PUSHING THE BOUNDARIES OF ROAD SAFETY RISK ANALYSIS

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ABSTRACT

In order to address the safety and efficiency issues out on the transport network, traffic and road safety engineers often come up with innovative design solutions. The safety of such schemes can be difficult to assess given that most of the safety research has been developed for standard intersections. For example in the Economic Evaluation Manual: Appendix A6 crash prediction models and crash reduction factors are provided for standard intersections and road links and common treatment types. There are also limited models around that can assess the risk of serious and fatal crashes.

This paper discusses three studies that have considered non-standard intersection and rural road upgrades/treatments in the Bay of Plenty. The first two include a signalised roundabout at the Takitimu/Elizabeth Street and Te Maunga (SH29)/Tauranga Eastern Link (TEL) intersections and also a displaced right turn signalised T-junction at the latter intersection. Crash prediction models and overseas research have been used to assess the relative safety of these alternative intersection designs. These have also been compared with standard intersection configurations. For intersections the risk of serious and fatal crashes is assessed using various research on severity including factors provided in the High Risk Intersection Guide. Specific research on crash rates and crash severity were also used to look at combination of clear-zones and barriers on the shoulder of the TEL and the effect on the risk of serious and fatal crashes.

INTRODUCTION

To address congestion and high crash rates in urban networks, traffic engineers use a combination of standard and innovative treatment options. Standard improvements might involve converting a regular priority cross-road to a regular roundabout or traffic signals or four laning a two-lane road. More innovative solutions might involve use of signalised roundabouts, closely spaced or staggered signalised intersections, an “egg-about”(or oval) roundabout, a non-standard motorway interchange or various alternative at-grade intersection options, such as displaced right turn lanes at traffic signals. There is often a resistance to using innovative designs given the uncertainty around the likely safety and efficiency performance of such improvements. Even more standard improvement projects, such as converting a roundabout to traffic signals, may have design elements that create uncertainty in how the intersection will operate.

Often innovative designs are required due to surrounding topography, land-use and build form, especially in urban areas where land available for improvements is restricted. In such circumstances design guidelines and standards are regularly compromised, to fit around all the constraints. The ability to assess the safety of design compromises is important so that evidence of the likely crash impact can be provided when undertaking value engineering exercises. The cost saving of such a compromise might be attractive to a road controlling authority, but if this is likely to lead to a much greater risk of serious or fatal crashes then the decision should be made not to compromise. Likewise, if the compromise has very little impact on the risk of crashes, especially more severe crashes then it may be worth progressing with.

Traffic engineers have many ‘tested’ tools that they can use to assess the efficiency of both standard and non-standard intersection (and road link) improvements, including micro-simulation packages, TRANSYT, LinSig and SIDRA. This is not the case in road safety where there are limited tools available, most are unable to deal with non-standard intersection designs or non-standard elements of intersection design. There is also limited use of such tools, which makes them to a degree un-tested. In the absence of such adequate tools traffic and road safety engineers often use judgement and what research they can easily find to assess safety. In Turner et al. (2007) it was suggested we need a Sidra for road safety in New Zealand. We now have much of the research required to develop a basic assessment tool and there are some simple tools emerging that can be used to assess the safety of some standard intersections and road links designs.

The problem is that many intersections and some road link improvements are not standard and the current crash models and modelling tools are not suitable on their own to assess the safety of these designs. There also remains a number of gaps in the local research, due to the costs of doing such research, and that in a small country, with a relatively small road network, some design elements, such as signalised roundabouts and staggered junctions are not present in sufficient numbers to develop quality crash models. Given that it is important that we are as scientific as we can in assessing the safety of new roading designs and therefore make the correct decisions, it is important we have a process for assessing the likely safety of these designs. This paper outlines such a process and demonstrates how it has been used to assess the safety of improvement options on three different projects.

OPTION SAFETY ASSESSMENT PROCESS - ESE

Many traffic and road safety engineers have attempted to assess the safety consequences of (major) roading improvements using logic and the limited research they are able to obtain on the safety of a particular improvement. There have been some who have utilised the crash prediction models and crash reduction factors in Appendix A6 of the NZTA Economic

Evaluation manual (EEM, NZTA, 2010). Often these crash models or reduction factors do not cover the specific design that is being proposed and so adjustments need to be made to the prediction. The ESE process presented here, and showcased in the case studies, indicates what steps should be undertaken to carry out such an assessment. The three key elements of the ESE (or EASY) process are:

1. Estimation of expected crashes using the best available base (crash) model
2. Safety observation based on experience
3. Evidence from national and international road safety research

To give confidence in the results the ESE process includes checking throughout the process by reviewing and comparing with other available information sources.

Each element of this process is further described below.

