form of the final model)
    b The residuals were regressed on all geometric predictors, and those with lowest p-value selected
    c Scatterplots of the residuals against all these potential contributors to the design index were constructed and assembled in tables
    d A subset was selected, based on p-value and traffic experience applied to the situation being studied
    e Each of these variables was transformed (if necessary) to a 1-to-5 scale, with high values corresponding to unsafety
    f The values were summed and normalised to a final 1-to-5 scale to be used as a design index in the modelling phase.
2 Fitting of the model:
    a Minitab macros were used to fit a generalised linear model relating crashes to flows, speed and the design index
    b Plots of the crashes against each predictor in the model were drawn, to check on the strength of each relationship.

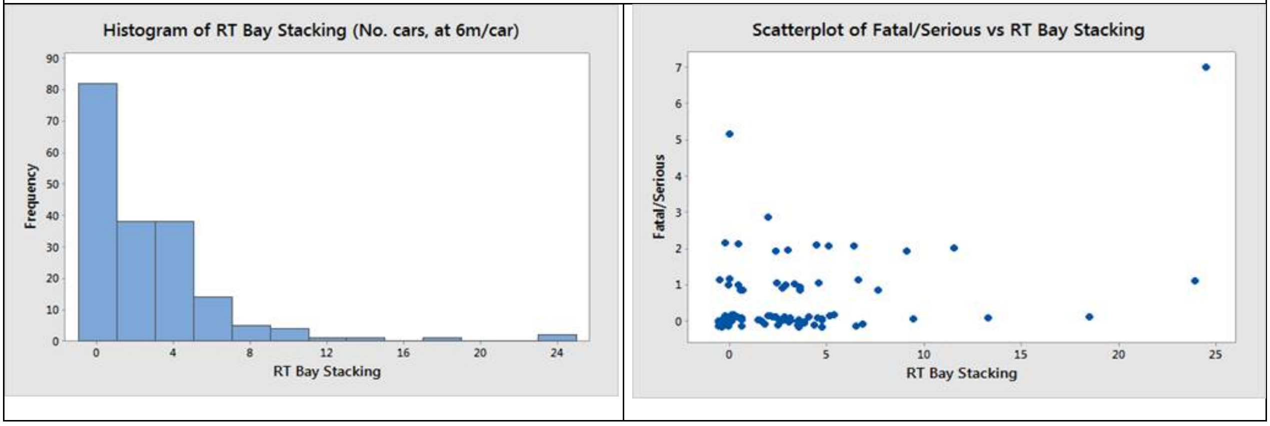
Appendix I: Analysis of predictor variables

I1 Right-turn bay stacking

Figure I.1 Right-turn bay stacking (data in the right-hand graph is jittered to be helpful)

(4) Right-turn bay stacking TLRJA, SRLB

[Larger values safer for TLRJA but less safe for SRLB]



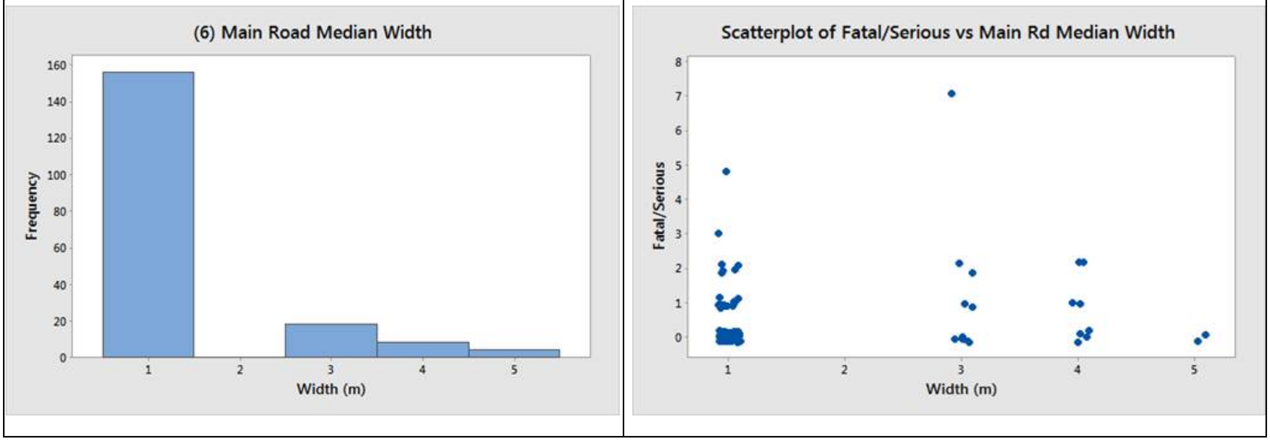
The graphs show that serious injury and fatal crashes tend to increase with right-turn bay lane width and reduce as the right-turn bay lengthens.

I2 Main road, near-side lanes

Figure I.2 Main road median width

(6) Main road median width (m) SUJA, SRJA, TUJA, SRLB

[Wider is safer for all seagull scenarios but less safe for TUJA]

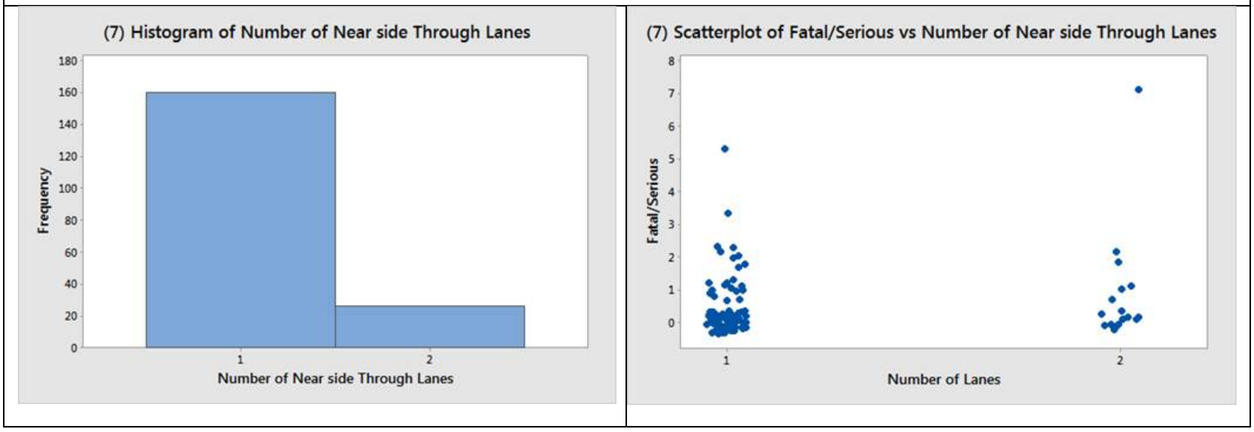


There is some evidence that serious injury and fatal crashes increase as the width of the main road median increases.

Figure I.3 Main road near-side number of lanes

(7) Number of near-side through lanes TUJA, TULB, SRJA SRLB

[The greater the number of near-side lanes, the less safe, in all cases]

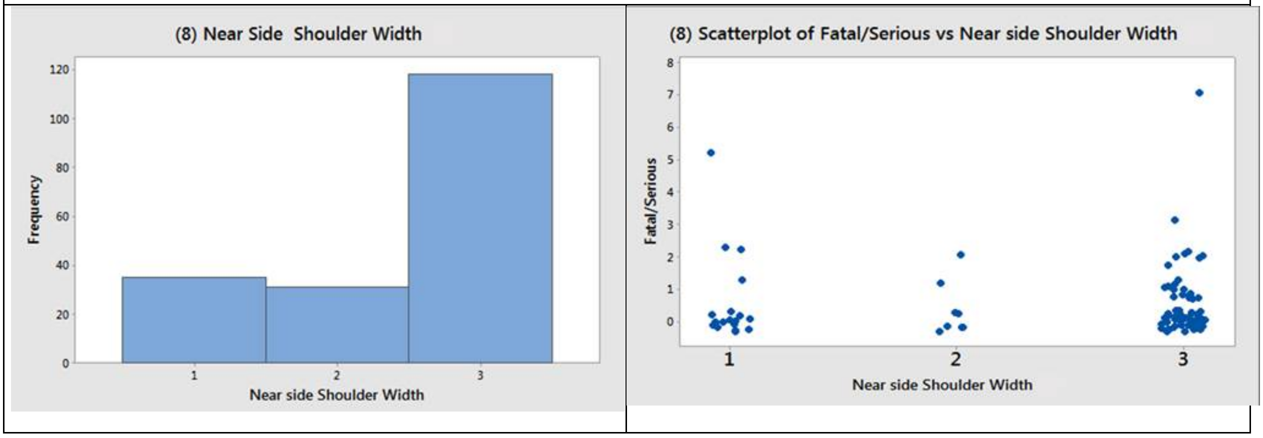


The frequency of serious injury and fatal crashes is lower when there are two near-side through lanes compared with one near-side through lane.

Figure I.4 Main road near-side shoulder width

(8) Near-side shoulder width SUJA

{The greater the shoulder width, the less safe]

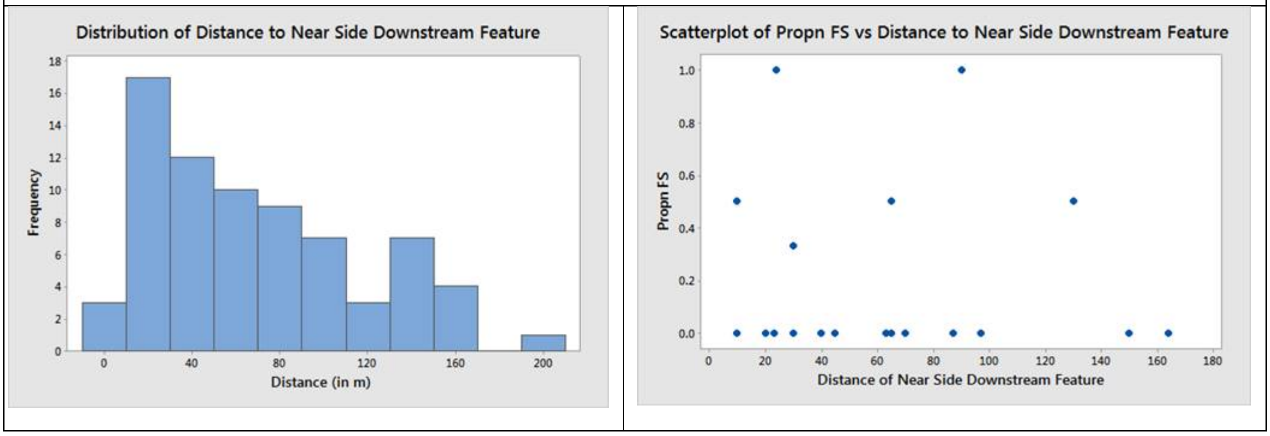


The greater the shoulder width, the less safe the intersection. This may be associated with higher-speed roads.

Figure I.5 Distance to near-side downstream feature

(10) Distance to near-side downstream feature (m) TUJA

[For TUJA, the greater the distance, the less safe]



The further away the near-side downstream feature the less safe the intersection.

I3 Main road, far-side lanes

Figure I.6 Main road number of far-side through lanes

(13) Number of far-side through lanes TULB, SRJA, SRLB

[The more lanes, the less safe for JA and LB turns, in all cases]

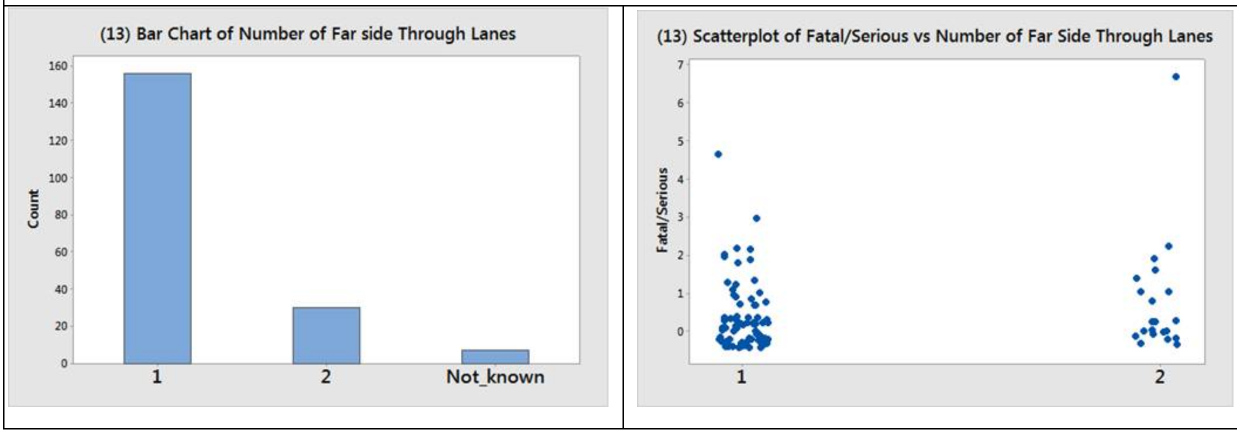


Figure I.7 Distance to far side upstream feature

(16) Distance to far side upstream feature (m), TRJA, TUJA, SUJA
[Greater the distance, the less safe for SUJA and TRJA, but safer for TUJA]

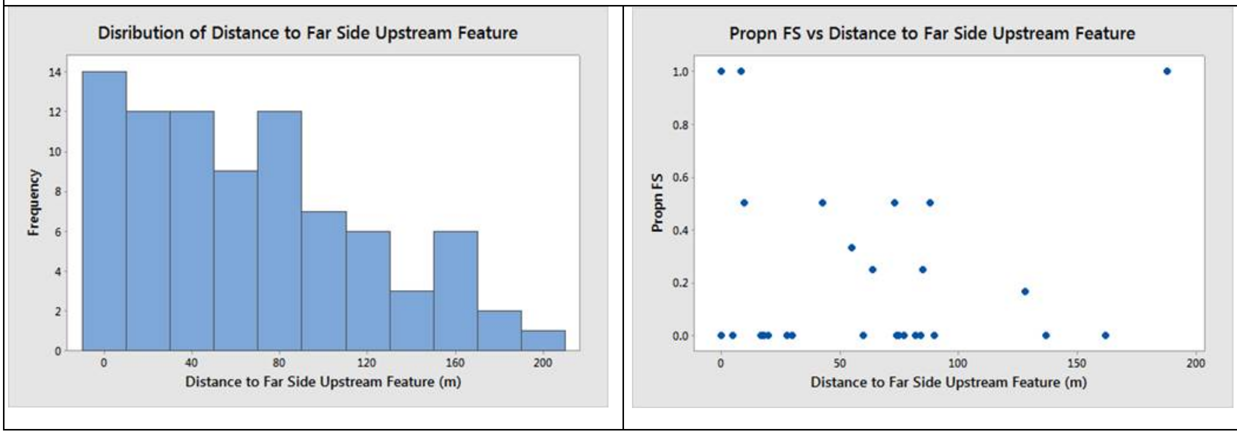
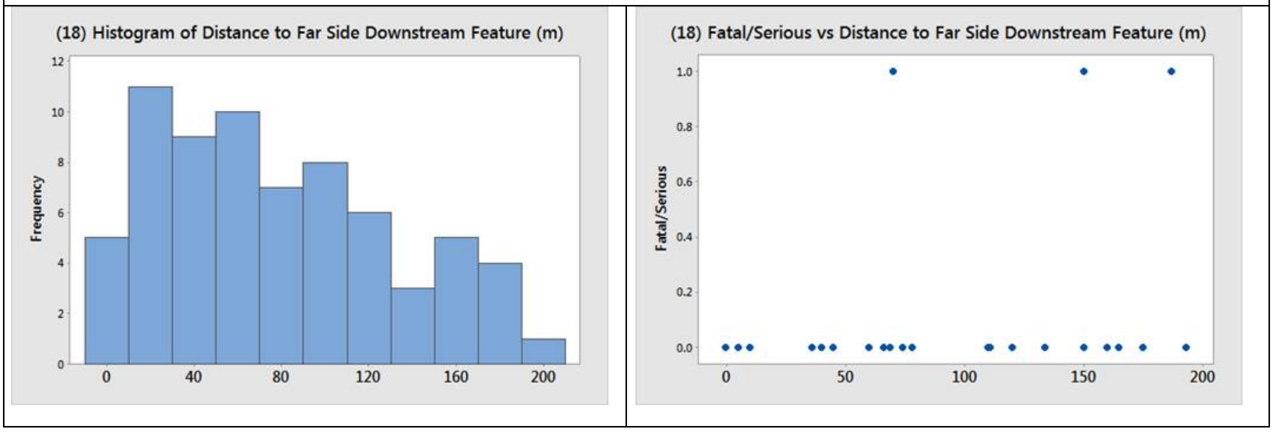


Figure I.8 Distance to far-side downstream feature

(18) Distance to far-side downstream feature (m) TULB
[Greater distance is less safe for TULB]



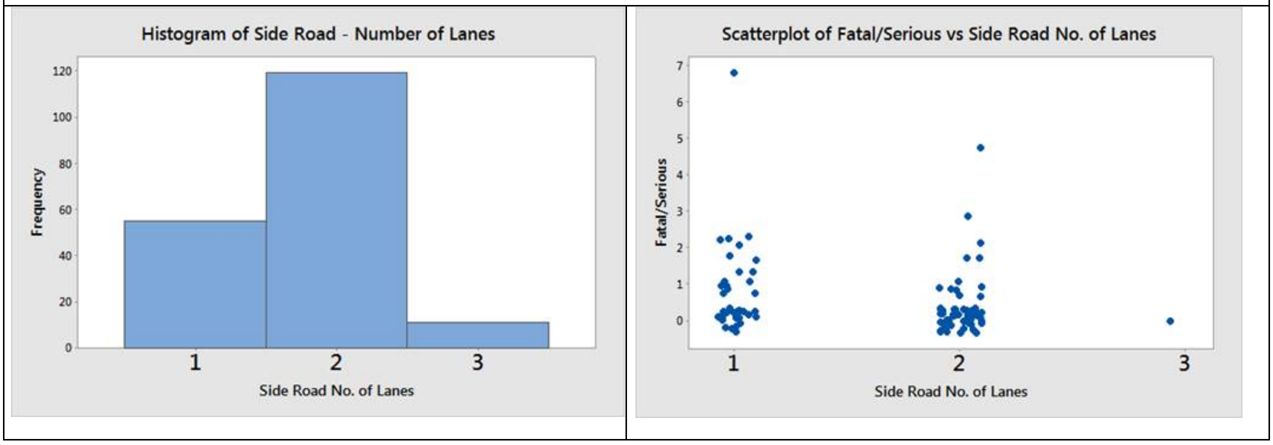
The risk of serious injury and fatal JA and LB crashes is higher for two far-side through lanes. The distance to a far-side feature has a mixed effect on the risk of a serious injury or fatal crash. For some models it made the intersection less safe, but more safe for others. Interestingly the closer the feature the less safe the intersection is for most urban T-intersections.

