

RURAL INTERSECTION RISK ASSESSMENT TOOL

Dr Shane Turner, Technical Director – Transportation

PhD, Civil Engineering, University of Canterbury

BE (Hons), Civil Engineering, University of Auckland

Beca Infrastructure Ltd, PO Box 8141, New Zealand

E-Mail: shane.turner@beca.com

Robyn Gardener, Road Safety Manager

GDipRS, University of New England

PGDipT&T, Monash University

Christchurch City Council , PO Box 73014, Christchurch

E-Mail: robyn.gardener@ccc.govt.nz

ABSTRACT

Road safety risk assessment tools are increasingly being used in New Zealand to help understand the crash risk on roads, at intersections and other sites (eg. bridges and railway crossings). Two such tools for rural roads are the KiwiRAP road ratings and RISA (Road Infrastructure Safety Assessment). KiwiRAP has been used to assess the relative safety risk along the State Highway network, while RISA is a tool used to assess the relative safety of a sample of local authority rural roads, as an alternative to existing road audits. Neither tool is particularly good at assessing the safety of rural intersections. The development of such a tool is well overdue.

Christchurch City Council are in the process of developing and trialling a rural intersection road safety risk assessment tool (for priority controlled intersections) for local authority roads. This paper will discuss the local and international research on crash prediction models and crash reduction factors that was collated for rural intersections for this project. It also presents the risk assessment tool that is being developed, and how it will be applied. Along with all injury crashes, the tool also predicts the risk of fatal and serious crashes at rural intersections, by utilising adjusted severity factors from the High Risk Intersection Guide.

INTRODUCTION

New Zealand and Australian jurisdictions have moved to a safer system approach to road safety. Under a safer system approach, the focus is on fatalities and serious injuries (FSi) rather than all crashes or all injury crashes. Given high severity crashes are quite rare, and often occur at sites with no history of such crashes, the crash history is normally not useful in assessing where future FSi crashes may occur. This is particularly true at individual sites, such as bridges, railway crossings and intersections, where crash occurrence can be highly stochastic. Over longer lengths the crash history may be of limited use in identifying high risk road sections.

The preferred method for understanding and targeting road safety improvement projects at sites and along road lengths is to assess the risk of fatal and serious injuries (FSi) based on the physical features at each site. Two existing tools for assessing risk of FSi are KiwiRAP for rural State highways and RISA for local authority rural roads. While both risk rating tools consider rural intersections, improvements are required to produce a more robust intersection crash risk that is based on a wider set of casual factors.

The purpose of this project was to develop an intersection risk rating tool which links to the high risk intersection guide (HRIG) but without the costs required for KiwiRap, for local authority rural intersections. In an environment where funds allocated to safety projects are hard-won, this will allow programmes to be developed where a risk reduction per dollar spent over the network can be demonstrated, and low cost network-wide interventions can be shown to produce a very acceptable benefit cost ratio.

With almost all local authority intersections having priority control or no control, and hence the tool focuses on these intersection types and at this stage does not include roundabouts or traffic signals.

Many local authority intersections have relatively low traffic flows and in most cases a low level of FSi risk. It is important that the method does allow the higher risk intersections to be identified quickly, so that more detailed assessments focus on the intersections where the FSi needs to be managed. The intention is to develop a value for money data collection exercise, utilising desktop, rapid and more detail inspections. In order to do this some assumptions will need to be made around operating speeds, traffic volumes and sight distances, as the detailed collection of such data can be very time consuming.

This paper discusses the local and international research on the safety of rural intersections and how this research has been used to develop a safety index for rural intersections. It also talks about how the data would be collected and scoring of intersections undertaken, plus the proposed validation methods.

RELEVANT LITERATURE ON RURAL INTERSECTION RISK

There are two relevant rural intersection studies in Australasia. This includes work undertaken in Queensland by Arndt and Troutbeck (2005) and in New Zealand by Turner and Rozenberg (2006).

The study by Arndt and Troutbeck (2005) developed crash prediction models based on 206 priority intersections, 63 of which were 4 leg and 143 were 3-leg. The sample had intersections with operating speed between 40 and 110km/h. Hence the sample contained both rural and urban intersections. Crash prediction models were developed for the three major multi-vehicle crashes, angle-minor vehicle crashes (predominately JA and HA crossing crashes), angle-major vehicle (LB right turn against crashes) and rear-end major vehicle

crashes (GA rear-end into right turners crashes). A crash prediction model was not developed for total crashes.

