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

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Key Findings

- Larger rural and urban seagull intersections, especially those on four-lane roads and those with wide medians, have higher crash rates (per vehicle) than smaller seagull intersections;
- Distraction to the left of side-roads resulting from road features, such as parking and movement from nearby accesses/side-roads and the operation of right turn bays does increase right turn out versus through vehicle crashes at T-intersections;
- The design of left turn slip lanes, especially where this restricts visibility to through vehicles, does increase the risk of right turn out versus through vehicle crashes at rural seagull intersections.

Abstract

Alternative intersection layouts may reduce traffic delays and/or improve road safety. Two alternatives are reviewed in this research: 'priority-controlled Seagull intersections' and 'priority-controlled intersections with a Left Turn Slip Lane'. Seagull intersections are used to reduce traffic delays. Some do experience high crash rates, however. Left Turn Slip Lanes allow turning traffic to move clear of the through traffic before decelerating, thereby reducing the risk of rear-end crashes. Although there is debate about the safety problems that occur at Seagull intersections and Left Turn Slip Lanes there has been very little research to quantify the safety impact of different layouts. In this study, crash prediction models have been developed to quantify the effect of various Seagull intersection and Left Turn Slip Lane designs on the key crash types that occur at priority intersections. The analysis showed that seagulls are not safe on 4-lane roads, that roadway features like kerb-side parking and nearby intersections can increase crash rates and that left turners in LTSLs can restrict visibility and create safety problems.

Introduction

The majority of urban and rural intersections in New Zealand have priority control (Stop or Give-Way) or no formal control. National crash 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 is also 64% for rural intersections but 52 % for urban intersections.

Despite the high proportion of crashes and the high severity of these crashes only a small proportion of the research literature focusses on crashes at priority intersections, compared with the number of studies that have been undertaken of for signalized intersections, roundabouts and road links, especially in urban areas. In New Zealand this leads to a gap in the crash prediction models that are 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 priority-controlled intersections, 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 Left Turn Slip Lanes (LTSL) which seeks to reduce rear-end crashes by removing slower moving turning traffic from the through traffic. There are however concerns that some designs may increase the risk of crashes involving through and right turn out vehicles (JA crashes), due to left turners masking following through vehicles.

