Making Evidence-based Crash Risk Estimation Routine by using the SESA Process

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Key Findings

• The case studies presented in this paper demonstrate how more robust road safety assessments are possible using the SESA process and various crash prediction tools

• This process can be used to estimate the all-injury and fatal-and-serious injury crash risk at an existing intersection and for various improvement options, even when the intersections have complex and unusual layouts.

• That new crash risk assessment methods like X-KEMM-X can be incorporated into the process to develop even better predictions of expected severe crash risks.

Abstract

Achieving safe system or vision zero outcomes at high-risk urban intersections, especially priority cross-roads and high-volume traffic signals, is a major challenge for most cities. Even after decades of crash analysis and improvement works many of these intersections still perform poorly. While best practice for optimising the efficiency of intersections requires the use of modelling tools, like Sidra, this is rarely the case with optimising road safety outcomes. This is despite the large number of evidence-based safety analysis models and tools that are now available to understand intersection crash risk. This paper outlines the SESA (Site-specific Evidence-based Safety Analysis) Process that has been developed to enable transport professionals to estimate and predict crash risk at intersections and other sites. This process utilises existing crash risk estimation tools (based on crash prediction models and crash reduction factors), relevant road safety research, crash severity factors, professional judgement and crash data to predict the underlying crash risk at intersections (and other sites) and the effectiveness of improvement options. The output includes both the number and return period of ‘all injury’ and ‘fatal and serious injury (FSI)’ crashes for each option. The paper includes three applications of the process to high risk intersections in three New Zealand cities, consisting of two priority cross-roads and one high speed roundabout. The case studies demonstrate how the process can be used to assess intersection features and improvement options that are not covered within the available crash estimation tools.

Keywords

Evidence-base crash analysis, crash risk estimation, crash prediction models, safety performance functions (SPFs), X-KEMM-X

Introduction

The majority of urban crash blackspots and many rural blackspots occur at high risk intersections. Even after decades of crash analysis and improvement works, many of these intersections still perform poorly. There is a need for more detailed crash risk analysis to understand the underlying crash risk at these intersections and to assess the effectiveness of improvement options and particularly those that achieve vision zero outcomes.

Best practice in crash risk estimation does not currently require the same depth of analysis as when estimating travel time and vehicle operating costs, using tools like Sidra. It is still fairly common for professionals to ‘estimate’ the likely change in crashes (usually reductions) based on their ‘safety experience’. At best, evaluations reference crash reduction factors and apply these to historical crash data, which in many cases does not accurately reflect the likely trend in future crashes. Only in rare situations does the crash risk estimation involve a detailed crash modelling exercise. Safety evaluations of larger transport projects (Oppenhius and Paris 2000 and Muirson, 2006) indicate that transport engineers are not particularly good at estimating crash benefits. This is likely to be due to the limitations in the crash analysis methods being used.
But why are less robust crash risk estimation methods still being used? There are four fundamental issues: 1) in many jurisdictions there is no requirement (or process) for estimating crash risk using crash prediction (evidence-based) methods, 2) many transport professionals are unaware of the evidence-based tools that are available, 3) few have experience in using such tools and 4) those that have used such tools may have run into difficulties using them, as the tools rarely cover all the crash causing factors present at complex existing intersections and innovative upgrade options.

This paper presents the SESA Process and how it has been applied to intersections in New Zealand. This process can be used to undertake more robust crash risk estimation. Variations of this process have been applied at over a dozen intersections across New Zealand and Australia. The results of a SESA process assessment have many applications, including economic appraisal, public consultation, understanding design compromises and assessing how close various improvement options are to achieving safe system. It is particularly useful when there are a large number of improvement options and it is important to understand the safety outcomes that each may achieve.

To do a robust assessment, analysts must first become familiar with the basic crash estimation tools that are available and of other road safety research. In terms of the basic crash estimation tools, there have been numerous toolkits developed for intersections and other sites that have emerged internationally over the last 20 years. These include Urban Crash Risk Assessment Tool (UCRAT) in Australia (developed by VicRoads), SafeNET in the UK (developed by TRL). In the USA, 1) ISAtc (for free-way interchanges) and the 2) the Highway Safety Manual (HSM) analysis software. There are also a number of lesser known crash prediction tools, including the traffic signals crash prediction toolkit developed in New Zealand. Many of these tools can be calibrated to local conditions. It is preferable to use tools that estimate crashes rather than produce risk scores, although the latter can be useful when comparing the effectiveness of various improvement options.

