

URBAN KIWRAP IDENTIFYING ROAD SAFETY RISK ON NEW ZEALAND'S URBAN ROADS

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1. ABSTRACT

Road Assessment Programmes have been around for well over a decade now, however typically they have focussed on rural corridors and townships these pass through. Urban KiwiRAP, New Zealand's Road Assessment Programme, looks to apply road risk ratings to major urban transport networks.

The first stage was to develop risk maps for road links and intersections for motorised vehicles (cars, trucks, motorcyclists) and vulnerable road users (pedestrians and cyclists) using reported crashes and converting these into estimated death and serious injury casualty equivalents. These have now been completed for several cities and regions in New Zealand. The risk maps are changing the road safety conversation from a reactive response to one targeted at risk.

The second stage, which is currently underway, is the coding of some 3,000km of urban roads using the iRAP v3 star rating model for various road user groups. The star rating model is a wholly proactive assessment of risk of various elements of the transport network for different road users groups.

This paper will be of interest to everyone involved with the planning and delivery of road safety outcomes for transport networks, especially where budgets are tight but community expectations remain high.

2. INTRODUCTION

Road Assessment Programmes (RAPs) aim to significantly reduce serious road casualties by improving the safety of road infrastructure. They provide a proactive means of managing road safety, and one that does not rely solely on death or injury statistics to identify road safety problems.

The Road Assessment Programme (RAP) started in Europe in the early 2000s when the Automobile Associations piloted a process for assessing the relative safety performance of

different European roads (EuroRAP). It was then picked up in Australia (AusRAP) and trialled in some US states (usRAP). In 2006, an umbrella organisation iRAP (International Road Assessment Programme) was formed to oversee the global RAP programmes, to ensure some level of consistency and to promote them in developing countries.

KiwiRAP is part of the international family of Road Assessment Programmes (RAP) under the umbrella of the International Road Assessment Programme (iRAP). Like its partner programmes, which have now been applied in over 80 countries, KiwiRAP incorporates three protocols:

1. **Risk Mapping** – using historical traffic and crash data to produce colour-coded maps to illustrate the relative level of risk on sections of the road network.
2. **Star Rating** – road inspections to look at the engineering features of a road (such as lane and shoulder width or presence of safety barriers). Between 1 and 5 stars are awarded to road links depending on the level of safety which is ‘built-in’ to the road.
3. **Performance Tracking** – involving a comparison of crash rates over time to establish whether fewer or more people are being killed or injured and determine if countermeasures have been effective.

KiwiRAP has been under development since early 2006 and from the outset it has been a joint agency initiative involving the Ministry of Transport, Automobile Association, New Zealand Police, Accident Compensation Corporation (ACC) and the New Zealand Transport Agency. KiwiRAP was the first Road Assessment Programme to use a joint agency approach, and this partnership model has now been adopted by iRAP as the preferred approach [1].

Risk Maps for the high-speed (≥ 80 km/h) “rural” sections of New Zealand’s State Highway network were first published in January 2008 in the document ‘KiwiRAP How Safe Are Our Roads? - Rating New Zealand’s State Highways for Risk’ based on traffic and crash data for the five-year period between 2002 and 2006. Star Ratings were then calculated for the same roads and published in June 2010 in the document ‘KiwiRAP How Safe Are Our Roads? - Star Rating New Zealand’s State Highways’.

In 2012, the final RAP protocol a Performance Tracking report ‘KiwiRAP How Safe Are Our Roads: Tracking the Safety Performance of New Zealand’s State Highway Network’ was published. The Performance Tracking report used crash data for the five-year period between 2007 and 2011 and compared it to the original 2002 to 2006 period.

The Performance Tracking report showed significant gains in safety performance across the State Highway network between the two periods. The number of kilometres of State Highway network in the high Collective Risk band more than halved from 806 km in the 2002-2006 period to 393 km in 2007-2011 period – a drop from 7% of the national network down to 4%. Similarly, the percentage of State Highway in the Low and Low-Medium Collective Risk bands increased from 56% to 65% in the latest time period.

