

Enhanced Identification of High Risk Intersections

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Abstract

The NZ Transport Agency's High-Risk Intersections Guide introduces new assessment techniques for identifying the risk of someone dying or being seriously injured in the future. The assessment techniques have been developed using industry knowledge of the inter-relationships between speed environment, intersection form and control type and crash movements to estimate risk. The departure from a wholly reactive approach to road safety allows high-risk intersections to be identified before people are killed or seriously injured.

Having assisting the NZ Transport Agency with the development of the risk assessment techniques the next challenge confronted by Abley Transportation Consultants was to develop a mechanism for calculating the risk profile of all intersections in a town, city or region in a cost-effective and time-efficient compared to the manual equivalent. This paper describes the GIS-based process that was developed to ensure each intersection is assessed in a standardised and equitable manner. Aside from enabling Road Controlling Authorities to make informed decisions about prioritising countermeasure improvements, the process has helped unlock the true value of the transport related data that organisations often put great effort and expense into collecting. The paper goes on to demonstrate the robustness of the risk estimation process by comparing recent fatal and serious crashes at intersections against prior risk estimates of the occurrence of those high-severity crashes.

This paper will be of interest to everyone involved with the targeted identification, prioritisation and funding of road safety improvements, and those seeking to unlock the true value of transport datasets.

Changing the approach to road safety in New Zealand

Safer Journeys, New Zealand's Road Safety Strategy 2010-20 has a vision to provide a safe road system increasingly free of death and serious injury. It adopts a safe system approach to road safety focused on creating safe roads, safe speeds, safe vehicles and safe road use (MoT, 2010). These four safe system pillars need to come together if the Government's vision for road safety is to be achieved.

Improving transport infrastructure to create a safe road environment is one method for reducing the number of people killed and seriously injured on New Zealand's roads. However, the traditional approach to road safety in New Zealand has been to focus efforts on reducing crash occurrence at sites with the greatest number of observed crashes. This reactive approach to road safety has often been the subject of criticism by the general public. "Do we have to wait until someone dies or is seriously injured before this gets fixed?" has been a much too commonly heard phrase.

The Government has sought to redress this reactive approach over the past decade through their support of proactive and risk-based industry initiatives. Some of the initial actions of Safer Journeys have already been implemented, including the publication of the 'High-Risk Rural Roads Guide' and the 'High-Risk Intersections Guide'. These guides shift away from the wholly reactive approach to road safety and provide a better balance between performance (reactive) and risk (proactive) profiling approaches.

The High-Risk Intersections Guide

The 'High-Risk Intersections Guide' (NZTA, 2013) provides practitioners with best practice guidance to identify, target and address key road safety issues at high-risk intersections. It has been prepared by the NZTA to provide guidance on the Government's Safer Journeys 2020 Strategy (MoT, 2010) initiative to focus efforts on high-risk intersections.

The High-Risk Intersections Guide focuses on identifying intersections with an established or estimated occurrence of fatal and serious injury crashes, as opposed to crashes that result in less severe outcomes. The incorporation of proactive techniques allows high-risk intersections to be identified before people are killed or seriously injured, which is a positive step for promoting and providing a safer road environment in New Zealand.

Assessing the Risk of Death and Serious Injury

A number of inter-related factors associated with road design, speed, vehicles and road use contribute to the likelihood and severity of intersection crashes (NZTA, 2013).

High-risk intersections are broadly defined as those intersections that have a history of reported Fatal or Serious crashes or an estimated number of Death and Serious injury (DSi) casualty equivalents, based on all injury crashes, that suggest a disproportionately higher than normal risk that someone will be killed or seriously injured in the future (NZTA, 2013). It is important that these intersections are identified because they are the places where targeted safety improvements are likely to be most successful at preventing deaths and serious injuries from occurring in the future.

The High-Risk Intersections Guide sets out the technique for estimating the DSi casualty equivalents for an intersection. It does this by combining knowledge of the inter-relationship between speed environment, the intersection form and control type and crash movement type factors. This approach acknowledges that some crash movement types are likely to result in more severe outcomes than others. For example, crashes involving drivers turning right out of a side road typically result in more severe injuries than rear end collisions.