Specialised tools can also be readily developed for each jurisdiction using crash prediction models (also called safety performance functions, SPF’s), crash (or accident) modifying factors (CMFs and AMFs) and crash/accident severity factors (SF). In Australasia, New Zealand has the largest repository of crash prediction models. Many of these models are contained within the ‘Crash Estimation Compendium’ (NZ Transport Agency, 2018). Calibration of these models to Australian conditions has already been undertaken for a number of intersection types. Most Australian State and Territories have crash reduction factor tables for common road features and countermeasures, which can easily be converted to crash modifying factors. Where there is limited local crash modifying factors there are a number of international sources of crash modifying factors, including the CMF Clearinghouse (USA), the Highway Safety Manual (AASHTO, 2010) and the Handbook of Road Safety Measures (Elvik et al. 2009) developed in Europe from international research.

Site-Specific Evidence-Based Safety Analysis (SESA) Process

The SESA process has been developed and refined for predicting crashes at a site or intersection level. The intention is to try and understand the underlying injury crash risk at a site and the likely benefits of upgrade options in reducing both injury and trauma (fatal and serious) crashes.

At an intersection or site level, crash observations (from historical records) can be highly stochastic (random), and may differ to the predictions that are made from crash prediction models, which in most cases better reflect the underlying crash risk. At the urban network level, as might be observed across a dozen or more major intersections, the sum of the crash predictions is normally closer to the sum of the crash observations, due to some sites having higher and other sites having lower observations to the underlying crash risk (Turner, 1995). Many network level tools such IRAP rely on this averaging-out effect. At an intersection level, care needs to be taken when relying on crash observations. In some cases, a high number of crashes may reflect a higher level of risk while at others it may be due to random fluctuations. Hence analysts should tread carefully when using previous crash observations when assessing the safety of intersections and improvement options.

Ideally at the intersection level more detailed crash prediction models and crash modifying factors need to be used, when compared to safety analyses that are undertaken at a network or corridor level. In some cases, network level analysis relies primarily on the traffic volumes, intersection control and number of arms. However, even with the current suite of crash prediction models and crash modifying factors available across New Zealand/Australia (NZ Transport Agency, 2018) and in North America (Highway Safety Manual, AASHTO, 2010) there are a number of localised risk factors that are still not well understood. So especially for complex and unusual intersection layouts the crash observation is often considered in the assessment. The empirical Bayes approach allows a crash prediction to be developed that incorporates the crash history. The weighting placed on the prediction and the crash history depends on the confidence the analyst has in each risk estimate. In some cases, only the crash history is used while in many cases only the crash prediction.

SESA is a process that can be used to develop crash risk estimates for complex intersection layouts and innovative upgrade options (e.g. signalised roundabouts, channelised priority intersections and displaced left turn traffic signals) not covered within the current crash prediction toolkits. Given the safety judgements that need to be made through the process, the assessment often requires input from specialised road safety engineers with design and research experience. Figure 1 shows the typical SESA process.

Many of the crash risk modelling tools predict all-injury crashes. To estimate the risk of fatal and serious injury crashes (FSI) or deaths and serious casualties (DSI), there is a need to use crash severity factors. Crash severity factors
can readily be developed from historical state-wide crash databases, by intersection type, speed limit, road user involved and crash type. In New Zealand severity factors are available in the Crash Estimation Compendium (NZTA, 2018), the High Risk Intersection Guide (HRIG, NZTA, 2013) and High Risk Rural Road Guide (HRRRG, NZTA 2011).

Crash severity factors can also be developed using kinetic energy models like X-KEMM-X (Jurewicz et al., 2017). How to use X-KEMM-X to develop severity factors is discussed in Case Study 2. In some jurisdictions crash prediction models may also be available for fatal and serious injury crashes. For example, the ANRAM models developed in Victoria.

Case Studies – Applications of the SESA Process

The SESA process has now been applied in excess of a dozen different sites (all intersections), including priority cross-roads, complex traffic signal layouts (e.g. two closely spaced traffic signals) and multi-lane roundabouts. At the majority of these sites there have been in excess of four improvement options. Improvement options are often developed to increase intersection capacity. Options considered include, signalised roundabouts, standard traffic signals, displaced right turn traffic signals, grade separation, three-lane circulating roundabouts and restricted turn options.