I4 Side road

Figure I.9 Side road lane classifications

(19) Side road – number of lanes TUJA, TULB, TLRLB

[Safer in all cases as the number of lanes increases]



The more side road traffic lanes, the safer the intersection. The fatal and serious injury crash rate increases the greater the distance to far-side downstream features.

Figure I.10 Side road median island

(20) Side road – median island (yes/no) TUJA

[Presence of median island for TUJA decreases safety]

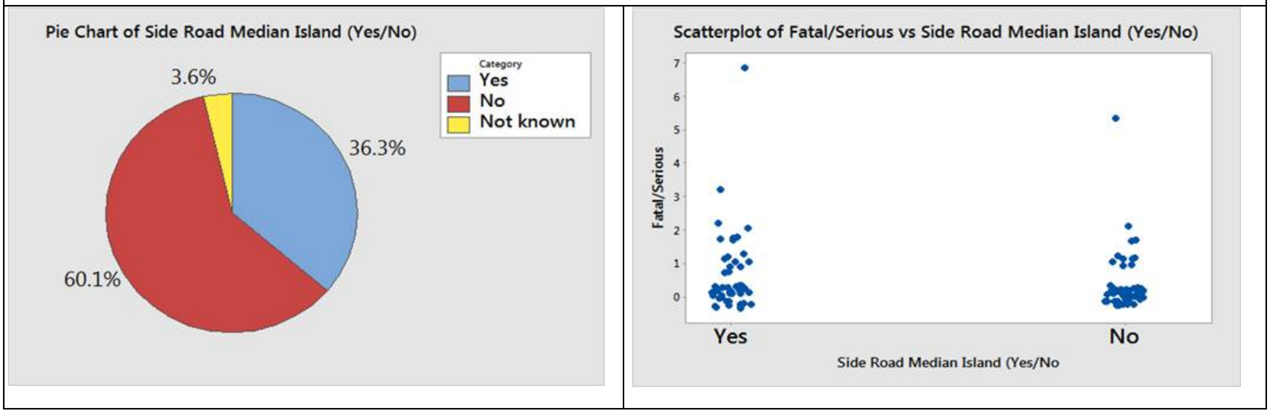
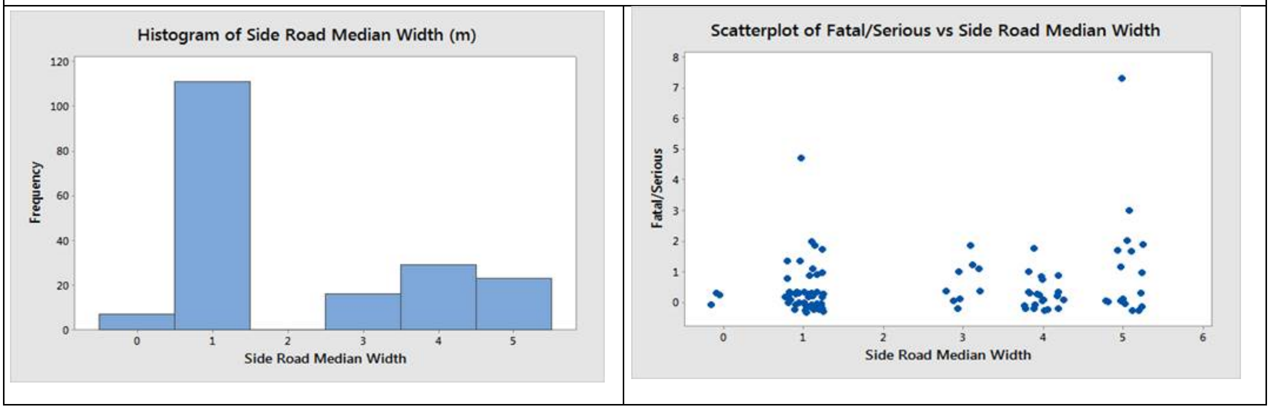


Figure I.11 Side road median island width

(21) Side road median width (m) TULB, TLRLB

[The wider the median, in both cases the less safe for LB turns]



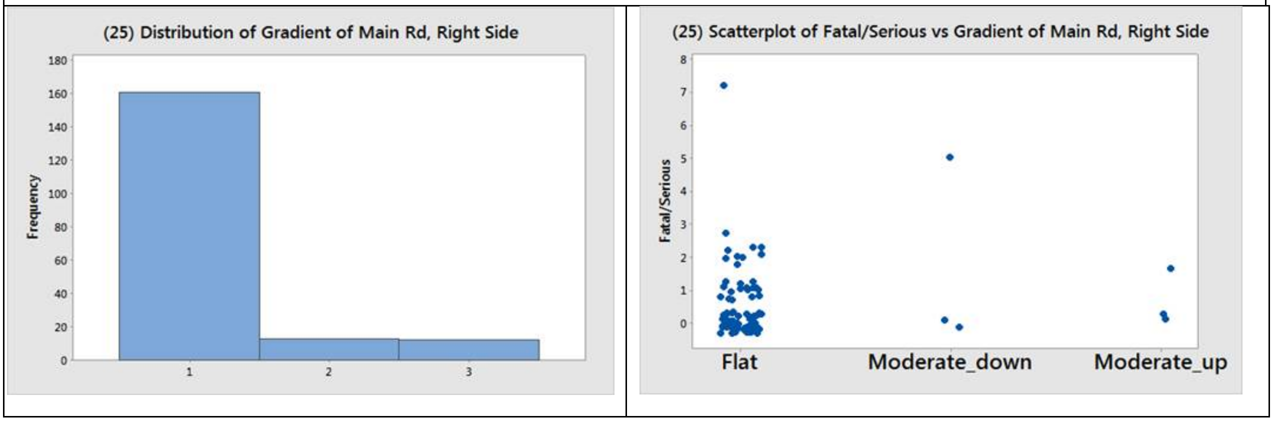
The presence of a side road median island appears to increase crashes. This may be a result of bias by selection. A median island is often applied to intersections that already have a high number of crashes. Hence there is a bias in where such treatments are applied. Before and after research indicates that crash rates generally reduce when side road medians are present. Some of the other variables are influenced by bias by selection.

I5 Gradient

Figure I.12 Gradient of main road

(25) Gradient of main road right side TUJA

[The greater the gradient in the case of TUJA, the less safe]



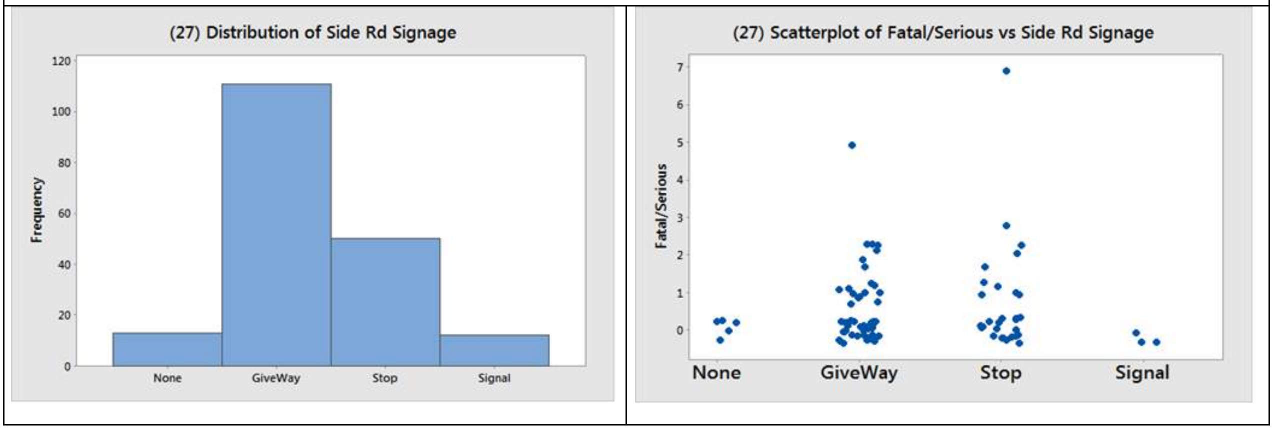
While the sample set is small, crash rates tend to increase with steeper approach gradients.

I6 Signage

Figure I.13 Side road limit line signage

(27) Side road signage (give way or stop) SRJA

[The greater this index, in the case of SRJA, the less safe]

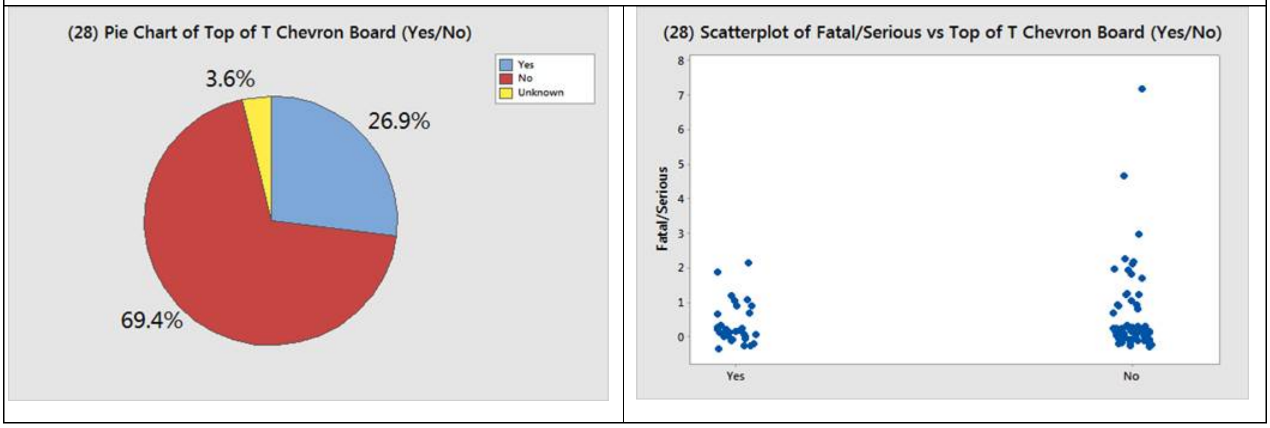


Intersections with a stop control tend to be less safe than those with a give way control. This makes sense as visibility is often restricted on the approach to stop controlled intersections. Side roads with low sight distances tend to use ‘stop’ signs. Roundabout controlled T-intersections were excluded from the study.

Figure I.14 Chevron boards

(28) Top of T- presence of Chevron board (Yes/No) TLRLB

[When chevron is absent, TLRLB is less safe]



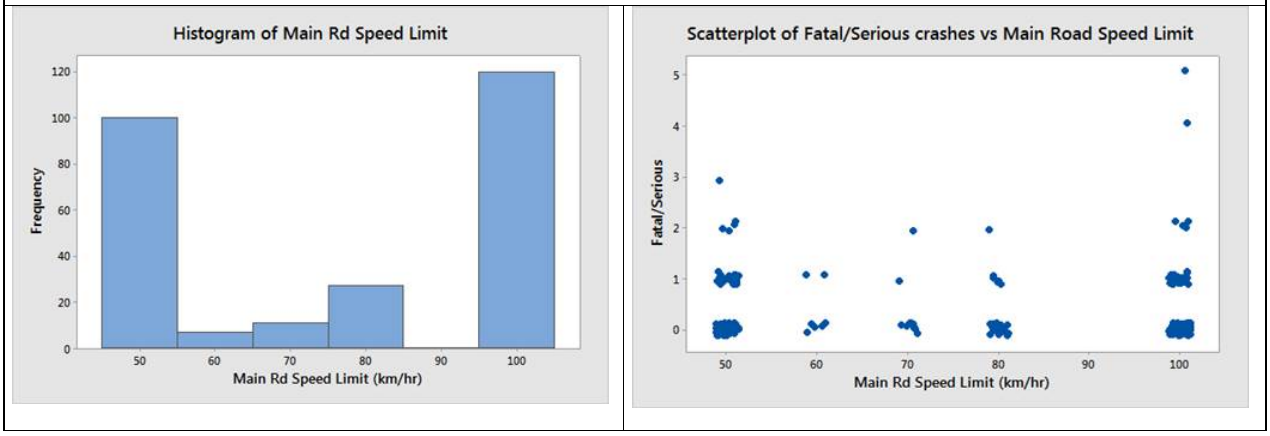
The addition of a chevron board at the ‘top of the T’ appears to result in a lower crash risk.

I7 Speed

Figure I.15 Main road speed limit

(29) Main road speed limit (in all models except SRLB and SUJA)

[The power of this predictor is positive in all models except TULB; it is not included in SRLB and SUJA]

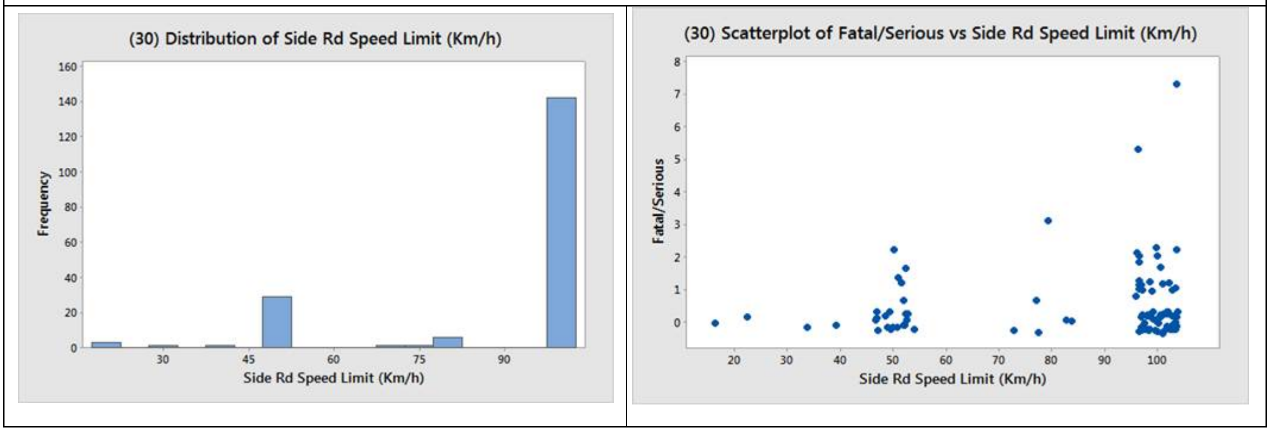


The crash risk is typically higher for intersections with main road speed limits of 100 km/h compared with 80 km/h.