A large number of variables were utilised in the crash prediction models. This included traffic volume (by movement), 85th percentile speed, visibility, number of minor road lanes, observation angle, width of the major road, the type of right turn lane treatment on the major road and driver recognition of an opposing leg for cross-roads (the degree to which the road looks like it continues straight through). The visibility was measured differently for each crash type to reflect the inter-visibility between the vehicles that collide. The observation angle is a measure of the degree to which minor road drivers need to look side-ways or backwards in order to view vehicles on the main road. The right turn treatment on the main road varied from shoulder widening through to various types of right turn bay.

The key findings of the research were that large observation angles increase the angle-minor (JA and HA) crash rates. This supported minimising the skew of an intersection. The skew of an intersection is used as a variable in the USA crash models, rather than observation angle. Higher relative speeds also increase this crash type. Speed was also a critical factor in rear-end crashes, with standard length right turn bays having a much better crash reduction than localised widening and other treatment types, such as short right turn bays. Reduced sight distance increased all the crash types.

Turner and Rozenberg (2006) developed crash prediction models for high speed (typically rural) intersections. The sample size was similar to Arndt, at 200 sites, half of which were 3-leg and half were 4-leg. All the intersections had speed limits of 80 or 100km/h and most had mean operating speeds above 80kph.

Five crash prediction models were developed for 3-leg intersections, including crossing with vehicle turning (JA), right turn rear-end (GA), right turn against (LB) and other. Models were developed for six crash types at cross-roads. The only difference being crossing with vehicle going straight ahead (HA), from left and right separately, replacing the crossing with vehicle turning (JA). Various models included traffic volume (by movement), sight distance, mean speed and presence of a right turn bay,

Key findings included that a right turn bay reduces rear-end into right turn vehicles by around 78%. Crash rates for crossing crashes (HA and JA) increased as the sight distance reduced (taken as a deficiency compared with the Austroads standard). Higher approach speeds lead to more crashes. These results were generally consistent with those found by Arndt.

Turning now to international studies on the safety of rural intersections. Montella and Mauriello (2012) developed a ranking procedure for unsignalised intersections in Italy. They developed risk ratings from a number of factors based on international research sources, primarily from North America and Europe. Key sources were Agent et al (2003), Transportation for Canada (1999), Kindler et al (2003), Highways Agency (1995), Canadian Guide to in-service road safety reviews (2004), Odgen (1996) and Elvik and Vaa (Handbook of Road Safety, 2004).

Risk factors were developed under the following categories; intersection type, sight distance horizontal alignment, vertical alignment, left turn and right turn lanes, chanelisation, markings and signs, pavement and driver behaviour. In the absence of local risk factors we have used many of the factors developed by Montella and Mauriello (2012) in our safety index.

Other international sources are the Highway Safety Manual (ASSHTO, 2011), the CMF Clearinghouse (2012) and studies by Harwood et al. (2002), Oh et al (2003) and Lyon et al (2003). The highway safety manual is a more recent document which has risk rating factors for intersection and links on 2-lane rural roads, urban arterials and dual carriageway rural

highways. The CMF clearinghouse has been set-up by FHWA to list risk factors from multiple international sources. It includes the highway safety manual factors. It includes a star rating for each risk factor, based on the quality of the study for which the factors were extracted. The source studies include both crash prediction models and before and after studies. The highway safety manual (HSM) factors have the highest rating with other risk factors, which were not considered suitable for the HSM, or from many sources outside North America, having a lower rating.

While there is a reasonable body of research on the factors that influence crashes at rural intersections there are a number of factors where there is limited research. This includes the benefits of advance intersection static warning signs (especially on side-road), impact of pavement condition factors, the benefits of flag lighting (if any), the benefits of chevron boards on the top of T-junction, the impact of gated stop signs and impact of road-side hazards in the vicinity of intersections on both all crashes and sever crashes.

RURAL INTERSECTION SAFETY RISK ASSESSMENT FRAMEWORK

A safety index has been developed for rural intersection to allow ranking of rural intersections from those with a high potential for injury crashes to those with a low potential for injury crashes. The safety index includes both an exposure and risk measure and is directly related to the crash risk. The exposure measure is called the base model (BM) and considers both the traffic volume and the operating speed through the intersection. The risk measure is called the risk index (RI) and is a multiplier that is applied to the base model crash prediction to obtain the safety index value. The risk index is comprised of a number of risk factors that take into account various features of an intersection, such as the visibility. These factors only come into effect when a feature of an intersection differs from that in the base intersection, otherwise they are set at zero. The following equation is used to calculate the safety index (SI) for a rural index.