Figure 1. Flowchart of SESA Process
To demonstrate the application of SESA process, three studies have been selected from three different cities across New Zealand, from Christchurch, Tauranga and Nelson. The following summary introduces each of the three intersections along with, why the site is being upgraded, its current intersection control and the main types of upgrade options.

1. Hampden Street/Waimea Road Priority Cross-road (Nelson)
   a. Upgrade required to reduce bicycle crashes
   b. Upgrade options include traffic signals and left-in and left out restrictions.

2. Breens/Gardiner/Harewood Road Priority Cross-road (Christchurch)
   a. Upgrade required to address community concerns, especially pedestrian crossing risk across dual carriageway (Harewood Road);
   b. Upgrade options include traffic signals, turning restrictions, road diet and signalised pedestrian crossing.

3. Elizabeth Street/Takitimu Drive (two circulating-lane) Roundabout (Tauranga)
   a. Upgrade required due to capacity improvements on Takitimu expressway;
   b. Upgrade options include 3-lane roundabout, traffic signals and signalised roundabout.

The following sections provide more detail on each intersection safety study and the expected safety outcomes from the intersection upgrade options. This includes the ‘before and after’ predicted ‘all injury’ and ‘fatal and serious injury’ crash rates for the current intersection and each of the intersection upgrade options (Step 1). The before and after upgrade crash rates are also expressed as return periods. For example, if the return period is one injury crash every 2 years or 24 months, then on average an injury crash is expected to occur every 2 years. So, in ten years, the intersection is expected to have on average five injury crashes. Obviously, a long return period is best as this indicates that on average crashes will occur less often.

**Case Study 1: Hampden Street/Waimea Street Priority Crossroad Upgrade**

This first study is focused on an intersection that has a number of crashes between motor vehicles and bicycles. With less crash prediction models for bicycle involved crashes this does add an additional challenge. Bicycle-involved crash models are only available for some intersection types.

The Hampden Street Intersection is located on Waimea Road, which is an important and busy regional arterial road in Nelson’s transport network. This corridor connects the Nelson Central Business District with destinations to the south. The intersection (see Figure 2) comprises a crossroads priority controlled intersection with a give-way control.

On the Hampden Street approaches. The intersection has a flush (painted) median, cycle lanes and right turn bays. All approaches have downhill grades, except the northern approach which is relatively flat. The signalised pedestrian crossing is located 30m north of the intersection. Queues from the crossing extend back across the intersection. Hampden Street Primary School and Nelson College High School are situated close to the intersection. A reduced speed of 40km/h is operative during the 8:15-9:00 am and 2:55 to 3:30 pm periods.

At Waimea Road/ Hampden St intersection there have been 26 reported crashes in the past ten-year period. This includes three crashes resulting in serious injuries, 11 minor injuries and 12 crashes without injury. The site-specific problems are:

- Seven of these crashes involved cyclists (27%), with two serious injuries and three involving school children.
- A high proportion (31%) of crashes involved a driver turning right into the Hampden Street western arm and colliding with a vehicle heading north on Waimea Road (NZ crash type LB right turn agent or right turn opposing).
- The two serious injury crashes were cyclists travelling through on Waimea Road being hit by drivers turning right into Hampden Street West (crash type LB).
- The third serious crash involved a vehicle travelling straight through on Hampden Street being hit by a straight through vehicle on Waimea Road.

Of the seven cyclist crashes, six were because of two movement causes, either vehicles travelling south on Waimea Road and turning right to Hampden Street or vehicles travelling west on Hampden Street crossing straight through the intersection. The queued traffic from the pedestrian crossing does restrict the visibility that drivers have to cyclists on Waimea Road when turning right into Hampden Street or travelling straight through on Hampden Street. Another exacerbated factor is the high speed of cyclists travelling north on Waimea Road, who are travelling down a steep grade.