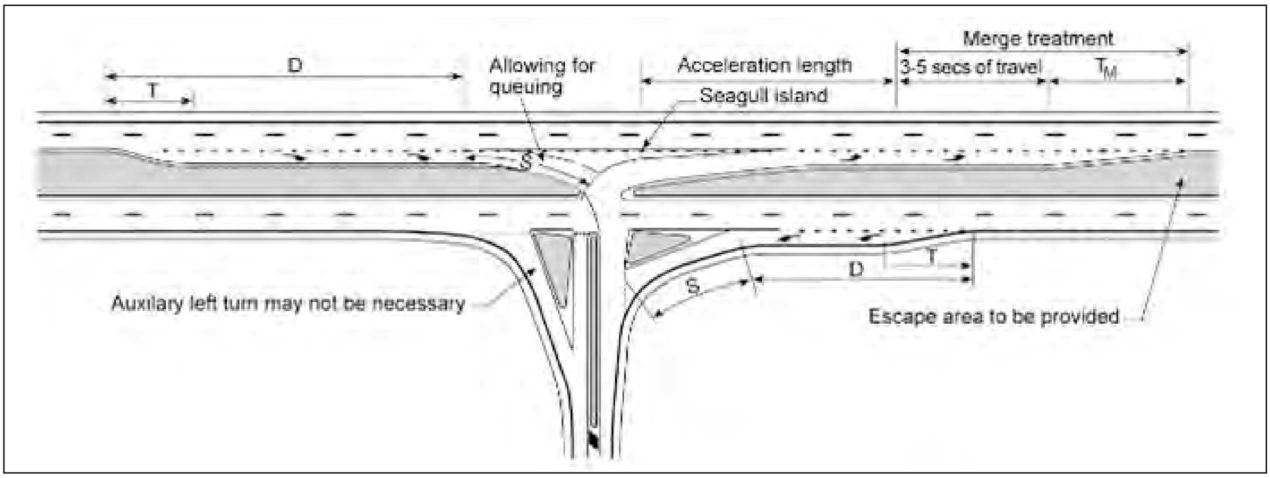

Figure 1: Typical Seagull Intersection Layout with Raised Islands

Another treatment type, which is less common, is the 'Seagull' layout, where drivers can break their right turn movement into two stages (see Figure 1, which also includes one type of LTSL). In the first stage drivers cross over to a painted or solid median area. 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 (right turn out crashes) and LB (right turn against or right turn versus opposing through vehicle) crashes (see Figure 3).

In New Zealand seagull intersections are mostly priority controlled but can also operate with traffic signals. At priority-controlled seagulls both through movements are free-flowing, with sideroad traffic having to give-way when crossing to the median. The signalised seagulls typically involve three signal phases allowing the through movement in only one direction (top of the tee) to flow continuously. On the side with the side-road the through traffic is stopped to allow traffic to move from the side-road into the central median and then merge with through traffic via the acceleration lane.

This project focuses on priority-controlled seagull intersections, as they typically have a higher number of crashes than signalised seagulls. Crash prediction models have been developed for standard priority three leg intersection layouts (see Figure 2), with and without Left Turn Slip Lanes, and Seagull layouts. The first section of the paper looks at the limited research available on the safety performance of Seagull intersections and the safety issues associated with LTSL. The paper then presents the data collected and the crash prediction models produced in this research, followed by a discussion of the research findings.

Literature Review

The literature review focused on research of priority-controlled Seagull intersections and standard priority intersections with and without LTSLs (particularly from the main road into a side-road). Across New Zealand there are a variety of existing types of Seagull intersection and general priority tee-junctions. Priority controlled Seagull intersections (see Figure 1) have three key characteristics, 1) a seagull shaped 'splitter' island between through and right turning traffic on the main road, 2) a merge lane with acceleration taper for traffic turning right out of the side road and 3) at least one bypass lane for main road traffic traveling straight through from left to right.

Many of the higher volume standard priority intersections have some characteristics that are similar to Seagull intersections, such as left turn slip lanes and also areas in the median where drivers can wait and merge with through traffic, especially when the road has a central median island. However, unless they have all three characteristics specified they are not considered Seagull intersections.

Figure 1 also shows two LTSLs into and out of the side-road. There are a variety of different LTSL layouts, from small painted islands up to large solid islands, with different deceleration lane lengths. The focus in this study was the LTSL from the main road into the side-road.

There is limited research available on Seagull layouts (called chanelised layouts in other parts of the world). Tang and Levett (2009) identified that two major crash types (right-near and right-through) were predominant in all crashes at Seagull intersections in New South Wales (refer to Figure 3 for equivalent crash types in New Zealand). The multivariate study of potential crash causing factors provided very little evidence on why these crashes were occurring. However, the study did show that young female drivers and older (≥ 67 years old) male drivers were over-represented in the two main crash types. A potential explanation for the older age group demographic was the diminishing cognitive ability of older drivers, which may be causing them to misjudge appropriate gaps in the traffic.