The New Zealand Transport Agency then carried out a retrospective analysis to ascertain whether the improvements in safety performance on the rural State Highway network were also achieved on rural roads managed by local Council Road Controlling Authorities (RCAs). For comparative purposes, the analysis extended to include low-speed (≤ 70 km/h) “urban” networks. The results of the analysis are presented in **Figure A**.

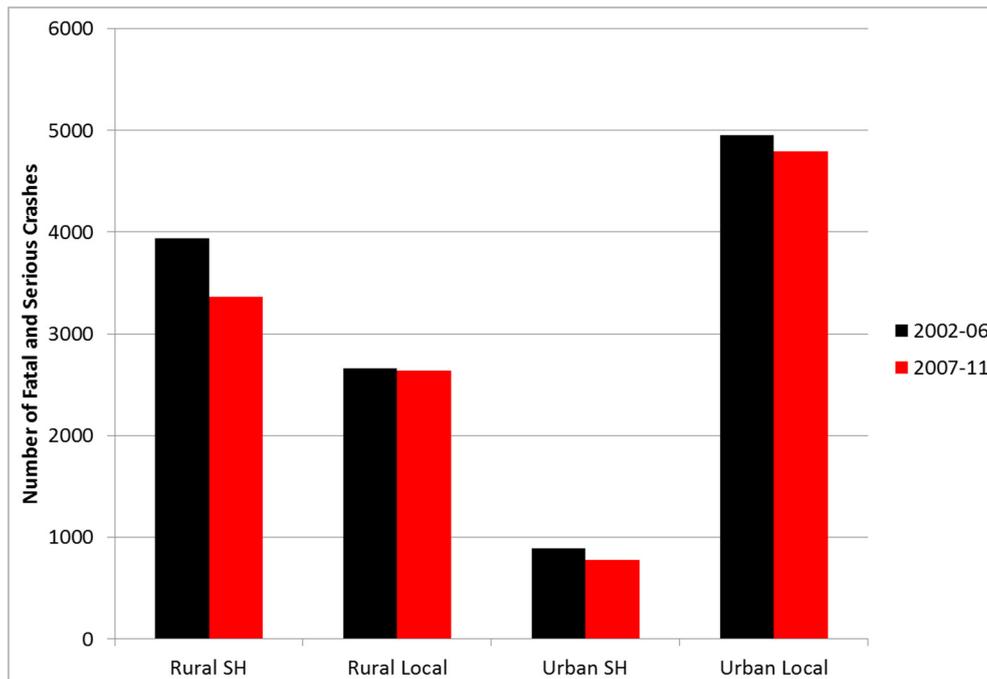


Figure A - Comparative Safety Performance of State Highway and Local Roads in Urban and Rural Speed Environments

Figure A provides evidence of disparate performance between the State Highway network and Local Roads between the two analysis periods. While State Highways experienced fatal and serious crash reductions of 15% and 13% in rural and urban speed environments respectively, local road networks only improved by 1% and 3% respectively.

As a result of these findings, in August 2012 the New Zealand Transport Agency established a new KiwiRAP technical committee charged with overseeing and directing the risk assessment process for local roads with an emphasis on the urban network as this appeared to be where the next biggest gains could be made. This risk targeting programme was referred to as 'Urban KiwiRAP' even though some of the urban authorities have significant rural road components.

The new committee comprised representatives from the New Zealand Transport Agency, Auckland Transport, the Tauranga, Christchurch and Dunedin City Council's as well as representatives from the consulting industry. Each of the local authorities represented on the committee participated in a trial to develop and test risk mapping and star rating assessment processes for urban corridors on their networks.

3. SHIFTING THE FOCUS: FROM CRASHES TO CASUALTIES

3.1 Safer Journeys, New Zealand's Road Safety Strategy 2010-20

The New Zealand Road Safety Strategy 2010-20, *Safer Journeys*, introduced a vision to provide a safe road system increasingly free of death and serious injury. The strategy is founded on the safe system approach to road safety, which focusses on creating safe roads, safe speeds, safe vehicles and safe road use [2].