Step 1: Estimation of expected crashes using the best available base model

This step involves producing a base estimate of the likely number of annual crashes for each option using the best available New Zealand research. As already specified, NZTA (2010) Appendix A6 contains a number of base models (or crash prediction models) for New Zealand intersections and road links and crash reduction factors for treatment and road features. In addition there are further crash prediction models and reduction factors available in NZTA, Road Safety Trust and Austroads research reports, as specified latter on. There are also local and international crash prediction toolkits available to use in this step. The base models and tools are explored more in the following sections.

Step 2: Safety Observations based on Experience

In this step an experienced road safety practitioner identifies design elements of an intersection or road link improvement that differ from the typical intersection or road links for which the crash prediction model and crash reduction factors applies. While NZTA (2010) does provide some commentary on what intersection and link layouts the crash models and reduction factors apply to, a full appreciation requires review of the research reports and papers.

Step 3: Evidence from national and international road safety research

In this step the base crash prediction is modified using the best available information from the international (and national) literature. Care needs to be taken when applying overseas research. It is important that the context where the research results were obtained is understood. For example, traffic signal layouts vary widely around the world and the application of a particular treatment may differ considerably depending on what traffic signal layout it was applied to. Research can also be of variable quality and care needs to be taken in selecting findings to use. In the absence of suitable research then logic can be used by an experienced road safety engineer to estimate the likely change in crash rate that a particular design element might have. However this should be a last resort after having made suitable attempts to extract valid research on the factor. The use of judgement, due to the lack of suitable research, should be specified.

There are some obvious similarities between Step 2 and elements of road safety auditing. The ESE process will not replace safety auditing, but will assist in making the right decisions at concept stage on road layout or intersection type and control, which will then be refined during the detailed design and safety auditing process. There will be some merit in the same parties carrying out both processes, so that the correct matters are identified in Step 2 (by a team).

The ESE process considers both the risk of all injury crashes and fatal and serious injury only crashes. While the majority of crash prediction models and risk reduction factors are for all injury or all crashes (including damage only) under a safer system approach the focus is on the fatal and serious crashes (FSi) and so a risk rating for these more serious crashes is of particular interest. In most cases the prediction of all injury crashes is made first and then a prediction is made of the more severe crashes. This can be achieved by using available information on severity factors and adjustments including the High Risk Intersection Guide (HRIG – NZTA 2012a) and the High Risk Rural Roads Guide (HRRRG – NZTA 2011). These calculations are illustrated in the case studies.

To improve interpretation of the ESE assessment findings the results are presented as return periods alongside injury crashes expected per year. The return period is the occurrence of FSi crashes expressed in number of years or number of months per occurrence. This provides a readily and easily understandable comparison between options and avoids crashes being expressed in decimal places.

The three case studies that follow demonstrate how the ESE process can be applied. Two of the studies focus on intersection improvements. Both are roundabouts that need to be modified to address congestion. Options include signalised roundabouts (part-time and full-time), traffic signals, one with a displaced right turn configuration and grade separation. The third example looks at the safety of different road-side treatments on a rural expressway. Work is also underway to consider other improvement projects in both New Zealand and Australia, including 1) grade separation of railway crossing between two closely spaced traffic signals, 2) installation of high speed signals on a 4-lane highway at the bottom of a steep grade, and 3) Improvements options for a narrow bridge on a poor alignment rural highway (horizontal and vertical).

NEW ZEALAND BASE MODELS AND SAFETY PREDICTION TOOLKITS

Appendix A6 of the NZTA Economic Evaluation Manual contains a large number of base models (crash prediction models) and crash reduction factors for intersections and road links. Further New Zealand base models and crash reduction factors can be found in NZTA research reports and conference papers. A selection of these sources is identified below:

- Rural Roads (Cenek et al. 2012, Turner et al. 2011, Nates et al. 2012)
- Rural Priority Intersections (Turner and Roozenburg 2006a and 2007)
- Traffic Signals (Singh et al 2011)
- Roundabouts (Harper et al 2005, Turner et al 2006b and 2009)
- Pedestrians and Cyclists (Turner et al 2006c, 2006d and 2006e)
- Urban Links and Intersections (Turner et al 2001)
- Crash reduction Factors (LTSA 1995)

There are a number of crash prediction toolkits that are available, most of which are international and require calibration. Two New Zealand toolkits are illustrated in Figure 1. The first (left-hand side) is the Beca intersection crash prediction toolkit and the second is a NZTA toolkit for traffic signals only. The first (Beca) toolkit provides an estimate of crashes at intersection based on the volume of traffic and some selected factors (for some intersection types) such as bicycle and pedestrian flows, sight distance and approach speed. The second (NZTA) toolkit is available on the NZTA website (NZTA, 2012b) It provides a crash prediction for traffic signals based on traffic volume, geometric factors, signal factors and other factors, such as presence and proximity of bus stops.