![Figure 2. Current Layout of the Wimea/Hampden Intersection](image)

- To demonstrate the application of SESA process, three studies have been selected from three different cities across New Zealand, from Christchurch, Tauranga and Nelson.
- The following summary introduces each of the three intersections along with, why the site is being upgraded, its current intersection control and the main types of upgrade options.
- Case Study 1: Hampden Street/Waimea Street Priority Crossroad Upgrade
  - This first study is focused on an intersection that has a number of crashes between motor vehicles and bicycles. With less crash prediction models for bicycle involved crashes this does add an additional challenge. Bicycle-involved crash models are only available for some intersection types.
  - The Hampden Street Intersection is located on Waimea Road, which is an important and busy regional arterial road in Nelson’s transport network. This corridor connects the Nelson Central Business District with destinations to the south. The intersection (see Figure 2) comprises a crossroads priority controlled intersection with a give-way control.
A review of cycle crashes at other priority cross-roads across New Zealand was undertaken. There are very few other priority intersections with seven or more cycle crashes or two serious cycle injury crashes in the last ten years. Hence why this intersection requires improvements to reduce the cycle crash risk.

A large number of potential improvement options were developed to improve safety at this intersection. A list of the options shortlisted and modelled follows:

- **Option 1** – Priority intersection with banned right-turn from Waimea Road north approach into Hampden Street (install signage).
- **Option 2** – Ban all right turn movements at the intersection so it is left in and left out (LILO) only (install concrete median).
- **Option 3** Ban all right turns and make intersection LILO (left in left out) from the Hampden Street East approach and left out only from Hampden Street West approach (install concrete median and kerb protrusion).
- **Option 4a**: Traffic signals at intersection and parallel pedestrian crossing (remove mid-block pedestrian signals in all traffic signal options).
- **Option 4b**: Traffic signals at intersection with Barnes Dance (scattered) pedestrian phasing.
- **Option 4c**: Traffic signals at intersection with Barnes Dance pedestrian phasing and entry only to Hampden Street East approach.

Step 1 in the SESA process is to determine what crash prediction models are available for the analysis (in the Crash Estimation Compendium, NZTA, 2018). Two different intersection crash prediction models were identified:

1. Urban priority crossroads model (for motor vehicles) and,
2. Urban signalised crossroads model (for motor-vehicles & cyclists).

The crash risk at the mid-block traffic signals was estimated using the pedestrian crossing models and crash modifying factors in the Crash Estimation Compendium. Pedestrian and cycle counts were collected for peak hours, then scaled up to 24-hour count estimates using the tools and factors in Turner et al. (2006).

A few assumptions were made in order to calculate the crash predictions. The assumptions made were:

- That the mid-block signalised crossing will be removed for all of the traffic signal options, and that all pedestrians would use the intersection and not cross mid-block.
- Where movements are banned but measures are not put in place to physically stop the movement, it has been assumed that all drivers will obey the signage.

A 'base model' crash rate was calculated for the existing layout at Waimea Rd/ Hampden St intersection using the crash prediction models for motor vehicles, cyclists and pedestrians.

In Step 2 the main concern was how valid the cyclists crash rates were for this priority cross-road. The three key concerns being 1) using a traffic signal crash model rather than priority crash model, 2) that the main road queuing (due to the pedestrian crossing) was not considered in the crash models, and 3) the speed of cyclists entering the intersection (travelling downhill from the south) is expected to influence crash severity. The output from the model was compared against the reported ten-year crash history to assess validity of the model. Two safety specialists determined that the 'base model’ crash predictions needed to be modified to better reflect the crash history rates.

### Table 1. Hampden Street/Waimea Street Intersection Upgrade safety results

|                                      | Base | Option 1 | Option 2 | Option 3 | Option 4a/4b | Option 4c |
|--------------------------------------|------|----------|----------|----------|--------------|----------|
| Estimated number of injury crashes per year (motor vehicle only) | 1.05 | 1.02     | 0.65     | 0.65     | 0.81         | 0.78     |
| Estimated number of injury crashes per year (cyclist v motor vehicle) | 0.85 | 0.70     | 0.25     | 0.21     | 0.37         | 0.34     |
| Estimated number of injury crashes per year (all) | 1.90 | 1.72     | 0.90     | 0.86     | 1.18         | 1.12     |
| Estimated return period for injury crashes (years) | 0.53 | 0.58     | 1.11     | 1.16     | 0.85         | 0.89     |
| Estimated number of FSI² crashes per year | 0.33 | 0.30     | 0.15     | 0.14     | 0.19         | 0.18     |
| Estimated return period for FSI crashes (years) | 2.99 | 3.37     | 6.85     | 7.29     | 5.36         | 5.68     |
Based on a review of the crash history, the cycle crash history at other priority intersections across New Zealand and crash causing factors, like speed of downhill cyclists and the queuing through the intersection, it was determined that the intersection had a cycle crash rate well beyond that observed elsewhere in New Zealand. It was concluded by the specialists that the available crash prediction model for cyclists (at traffic signals) was not suitable and hence the injury crash risk from the ten year crash history should instead be used for cyclist crashes at this intersection (Step 3). With seven cycle crashes in total this was considered a suitable number of observations to establish a site crash risk from the crash history. The base crash estimates from the crash models were considered suitable to assess the crash risk for motor-vehicle and pedestrian crashes.