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

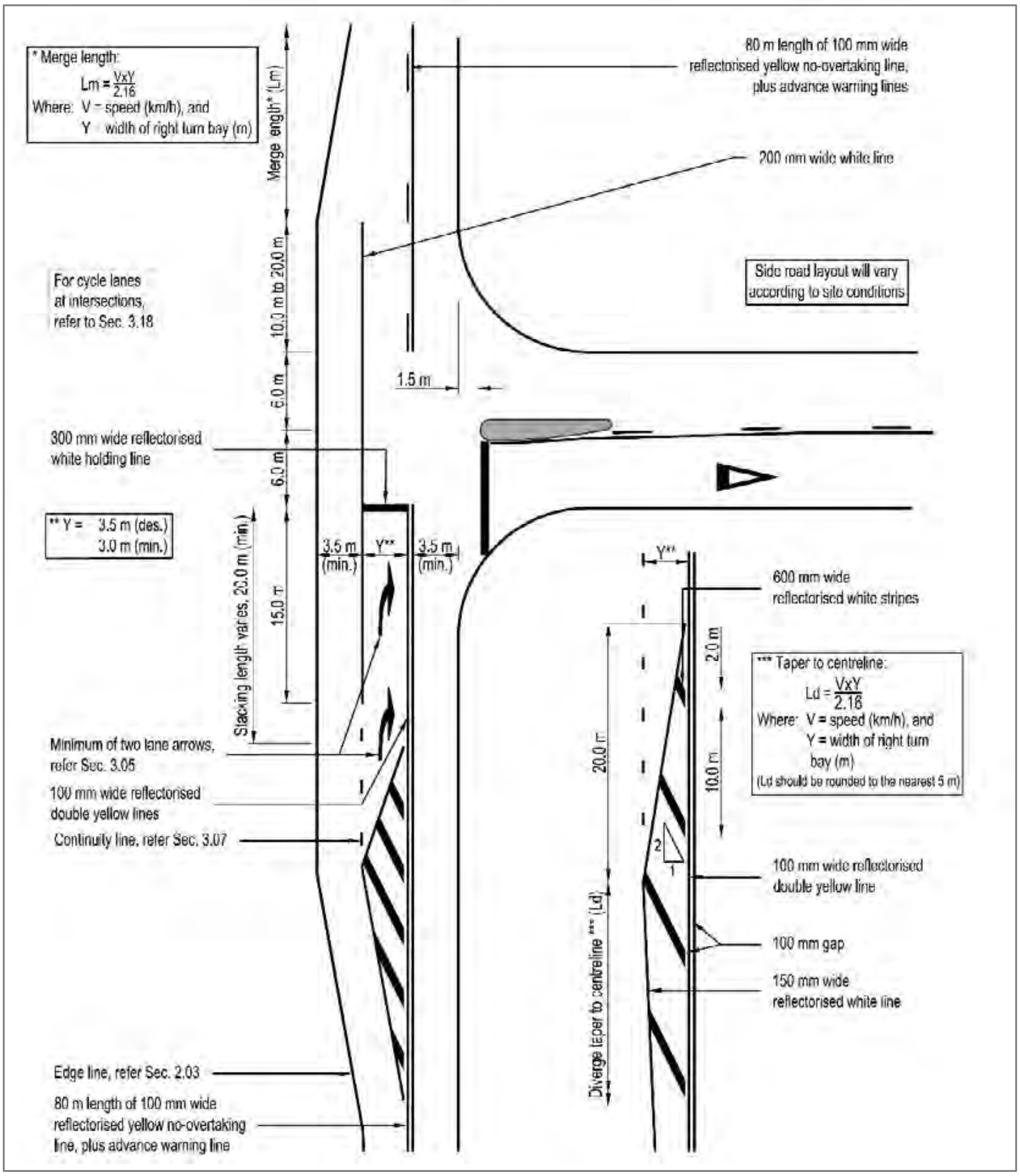

Figure 2: Standard Rural Priority Intersection (source: MOTSAM 2 Section 3 Figure 3.25)