Figure I.16 Side road speed limit

(30) Side road speed limit (km/h) (not in models, but included for reference)

[Generally highly correlated with main road speed limit]



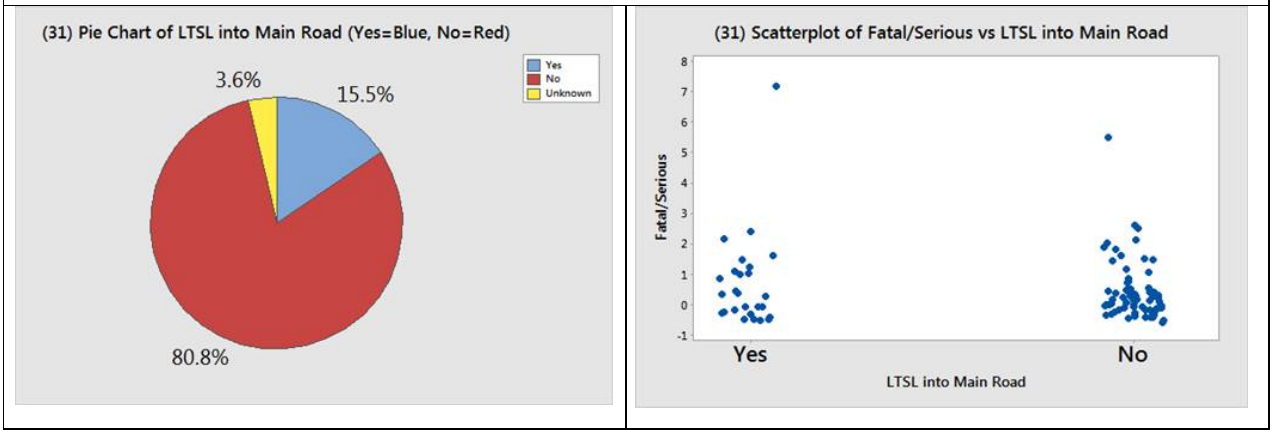
The crash risk is higher on side roads with higher speed limits.

I8 Left-turn slip lanes

Figure I.17 LTSL into main road

(31) LTSL into main road (Yes/No) SUJA

[In case of SUJA, presence of LTSL into main road is associated with greater unsafety]

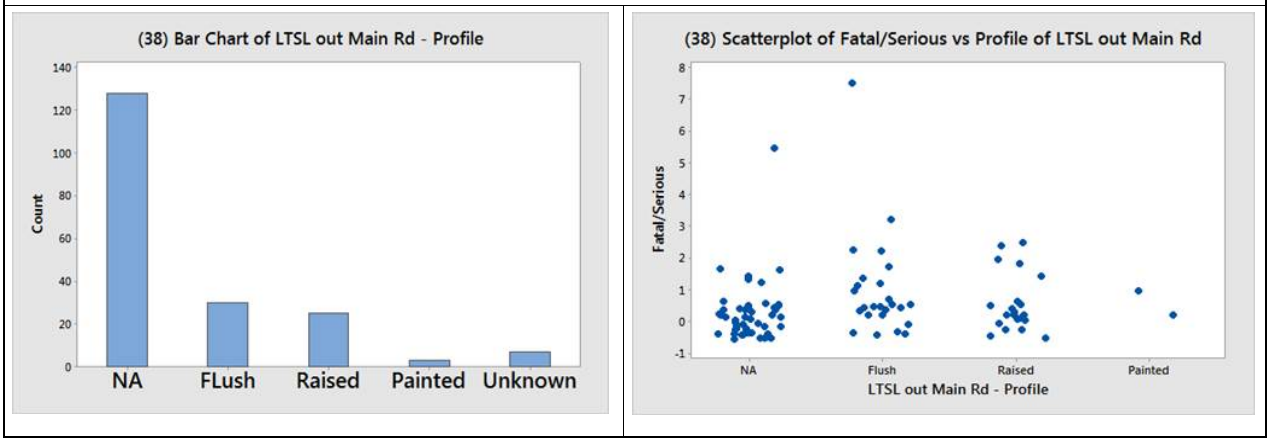


The presence of a LTSL into the main road is associated with a higher crash risk.

Figure I.18 LTSL off main road

(38) LTSL off main road – profile SRLB

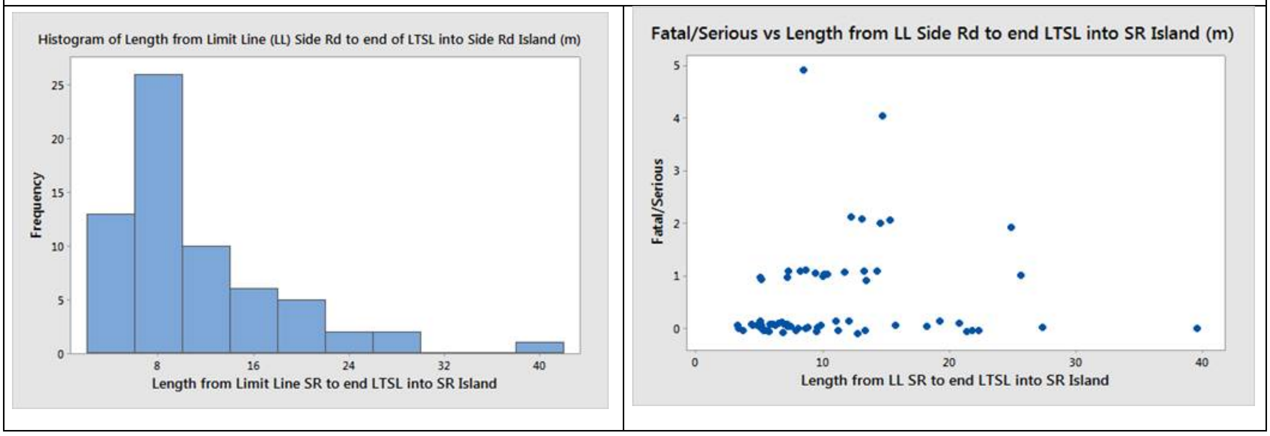
[For SRLB, the higher this index, the less safe]



Intersections with a LTSL off the main road tend to have higher crash rates than those without a LTSL.

Figure I.19 Length from side road limit line to end of LTSL into side road island

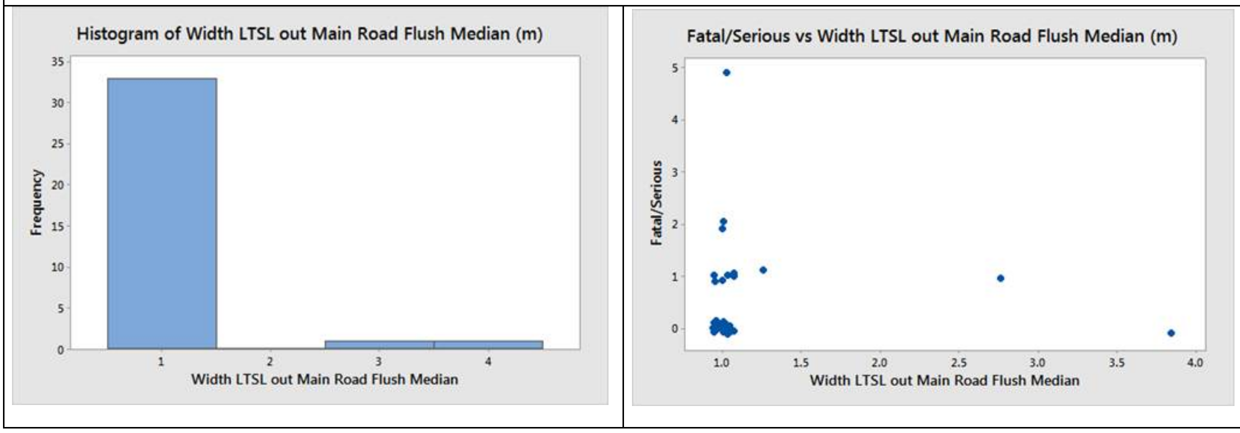
(41) Length from limit line side road to end of LTSL into side road island (m) -TLRJA
[For TLRJA, the greater this length, the safer the intersection]



Typically the further the LTSL diverge is away from the side road, the safer the intersection.

Figure I.20 Width flush median of LTSL off main road

(42) Width of LTSL off main road flush median SRJA
[For SRJA, the wider this median, the safer the JA turn]

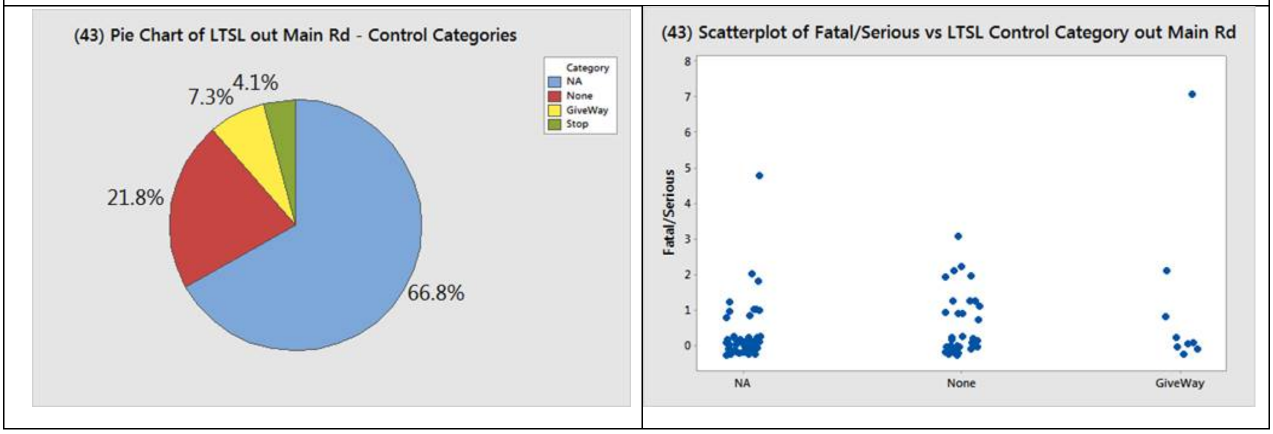


The risk of fatal and serious injury appears to reduce when a flush median is provided between the LTSL and the through lane in rural areas.

Figure I.21 Control of LTSL off main road

(43) LTSL off main road – control TLRJA

[For TLRJA, the higher this index, the safer; ie a stop control is safer than give way, which is safer than no sign]

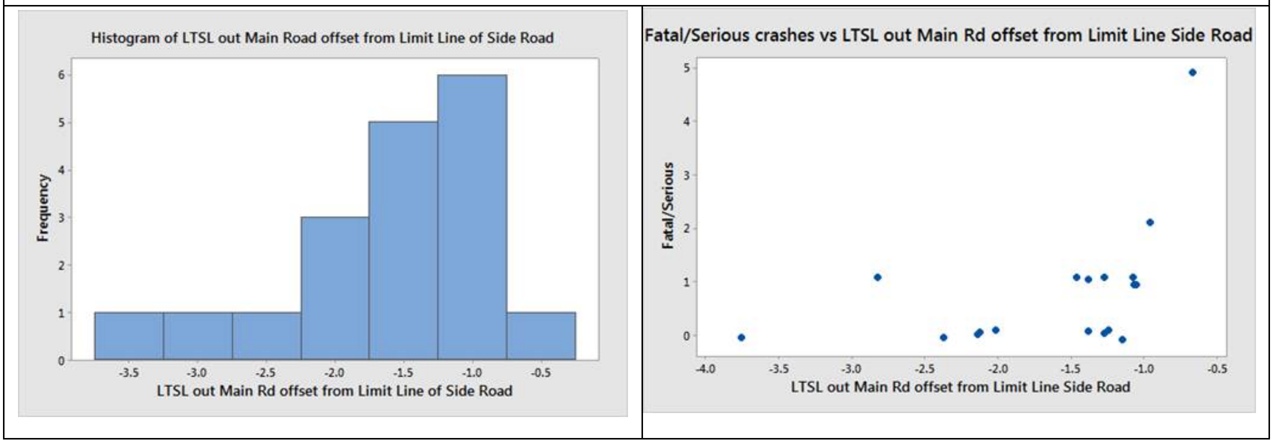


The control on the LTSL also impacts on safety in rural areas. A give way control is safer than no control.

Figure I.22 The offset of LTSL off main road from limit line side road

(44) LTSL off main road offset from limit line side road SRJA, SRLB

[The higher this offset, in both scenarios, the less safe the turn]



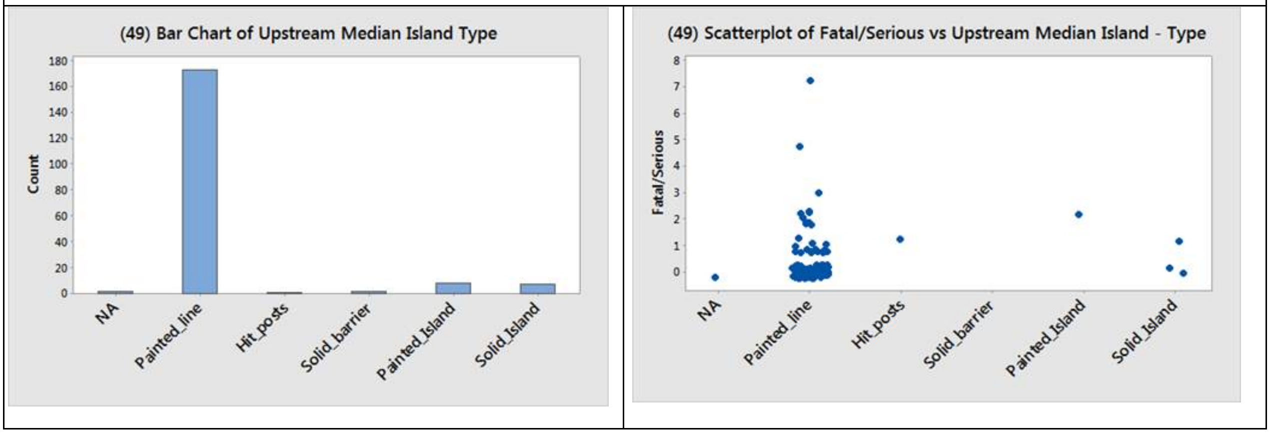
In rural areas the greater the off-set between the side road limit-line and the lane marking between the left-turn lane and through lane, the greater is the risk of crashes. When this off-set is high then left-turning vehicles are more likely to block visibility to through vehicles for vehicles turning right from side roads.

I9 Islands

Figure I.23 The type of median island upstream of main road

(49) Upstream median island – type SUJA

[The higher this index, the less safe the JA turn is for SUJA]

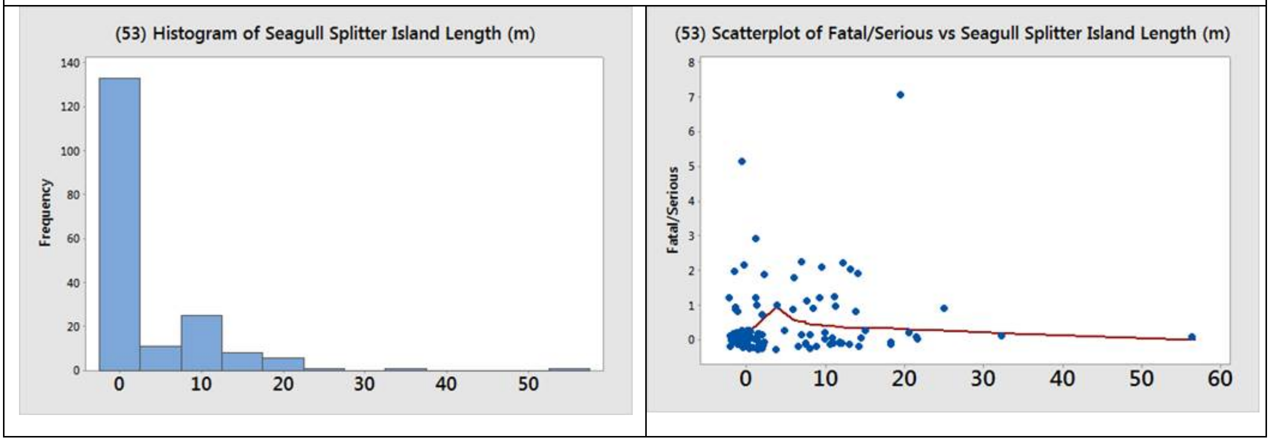


In urban areas, seagull junctions with upstream median islands (painted and solid) appear to be less safe than those with line markings only.