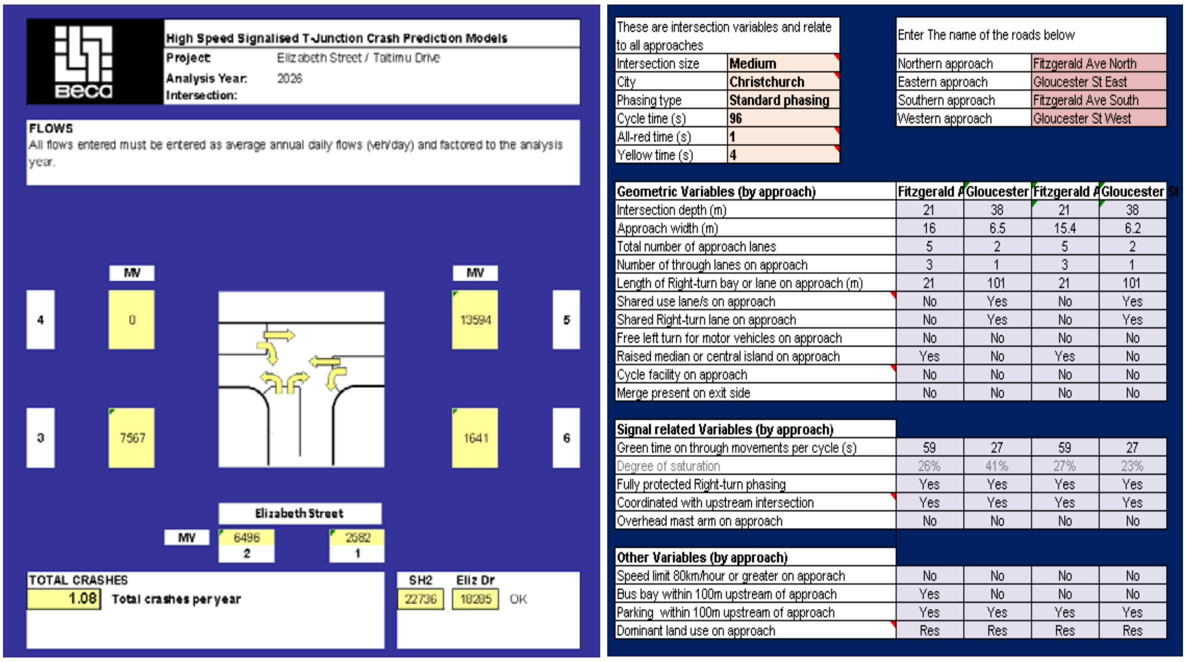

Figure 1 – Intersection Crash Prediction Toolkits

There are a number of crash prediction tools available overseas, including ISAT (Motorways, USA), SafetyNet (Urban links and intersection, UK), IHSDM (Rural Roads, USA), Safety Analyst (Highway Safety Manual models, USA). Several of these tools are profiled in Turner et al (2007). ISAT is a freeway (motorway) crash prediction tool for interchanges and main line sections. Figure 2 shows the various motorway elements that are used in ISAT and for which crash predictions are available. Figure 3 show the some of the detail on interchanges that is included within the ISAT tool. Note that it is set up for right-hand driving and thus New Zealand users need to be careful when using the tool as results will be reversed for NZ.

ISAT has been calibrated separately for the Auckland motorways and for interchanges outside Auckland. The calibration is only based on six interchanges in each category, at this stage. The calibration so far shows that overall Auckland motorway interchanges perform slightly better safety-wise than equivalent US interchanges; with an adjustment factor of 84%. This improves substantially for interchanges outside of Auckland to an adjustment factor of 46%. This may be in part due to lower reporting rates of injury crashes outside Auckland, as Auckland has a dedicated Motorway Patrol. ISAT has been used in some of the ESE assessments.