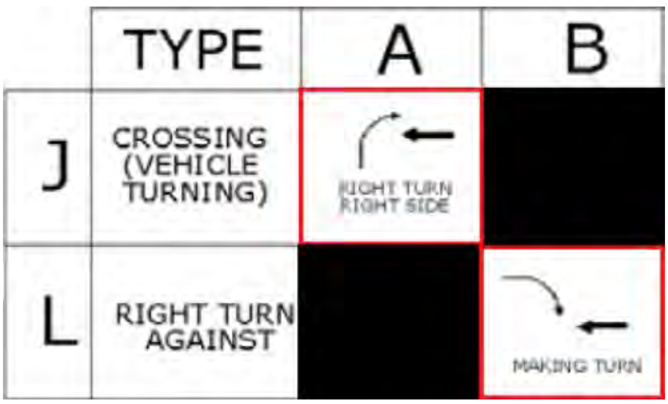

Figure 3: Common crash types at seagull intersections (NZ crash coding)

(positive or negative) change in the type or number of crashes. However, where the intersection angle did not conform to the recommended guidance, the crash numbers and severity increased, especially the latter. The authors recommended that seagull islands should not be considered as an intersection safety treatment (as they had been in the past), as at best they tend to have a similar safety record to a standard T-intersection, and at worst can have a much worse safety record.

Both Summersgill et al. (1996) and Elvik et al. (2009) concluded that the effect of channelised passing lanes at T-intersections (Seagull intersections) is to increase the crash risk. In the case of Elvik, a 26% overall increase in all crashes is recorded, while the Summersgill study found a 50% increase in 'JA' crashes. This research supports the concerns of most road safety specialists that Seagull intersections are less safe than traditional T-intersections, especially if poorly designed.

Harper, et al. (2011) researched the safety performance of three design variations of a Seagull intersection for the A1 Highway / Island Point Road intersection in New South Wales, Australia. After the Seagull intersection was constructed a number of 'right near' (JA) type crashes began to occur. The intersection was subsequently modified to include a short left turn splay that included a small raised concrete splitter island and priority control. However, this did not effectively address the 'right-near' crashes, and consequently right-through (LB) type crashes began to occur more frequently. A final modification increased separation between the left-turn deceleration lane and the straight through lane of the major road, after which the crashes reduced appreciably. The separation of the left turn lane from the through movement by a painted splitter island improved visibility for vehicles turning out of the side-road. This design of LTSLs has safety benefits at Seagull and standard priority T-junctions, especially in higher speed areas.

There is more extensive safety research on LTSL. While the functions and use of these 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 LTSL at T-intersections acts to increase the number of injury crashes by 12%. The study reasoned that LTSL may create blind spots where a vehicle turning left can obscure through traffic coming from the right side of the side road. He also added that large scale intersection channelisation can complicate the road layout, and may increase driver error.

Masters research by Urlich (2014) considered the safety performance of LTSL facilities at rural intersections in New Zealand. The study focused on how LTSLs impact on the available sight distances for side road traffic to through vehicles and how this related to the crash rates. The analysis showed that the installation or modification of LTSLs (into side-roads) can increase injury crash rates. The key reason is that left turn vehicles do mask following through vehicles on a regular basis. This research indicates that careful consideration needs to be made on the design of LTSLs so that they do not compromise the safety of the intersection.

The previous research indicates that for both Seagull intersections and LTSLs there is evidence that crash rates can go up if intersections are not well designed. The experience in Perth (by Radalj) showed that Seagulls should not be considered a road safety treatment. Seagulls do reduce traffic delays and may be constructed to reduce delays. However it is important that they are well designed, especially in high speed areas where crash severity is often higher, to ensure a neutral road safety outcome. In terms of the design of LTSLs, there is some evidence that they can mask through vehicles and lead to increased crashes between right turn out and through vehicles. Especially in higher speed areas and where traffic volumes (left turn in and right turn out) are at higher levels, then the design should look to address visibility problems. Each of these matters was considered in this research study.

Data Collection and Sample Size

The current study utilised data that had previously been collected for standard three-arm urban and rural priority T-intersections (Turner 2001; Turner and Roozenberg 2007). In these studies data was collected for more than 190 priority T-intersections. The majority of these older sites did not have LTSLs and none had a Seagull layout. The ones with LTSLs were separated and combined with the new sites added to the dataset. The intention was to compare the safety performance of sites with LTSL and Seagulls with 'standard (unmodified)' priority intersections.