Different intersection types and controls also affect the typical severity of a crash. Roundabouts in particular have a lower crash severity profile than priority or signalised intersections because the crash impacts in multi-vehicle crashes are minimised through controlled entry speeds and the angle of collision.

Risk Metrics

The High-Risk Intersections Guide defines two main types of risk metric: Collective Risk and Personal Risk.

- **Collective Risk** is measured as the total number of fatal and serious crashes or estimated deaths and serious injuries within 50 metres of an intersection in a crash period.
- **Personal Risk** is the risk of death or serious injuries per 100 million vehicle kilometres travelled within 50 metres of an intersection.

Collective Risk

There are two methods for defining Collective Risk.

According to the High-Risk Intersection Guide, the simplest definition of Collective Risk is to consider the number of fatal and serious crashes that have occurred at an intersection in a period of time; normally five or ten years. However, using these crashes alone can be fraught with the risk of reaching false conclusions about crash risk based on small numbers. It can easily result in road controlling authority's addressing randomly occurring crashes within the network (NZTA, 2013).

For this reason, the criteria are set fairly high to minimise the risk of falsely identifying sites that are not high-risk. To be confident that an intersection is high-risk there needs to be three or more serious and/or fatal crashes in five years (or five or more serious and fatal crashes in ten years). However even with such thresholds, only about 80 intersections in New Zealand have three or more fatal and serious crashes in a five-year period.

The second definition involves the estimation of the number of DSi casualty equivalents based on all injury crashes that have occurred at an intersection. It involves the multiplication of each reported injury crash at an intersection by the corresponding Severity Index ratio. Severity indices have been calculated for each primary crash movement type, for five different intersection forms and control types in both urban and rural speed environments. A 'Severity Index' is the expected ratio of Death and Serious injury (DSi) casualties to all injury crashes.

The DSi casualty equivalents method acknowledges that actual fatal and serious crash data alone is not a good indicator of the underlying risk of a high-severity crash at many intersections. It is especially effective at identifying intersections with a moderate reported crash rate, but have an incidence of crashes with high Severity Indices suggestive of any similar future crashes at that intersection having a high probability of next crash being high severity.

The Collective Risk thresholds based on the estimated DSi casualty equivalent approach is set out in Table 1. The thresholds have been determined by analysing a large number of existing intersections, and set so that Medium High and High Collective Risk intersections together make up approximately 5% of all intersections in New Zealand.

Table 1
Criteria for Identifying Intersection Collective Risk

Risk Category	Collective Risk Thresholds (estimated DSI casualty equivalents)
Low	<0.3
Low Medium	0.3 - <0.6
Medium	0.6 - <1.1
Medium High	1.1 - <1.6
High	≥1.6

Intersections that are assessed as having a ‘Medium High’ or ‘High’ Collective Risk are deemed to be high-risk intersections (NZTA, 2013).

Personal Risk

Personal Risk measures the risk to each person using the intersection. In practice only the number of motor vehicles is routinely available, so the personal risk is calculated from the collective risk divided by a measure of traffic volume exposure. Intersections with the highest risk per vehicle are ranked as the worst from a Personal Risk perspective.

The measure of traffic exposure used to calculate Personal Risk is based on the product of the conflicting flows entering from each approach (Product of Flow). In theory, the crash risk would follow a relationship that is the square root of the conflicting flows (mathematically raising the product to the power of 0.5), but in practice, raising the flows to a power of 0.4 provides a better straight line fit to the crash data, and better compensates for the reduced risk that is observed at higher traffic flows.

The daily Product of Flow formula (PoF) is:

$$PoF = \left(average(Q_{major_1}, Q_{major_2}) \cdot average(Q_{minor_1}, Q_{minor_2}) \right)^{0.4}$$

- Qmajor 1 and 2 = the two-way link volume (AADT) on each leg of the major road.
- Qminor 1 and 2 = the two-way link volume (AADT) on each leg of the minor road. At a T intersection the same equation is applied, but with Q_{minor_1} set as the side road AADT, and Q_{minor_2} defined to be zero.

To generate a reliable estimate of Personal Risk, this risk metric is only calculated for intersections with four or more recorded injury crashes in the past five years. This overcomes reaching potentially misleading conclusions about the risk of intersections with low traffic volumes, which are especially sensitive to small changes in crash numbers.