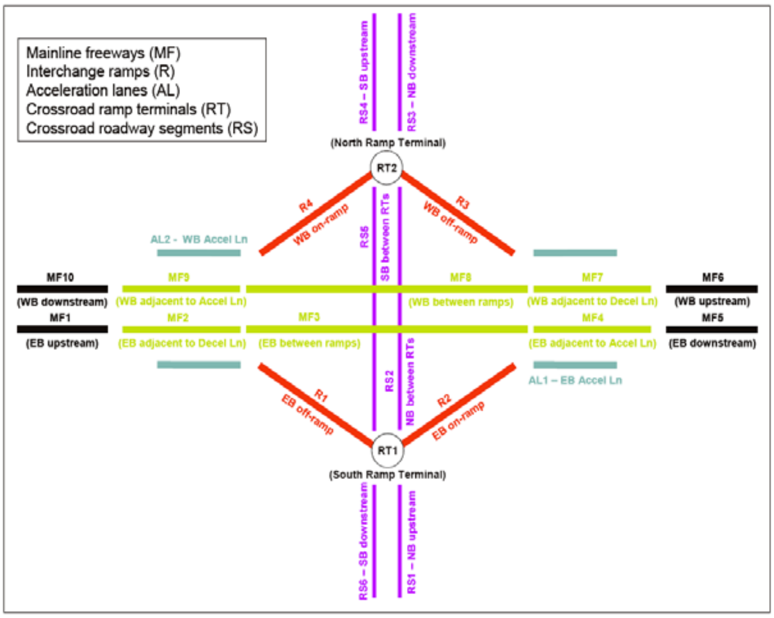

Figure 2 – Motorway Elements used in Crash Prediction

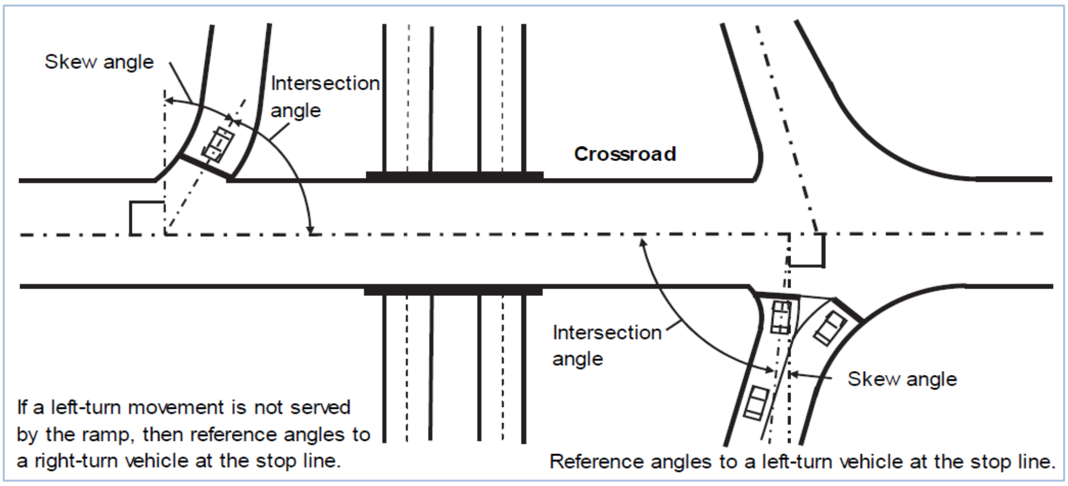

Figure 3 – Example of Detailed Factors Included in ISAT Predictions

CASE STUDY 1 – TAKITIMU DRIVE AND ELIZABETH STREET

The Elizabeth Street/Takitimu Drive intersection consists of a two lane, three arm roundabout located on State Highway 2 bypass on the western side of the Tauranga isthmus. The roundabout provides access to the city centre and surrounding commercial areas, and is also a major route for freight traffic travelling to and from the Tauranga Ports. Eastbound traffic along Takitimu Drive accesses the roundabout from a right lane diverge exit, and northbound traffic from Elizabeth St accesses Takitimu Drive by a right lane merge entry. Northbound traffic along State Highway 2 is not required to negotiate the roundabout, and bypasses it completely. Figure 4 shows the site location and layout.

Figure 4 Takitimu Drive/Elizabeth Street Intersection Location and Layout

The current roundabout is experiencing congestion during peak periods as a result of high traffic flows and uneven traffic movements. This is forecast to get worse if the intersection is not upgraded. Options at the intersection include

1) Modifying the existing roundabout (Figure 4),
2) 3-leg traffic signals (Figure 5),
3) Part time signalised roundabout (metered roundabout), and
4) Full-time signalised roundabout (Figure 5).

In each case additional traffic lanes are proposed at the intersection. The close proximity of buildings and associated facilities (eg. car parking) on Elizabeth Street is a key constraint in option development.