A further 69 new intersections that had Seagull treatments and LTSLs 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. Table 1 shows the number of sites selected by type and location (urban or rural).

Table 1: Number of Seagull intersections and LTSL sites selected

Intersection type	Urban	Rural	Total
Seagull T-intersection	17	14	31
T-intersection with LTSL	4	34	38

Approximately half of these 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). These new sites were combined with the 'old' sites from previous studies (Turner (2001) and Turner and Roozenberg (2007)). Table 2 shows the combined dataset.

We note that the 261 intersections described are necessarily a convenience sample, a mix of previously sampled and more

Table 2: Total Number of Priority Sites by type and location (urban or rural)

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

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. However, the effect of the Canterbury earthquakes on traffic flows 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 results of the analysis 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, which is normally the case with this type of study. We are aware that there are regional differences in New Zealand and hence the models may not be accurate for all New Zealand regions.

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, with checking on-site at most locations. Data included 1) turning traffic volumes (six movements), 2) crash data, 3) operating speed and/or speed limit (on through road) and 4) layout data. For standard T-intersections there were 25 layout variables. For LTSL and Seagulls this increased to 51 variables and 67 variables respectively.

Crash data was extracted from the 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 (along with recent traffic volumes). 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

Table 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 median(s)	Length and width
Near side characteristics	Number of lanes and shoulder width
Features within wider intersection and proximity	Near side upstream and downstream, far side upstream and downstream eg. parking and side-roads
Far side characteristics	Number of lanes and shoulder width
Side road details	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

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 tested for rural roads, and operating speed was found to be a better predictor variable.

The layout data included the general geometry of the intersections (e.g. 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 (e.g. another side road, parking, bus bay). A summary of the layout variables collected is listed in Table 3.

Crash Causal Factors

Expert Opinion of Crash Causal Factors

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. This work was undertaken to help identify some of the variables that needed to be considered in the modelling. Note that a number of these factors are picked up and addressed in the design process or safety audits and hence some cannot be tested in crash modelling due to few sites having these faults. Indeed the fact that many are picked up before construction is a good thing. The concerns raised (in no particular order) include:

1. **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.

2. **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.

3. **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.

4. **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.

5. **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 serious injury and fatal crashes than lower-speed intersections. High speed in combination with a poorly designed intersection or one on a curve is undesirable.

6. **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 in New Zealand as most merges are from the left to the right.

7. **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 (e.g. research by Harper, 2011).

8. **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.

9. **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) location and length of the LTSL. In particular dynamic queuing in a LTSL can temporarily restrict visibility of through traffic when turning right out of the side road.

Crash Analysis

An analysis of crashes at the rural intersections (Figure 4) shows that the proportion of 'JA' and 'LB' (see Figure 3 for crash codes) increase at sites with a LTSL and at Seagulls (note that most Seagulls have LTSLs). This is partly explained by higher traffic volumes at these enhanced intersections. Understanding whether this increase can be attributed to the increase in traffic volume or the layout (LTSL or Seagull) is a key question that we sought to address in this research study.