As with Collective Risk, a key issue is to understand how reflective the crash history is of the underlying DSI crash risk. For this reason, the Personal Risk calculation is based on the greater of the ‘Reported Fatal & Serious crashes x 0.5’ or ‘Estimated DSI casualty equivalents’ calculated over a five year period.

The traditional traffic exposure measure that is used in road safety analysis is crashes per 100 million vehicle kilometres travelled. So the Personal Risk metric is also adjusted to represent DSi casualty equivalents per 100 million vehicle kilometres travelled.

The Personal Risk calculation formula is:

Personal risk

$$= \frac{\max(\text{reported F\&S crashes} \cdot 0.5, \text{estimated DSIs based on severity indices}) \cdot 10^8}{\left(\text{average}(Q_{\text{major}_1}, Q_{\text{major}_2}) \cdot \text{average}(Q_{\text{minor}_1}, Q_{\text{minor}_2})\right)^{0.4} \cdot 5 \text{ years} \cdot 365 \text{ days} \cdot 1.7}$$

The 1.7 value on the bottom line of the Personal Risk formula is a conversion factor to make the exposure equivalent to vehicle kilometres travelled through the intersection.

The Personal Risk thresholds based on the estimated DSi casualty equivalent approach is set out in Table 2. The thresholds have been determined by analysing a large number of existing intersections, and set so that Medium High and High Personal Risk intersections together make up approximately 5% of all intersections in New Zealand.

Table 2

Criteria for Identifying Intersection Personal Risk

Risk Category	Personal Risk Thresholds
	(estimated DSi casualty equivalents)
Low	<6
Low Medium	6 - <10
Medium	10 - <16
Medium High	16 - <32
High	≥32

Intersections that are assessed as having a ‘Medium High’ or ‘High’ Personal Risk are deemed to be high-risk intersections (NZTA, 2013).

Level of Safety Service

Level of Safety Service (LoSS) is a measure of actual intersection safety performance relative to that expected based on a reference set of intersections. A conceptual framework for using LoSS to identify dangerous sections of road was formalised by Kononov and Allery (2003) in North America, under the name Level of Service of Safety. This was included as a performance measure in the Highway Safety Manual (AASHTO, 2010), and extended to intersections. Ideas from this publication were drawn on to develop existing work by Durdin (2010) into LoSS as it now exists in the High Risk Intersections Guide.

The LoSS method defined in the High-Risk Intersections Guide is derived from the general flow crash prediction models contained within the NZTA’s Economic Evaluation Manual (NZTA, 2010). The method takes into account the speed environment, intersection form and amount of traffic travelling through an intersection.

The injury crash performance of an intersection has been separated into five LoSS bands as shown in Table 3.

Table 3
Level of Safety Service Bands

Level of Safety Service (LoSS)	Safety	Performance	Definition
LoSS I	0-30 th percentile		The observed injury crash rate is lower (better) than that expected of 30% of similar intersections.
LoSS II	30 th -50 th percentile		The observed injury crash rate is lower (better) than that expected of 50% of similar intersections, and higher than that of 30%.
LoSS III	50 th -70 th percentile		The observed injury crash rate is lower (better) than that expected of 70% of similar intersections, and higher (worse) than that of 50%.
LoSS IV	70 th -90 th percentile		The observed injury crash rate is in the worst 30%, lower (better) than that expected of 90% of similar intersections, and higher (worse) than that of 70%.
LoSS V	90 th -100 th percentile		The observed injury crash rate is in the worst 10 percent band - higher (worse) than that expected of 90% of similar intersections.

Intersections where the actual injury crash performance is substantially greater than the predicted injury crash performance (LoSS IV and V) can be suggestive of a fundamental deficiency with the intersection. In some instances these deficiencies can be addressed with lower cost countermeasures, such as modifications to signal coordination, controlling approach speeds or improving sight distances. It is important to note that LoSS is a prioritisation technique that only compares an intersection against other intersections of the same form. Therefore those intersections where the actual injury crash performance is better than the predicted injury crash performance (LoSS I and II), but have high Collective or Personal risk metrics are likely to require safe system transformation countermeasures to deliver safety improvements, such as changes the intersection form.