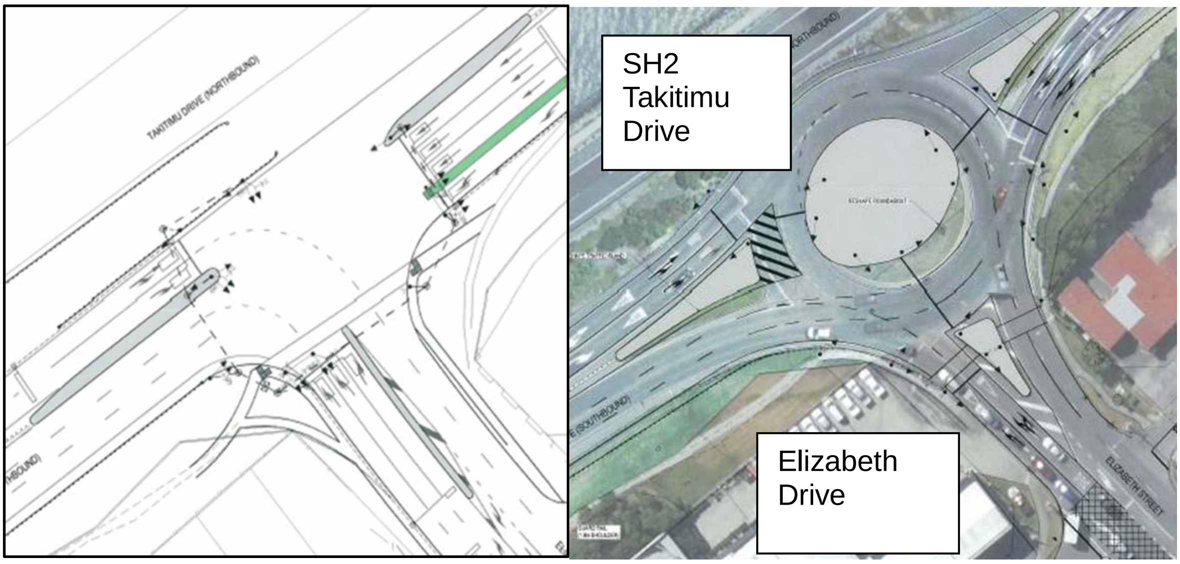

Figure 5 – Traffic signal and signalised roundabout options

The Beca crash prediction toolkit was used to assess the safety of both a high speed signalised T intersection and an un-signalised roundabout at this location. International research was reviewed to assess the safety of part-time and full-time traffic signals (County Surveyors Society, 1997) and lack of roundabout deflection, caused by the cutting down to the central island to avoid land take from properties on Elizabeth Street.

The results of a study carried out into the safety of signalised roundabouts in the UK (County Surveyors Society 1997) highlighted the following;

- Continuous operation high speed signalised roundabouts resulted in an 11% reduction in crashes and a reduction in severity by 44%.
- In the case of part-time signals an 8% reduction in crashes occurred during operation and a 66% increase in crashes resulted outside of operation. No change in severity was noted.
- Part-time operation may lead to confusion as to the method of control
- Part-time operation can result in a compromised layout due to the differing requirements for good lane definition necessary for signals and the easier curves and flared entries necessary for an effective roundabout.
- Part-time operation may create difficulties with signalised pedestrian crossings due to confusion over state of operation

Lack of deflection on the south-bound 3-lane entry in low flow conditions (when approaching on a green signal) is likely to result in some drivers using the path of least resistance (crossing lane lines), which in turn may result in higher entry speeds. This is expected to increase the likelihood of a vehicle losing control and collisions with drivers emerging from Elizabeth Street, who may have difficulty judging entry speeds of approaching vehicles. It is also likely to increase the impact speed and hence severity of crashes between southbound traffic and right turners from the south. Research has shown that lane lines help to reduce this risk (Arndt and Troutbeck, 2005). In addition having the signals resting on a red default setting outside of peak hours and restricting approach visibility will reduce this risk by reducing speeds. Even with these measures it was assessed that the poor deflection on this approach would increase loss-of- control crashes by 20%. Table 2 shows the results of the analysis.

Option	**All crashes in 5 years**	**FSi Return Period**
Roundabout with Continuous Signals	4.6	15.0 yrs
Roundabout with Part-time Signals	4.8	13.5 yrs
Roundabout with Continuous Signals and bigger cut into central median (to cut down on costs)	5.85	14.5 yrs
Signalised T	5.35	6 yrs

Table 2 – Crash Predictions and Return Periods

It can be seen that the roundabout option with continuous signal operation generally performs better than part-time signalisation or a signalised T. Signalised roundabouts are generally considered to remove the indecision that can result from vehicles on roundabout entry. Part-time signals are considered to be less effective, leading to an increase in crashes when compared with the other layouts due to the added confusion that can result. The option with central island reshaping also perform slightly less well as they are not as intuitive as a circular island, although due to the roundabout being of 3 arm configuration this is considered to be of minor consequence, being mainly likely to affect the traffic on approach from Elizabeth Street. Signalised T intersections are inherently less safe, particularly in higher speed environments. This is due to the potential for right angle crashes which research has shown to result in higher severity crashes. NZTA have adopted a 'safe system' approach to road safety where designs are predictable and forgiving of mistakes. It is therefore considered that this layout is not safe system compliant.