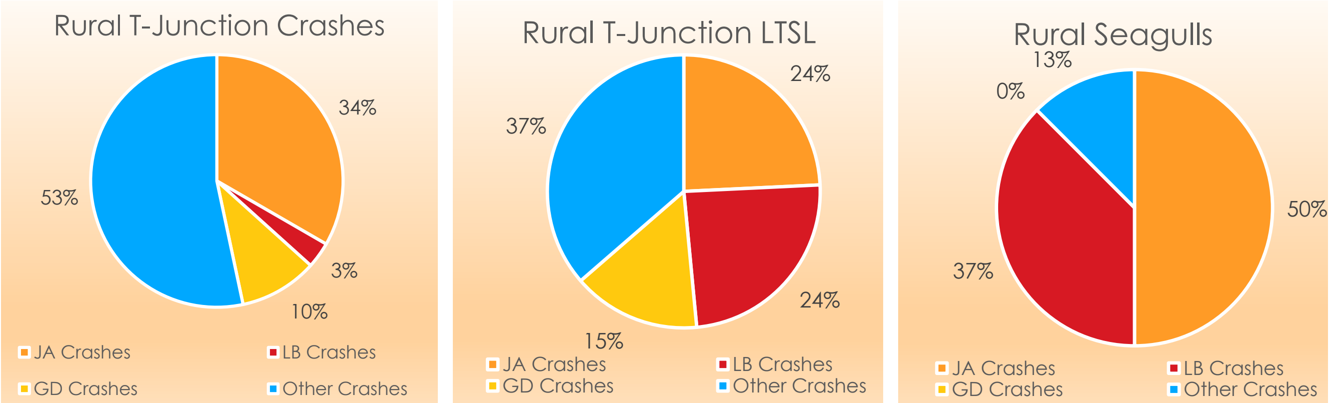

Figure 4: Key crash types at T-intersections

At urban intersections a comparison between standard and Seagull layouts indicates that the proportion of JA crashes increases from 24% to 34% and the proportion of LB crashes increases from 16% to 20%. Again this may be due to higher average traffic volumes at Seagulls.

Crash Prediction Modelling

In this study generalised linear models (GLMs) were developed for the key crash types at standard priority T-intersections, T-intersections with LTSL and for seagull intersections. The same statistical methods were used to develop the original urban and rural priority T-intersection models (Turner 2001; Turner and Roozenberg 2007). While a number of other crash modelling methods have been used by researchers for crash analysis, GLMs, with either a Poisson or negative binomial error structure, still remain one of the most popular modelling methods internationally. Hence it is still relevant to use GLMs. The main change in the modelling from the previous studies is the addition of speed for the urban models and a design index for both the urban and rural models. The dataset of course also includes Seagull intersection layouts and intersections with LTSLs.

Generalised Linear Models (GLMs)

Generalised linear models were first introduced to road crash studies by Maycock and Hall (1984), and extensively developed in Hauer et al. (1989). These models were further developed and fitted using crash data and traffic counts for motor-vehicle crashes in New Zealand by Turner (1995).

The aim of the modelling exercise is to develop relationships between the number of crashes annually (the dependent variable), and traffic flows, speeds and road layout (the explanatory variables). Influential road layout variables are captured in a design index. For this study the generalised linear models are of the following form:

Equation 1 $Y = \exp(b_0)\, Q_1^{b1}\, Q_2^{b2}\, \text{Speed}^{b3}\, \text{Design Index}^{b4}$

where,

Y is the annual number of crashes,

Q_1 and Q_2 are the average daily flow of vehicles in conflict for the crash type,

'Speed' is either the main road speed limit (MRSL) or operating speed,

'Design Index' is a combination of road design features that impact on safety (more on this below),

b_i are the model coefficients, i=0,1,…,4.

The selected model error structure is either Poisson or negative binomial. The "Poisson" model is used where the variance in crash numbers is roughly equal to the mean over the majority of the explanatory variable range. Generally, however, the variance is higher than the mean and hence the "negative binomial" model is more commonly used. The negative binomial model is a mixture of Poisson distributions by a gamma distribution. The model is described using two parameters k and μ, where k along with the coefficients $b_0,\ldots,b_n$ must be estimated from the data. A more detailed explanation of the models is given in Turner (1995) and Hauer et al. (1989).

The Akaiki information criterion (AIC) has been used to select the most appropriate model. It is defined as AIC = 2n-2ln(L), where n 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 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.

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, this 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 method indicates intersections with exceptional performance, either highly unsafe or highly safe.