In Step 4 the predicted number of fatal and serious crashes was calculated using the severity factors in the Crash Estimation Compendium. The results of the analysis are shown in Table 1.

The analysis shows that Option 2 and 3 (restricting right turning movements) provide the greatest reduction in the estimated number of injury crashes and fatal and serious injury crashes at the intersection, with each of the Option 4 sub-options still providing improved safety outcomes. Some safety effects are not fully captured in this analysis, such as drivers and cyclists having to use alternative routes (and intersections) due to turning bans. Such effects can reduce the benefit of some options. In this case the effects are minimal compared to the safety benefit at this intersection.

Case Study 2: Breen/Gardiners/ Harewood Intersection Upgrade (Christchurch)

In this recent SESA, Abley were asked to do an independent safety review of a number of intersection improvement options that had been proposed at the Breens / Gardiners / Harewood intersection. Both the Breens Road and Gardiners Road legs of the intersection (see Figure 3) are controlled with stop signs and markings. Harewood Road is configured as a four-laned median divided road with right turn bays within the median.

While this intersection does not have a high crash rate over recent years, there is a lot of public interest in what is perceived to be a very unsafe intersection on a key arterial route, especially for pedestrians (school children) crossing Harewood Road. This project had received over 1,000 public submissions with many wanting the intersection signalised.

The scope of the safety assessment was to assess the expected safety performance, particularly in terms of the risk of fatal and serious crashes, of the various options relative to the existing situation. Figure 4 shows that there are a lot of conflicting points at the current intersection due to the number of turning movements and four lanes of traffic on Harewood Road.

The site has had 28 reported crashes in the last 10-year period, with 21 of those crashes being right-angle crashes (no turns, or under NZ coding HA-type crashes). The majority of the crashes were of low severity, with only five injury crashes in the ten years (2.5 injury crashes every five years). There have also been no crashes between pedestrians and motorists, despite safety concerns and observations of risky crossing behaviour.

![Figure 3. Layout of Breens/Gardiner/Harewood Road Intersection](image1)

![Figure 4. Traffic Conflict Points at current Breens/Gardiners/Harewood Road Intersection](image2)
In Step 1 it was established that there are crash prediction models in the Crash Estimation Compendium for urban signalised crossroads and urban priority crossroads. The priority crash model was used to estimate the base crash rate at the existing intersection. The model estimated that there should be on average 2.8 injury crashes in a 5-year period. This compares favourably with the number of crashes observed and so the current intersection is performing as expected.

While the vehicle crash rate may be at the crash levels expected, and there have not been any pedestrian crashes over recent years, there is a major concern from the public that the intersection is unsafe for vulnerable road users and there is a need to install a signalised crossing so that these vulnerable road users, including school children, can safely cross Harewood Road. Hence why the Council are planning to upgrade the intersection to safely accommodate crossing pedestrians (and cyclists). There were three proposed options presented to the public (see Figure 5 and 6) as follows:

- **Option One**: Left-in/ left- out configuration and one single lane in each direction on Harewood Road (road diet), with right-turn movement permitted into Gardiners Road and nearby signalised pedestrian crossing (Figure 5).
- **Option Two**: Signalisation of the existing intersection. The impact of this is likely to be more traffic crossing between Breens and Gardiners, as many drivers currently use alternative routes (Figure 6).
- **Option Three**: Conversion of Harewood Road to a single lane in each direction (road diet) and retain stop control (Figure 6).

From a traffic conflict perspective Option 1 has a lot fewer conflict points (as shown in Figure 5) than the existing intersection and the other two options, although it will push some traffic to do U-turns in the median and onto other intersections. Option 2 has the same number of conflict points and Option 3 has a lower number only due to the single lane in each direction on Harewood Road. This is a major difference between the options that is considered in the crash severity analysis.