Safety Index (SI) = BM crash prediction * (1+ sum (risk factor values)) - Equation 1

The base models for 3-leg and 4-leg intersections are for a base intersection which has the following features:

- The 85thile speed on the priority road is 95km/h
- It has a stop or give-way control, with well positioned single sign
- Sight distances in both directions meet or exceeds the Austroads requirements
- It is located on a straight section of road or one with a radius exceeding 600m
- It is not on a crest curve and has no approaches with gradients exceeding 6%
- Localised shoulder widening is provided but no right turn or left turn lanes
- There are no raised or painted islands including splitter islands on side-road
- There is a chevron board at the 'top of the T' for 3-leg intersections
- The pavement condition is excellent and road marking is in good condition
- There are no major hazards within 15m of the intersection on all corner of a cross-road, and 'top of the T' at 3 –leg intersections
- Full lighting is not provided (flag lighting may be provided)

The base models for priority 3-leg and 4-leg priority intersection were developed from Turner and Rozenberg (2007) and are:

$$BM (3\text{-leg}) = b_0 Q_{\text{major}}^{0.2} \times Q_{\text{minor}}^{0.54} \quad \text{- Equation 2}$$

$$BM (4\text{-leg}) = b_0 \times Q_{\text{major}}^{0.37} \times Q_{\text{minor}}^{0.63} \quad \text{- Equation 3}$$

Where Q_{major} and Q_{minor} are the traffic volume on the priority and controlled (side) roads respectively. The value of b_0 is given in Table 1, and varies depending on the 85%ile speed on the main road.

85th Percentile Speed (km/h)	b_0 (T junctions)	Factor (T)#	b_0 (X-Roads)	Factor (X)#
95	4.9372×10^{-04}	2.5	2.61643×10^{-06}	2.5
85	3.7805×10^{-04}	1.9	2.00345×10^{-06}	1.9
75	2.7996×10^{-04}	1.4	1.48361×10^{-06}	1.4
65	1.9858×10^{-04}	1	1.05236×10^{-06}	1

Table 1 – Constant values (b_0) for the base model

The risk factors are discussed in the next section.

To enable road controlling authorities to focus on the higher risk crashes, the fatal and serious injuries (FSi), as required under a safer system approach, a severity index was also developed. The two key layout and operating features that were considered to impact on crash severity were the 85%ile speed on the main road and the presence of severe hazards close to the intersection. The following equation is used to calculate the severity index:

$$\text{Severity Index} = (\text{BM} \times \text{SR}) * (1 + (\text{sum (RF values)} + \text{severity RF for road-side hazards}))$$

Where

BM – base model

SR – severity ratio (see below)

RF – Risk Factor

The severity ratio is the ratio of FSi crashes to all crashes. Severity ratios for rural and urban priority intersections are available from the High Risk Intersection Guide (HRIG, NZTA, 2012). Figure 1 shows how the severity ratios increase as the speed limit increases. The effect is more pronounced in the 4-leg (or cross-roads) intersections.