Intersection 'Design Index'

The major new addition in all models (compared to previous models) is an intersection design index. In the past design variables have been added individually and often have

Table 4: Summary of models developed

Standard T-intersection			T-intersection – 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

In model name abbreviations T is standard T-intersection, TL is T-intersection with LTSL, S is Seagull, R is rural, U is urban and JA and LB are crash types

Table 5: Crash Prediction Models- JA Crashes

Model Names	bo	Q1 b1	Q5 b2	Speed b3	DI b4	GOF G^2	Fit
Rural Standard T-Intersections TRJA	-30.37	0.51	0.27	4.0	1.6	2.33	Reasonable
Urban Standard T-Intersections TUJA	-38.47	0.025	0.13	3.8	5.8	40.79	Very Poor
Rural T-intersection with LTSL TLRJA	-26.13	0.92	0.42	2.2	5.3	??	Excellent
Rural Seagull Intersection SRJA	-21.00	1.11	0.23	1.9	2.8	3.96	Moderate
Urban Seagulls Intersection SUJA	-13.42	1.04	0.25	-	3.6	1.18	Excellent

Speed – operating speed or speed limit, DI – Design Index, GOF – goodness-of-fit & G^2 – Deviance statistic

very low predictive power on their own. A "design index" which combined influential design variables was generally found to have significant predictive power. 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/location/crash type case (e.g. 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 up to 63 intersection variables (in the case of Seagulls) and those factors explaining some variation in the residual crash rate were noted. These were initially given equal weight and combined into a single design index. Improved models were obtained by upweighting the more important factors (by using weights proportional to the reciprocal of the *p*-values).

Crash Prediction Modelling Results

Crash prediction models have been built for all combinations of location (rural and urban), intersection type (T-intersections, 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 4.

The number of intersections in each row of each sub-table is shown (for example, there are 93 rural standard T-intersections). There were insufficient intersections or crashes for four of the combinations (those marked 'X'); in these cases models could not be fitted. For each of the remaining eight combinations a design index was developed, built using the geometric variables found to influence the safety of the combination. The key contributing 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. Table 5 and 6 show the crash models developed for both the JA and LB crash types. The tables also show the quality of the model fits. Some models have an excellent fit while others, especially some urban models, have a poor fit.

Table 7 shows the design elements that make up the design index (DI) for each model. For more detail on variables refer to Turner et al. (2018).

In some cases the addition of the design index was the key reason for achieving a well-fitting model. This is the case with the TLRJA model, which has a constant term, flows Q1 and Q5, Speed and the TLRJADI design index providing an excellent fit. The model with only constant term, or constant term with Q_1, or constant term with both Q_1 and Q_5 fails to fit (the fitting algorithm does not converge). When speed 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). The design index in all cases considerably improves the model, reducing the AIC.

Summary of Findings and Future Research

The previous research in this area, and an analysis of national crash data and crashes at the study intersections, identified that there were two main crash types at high-volume priority T-intersections: JA (right-turn crossing) and LB (right-turn-against) crashes. 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.

The following sections outline the key findings of the research as they apply to urban and rural Seagulls and LTSLs in rural areas. These findings were identified in the literature review and through crash prediction modelling. Each of the models had an excellent fit to the data.

Urban seagull intersections (SUJA)

The key road safety findings at urban Seagulls are as follows – note that the human factors mentioned are one possible interpretation of why a variable was shown to be important:

Table 6: Crash Prediction Models- LB Crashes

Model Names	bo	Q3 b1	Q5 b2	Speed b3	DI b4	GOF G^2	Fit
Urban Standard T-Intersections TULB	1.21	0.40	0.21	-4.5	3.1	17.31	Very Poor
Rural T-intersection with LTSL TLRLB	-21.17	- 0.034	0.35	2.4	4.8	2.27	Excellent
Rural Seagull Intersection SRLB	-8.5	1.0	-	-	1.5	1.93	Excellent

Q_1 – right turn from side-road, Q_3 – right turn from main road & Q_5 through movement from right side of side-road