In this case the crash models that were available were suitable for the options (Step 2) and so no adjustment was required to the base estimates (Step 3). This was also confirmed by the validation of the crash history and crash prediction for the existing priority cross-roads. Turning bands can be modelled by assuming zero flows for the

![Figure 5. Option 1: Restricting right turn movements and road diet on Harewood Road](image)
banned movements. While crash prediction tools are available for pedestrian and cycle crashes at traffic signals (Option 1 and 2) and crossing aids (Option 3), the focus of this study was on motor vehicle safety. It is relatively clear that a signalised pedestrian crossing is safer than one with crossing aids only.

Traditionally in SESA, we use crash severity factors to estimate the risk of fatal and serious injury crashes for existing sites and each option. This approach, however, does not adequately take into account the reduction in the number of serious conflicts when traffic movements are banned, as is the case for Option 1, or when a road diet is applied. The removal of most of the crashes involving right turning vehicles and between two straight through vehicles is expected to reduce the overall severity of crashes at this intersection. To take this reduced severity into account we have used the X-KEMM-X kinetic energy model (Jurewicz et al., 2017) in Step 4 to estimate the severity of each conflict point and for each crash type based on speed and impact angle.

Application of the X-KEMM-X method to the existing intersection shows that 20 of the 32 vehicle/vehicle conflict points have a greater than 10% likelihood of producing a serious injury outcome. Overall, the average expected likelihood of a serious injury outcome across all 32 conflict points is 34%. Multiplying the expected number of injury crashes from the crash prediction models by the average expected likelihood of a serious injury outcome can provide an indication of the inherent level of safety of an intersection configuration. For the existing intersection configuration, this is 0.19 high severity crashes (including fatalities) per annum, or approximately 1 every 5 years.

As shown in Figure 5, Option 1 does involve major alterations to the intersection, and results in only four vehicle/vehicle conflict points (compared to 32 for the existing intersection) and eight vehicle/pedestrian conflict

Table 2. Breens/Gardiner/Harewood Intersection Upgrade Safety Results

| Option   | Expected Injury Crashes per annum | Number of High Severity Conflict Points | Expected High Severity Crashes per annum |
|----------|-----------------------------------|----------------------------------------|----------------------------------------|
| Existing | 0.55                              | 20                                     | 0.19                                   |
| Option 1 | 0.38                              | 3                                      | 0.10                                   |
| Option 2 | 0.78                              | 22                                     | 0.38                                   |
| Option 3 | 0.55                              | 12                                     | 0.13                                   |
| Safest Option | Option 1                         | Option 1                              | Option 1                              |
points. For Option 1 and the other two options the impact on crash severity (Step 4) has been evaluated using a combination of applying the crash prediction model and the X-KEMM-X derived severity values. Table 2 shows the results of the combined analysis.

Case Study 3: Elizabeth Street / Takitimu Drive Roundabout Upgrade

In this study the team were asked to review the relative safety of a number of options to improve the capacity of the existing roundabout (see Figure 7), as it was experiencing congestion during peak periods. The Elizabeth St/Takitimu Drive intersection consists of a two lane, three arm roundabout, with a northbound bypass lane, located on the State Highway 2 (Takitimu Drive) expressway in the city of Tauranga. SH 2 is a major route for freight traffic travelling to and from the Tauranga Port.

There were three main upgrade options with a number of sub-options developed as follows:

Option 1a - Signalised Existing 2-lane Roundabout (Full-time);
Option 1b - Signalised Existing 2-lane Roundabout (Part-time);
Option 2a - Signalised 3-lane Roundabout (Full-time) with widening to the east;
Option 2b - Signalised 3-lane Roundabout (Full-time) with reshaping of central island;
Option 2c - Signalised 3-lane Roundabout (Part-time) with widening to the east;
Option 3 - Signalised T-Intersection.

The part-time (or metered) signalised roundabout options involved managing the volume of traffic entering the roundabout on SH2 in the southbound direction during peak periods to allow traffic to enter the roundabout and expressway from Elizabeth Street. For the three-lane signalised roundabout options, one option was to widen to the east, but this required land purchase and associated changes to the parking areas and possibly two industrial buildings on Elizabeth Drive. The alternative option, to minimise land take, was to modify the shape of the roundabout central island to accommodate the third southbound lane. The impact of this was to reduce the deflection in the lanes heading south which would increase speeds and may increase crash severity.