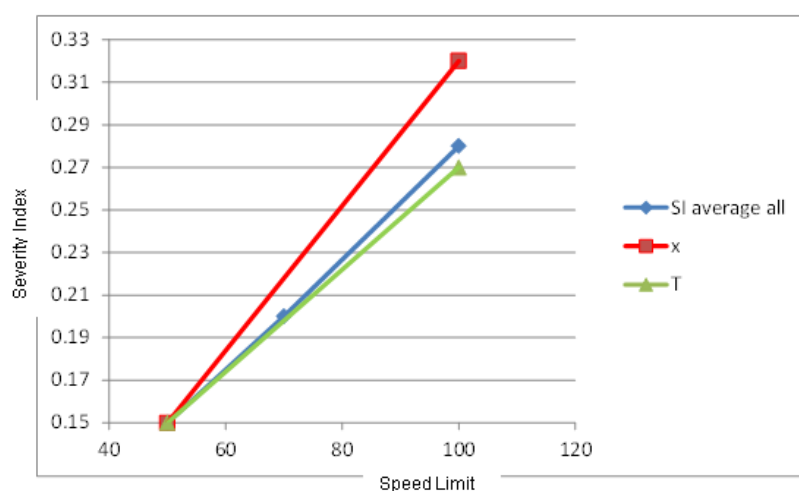


Figure 1 – Severity ratio for urban and rural priority intersections

It is proposed that the ratios in Figure 1 are used to calculate the severity index for different operating speeds at rural intersections. It is acknowledged that there are some limitations with these values, given they are based on speed limits, not operating speeds, and that the information is currently only evaluated for 50km/h and 100km/h roads and a linear relationship is assumed between the two (this relationship may not be linear). Further analysis of crash data is proposed to calculate severity ratios for different speed limits. Some adjustment will also be considered for the 100km/h speed limit severity ratios as some of these intersections have lower operating speeds, which will mean the ratios may on average only be for say a 90km/h operating speed.

The majority of roadside hazard research is for mid-block road sections and is focused on loss-of-control crashes. At intersections only around 31% of crashes are single vehicle loss-of-control crashes. Some of these crashes are mid-block type crashes that happened to be in the vicinity of the intersection, but many are also influenced by the intersection and involve vehicles turning into or out of the side-road. The majority of crashes involve two vehicles and so the collision with road-side objects is a secondary impact. In single vehicle crashes much of the energy dissipation occurs when hitting the road-side hazard while in a multiple vehicle crashes this occurs when two or more vehicles collide.

Research by Austroads (2011) identified the crash severity ratio of hitting various hazards, including guardrail, and no hazards for loss-of-control crashes on rural mid-blocks. On average the severity index of trees and poles is around 0.54, while for no hazards it is 0.38. The later result may seem surprising but it reflects the risk of rollover type crashes even with clear-zone type treatments. So the increase severity risk is around 42% when there are a lot of road-side hazards $((0.54-0.38)/0.38)$. For intersections we have assumed a similar effect on severity for the 31% of loss-of-control crashes that occur. The full effect occurs when the probability of hitting a road-side hazard is close to 100% due to the concentration of such severe hazards within 9m of the road for 15m either side of the intersection. Where there is a lesser concentration of hazards this increased risk is reduced.

For multiple vehicle crashes, the likely increase in severity is likely to be less (in the absence of better information considered to be half, at up to 20%) due to it being a secondary impact. The high risk area around the intersection is also likely to be smaller. Figure 2, from CASR (Doecke et al, 2011) shows the area around an intersection (based on a study of 70 crashes) that vehicles often traverse. For 3-leg intersection this equates to about 50% of multi-vehicle crashes encroaching with a hazard area of 15m either side of the intersection and up to 5.5m from the edge of seal on the 'top of the T' side of the intersection only. For a cross-road the hazard area is on both sides of the main road, over the same sized hazard area. Given the small area it is considered that for 3-leg intersection even one serious hazard in this conflict area has a high probability of being struck, and so a 20% increase in severity risk is assumed. For 4-leg intersections the full 20% would be applied only if severe hazards were present in the hazard area on both sides of the main road. Further work is proposed to identify other research that may help refine the increase in severity for both single and multiple vehicle crashes at intersections.