Figure I.24 Seagull splitter island length

(53) Seagull splitter island length (m) SUJA

[The longer the island length, the less safe it is for SUJA]

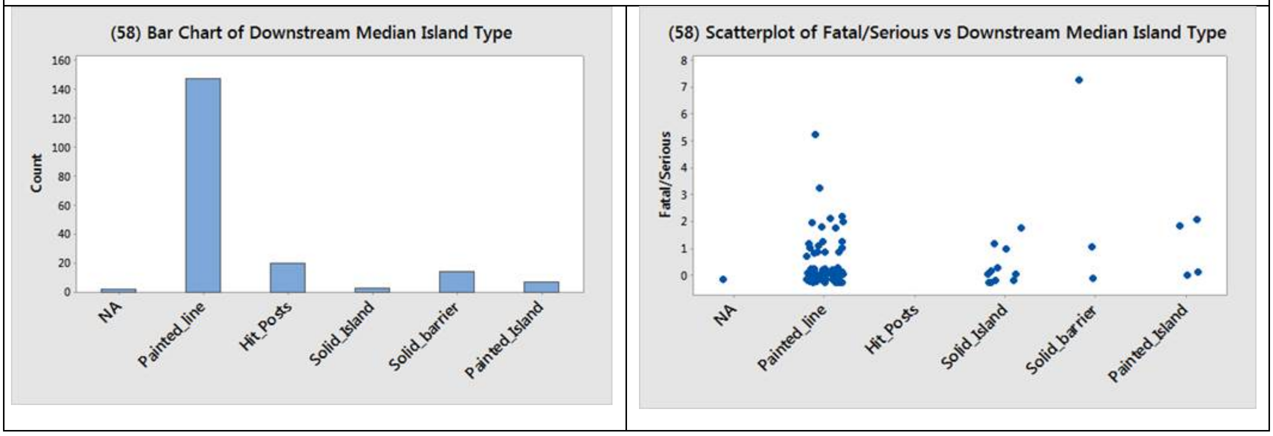


In urban areas the larger the seagull island, the less safe the seagull intersection. Hence shorter and smaller seagull intersection islands appear to be safer. A smoother line runs through the right-hand graph showing the trend.

Figure I.25 The type of median island downstream of main road

(58) Downstream median island – type TLRJA

[The higher this index for TLRJA, the safer the turn]

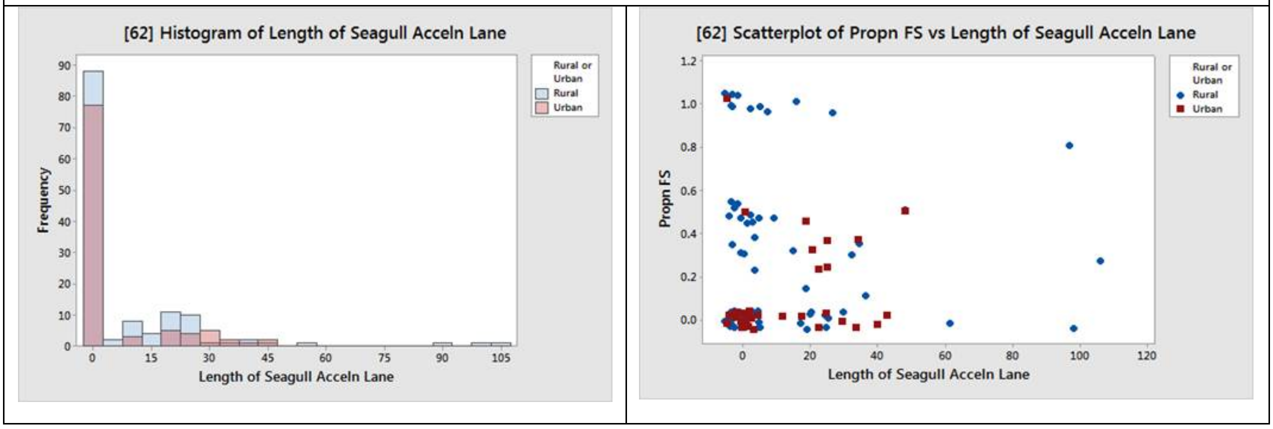


In rural areas, seagull junctions with downstream median islands and barriers appear to be safer.

Figure I.26 Length of acceleration lane

(62) Length of acceleration lane (m) SUJA

[The longer the acceleration lane for SUJA, the less safe the turn]



For urban seagull junctions, the longer the acceleration lane length the less safe is the intersection.

Appendix J: The design index and unsafety calculator

The models developed are available as an Excel file, the ‘Design index and unsafety calculator’ at www.nzta.govt.nz/resources/research/reports/644.

Appendix K: Alternative modelling approach

K1 Examination of JA crashes at T-intersections with standard and seagull layouts, both with LTSL

This section outlines a different approach to JA crash modelling, in which the JA turn is considered from a driver perspective. A crash model is proposed which incorporates the distance to be travelled, the time available (the ‘gap’), the sight distance and the number of such movements undertaken using the gap (via the Q1 and Q5 flows). All measurements except the sight distance are available in our datasets.

By fitting a model that includes all variables except sight distance and then plotting crashes against fits, we can find variables which explain lack of fit – these may contribute to sight distance. For example, we find the intersections, where a LTSL off the main road has a small angle with the main road, tend to have high crash rates. It is plausible that this angle being low obscures sight distance. Supporting this, the research found this variable raises the design index in the SUJA model, as presented in the main body of the report. This approach provides an alternative method for finding variables contributing to the unsafety of crash types.

K2 Assembling the key factors affecting JA crashes

When modelling the number of right-turn-against (JA) crashes at a T-intersection with a LTSL or seagull intersection layout, four factors are critical:

1. The distance the right-turning vehicle must travel to reach safety on the far side (in metres)
2. The distribution of gaps (gaps measured in seconds) in the right-to-left main road flow
3. The flows (in vehicles/hour) from the side road making right-turn-out movements and the flow of vehicles from right to left on the near side of the main road
4. The distribution of sight distance (in metres), namely distribution of the distance over which a driver waiting to turn right can adequately see oncoming vehicles.

Comments about these four factors:

- The driver of a right-turn-out vehicle needs to consider the distance to be travelled, the gap size and sight distance. The number of such movements with crash potential is determined by the flow on the side road and the flow on the main road. Together they arguably constitute the key factors determining crash numbers.
- Other factors will be at work, such as time of day, weather and local demographics. These are not quantified in our study and hence add to the ‘error’, in the statistical sense, in the modelling.
- The *distribution* of gaps should be dealt with in any analysis (since it may be that extremes are important), but that is beyond this study. Here we replace the distribution by the mean value.

K3 Building a model

In the current study we do have relevant measurements, namely:

1. D, the number of near side lanes and lane widths is a measure of distance to travel to safety.

2 The sight distance (SD) and main road speed limit (MRSL) enable us to calculate the average gap (G) as SD/MRSL, in units of time.

3 Q1 is the vehicle flow turning right out of the side road and Q5 is the right-to-left main road flow.

4 SD was not measured, but we do have a number of possibly related measures (eg offset of LTSL from limit line of side road).

We expect that the rate of JA crashes, Y(JA), can be expressed as

$$Y(JA) = C\, D^{b1}\, (1/G)^{b2}\, Q1^{b3}\, Q5^{b4} \qquad \text{(Equation K.1)}$$

where G is a proportionality constant. This can be re-expressed as

$$Y(JA) = C\, D^{b1}\, MRSL^{b2}\, Q1^{b3}\, Q5^{b4}\, SD^{-b2} \qquad \text{(Equation K.2)}$$

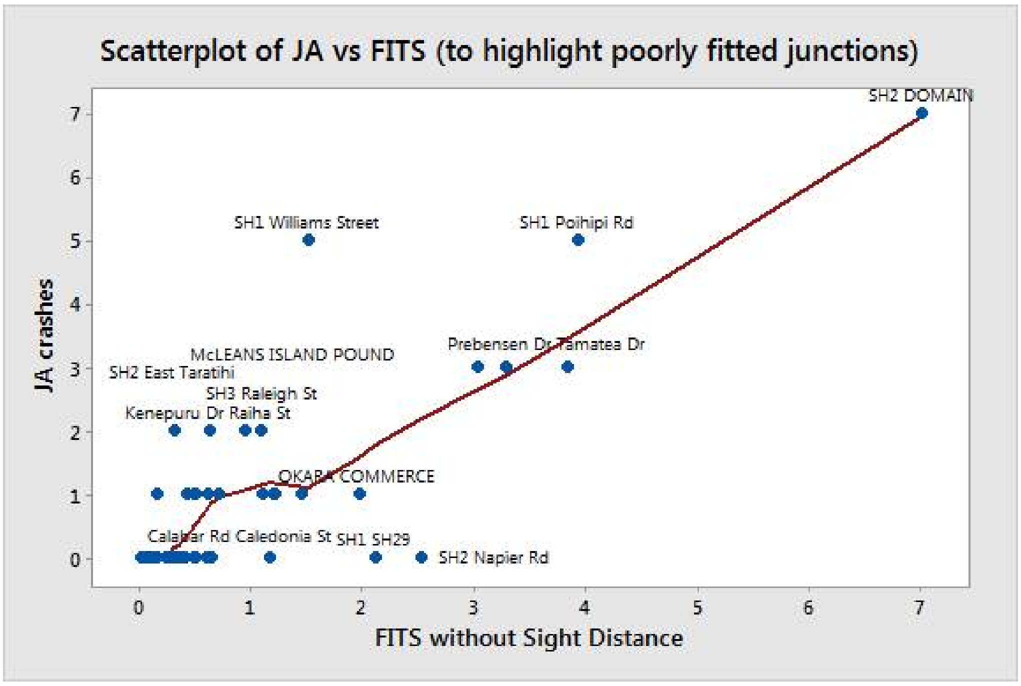
We do not have SD, so we fit this last model and look at the discrepancy between actual crashes and the line of fit. Here the fits are the expected number of crashes determined by a model that lacks a predictor of SD This discrepancy is attributable to other factors, a major one of which should be SD based on judgement.

To assess this visually we can plot the JA crashes against the fits and label points by their values on the SD variables impacting on SD. Points above the 45 degree line have unsafety not explained by the partial model. So a graph where the points above the line, for example, have shorter LTSL lengths would indicate that higher LTSL lengths could improve SD.

These graphs, separately for certain potentially SD-related variables (chosen to illustrate the approach), are shown now, with comments as appropriate. The first labels the points with the intersection road names, simply for reference.

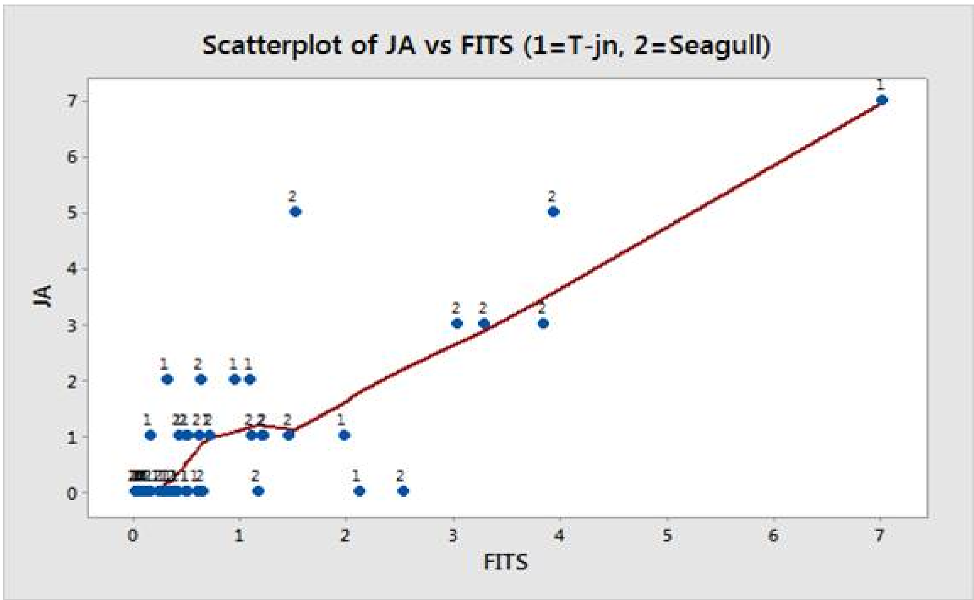
Figure K.1 plots JA crashes against the fits to the model that excludes SD. A set of intersections which are poorly fitted are named.

Figure K.1 JA vs FITS excluding sight distance



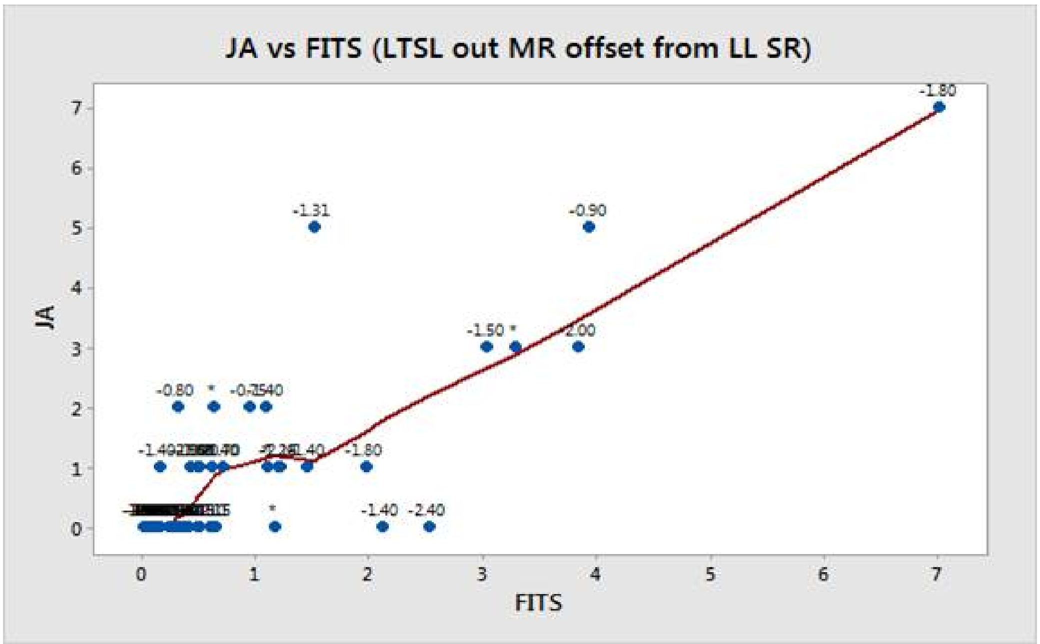
Seagull intersections are marked ‘2’ in figure K.2 below and T-intersections ‘1’. Seagull intersections slightly dominate the intersections not fully explained by the D, MRSL, Q1 and Q5 partial model:

Figure K.2 JA vs FITS (1=T-intersection, 2=seagull intersection)



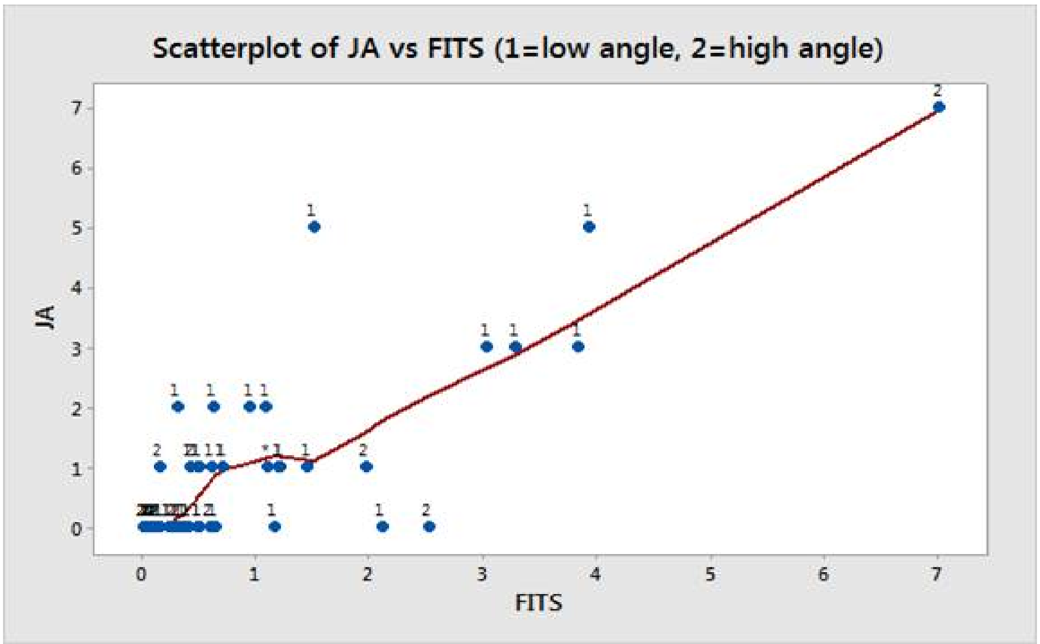
The offset of the line of the LTSL (marked line between through and left-turn lane) from the limit line of the side road is considered in figure K.3. No pattern is evident in this graph.