CASE STUDY 2 –TE MAUNGA (SH29) AND EASTERN LINK (TEL)

The Te Maunga/TEL intersection is also a two lane three-arm roundabout. The roundabout provides access to Tauranga from the east. It is part of a key freight traffic that links with the Tauranga Port. Travel speeds, particularly from the east are high and there is a 80km/h speed limit. The development of SH29 into an expressway; Tauranga Eastern Link (TEL) and associated development to the East of Tauranga will significantly increase the amount of traffic using this intersection. A number of options have been developed to increase capacity at the intersection, including a signalised roundabout, a three-arm signalised intersection, grade separation and a signalised intersection with a displaced right turn movement, as shown in Figure 6;

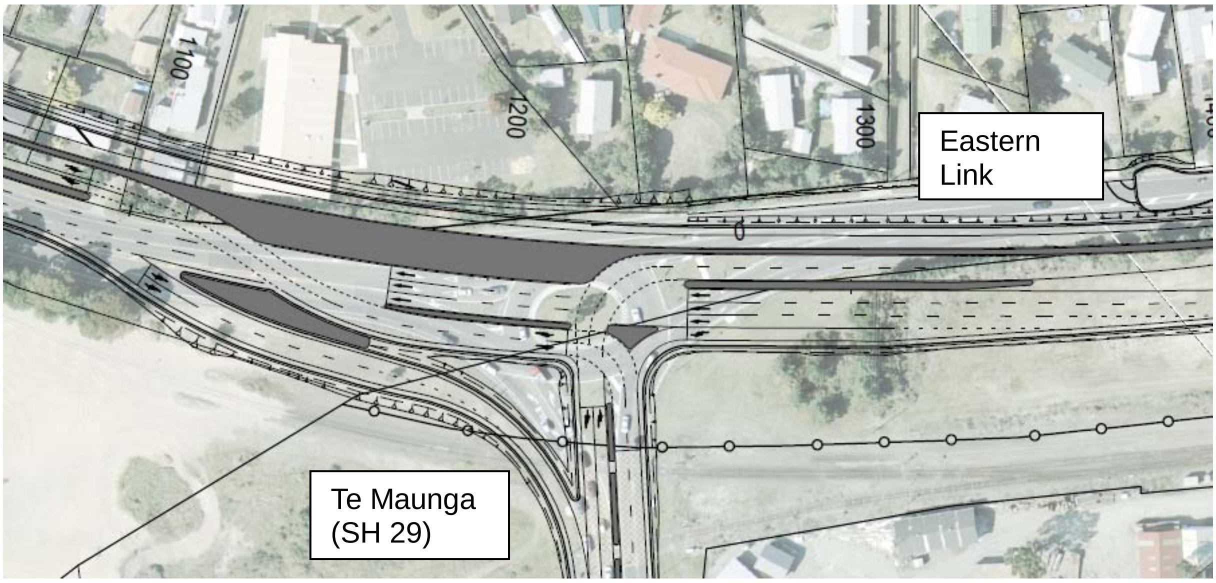

Figure 6 – Proposed SH29/TEL Traffic signals with Displaced Right Turn

Crash prediction toolkits are available for signalised T-junctions with high speed approaches and grade separation. The signalised roundabout can be assessed using the same approach as in Case Study 1. The only intersection where a process had not already been developed is the traffic signals with a displaced right turn. In order to understand the safety effects of this layout, research was sought on DRT layouts. Two research reports were found on displaced right runs, one from the UK (Simmonite and Chick, 2004) and one from USA (FHWA, 2009). Additionally, Beca contacted the FHWA Turner Fairbank Highway Research

Center in the USA who provided detailed before and after crash analysis of an operational Displaced Left Turn (DLT) site.

The UK DRT layout (Simmonite and Chick, 2004) was at the A4311 Motorola T-junction, which is within a 40mph (64km/h) speed limit area. This layout appears to be part of a new road network and so is without prior data for comparison. However, a 3-month post construction monitoring study has been undertaken of this intersection, including speed measurements and conflict studies and a comparison with a control site. It was found that speeds remained constant over the monitoring period, and were also around 5km/h lower than expected for straight ahead and left turn movements when compared to traditional layouts. During the conflict study a total of 14 serious conflicts were found, which was higher than the control site which had 4 conflicts. However, 65% of these conflicts were due to lane discipline issues, which could easily be mitigated by signage and road markings at and on approach to DRT. It was considered that once mitigated, the number of incidents at the DRT may be equivalent to a traditional highly trafficked signalised intersection, although mathematically this still represents a potential 23% increase in conflicts.