In Step 1 it was established that base estimates could be developed using the roundabout and signalised T-intersection (Option 3) crash prediction model in the Crash Estimation Compendium (NZTA, 2018). During Step 2 it was established that the current models could not be used to estimate the impacts of signalising the roundabouts (part-time (metered) or full) or the impact of the cut-through of the central island. Both factors were expected to impact on crash performance of the options.

In Step 3, the signalised roundabout international research was reviewed. A British study on part-time (or metered) and full-time signalised roundabouts was found (CCS, 1997) that looked at both the impact of the signals on all-injury and trauma crashes. The study found that:

- At full time, or continuous, high-speed signalised roundabouts there was an 11% reduction in crashes and a reduction in severity of 44%, compared with an unsignalised roundabout.
- In the case of part-time (metered) signals, an 8% reduction in crashes occurred during operation of the signals, but a 66% increase occurred when the signals were not in operation. No change in crash severity was noted.

To assess the impact of the cut-through central island option (Option 2B) a safety specialist referenced the advice in Arndt (1998) and used professional judgement to estimate the likely crash impacts (Step 3) of the reduced deflection and likely increase in speed caused by the cut-through.

In Step 4 the risk of serious injury and fatal crashes was estimated using the severity factors in the Crash Estimation Compendium (NZTA, 2018) and for the signalised roundabouts from the British research. The crash predictions for each of the capacity improvement options are shown in Table 3.

Table 3 shows that the full-time signalised roundabouts have the lowest number of expected injury crashes and more serious crashes (fatal and serious injury). The crash rates for the standard traffic signals (Option 3) is also higher. For capacity reasons the 3-lane roundabout options (2a and 2b) are preferable. There is not a lot of difference between these two options. With the lower costs of Option 2b, where there is no land take, it is the overall best option. However, there are still some safety concerns with the reshaping of the central island and the reduction in the deflection.
Discussion and Conclusions

Despite the increased availability of evidence-based crash estimation tools, the safety analysis of very few intersection upgrade projects receive anywhere near the level of attention that is given to the travel time assessments. One of the challenges is that many of the current road safety analysis tools (based on crash prediction models) are not in a user-friendly format like travel time assessment tools (e.g. Sidra and Paramics). Also, in many situations, it is necessary to model intersection designs that are different to those covered by the available crash estimation toolkits. To make better decisions on the selection of improvement options at intersections it is important to understand with more accuracy the expected road safety outcomes.

The SESA process outlines the various steps that can be followed to produce ‘all-injury’ and ‘fatal and serious injury’ crash risk estimates for both standard and complex intersection options, even where the current crash estimation tools do not cover the proposed design (e.g. signalised roundabout). The three studies profiled in this paper demonstrate how this process has been applied to different intersection types and potential intersection upgrade options. Each safety assessment has different challenges, especially when having to extend the crash prediction modelling tools to more complex and uncommon intersection types. Using a consistent process, like SESA with clear decision-making steps, is important in justifying the results of such assessments.

The majority of assessments made using the SESA process do require input from one or more experienced road safety professionals. However, our experience with this type of assessment does indicate that the bulk of the analysis, when the process is followed, can be undertaken by a less experienced person. Hence, we believe that this type of analysis should become common place in the profession and replace some of the less rigorous methods that are often used. More accurate safety assessments are important as they enable transport professionals to clearly present to decision-makers, stakeholders and the general public the safety outcomes that can be expected for various improvement options. In the past it has often been difficult to differentiate between improvement options on safety grounds due to the limitation of the safety analysis methods.

To date the SESA process has not been used to optimise intersection designs to achieve a safe system or vision zero outcome. Going forward this process, combined with kinetic energy models, such as X-KEMM-X, could be used to do a vision zero assessment for each option. This assessment would require a detailed analysis of the various conflict points at an intersection for all road users (using X-KEMM-X and other tools) and either managing speeds and impact angles to reduce the risk of fatal and serious injury crashes to very low levels or eliminating such risk through better design, such as banning turns. Note that X-KEMM-X is still under development and so not all traffic conflicts can be currently assessed. Where a design does not achieve safe system, such an analysis would indicate how close each intersection improvement option is to safe system.

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