For instance a priority rural crossroad with a medium LoSS could still have a high collective risk and conversion to a roundabout is likely to be much more effective than improvements under the same control type. The relative safety performance of different intersection controls with varying traffic volumes is presented in the High-Risk Intersections Guide. This enables the change in DSi casualty equivalents that could be expected from a transformation to a different control to be estimated. This can be compared with the existing DSi casualty equivalents to estimate the potential to crash saving benefits that might be achieved from a transformational change.

The LoSS indicator adds an extra dimension to the understanding of intersection safety performance. It provides a consistent and straightforward method for national, regional and local Road Controlling Authorities to assess their intersections against comparable intersections from around New Zealand (Cockrem et al. 2013). It enables practitioners to identify those intersections where road safety benefits are most likely to be realised, and indicates what type of improvement is likely to be most appropriate. The indicator is likely

to have a significant impact on how transport professionals prioritise safety improvement budgets and work. This approach helps to highlight intersections that perform poorly compared to similar intersections, even if their total or per-vehicle crash rate is not high enough to make them stand out.

Calculating Intersection Risk Metrics for a City or Region

Calculating the Collective and Personal risk metrics, and the LoSS indicator for an intersection requires the following information:

- Crash history;
- Speed environment;
- Intersection form and control type; and
- Traffic volumes (on all legs of the intersection).

The first three pieces of information are required to calculate Collective Risk, as application of severity indices to the crash history is a function of intersection form and control type as well as the speed environment in which the intersection is located. Personal Risk requires knowledge of the number of vehicles travelling through an intersection on a per leg basis. No further intersection specific information is required to calculate the LoSS indicator.

Crash history is obtained from the NZTA Crash Analysis System (CAS) while other information is typically collected by a Road Controlling Authority and stored in a Road Assessment and Maintenance Management (RAMM) database or equivalent system.

Given the information requirements are readily accessible; it is a relatively straightforward process to calculate the risk profile of any one intersection. With a sound understanding of the assessment techniques in the High-Risk Intersections Guide, in the author's experience it takes around 30 minutes to source information and manually calculate both risk metrics and the LoSS indicator for an intersection that has more than one reported injury crash.

In isolation this is not a time consuming exercise. However, calculating the risk profile of every intersection within a town, city or region quickly becomes impracticable. In Auckland for instance where there are around 20,000 intersections, the estimated timeframe to manually calculate the risk profile of all intersections would take an individual around 5 working years to complete. By that time, the crash history used in the analysis would be significantly out-of-date, and inappropriate for using as the basis for information where intersection safety interventions are most needed and likely to yield greatest benefit. This shows it is neither economic nor time-efficient to manually calculate the risk profile of every intersection in a large transport network.

Making a Network-Wide Intersection Study Economic and Efficient

Abley Transportation Consultants has developed a Geographical Information Systems (GIS) process that makes calculating the risk profile of all intersections in a town, city or region highly cost-effective and time-efficient compared to the manual equivalent. This has been achieved by utilising transport and road safety information collected by Road Controlling Authorities in combination with analytical skills to identify and prioritise high-risk intersections.

Transport data by its very nature is spatially referenced i.e. relative to a particular point or length of the transport network. For this reason, different sets of transport data can be brought together inside a geospatial environment and used for a variety of purposes, such as calculating the risk profile of every intersection within a transport network.

The GIS process involves running complex algorithms over a fully connected road centreline dataset, which includes speed limit and traffic volume attributes for every part of the network. Intersection form and control type are either included as part of the base centreline network from Road Controlling Authority data or populated based on intersection information extracted CAS.

Following completion of the base road centreline network, crashes are assigned to the road centreline network based on their geocoded location. Models are then run to identify those crashes located within 50m of an intersection. Complex models are then run which extract the crash movement types of injury crashes at each intersection before the corresponding severity indices are applied for the intersection type. The sum of the DSi casualty equivalents for each crash are then added together to give the overall DSi casualty equivalent value for the intersection, which is known as the Collective Risk.

Models are then run which derive the Personal Risk value from the Collective Risk value by extracting traffic flows on all legs of the intersection and calculating the PoF. The PoF is then inserted into the Personal Risk calculation formula.