Figure K.3 JA vs FITS (LTSL off main road offset from limit line of side road)



Low-angle LTSLs frequently appear in the upper region of the graph where the partial model is inadequate. It is reasonable that this reduces SD.

Figure K.4 JA vs FITS (1=low angle, 2=high angle)

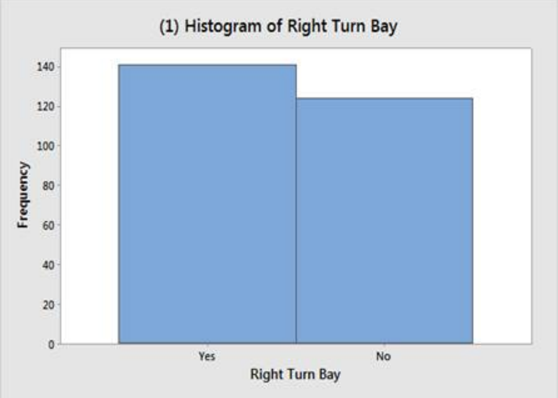


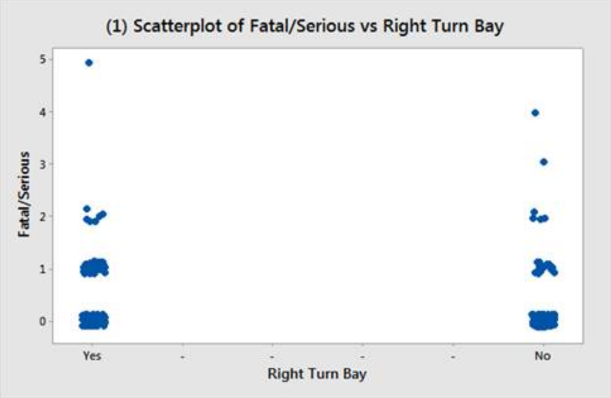
Based on the analysis we have the following findings and areas for future research:

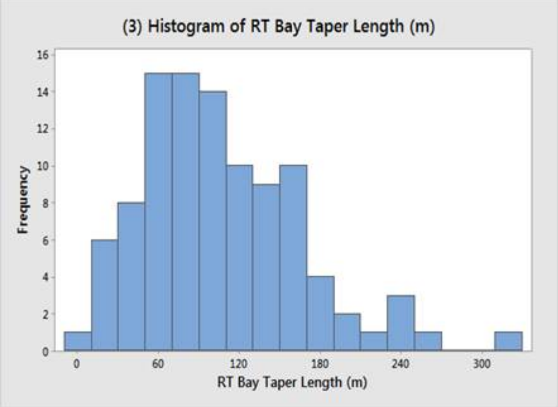
- Seagull intersections appear to have a risk factor not captured in the partial model (figure K.2).
- A likely predictor of SD is the LTSL into the side road entry angle. Low-entry angle appears less safe – and may keep left-turning-out vehicles obscuring through-right-to-left main road vehicles for longer, so affecting SD (figure K.4).
- Ideally, we need the SD measurement, to see if it explains the discrepancies around the line. If it does not, then the discrepancy must be due to other factors.
- The development of design indices and associated crash models for transitions from not just T-intersections to seagull intersections, but further from seagull intersections to roundabouts and roundabout to signals will provide an extended set of design tools.

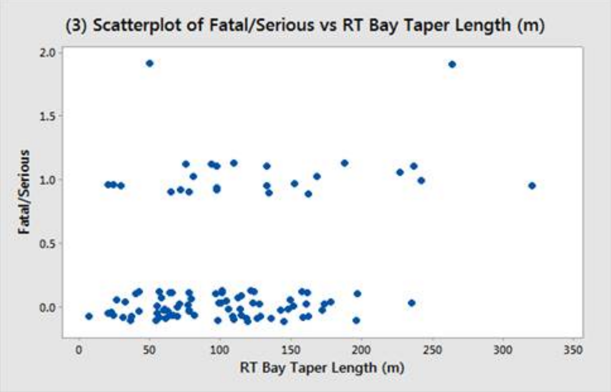
Appendix L: Graphics of variables not used in the models

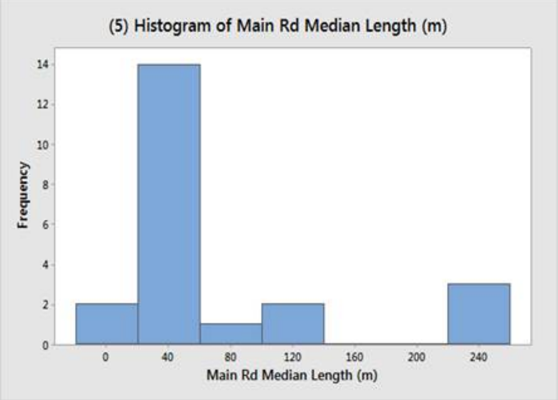
This appendix contains graphical analysis of the 37 variables that were not used in any of the models. These variables complement the graphs in appendix I and are given here for completeness.