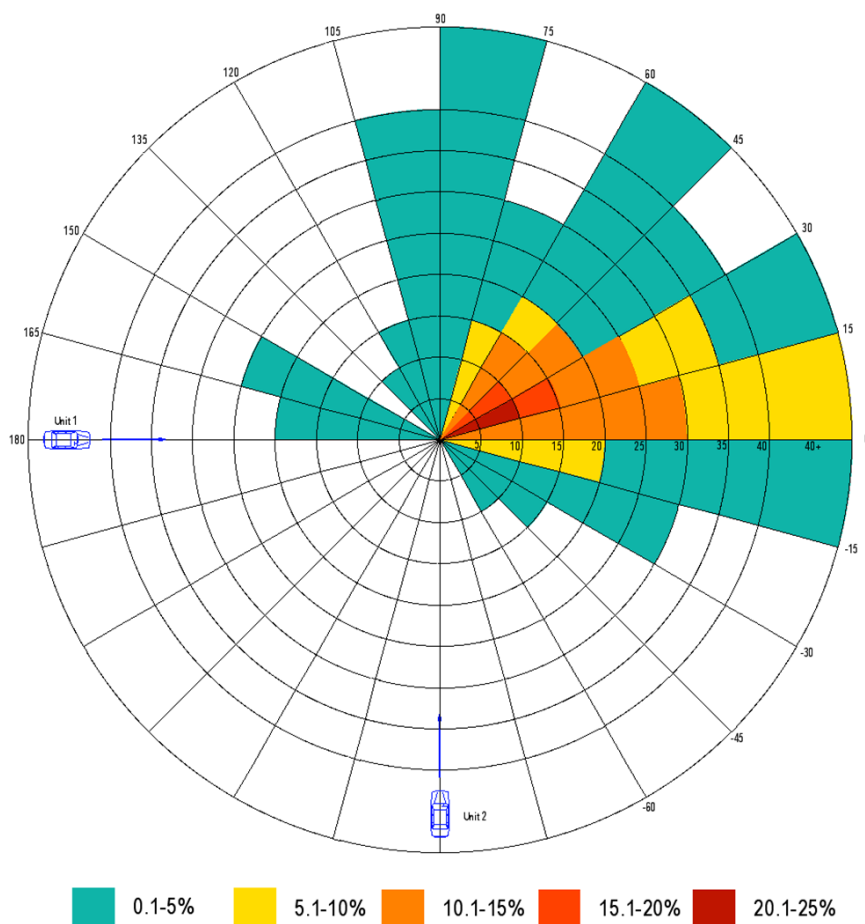


Figure 2- Percentage of vehicles that travel through a given sector surrounding the centre point of a rural intersection (source Doecke et al. 2011)

FEATURE RISK FACTORS

This section outlines the risk factors that were developed for the important road and operating features at rural intersections. Due to the potential for double counting some features were excluded from the risk values, including intersection skew and observation angle. There is still considerable potential for double counting of crash benefits and dis-benefits, which will be explored in the testing of the tool. Given industry concerns about the cumulative benefits of road safety improvements not being realised the overall reduction in crashes at an intersection has been capped at 70% in the process. Only with strong evidence of the cumulative benefit of multiple improvements would a benefit above this value be used. A source of such evidence is the Accident Monitoring Database (LTSA, 1995), which has crash reductions for many combinations of treatments (care must be taken with the using this database as it is no longer being maintained).

Table 2 that follows has the proposed risk factors for the safety and severity indexes. It is still a work in progress and some values are still being investigated in the study. . For example there are plans to compare the risk factors below with those used in iRAP.

Risk Type	Risk Factor	Source
Uncontrolled Intersection X -road	+33%	Montella
Uncontrolled Intersection T	+20%	Elvik and Vaa
Stop Or Giveaway Sign Poorly located	+24%	Montella (adjusted)
Stop Or Giveaway Sign poor reflectivity	+16%	Montella
Advanced sign on side road	-10	Montella
Advanced sign on main road approaches	-7%	NZTA Smartmovez
Sight Distance RF – <100m visibility	+15% per arm x roads +30% for T intersections	Turner (2005) / Montella
Sight Distance RF –100m-150m visibility	+7.5% per arm x roads +15% for T intersections	
Horizontal alignment <300m R inside <200m R outside	+35%	Montella
Horizontal alignment 300m -600m R inside 200m-400m R outside	+17%	Montella
Vertical crest close to intersection (Major road)	+10%	Montella
Vertical crest close to intersection (Minor road)	+5%	Montella
Gradient >6%	+17%	Elvik and Vaa
Right turn bay on 3 leg intersections	-30%	Montella (adjusted)
Right turn bay on 4 leg intersections	-15%	Montella (adjusted)
No shoulder widening T	+15%	Beca
No shoulder widening X	+15%	Beca
Splitter islands on side-roads of T-junctions (with extra signs)	-35%	NZTA Smartmovez
Splitter islands on side-roads of X-Roads (with extra signs)	-50%	Adjusted Hughes (2008)
Poor Pavement condition	+25%	Montella
Worn road markings on side road	+12%	Montella
Worn road markings on main road	+25%	Montella
Full lighting	-12%	Donnell et al (2010)/EEM/Jackett

Fig 3 – summary of Risk Factors (RF)

the increase in severity has been calculated as up to 40% for single-vehicle crashes (31% of all crashes) and up to 20% for multiple-vehicle crashes (69% crashes)

PROPOSED RISK RATING PROCESS – DATA COLLECTION

Many local authority intersections have low traffic volumes and, in most cases, have a low likelihood of crashes. The data collection process needs to enable intersections to be quickly screened so that the high collective risk sites (those with a higher traffic volume and

operating speed) and a high personal risk, or high risk index, can be identified for further attention. It is likely, that even for high personal risk sites that attention will be focused on those with a medium volume of traffic.