GIS enables the risk profile of each and every intersection in a network to be assessed in a standardised and equitable manner. In larger urban areas, it is simply uneconomical and inefficient to carry out a network-wide high-risk intersection assessment without the use of GIS.

Robustness of DSi Casualty Equivalents as a Predictor of Future High Severity Crashes

The advantages of the GIS process are not simply confined to the cost side of the equation. The real advantages are realised on the benefit side of the equation, which is demonstrated through Figure A.

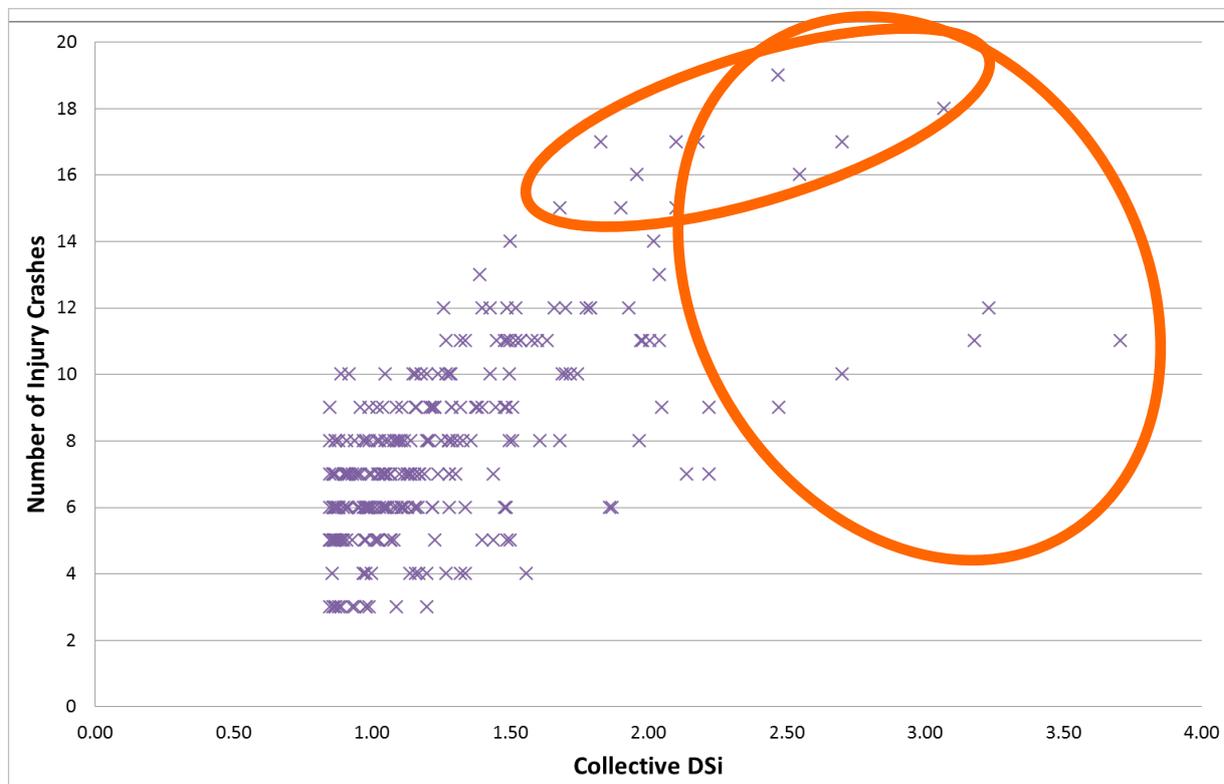


Figure A

Comparison of Injury Crashes and Collective DSi at Medium to High Risk Intersections

Figure A shows the relationship between the number of injury crashes and the corresponding Collective Risk value (based on DS_i casualty equivalents) for all intersections in Auckland that have a calculated Collective Risk of Medium and above. It shows that Collective Risk generally increases as injury crash numbers increase.

Under the traditional approach to road safety, it is likely that those with the greatest number of observed crashes would be prioritised ahead of others. The approach promoted by the High-Risk Intersections Guide however prioritises those intersections with the highest Collective Risk.