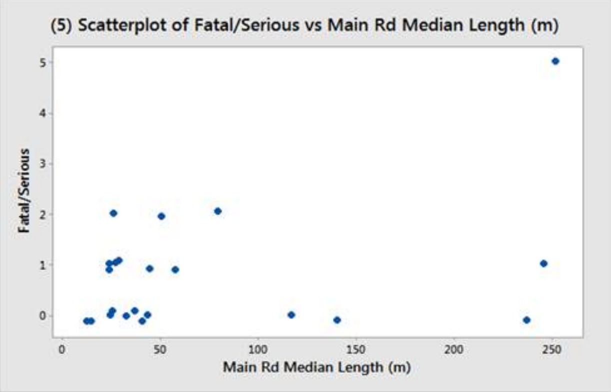


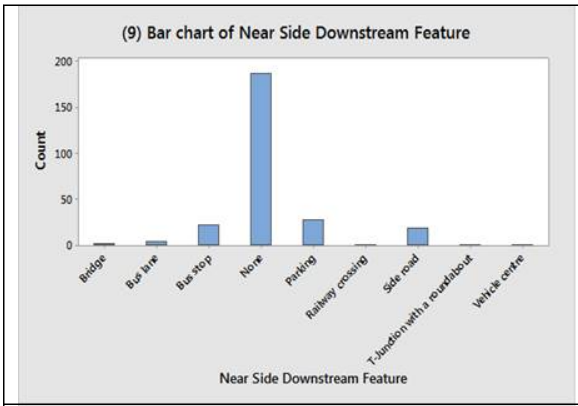


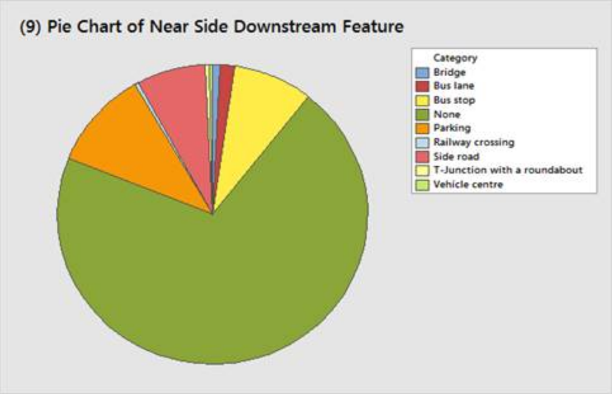


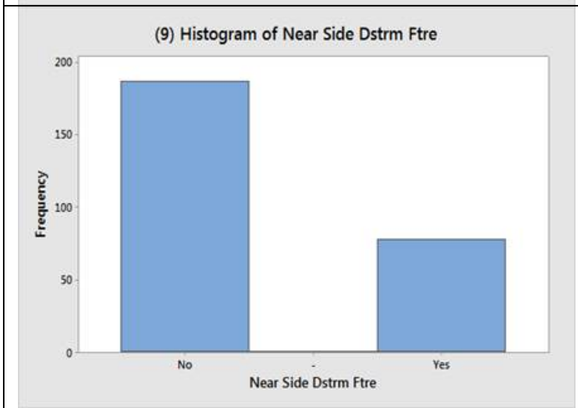


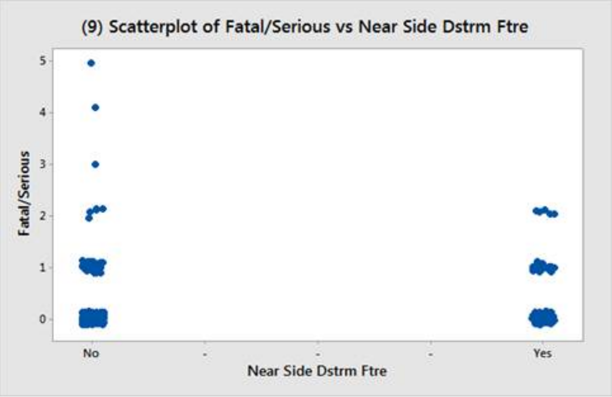


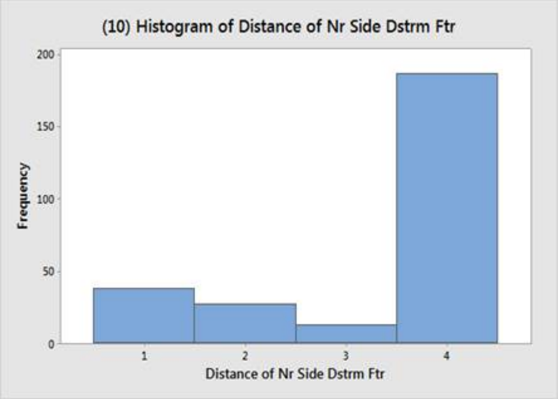


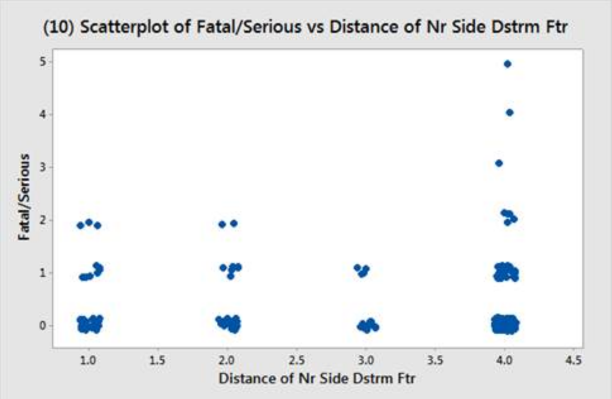

(9) Bar chart of Near Side Downstream Feature

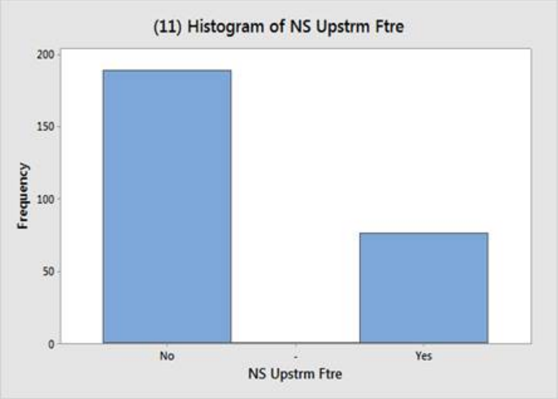

(9) Pie Chart of Near Side Downstream Feature

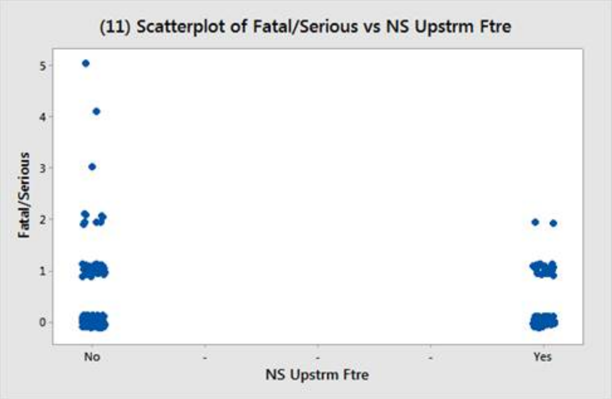

(9) Histogram of Near Side Dstrm Ftre

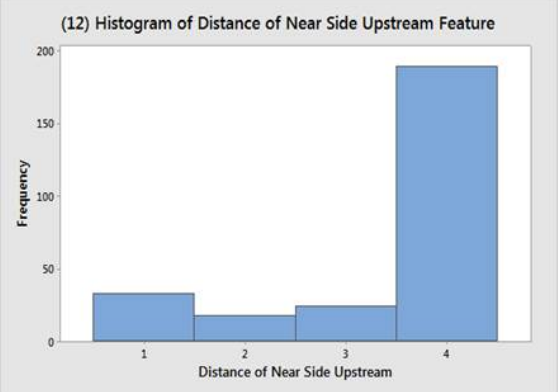

(9) Scatterplot of Fatal/Serious vs Near Side Dstrm Ftre

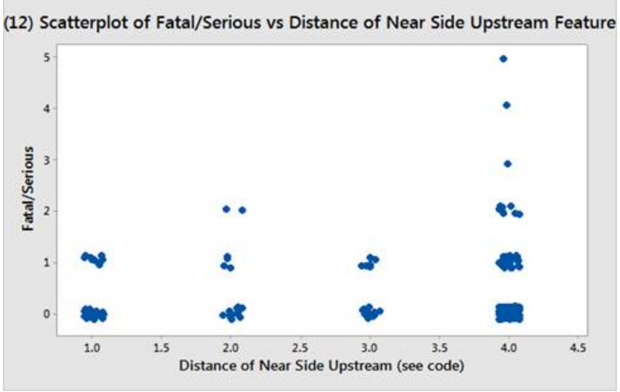

(10) Histogram of Distance of Nr Side Dstrm Ftr

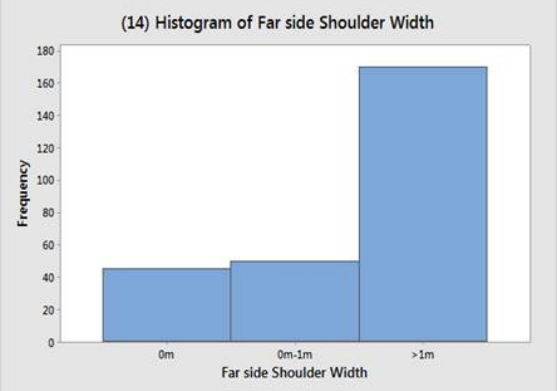

(10) Scatterplot of Fatal/Serious vs Distance of Nr Side Dstrm Ftr

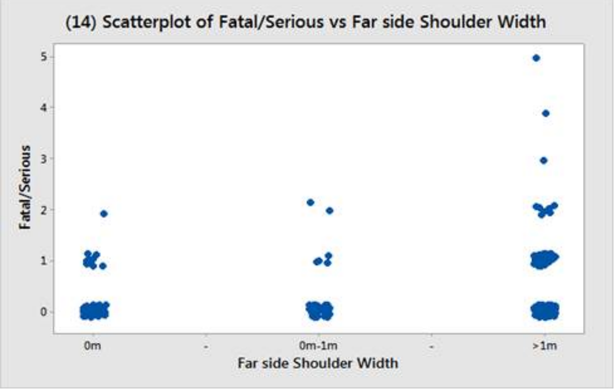

(11) Histogram of NS Upstrm Ftre

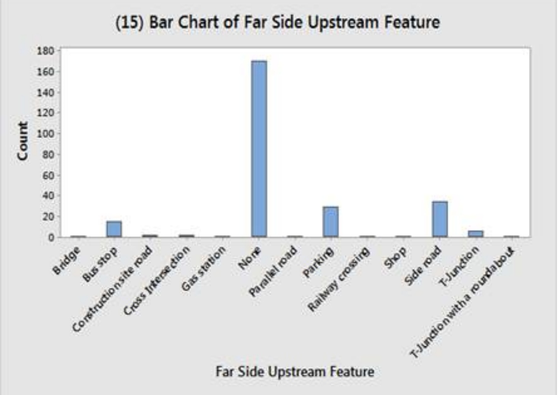

(11) Scatterplot of Fatal/Serious vs NS Upstrm Ftre

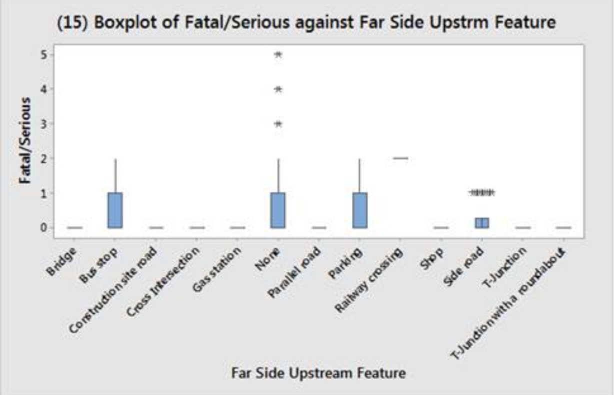

(12) Histogram of Distance of Near Side Upstream Feature

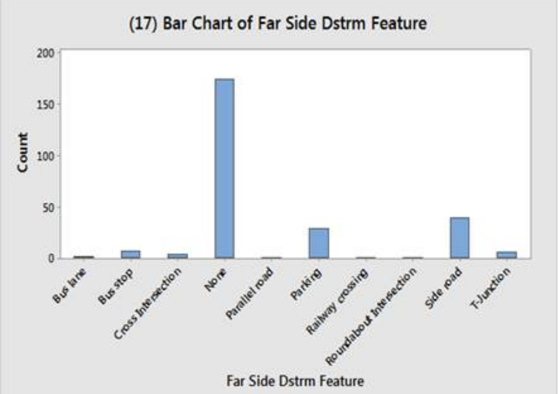

(12) Scatterplot of Fatal/Serious vs Distance of Near Side Upstream Feature

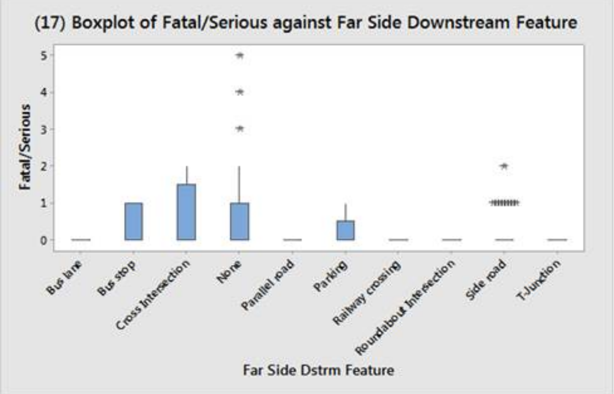

(14) Histogram of Far side Shoulder Width

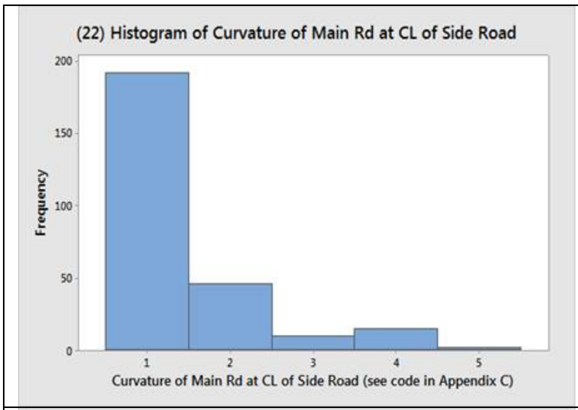

(14) Scatterplot of Fatal/Serious vs Far side Shoulder Width

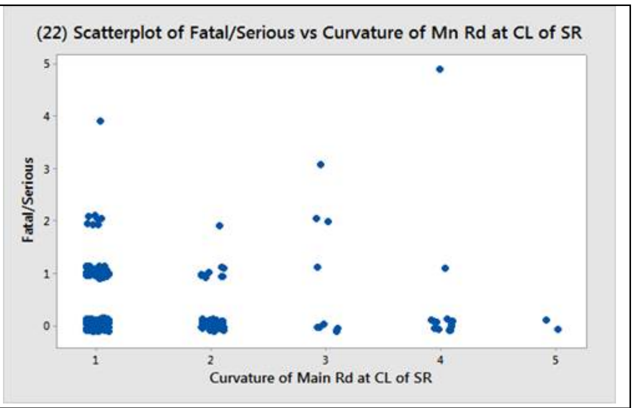

(15) Bar Chart of Far Side Upstream Feature

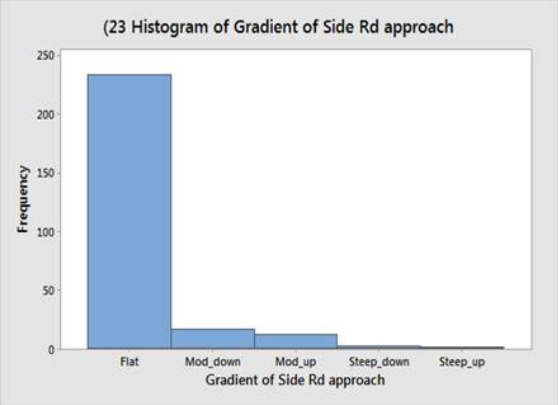

(15) Boxplot of Fatal/Serious against Far Side Upstrm Feature

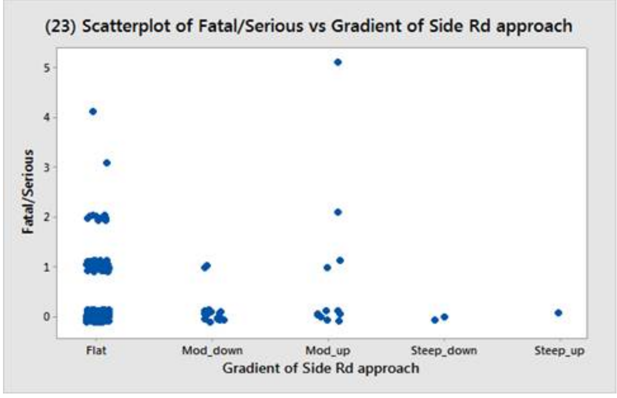

(17) Bar Chart of Far Side Dstrm Feature

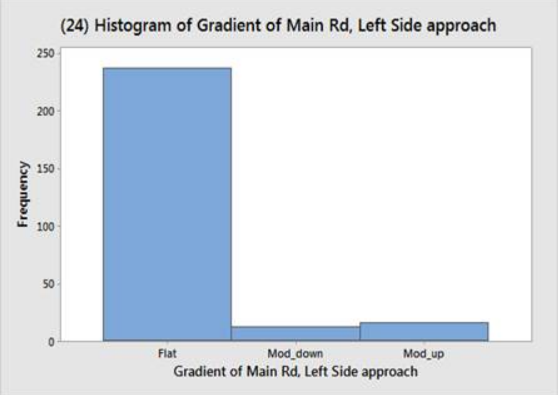

(17) Boxplot of Fatal/Serious against Far Side Downstream Feature

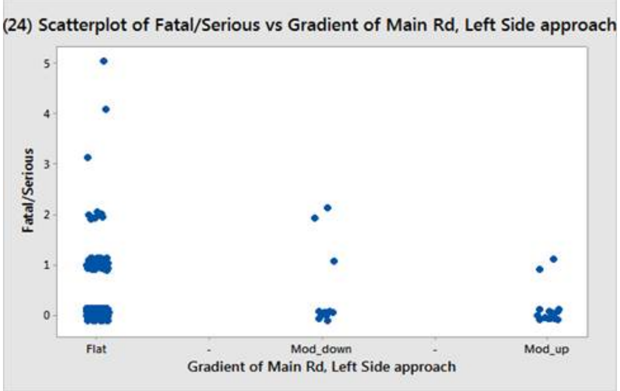

(22) Histogram of Curvature of Main Rd at CL of Side Road
Frequency
200
150
100
50
0
1
2
3
4
5
Curvature of Main Rd at CL of Side Road (see code in Appendix C)

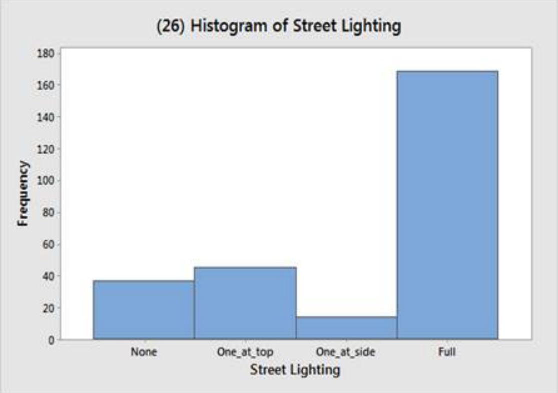

(22) Scatterplot of Fatal/Serious vs Curvature of Mn Rd at CL of SR
Fatal/Serious
5
4
3
2
1
0
1
2
3
4
5
Curvature of Main Rd at CL of SR

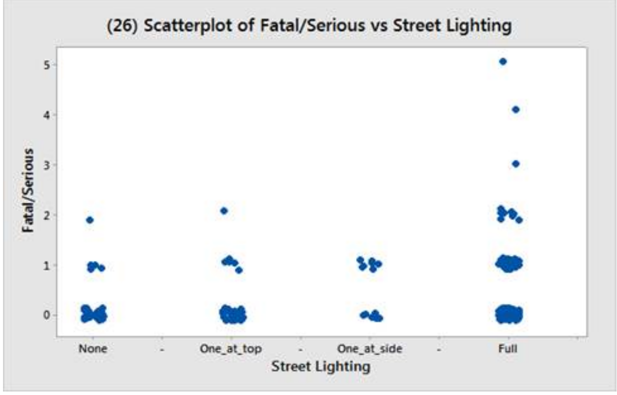

(23 Histogram of Gradient of Side Rd approach
Frequency
250
200
150
100
50
0
Flat
Mod_down
Mod_up
Steep_down
Steep_up
Gradient of Side Rd approach

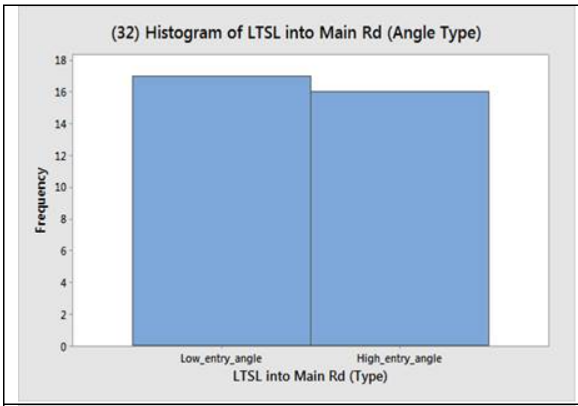

(23) Scatterplot of Fatal/Serious vs Gradient of Side Rd approach
Fatal/Serious
5
4
3
2
1
0
Flat
Mod_down
Mod_up
Steep_down
Steep_up
Gradient of Side Rd approach

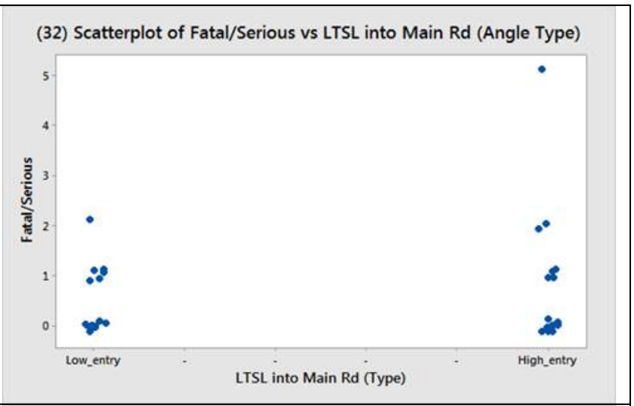

(24) Histogram of Gradient of Main Rd, Left Side approach
Frequency
250
200
150
100
50
0
Flat
Mod_down
Mod_up
Gradient of Main Rd, Left Side approach

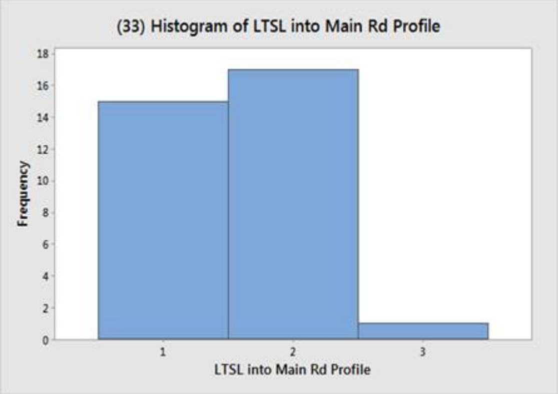

(24) Scatterplot of Fatal/Serious vs Gradient of Main Rd, Left Side approach
Fatal/Serious
5
4
3
2
1
0
Flat
Mod_down
Mod_up
Gradient of Main Rd, Left Side approach

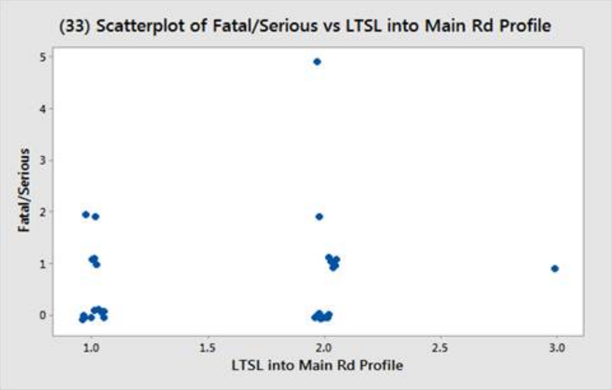

(26) Histogram of Street Lighting
Frequency
180
160
140
120
100
80
60
40
20
0
None
One_at_top
One_at_side
Full
Street Lighting

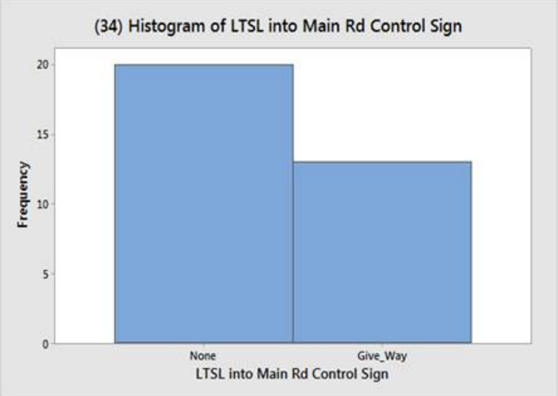

(26) Scatterplot of Fatal/Serious vs Street Lighting
Fatal/Serious
5
4
3
2
1
0
None
One_at_top
One_at_side
Full
Street Lighting

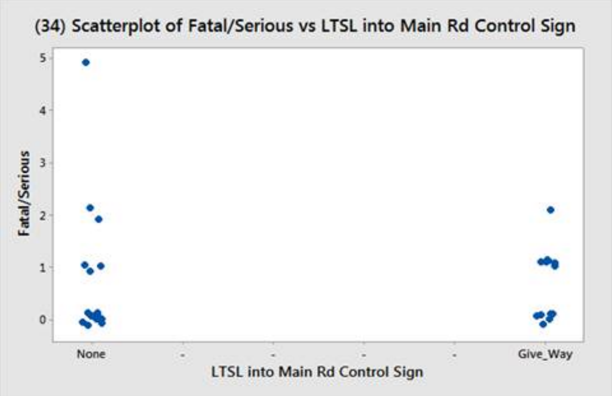

(32) Histogram of LTSL into Main Rd (Angle Type)

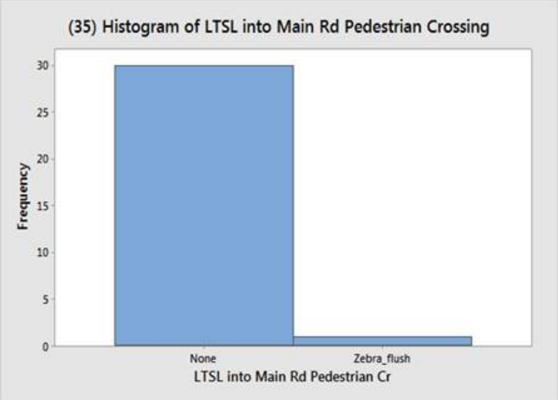

(32) Scatterplot of Fatal/Serious vs LTSL into Main Rd (Angle Type)