The Safe System philosophy is based on creating a forgiving road system that acknowledges that people make mistakes and have limited ability to withstand crash forces without being killed or seriously injured. Under the Safe System, all parts of the system - roads and roadsides, speeds, vehicles, and road use, all need to be improved and strengthened - so that if one part fails, other parts will still protect people involved in a crash.

Safer Journeys signifies a shift in focus, from reducing crashes to minimising the likelihood of high-severity crash outcomes. In order to give effect to *Safer Journeys*, new analytical approaches have been developed that prioritise sites on the likelihood of future fatal and serious casualty occurrence and risk.

3.2 Traditional Safety Approaches

The traditional approach of identifying and addressing road safety issues in New Zealand has generally been targeted on the basis of historic crash performance; through crash reduction programmes, black-spot and black route analysis and treatments. While the crash clustering approach served New Zealand well in the past, it tended to place a strong emphasis on crashes with minor injuries.

Alternative approaches were introduced to overcome this, including the ranking of sites by the social cost of crashes. However, this had the opposite effect and ended up placing excessive focus on recent fatal crashes. As fatal crashes very rarely occur at the same location within a five-year period, the approach of prioritising sites for treatment based on social crash costs is fraught with the risk of reaching false conclusions about crash risk because of a low number of observations. Prioritising in this manner also drew criticism from the general public who were unaccepting of an approach of waiting for someone to die or be seriously injured before the funding of improvements could be justified.

The relative rarity of fatal and to a lesser extent serious crashes at the same site is evidenced from analysis of crash data in Auckland. Analysis of crash data at intersections in 2013 showed that 79% of fatal and serious crashes occurred at sites with no previous fatal or serious crashes in the previous 5 years and 64% occurred at sites with 2 or fewer injury crashes in the same period. This suggests that an approach of prioritising based on previous fatal and serious crashes in particular, is not a strong indicator of the underlying risk of future high-severity crashes.

4. THE HIGH-RISK INTERSECTIONS GUIDE

The 'High-Risk Intersections Guide' was published by the New Zealand Transport Agency in 2013. It provides practitioners with best practice guidance to identify, target and address key road safety issues at high-risk intersections. The approach aligns with *Safer Journeys* focus on reducing deaths and serious injuries.

The *High-Risk Intersections Guide* introduces a new technique for identifying intersections that have a disproportionately higher than average risk of future deaths or serious injuries if recent crash trends continue. The new technique calculates an estimated number of Death and Serious injury (DSi) casualty equivalents based on relationships between speed environment, intersection form and control type and crash movement type factors. This approach is founded on knowledge that crash outcomes vary as a function of speed, intersection form and control type, and crash movement type. 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.

The High-Risk Intersections Guide provides DSI factors, referred to as 'Severity Indices', for all primary crash movement types for the following intersection types:

- Signalised crossroads
- Signalised T-intersections
- Roundabouts
- Priority (Give Way or Stop) controlled crossroads
- Priority (Give Way or Stop) controlled T-intersections

Different severity indices are provided for urban ($\leq 70\text{km/h}$) and rural ($\geq 80\text{km/h}$) speed environments. The severity indices in the *High-Risk Intersections Guide* are calculated based on nationwide crash statistics from 2008 to 2012 and represent the average number of deaths and serious injuries per reported injury crash for each primary crash movement type at a specific intersection form, control type and speed environment.

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 is calculated by multiplying each reported injury crash at an intersection over the past five years by the corresponding severity index and summing the values. The Collective Risk of an intersection is then categorised into a five-tiered risk threshold classification. The thresholds have been determined by analysing the safety performance of thousands of intersections in New Zealand, and set so that intersections with a 'High' or 'Medium-High' Collective Risk profile (i.e. high-risk) make up fewer than 5% of all intersections in New Zealand.

Collective Risk is the primary risk metric used for prioritising intersections for road safety countermeasures, as high-risk sites are locations that have the greatest potential for reduction in road trauma.

By contrast, Personal Risk measures the risk to each person using the intersection. In practice only the number of motor vehicles travelling through an intersection is routinely available, so Personal Risk is calculated from the Collective Risk divided by a measure of traffic volume exposure [3]. Intersections with the highest risk per vehicle are ranked as highest risk from a Personal Risk perspective. Personal Risk is the most relevant risk metric for communicating road safety issues with the public, as risk is defined at an individual level.