The USA research (FHWA, 2009) provided details of a number of DLT layouts (equivalent to our displaced right turns). A detailed safety performance review was undertaken for the Airline Highway at Siegen/Sherwood, Baton Rouge in Louisiana. This information was supplemented by more detailed information that was provided by the FHWA. This site comprised a crossroads DLT layout with the site having an entering flow on the main road of up to 45,000 AADT and speed limit of 55mph (88km/h). The monitoring was based on 4 years before data and 2 years after data. It was found that on average all crashes reduced by 36% and fatal and serious injury crashes dropped by 19%. All crash types reduced except side swipe crashes. It was found that the relocation of turn movements can lead to wrong-way movements. These can be reduced by providing adequate signage and pavement markings. While the USA research indicates significant reductions in crashes, the reductions are for a single site and it is based on a crossroads intersection configuration. It has a lower approach speed than the SH29/TEL intersection and there is greater potential to reduce a more complex range of conflicting movements. Hence it is unlikely that the benefits can be directly applied to the Te Maunga/TEL intersection.

Specific safety observations were noted, including

- potential driver confusion as to layout and operation of the DRT,
- a relatively shallow angle of approach on the southbound displaced right turn, from the first holding line across the northbound through lane, and
- issues with unexpected queuing back from the railway crossing backing up onto the main through road.

Based on the above review, and the higher approach speeds, it is necessary to use both a low and high figure for the crash prediction, ranging from a neutral effect (based on a safety benefit but adjusted for the higher approach speed) to a 23% increase in crashes, when compared with a standard signalised T based on the UK conflict data. On balance it is considered that any severity benefits seen in the US example are likely to be countered to some degree by the higher speed environment at Te Maunga.

The crash estimation for the Low option is considered equivalent to a high speed T intersection and the High option is considered equivalent to a high speed T intersection +23%. So the predictions from the high speed T intersection model will be modified using these factors. Table 3 shows the results of the analysis for each of the options and includes the existing roundabout, which currently performs better than expected, but this may be a result of random variability in crash occurrence and should not be relied on for future predictions.

It can be seen that the grade separated interchange is estimated to have the best performance in terms of both crash occurrence and severity. All of the signalised T layouts including the DRT layout have a similar crash occurrence to the other options. However, in terms of severity they perform; 2 - 3 times worse than both the grade separated option and the existing roundabout and; 1.8 - 2.3 times worse than the signalised roundabout. The costs of the various options is also a consideration in which option is selected.

	Standard high speed signalised T intersection	High speed signalised T intersection with EB bypass lane	Existing roundabout With EB bypass lane (actual crashes 02-11)	New Signalised Roundabout	DRT Intersection (Based on using option with SB bypass Lane) High (low)	Grade Separated Interchange
Estimated Injury Crashes per year	1.21	1.11	1.2	1.16	1.37 (1.11)	0.9
Estimated Number FSi Crashes per year	0.25	0.23	0.10	0.12	0.29 (0.23)	0.09
Return period for fatal and serious crashes	4 years	4 years	10 years	8 years	3 years (4 years)	11years
Estimated Crashes per 5 year period	6.1	5.6	6.0	5.8	6.9 (5.6)	4.5

Table 3 Crash Predictions and return periods for various improvement options at SH29/TEL

CASE STUDY 3 – SHOULDER TREATMENT FOR EASTERN LINK

The eastern link is an expressway to the east of Tauranga City. It will provide a higher speed link between Tauranga City and the outlying eastern areas. The traditional shoulder treatment for an expressway is to provide a clear-zone, normally of 9m width. However work by Doecke et al. (2011) and Austroads (2011) indicates that the majority of errant vehicles encroach into the road-side further than 9m and that there is a still a relatively high proportion of serious and fatal crashes (0.52 and 0.55 for trees and poles, 0.38 for no hazard hit and 0.23 for wire rope barriers). Utilising this research we have assessed the likely benefit of installing wire rope barrier at 4m from the edge-line on both sides of the expressway.

Local research is available in NZTA (2010) on standard crash rates for rural highways. Research is also available on the proportion of crashes that are loss-of-control to the left and the average severity of crashes, using extrapolation of graphs for high severity crashes in

HRRRG (NZTA 2011) and comparison with that expected in KiwiRap for a 4.5 star rating road (which is considered appropriate for a new high standard road).

To assess the effectiveness of clear-zones and shoulder barrier options on the likelihood of fatal and serious injury crashes, we referred to a number of Australian research studies (specified below). Historically, effective clear zone widths have been based on a relatively shallow angle of vehicle departure (less than 15 degrees). This assumption has been used to help justify the 9m clear-zone requirements commonly used. However, Austroads (2011) research shows that 74% of vehicles involved in run off road (ROR), or loss-of-control to left crashes have departure angles in excess of 15 degrees. This was also confirmed in another study by Doecke et al (2011), where similar departure angles were found. Furthermore this study also found that 83% of ROR crashes exceeded 9m distance of travel from the running lane (see Figure 8).