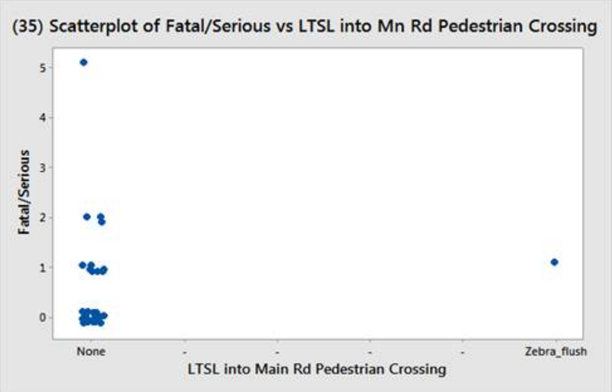

(33) Histogram of LTSL into Main Rd Profile

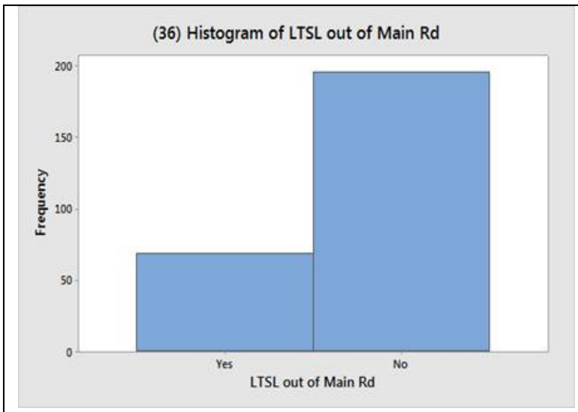

(33) Scatterplot of Fatal/Serious vs LTSL into Main Rd Profile

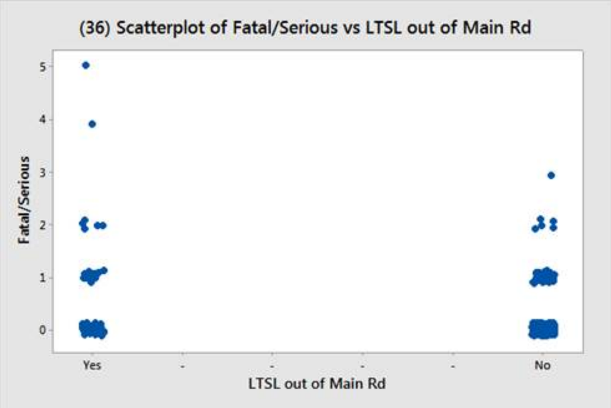

(34) Histogram of LTSL into Main Rd Control Sign

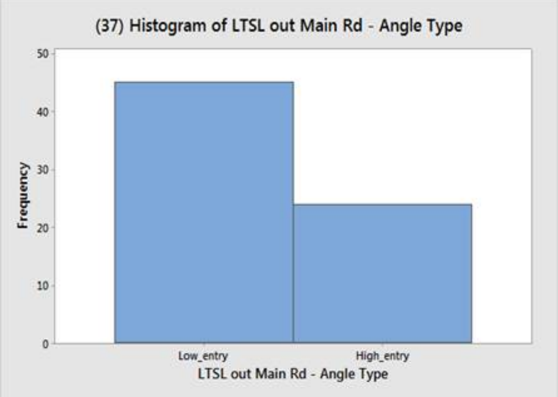

(34) Scatterplot of Fatal/Serious vs LTSL into Main Rd Control Sign

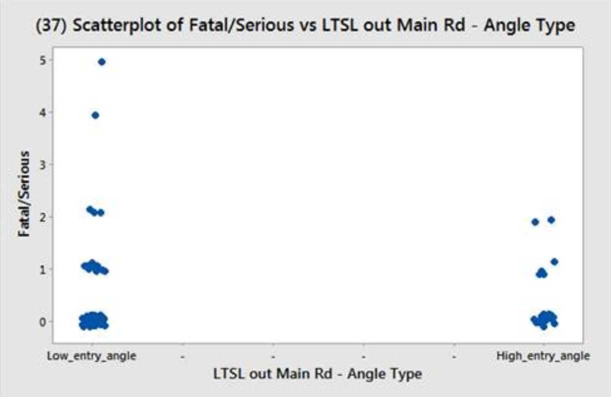

(35) Histogram of LTSL into Main Rd Pedestrian Crossing

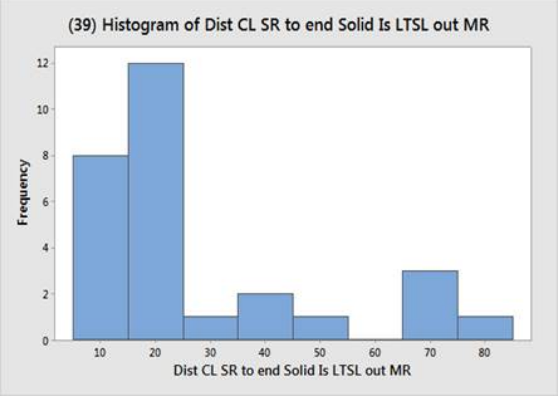

(35) Scatterplot of Fatal/Serious vs LTSL into Mn Rd Pedestrian Crossing

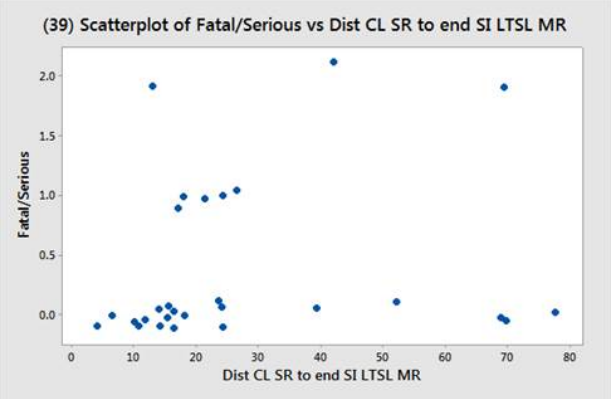

(36) Histogram of LTSL out of Main Rd

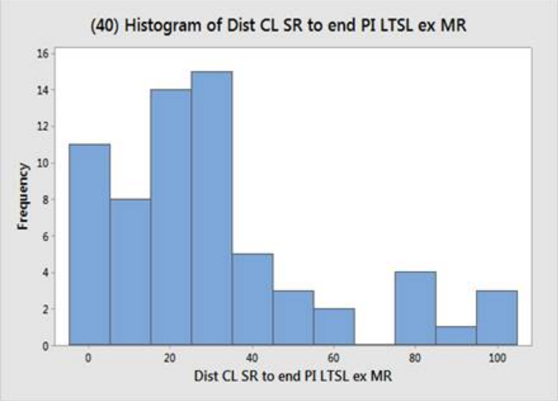

(36) Scatterplot of Fatal/Serious vs LTSL out of Main Rd

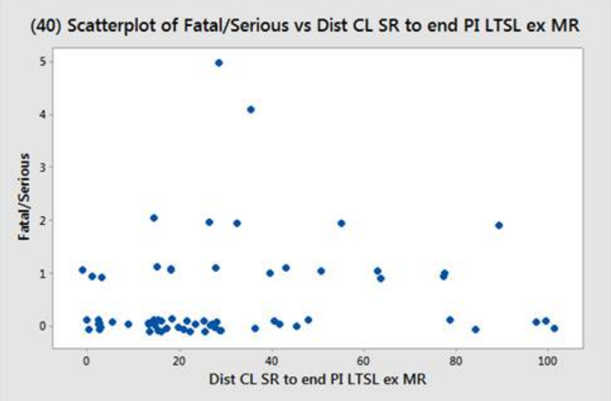

(37) Histogram of LTSL out Main Rd - Angle Type

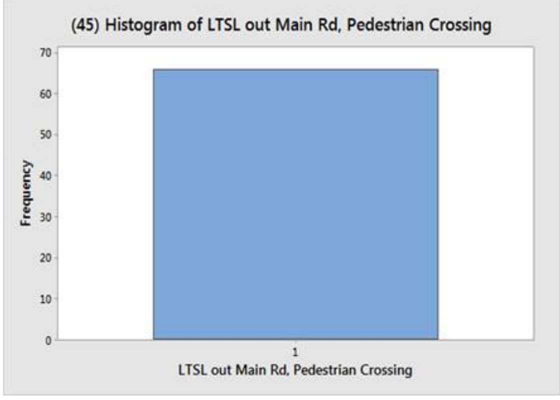

(37) Scatterplot of Fatal/Serious vs LTSL out Main Rd - Angle Type

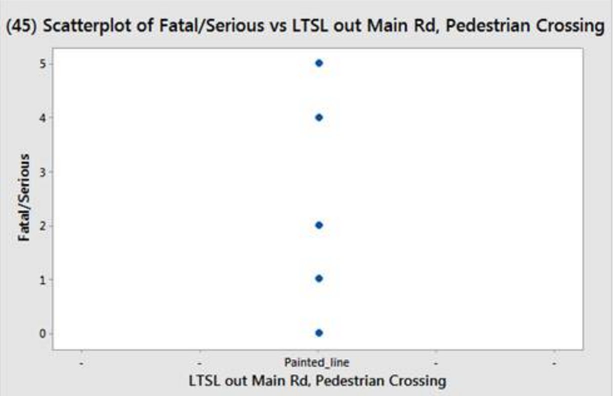

(39) Histogram of Dist CL SR to end Solid Is LTSL out MR

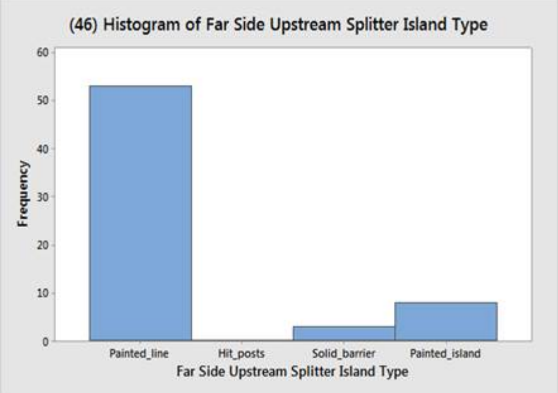

(39) Scatterplot of Fatal/Serious vs Dist CL SR to end SI LTSL MR

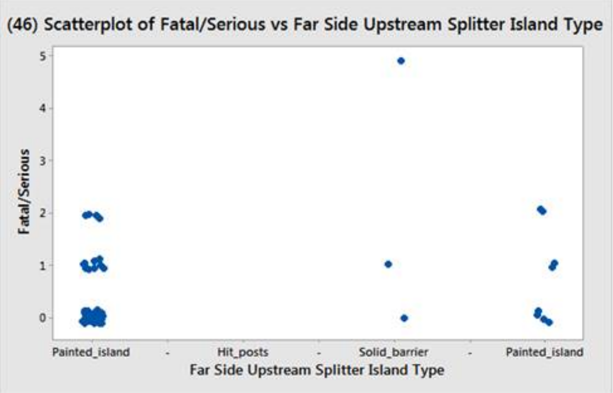

(40) Histogram of Dist CL SR to end PI LTSL ex MR

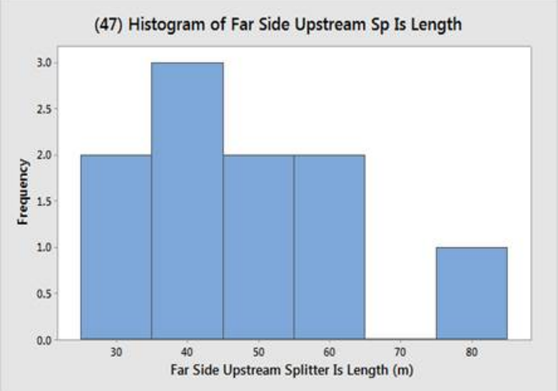

(40) Scatterplot of Fatal/Serious vs Dist CL SR to end PI LTSL ex MR

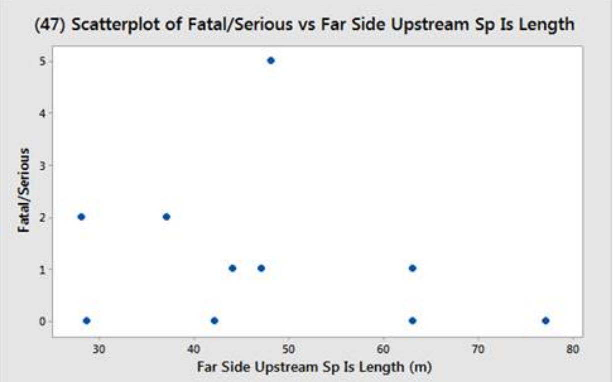

(45) Histogram of LTSL out Main Rd, Pedestrian Crossing
Frequency
0
10
20
30
40
50
60
70
1
LTSL out Main Rd, Pedestrian Crossing

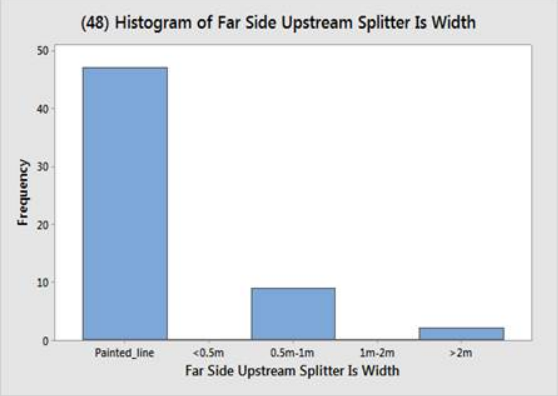

(45) Scatterplot of Fatal/Serious vs LTSL out Main Rd, Pedestrian Crossing
Fatal/Serious
0
1
2
3
4
5
-
-
Painted_line
-
-
LTSL out Main Rd, Pedestrian Crossing

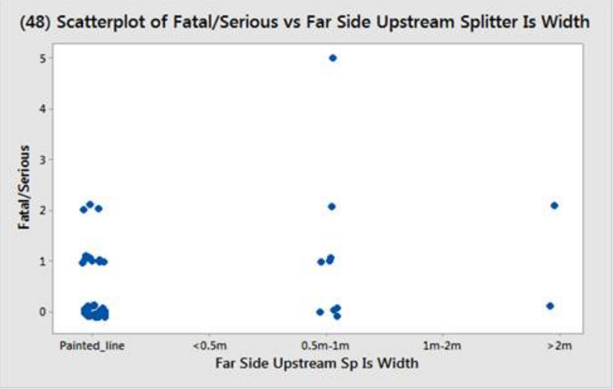

(46) Histogram of Far Side Upstream Splitter Island Type
Frequency
0
10
20
30
40
50
60
Painted_line
Hit_posts
Solid_barrier
Painted_island
Far Side Upstream Splitter Island Type

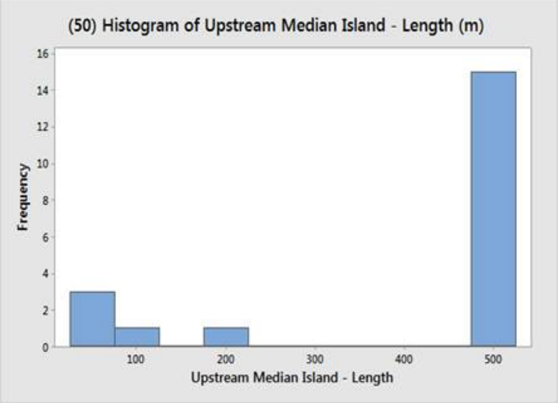

(46) Scatterplot of Fatal/Serious vs Far Side Upstream Splitter Island Type
Fatal/Serious
0
1
2
3
4
5
Painted_island
-
Hit_posts
-
Solid_barrier
-
Painted_island
Far Side Upstream Splitter Island Type

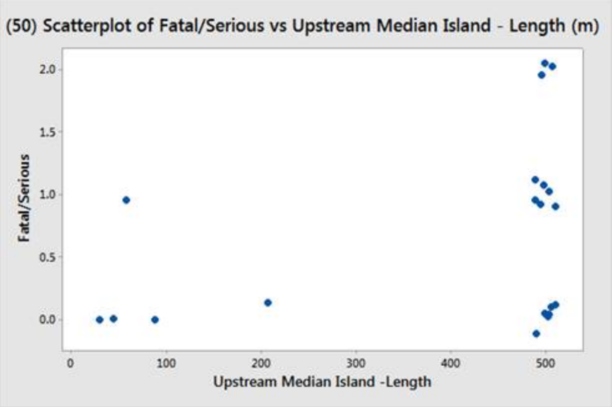

(47) Histogram of Far Side Upstream Sp Is Length
Frequency
0.0
0.5
1.0
1.5
2.0
2.5
3.0
30
40
50
60
70
80
Far Side Upstream Splitter Is Length (m)

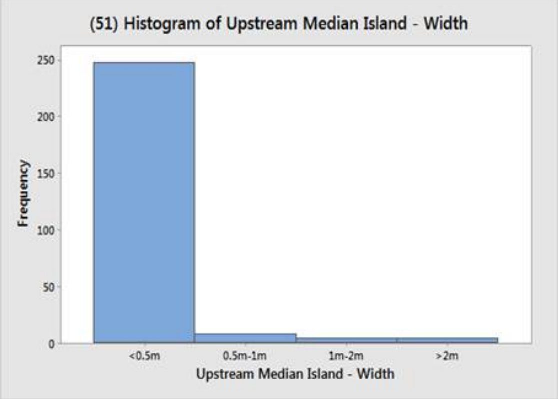

(47) Scatterplot of Fatal/Serious vs Far Side Upstream Sp Is Length
Fatal/Serious
0
1
2
3
4
5
30
40
50
60
70
80
Far Side Upstream Sp Is Length (m)