In this initial screening process, we would look to reduce the number of intersections for more detailed attention down to around 30% to 40% of all intersections. The desktop analysis process will include collection of traffic volumes (with some adjustments) from the RAMM database and an assessment of other factors likely to influence safety using google mapping (or perhaps other mapping tools when better than google maps) and google streetview to determine items such as;

- intersection type and geometry,
- presence of right turn bays,
- approaches including any curve radius,
- crests on approach,
- obstructions to visibility,
- presence of trees and bushes that may be reduce visibility,
- presence of roadside obstructions,
- presence and type of delineation road width,
- type and extent of nearby and adjacent development.

This data would be entered into a spreadsheet and a basic safety and severity index calculated. To speed up the process some assumptions will be made around operating speed and sight distances based on typical data collected at selected sites. Only where the aerial or street-view information seems to differ from these base assumptions will the default values in the spreadsheet be modified. It is expected that coming up with traffic volume data, especially for side-roads, will be the most time consuming element of this early work, given the low accuracy of some counts and estimates in RAMM. The approach will be to ensure that these side-road volumes are at least accurate in terms of flow bins, such as low, medium and high volumes. Where possible we will look for more accuracy.

A preliminary on-site assessment would then be carried out for the short listed intersection sites (around 30% to 40% of intersections). This assessment would involve a simple drive through the site to confirm the deficiencies identified from the desktop review for rectification. In order to ensure best use of resources it is anticipated that these sites would only be reviewed if they are in the vicinity of or; on en-route to; sites identified for detailed site assessment or where there are a number of such assessment sites identified within close proximity.

Once an intersection has been identified as high risk and reached priority for detailed assessment a full site investigation would need to be undertaken and include assessing all the identified risk factors and any other factors that become apparent. This would include determination of all geometric features, site photographs on all approaches, note of measurement of sight distance, estimation of through speeds (by driving through the site), review of type, condition and appropriateness of; surface, signage, delineation and lighting.

Where side road (or main road) counts are considered unreliable, short duration counts will be collected. The extent of data collected will be subject to numbers of sites visited and budget constraints. These can be factored up from the site sample using the daily flow profile.

Site assessment worksheets will need to be developed for this detailed assessment.

VALIDATION PROCESS

The overall safety and severity indexes will be validated using the following two methods. To assess whether the process is ranking the sites correctly, the method will be applied to two sets of 10 to 12 higher volume State Highway intersections. The sites will then be ranked according to number of all injury and FSi crashes and compared with the ranking by safety and severity index. Higher volume sites are necessary as we need sites which have a number of crashes, and also a variety of intersection features, such as splitter islands. It will be important to not select the worst performing intersections in New Zealand however, due to bias created by regression-to-the-mean. Any differences in ranking will be explored by more detailed review of the crashes that occur at the intersections assessed.

The other method will look at large groups of intersections across the Christchurch City rural network (say 30 to 40 intersections) and compare the sum of the safety (and severity) index to the number of crashes expected in total over these intersections. Given the safety index at each site is an estimate of the underlying true crash rate over a large number of sites it should be equal to the sum of the observed number of crashes.

CONCLUSIONS

Using both local and international research a prototype risk rating tool has been developed for rural intersections for use on local authority roads. The base crash models for exposure (the collective risk element of tool) uses New Zealand research, including adjustments for operating speed. The risk index and each risk factor is predominately based on overseas research which has been reviewed and validated in a number of different forums. There are concerns around double-counting as a number of the variables are likely to be correlated. For example sight distance and horizontal and vertical alignment. Validation will be required to check for double-counting and that these risk factors are suitable for New Zealand conditions.

Given that many rural intersections have low traffic volumes and also low levels of personal crash risk, it is important that the processes used to assess the safety of such intersections, and where investment needs to focus, are as expedient as possible. Hence the initial assessment of intersections should be by desktop using aerial photos and GOOGLE™ Streetview. In order that key intersections are not missed it is important that the list is cross referenced to the deficiency database to make sure all the intersections that are high priority make it onto the list of on-site work. It is expected that in the order of 30 to 40% of sites will have either preliminary (drive through) site inspection or a more detailed site inspections. The detailed site inspection will include collecting on-site speed data, sight distances and where volume data is low short duration traffic counts.

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