Table 7: Design Elements

Models DI	No. Variables	Variables
TRJA-DI	6	Provision of right turn bay and width and length of this bay, main road median width, presence of near-side upstream feature (e.g. parking, bus stops and side-roads and visibility to right 2m from limit line
TUJA-DI	10	Right turn bay taper length, main road median width and type (solid/painted), near side number of lanes, distance to far-side upstream feature, number of lanes on side-road approach and median width, gradient of main road, width of acceleration lane and presence of car parking near intersection.
TLRJA-DI	4	Length of right turn bay, off-set of LTSL from side-road limit line, LTSL control (none and give-way) and type of main road median.
SRJA-DI	7	Main road median width and type, number of near-side and far-side lanes, side road signage (stop or give-way), width of separation between LTSL and through lane and off-set of LTSL from side-road limit line.
SUJA-DI	9	Width of right turn bay, main road median type and width, near-side shoulder width, distance to far-side upstream feature, LTSL into main road prevision and type, length of seagull splitter island and length of acceleration lane.
TULB-DI	8	Distance to near-side upstream feature, presence and width of side-road median, presence of street lighting and top of tee chevron board and main road median island width and total road width.
TLRLB-DI	5	Width of right turn bay, width of side-road median and number approach lanes, presence of top-of-tee chevron and type of LTSL
SRLB-DI	6	Right turn bay length, main road median width, number of near-side and far-side lanes, type of LTSL and off-set of LTSL from side-road limit line.

1. Wider right-turn bays (on the main road) increase JA crashes (this may cause higher entry speeds into the right turn bay and distract drivers turning right out of the side-road)
2. 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).
3. A greater nearside shoulder width increased JA crashes (this could be due to a greater crossing distance to the safety of the median).
4. Far-side upstream features impact on JA crashes (this may draw the attention of drivers turning right into the main road to the left, rather than looking to the right where they should be primarily focused).
5. Larger seagull islands (and typically larger intersections) increase JA crashes (most likely due to higher negotiation speeds).
6. The longer the Seagull acceleration lane is for drivers on the main road the more JA crashes are expected (may be due to higher intersection negotiating speeds).

Rural T-intersections with LTSLs (TLRJA and TLRLB)

The key road safety findings at rural intersections with LTSLs are as follows:

1. 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 where they should be focused).
2. A greater number of side road traffic lanes reduces LB crashes (greater distance to safety of the side-road).
3. The presence and greater width of the 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).
4. 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).
5. 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).

Rural Seagull intersections (SRLB)

The key road safety findings at rural Seagulls are as follows:

1. Longer right-turn bay increases LB crashes (may be a surrogate for high right-turn movement and create pressures on drivers to make the right turn into the side road).
2. Seagull intersections with wider main road medians have more LB and JA crashes (see comments on urban seagulls - SUJA).
3. The presence of two near-side lanes increases LB and JA crashes (this may be due to the wider distance to cross to a safe area).
4. 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).
5. 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).
6. The type of LTSL treatment impacts on LB crashes (this has been found in other studies – it might be that right-turn-out of side road drivers are expecting vehicles to turn left rather than travel straight through).
7. 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).

Goodness-of–fit and Analysis Tool

Generally the rural crash models had a good fit to the crash data. Based on the good fit there is a level of confidence that these models are useful for estimating crashes in rural areas. In comparison 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 priority intersections.

An Excel toolkit was developed to assess the safest form of control for a given combination of variables, including flows (see Turner et al. 2018 for more detail on this spreadsheet tool). 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.

Future Research

The focus of future research should be to:

1. Examine further the impact on crash rates of various LTSL types and combination of left-turn and through traffic volumes and speeds. The number of sites may need to be doubled from the existing sample size of 37 rural intersections to produce robust 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, especially for urban 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 would also be useful for urban roads, in particular, to look at how road features (eg. parking) impact on approach speeds.
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, as most of the intersections had low traffic volumes.

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