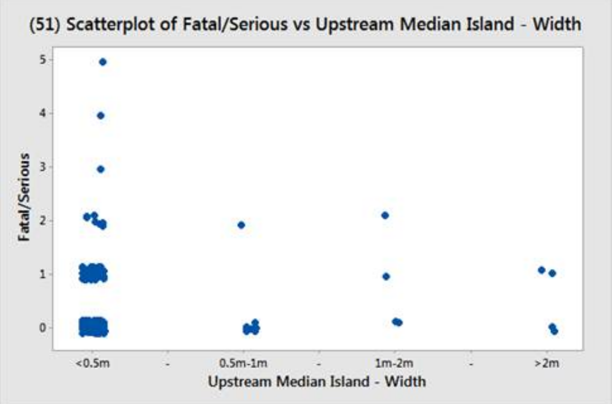

(48) Histogram of Far Side Upstream Splitter Is Width
Frequency
0
10
20
30
40
50
Painted_line
<0.5m
0.5m-1m
1m-2m
>2m
Far Side Upstream Splitter Is Width

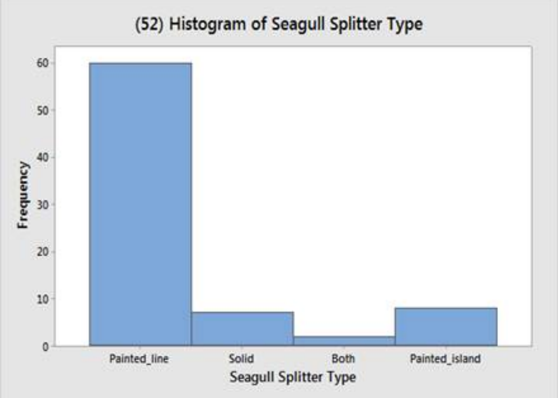

(48) Scatterplot of Fatal/Serious vs Far Side Upstream Splitter Is Width
Fatal/Serious
0
1
2
3
4
5
Painted_line
<0.5m
0.5m-1m
1m-2m
>2m
Far Side Upstream Sp Is Width

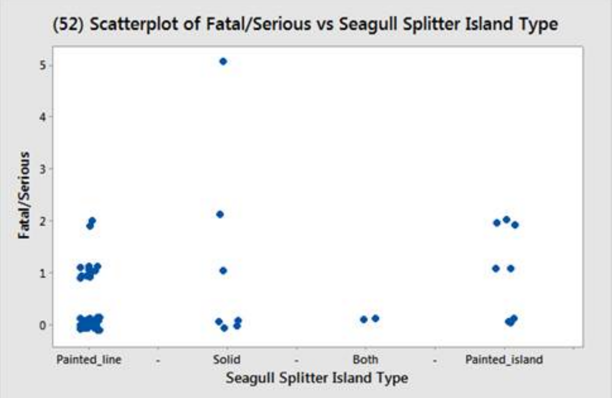

(50) Histogram of Upstream Median Island - Length (m)

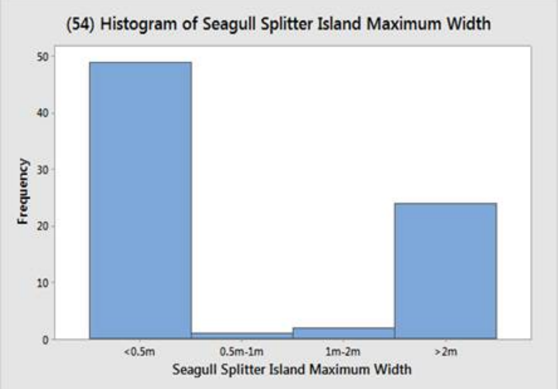

(50) Scatterplot of Fatal/Serious vs Upstream Median Island - Length (m)

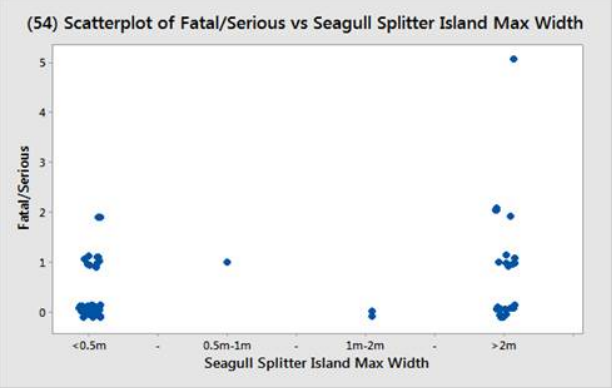

(51) Histogram of Upstream Median Island - Width

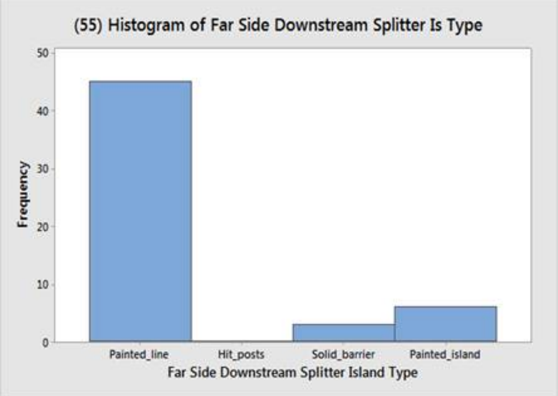

(51) Scatterplot of Fatal/Serious vs Upstream Median Island - Width

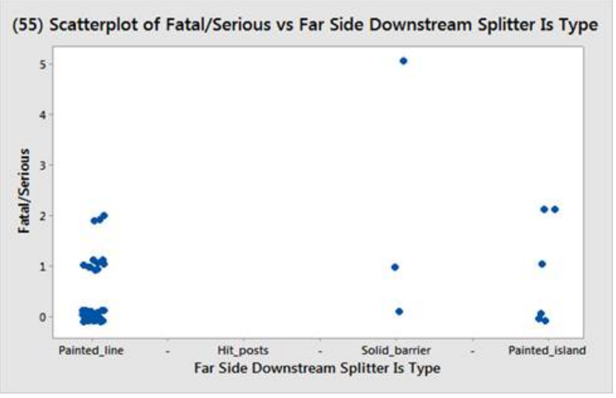

(52) Histogram of Seagull Splitter Type

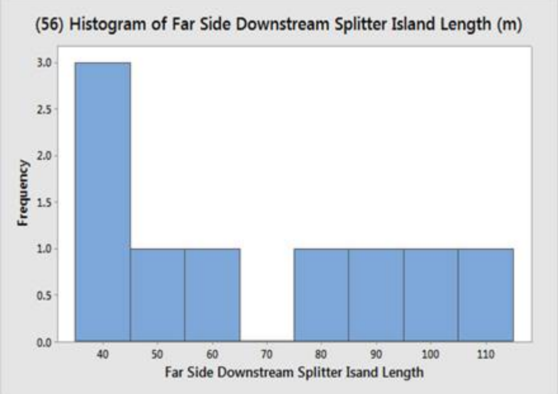

(52) Scatterplot of Fatal/Serious vs Seagull Splitter Island Type

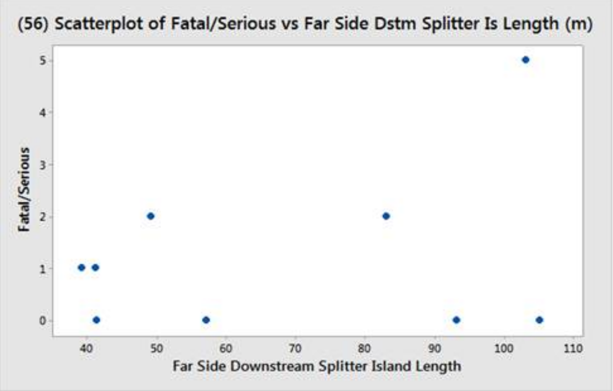

(54) Histogram of Seagull Splitter Island Maximum Width

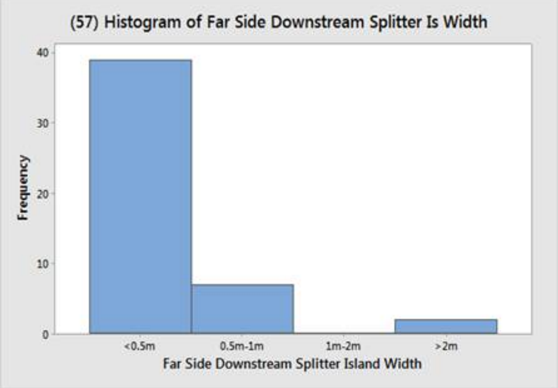

(54) Scatterplot of Fatal/Serious vs Seagull Splitter Island Max Width

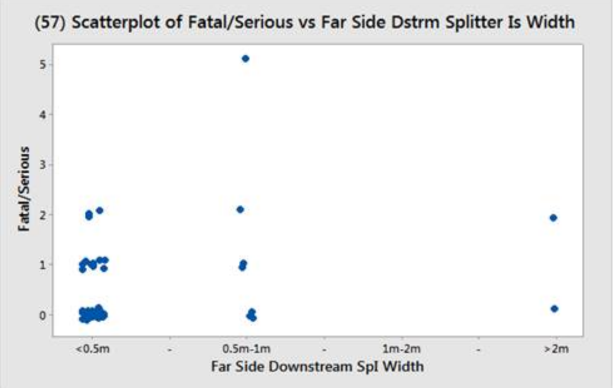

(55) Histogram of Far Side Downstream Splitter Is Type

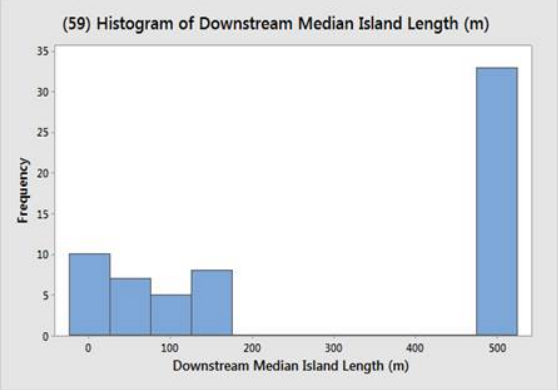

(55) Scatterplot of Fatal/Serious vs Far Side Downstream Splitter Is Type

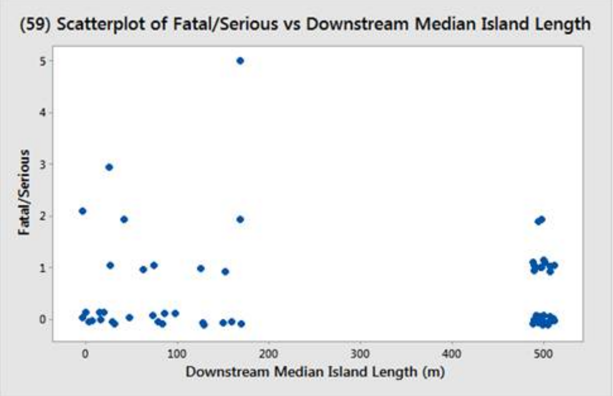

(56) Histogram of Far Side Downstream Splitter Island Length (m)

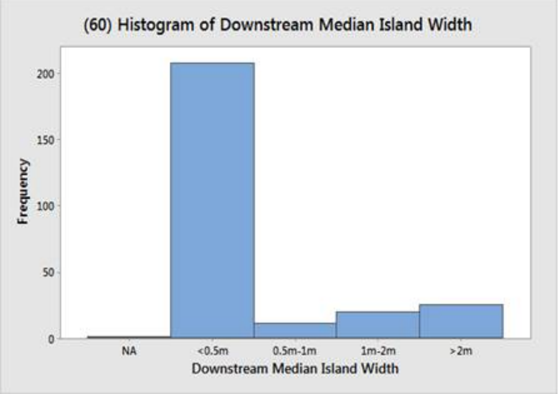

(56) Scatterplot of Fatal/Serious vs Far Side Dstm Splitter Is Length (m)

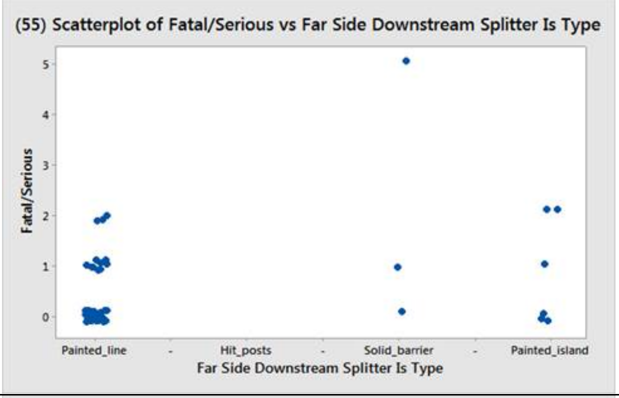

(57) Histogram of Far Side Downstream Splitter Is Width

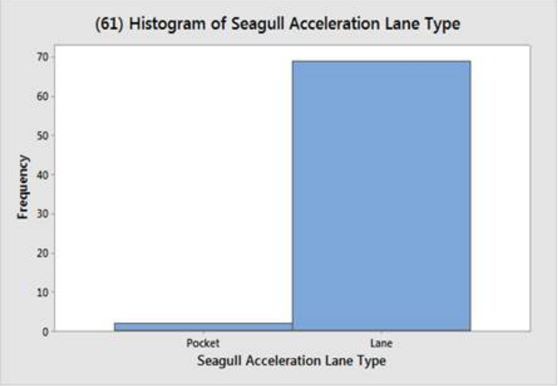

(57) Scatterplot of Fatal/Serious vs Far Side Dstrm Splitter Is Width

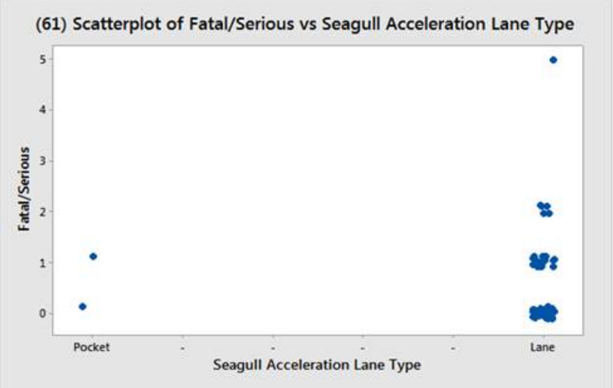

(59) Histogram of Downstream Median Island Length (m)

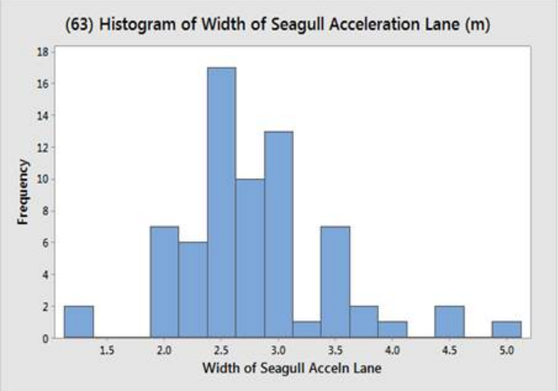

(59) Scatterplot of Fatal/Serious vs Downstream Median Island Length

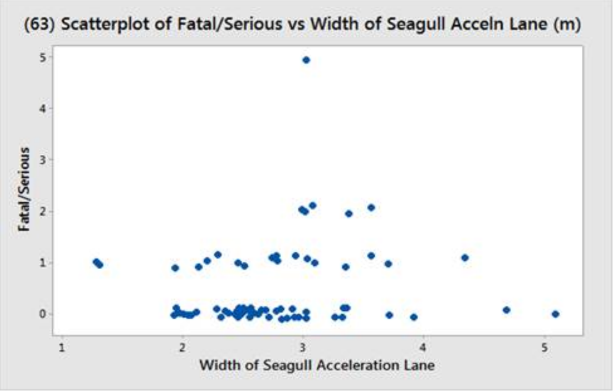

(60) Histogram of Downstream Median Island Width


(55) Scatterplot of Fatal/Serious vs Far Side Downstream Splitter Is Type


(61) Histogram of Seagull Acceleration Lane Type


(61) Scatterplot of Fatal/Serious vs Seagull Acceleration Lane Type


(63) Histogram of Width of Seagull Acceleration Lane (m)


(63) Scatterplot of Fatal/Serious vs Width of Seagull Acceln Lane (m)