Doecke et al (2011) simulated departure angles between 14.5 and 20.1 degrees and found that the impact speed at the 9m interval would be between 56-72km/h. Under a safe system, a side impact with a pole or tree should not exceed 30 to 40 km/h. Hence a 9m clear-zone is not adequate under a safer speed regime. Austroads research AP-R387-11 (Improving Roadside Safety - Stage 2: Interim Report 2011) also indicates that crash severity can increase with wider clear zones, which appears to be due to crashes that would otherwise be in collision with objects either within or outside the clear zone being replaced by rollover type crashes

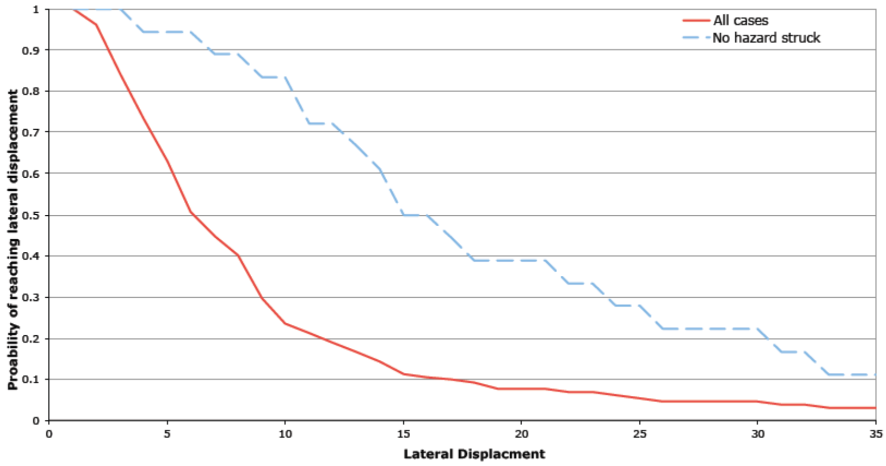

Figure 8 – Encroachment distances for Run-of-road crashes (Doecke et al., 2011)

For the Tauranga analysis, two severity factors have been used for the clear zone area based on the Austroads (2011) data. This data includes a variety of roadsides, including existing roads that may have a lower standard of design. The severity ratio (F+S/All injury) for no object hit is 0.38; a figure 20% lower was assumed to take into account the likely higher standard of road design**.** These result in a high and low crash estimation.

The analysis showed that for a 9m clear zones it is anticipated that there is still likely to be a 'High severity road-side' value of 4.4 FSi crashes per year (CPY) and a 'Low severity road-side' value of 3.6 FSi CPY. The installation of WRB at 4m from the edge-line would reduce these crashes to 2.9FSi crashes per year, representing a minimum likely saving of 0.7 FSi CPY. When considering this saving in FSi crashes and allowing for the migration of these crashes to more minor injury crashes this equates to a social cost saving of $1.35 Million annually. Over 20 years there is potential to save 18 Fatal and/or Serious crashes with an undiscounted social cost saving of $24.3 Million.

FINAL REMARKS/SUMMARY

The use of road safety research to understand the safety consequences of new roading designs is nothing new. In New Zealand a safety assessment can vary from a basic safety audit to a full safety assessment based on research, especially when economic evaluation is required to justify funding. What is less established is a formal process that should be followed to obtain the best prediction of future crash occurrence. It is important, given the increasing body of research in this area, that future crash predictions are increasingly based on the best scientific information available and that such assessments are undertaken by people who have the necessary experience in road safety, or at the very least are reviewed by experienced road safety practitioners. This is particularly important in an area where well tested analysis tools are not yet fully developed.

The ESE process, which has been applied to three case studies in this paper, formalises the process that road safety professionals should go through to develop a crash predictions for new roading designs. It recommends greater use of the growing body of local research on crash risks, supplemented with valid overseas research. The development of crash prediction toolkits will make this process more accessible over time. It also suggests using both low and high risk estimates when there is uncertainty in the research factors. Like other areas of traffic engineering, interpretation of the modelling results and selection of the correct methods does require experience both in practical safety studies (road safety audit and crash reduction studies) and a knowledge of the road safety research, and in particular its limitations (e.g. valid AADT ranges).

Under a safer system approach we are particularly interested in fatal and serious injury crashes. Most of the current risk relationships (models) are for all injury crashes. As illustrated in the first two case studies crash severity can be a key factor in selecting the correct design. While the injury crash rate of standard traffic signals is not too different for roundabouts, or signalised roundabouts, in high speed environments, the likelihood of more serious crashes, shown as a return period for such crashes, is a lot worse. Hence despite the efficiency benefits of traffic signals, the assessments indicate that a preference should be given to designs that include a roundabout or a grade separation. While this is not a new finding, the ESE assessment does provide evidence of what the increased risk of a serious and fatal crash is likely to be. This information can then be used to inform decision makers.

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