Undoubtedly there is overlap between the two approaches as indicated by those intersections that fall within both circles on Figure A, which show the Top 10 ranking intersections using different methods of prioritisation. However, there are five intersections that would not be identified looking at crash numbers alone. One of those intersections, the one on the extreme right, was classified as the highest-risk intersection in Auckland based on the DS_i Collective Risk metric approach.

That particular intersection, a priority controlled crossroads in a high speed environment had a crash history of two serious injury crashes and ten minor injury crashes in the five year analysis period meaning it did not exceed the threshold to be classified as high-risk based on the number of fatal and serious crashes alone. Prior to completion of the risk profiling of the Auckland network, the intersection had previously been identified by the Road Controlling Authority as an intersection with safety issues, however it was not considered a high-priority intersection for treatment, and improvements were ultimately deferred as budgets tightened.

Within weeks of the risk profiling being completed there were two separate high-severity crashes at the intersection which resulted in the deaths of two people. These unfortunate crashes at the intersection, which were of the same crash movement type that provided the high DS_i value, provide an indication of the robustness of the DS_i methodology. This suggests that lives can be saved by following the assessment techniques described in the High-Risk Intersections Guide and prioritising intersections for investigation and improvement based on the risk of DS_i crashes occurring in the future.

Road controlling authorities put great effort and expense into collecting large quantities of high-quality transport related data. However, the true value of this data is often unrealised because of the narrow range of applications for which the data is used. The network-wide risk profiling process developed by Abley Transportation Consultants demonstrates the value that can be added to a road controlling authority's activities and shows how GIS is an ideal platform for unlocking value from existing assets.

New Zealand's 100 Highest-Risk Intersections

In March 2014, the NZ Transport Agency published a list of New Zealand's 100 highest-risk intersections. The list was produced as an identified action of the Safer Journeys Action Plan 2013-2015 (MoT, 2013). The identification of the 100 highest-risk intersections, the development of solutions for 30 intersections by September 2014 and improvement of 20 intersections by June 2015 were key actions identified in the Safer Journeys Action Plan (MoT, 2013) under the 'Safe Roads and Roadsides' pillar of the safe system approach to road safety in New Zealand.

The list of intersections was compiled by Abley Transportation Consultants using the DS_i casualty equivalents method set out in the High-Risk Intersections Guide (NZTA, 2013). A 10-year crash history (2003 – 2012) was used to inform the analysis with double the weighting of crashes being assigned to crashes in the most recent 5-year period.

In May 2014, the list of the Top 100 highest-risk intersections in New Zealand was updated based on 2004 – 2013 crash statistics. As part of this update, those fatal and serious crashes that occurred in 2013 were compared against the DS_i risk estimates of the previous Top 100 intersection list to measure the robustness of the DS_i casualty equivalent methods as a predictor of future high severity crashes.

The analysis showed that 30 fatal and serious crashes occurred at intersections in the Top 100 highest-risk intersections. By way of context, in 2013 there were 590 fatal and serious crashes at intersections in New Zealand. This translates to 5% of all fatal and serious intersection crashes in 2013 occurring at the 100 highest-risk intersections, just 0.1% of all intersections in New Zealand¹.

Of further interest is that 21 of the 30 fatal and serious intersection crashes occurred the 63% of intersections that did not meet the definition of a high-risk intersection based on actual fatal and serious crash thresholds specified in the High-Risk Intersections Guide (NZTA, 2013). Whilst it is premature to make claims about the effectiveness of an indicator using a limited sample of ‘after’ data, these early results indicate the DS_i casualty equivalent method of assessing risk at intersections appears to be a sound predictor of the likely incidence of future fatal and serious crashes.

Under a traditional approach to road safety many actual high-risk intersections may have been overlooked from investigation because their overall crash history may not have been considered sufficiently high to warrant investigation. Therefore by prioritising intersections for investigation and improvement based on the DS_i casualty equivalent based approach to risk suggests that more lives can be saved in the future.

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¹ Estimate of 100,000 intersections in New Zealand based off intersection risk profiling in Auckland, Tauranga, Christchurch and Dunedin completed as part of the Urban KiwiRAP risk mapping project.