5. URBAN KIWRAP

5.1 Risk Mapping Methodology Development

One of the first tasks for the Urban KiwiRAP Technical Committee was to decide whether corridor risk would be assessed using a fatal and serious crash based approach, such as that adopted for the original KiwiRAP work on the rural State Highway network, or an estimated DSI casualty equivalents approach as incorporated in the *High-Risk Intersection Guide*. Given fatal and serious crashes tend to be relatively rare and random events in urban environments, and the shifting focus from crashes to casualties expressed in *Safer Journeys*, the decision was made to adopt the estimated DSI casualty equivalents approach [4].

Before any corridor risk metrics could be developed, a standard method for defining an urban corridor needed to be developed; one which could be applied to any Road Controlling Authority's transport network. The critical factor in developing such a methodology is to base the influencing variables on information that is common to and/or applicable to any region.

Defining a corridor based on the hierarchical classification of the road and intersecting roads was the preferred approach. This approach was favoured as it generally resulted in a logical segmentation of roads into corridors where there were distinct changes in the physical nature and/or operation (traffic volume) of the road.

The process used to define a corridor as a contiguous group of roads as corridor were:

- A change in road hierarchy along the road;
- A change in speed environment from urban to rural (and vice versa);
- A change in road name; and
- At intersections with a side road with the same or higher order hierarchy

5.2 Corridor Risk Metrics Development

As with intersections, severity indices were developed for primary crash movement types for mid-block road sections with different lane and speed environments. The severity indices were calculated by extracting all mid-block crashes from the New Zealand Transport Agency Crash Analysis System (CAS) between 2008 and 2012 and determining the average number of DSI casualties for each injury crash in each category. A sample of severity indices for two-way, two-lane is presented in **Table 1**.

Table 1 – Example Mid-Block Severity Indices

Primary Crash Movement Type	DSi Severity Index Urban Speed Environment	DSi Severity Index Rural Speed Environment
Head on	0.368	0.818
Loss of Control (cornering)	0.275	0.327
Pedestrian	0.274	0.660

Corridor risk was calculated in two parts; an **intersection component** and a **mid-block component**. Because crashes at intersections typically involve the collision between two vehicles travelling on different, often adjacent legs of an intersection, a means of apportioning an intersection crash to the corridor had to be agreed.

5.2.1 Intersection Risk Metric Component

The initial approach adopted by the committee involved apportioning an intersection crash to all intersecting legs; however this produced some anomalous results where the lowest order roads in the hierarchical classification intersected a higher order road, particularly in terms of Personal Risk on the lowest order roads. Accordingly, the method was modified so crashes were apportioned to the higher order roads only at intersections where at least one, but not all, legs was a lowest order road. This meant the lowest order road corridors were assessed in a slightly different manner to higher order corridors, although safety issues at intersections would still be identifiable from the intersection risk mapping component. The intersection component of the corridor risk is calculated by summing the DSi casualty equivalents of all intersections along the corridor.

5.2.2 Mid-Block Risk Metric Component

The mid-block component of a corridor relates to all parts that are not classified as an intersection. All injury crashes along mid-block sections are multiplied by the corresponding severity index based on the crash movement type, the lane configuration and speed environment. The mid-block component of the corridor risk is calculated by summing the DSi casualty equivalents of all mid-block sections along the corridor.

The Collective Risk of a corridor is calculated by adding together the intersection and mid-block DSi casualty equivalents and dividing by the total corridor length in kilometres. Dividing by corridor length enables direct comparisons to be made between corridors of different lengths.

As with intersections, Personal Risk for a corridor measures the risk to each person travelling along the corridor. It is calculated using the formula:

$$\text{Corridor Personal Risk} = \frac{(\text{Corridor Collective Risk} \times 10^8)}{Q_{\text{corridor}} \times 5 \text{ years} \times 365 \text{ days}}$$

Q_{corridor} is the weighted average daily traffic volume along a corridor.

5.3 Corridor Risk Threshold Development

Risk threshold categories were developed by reviewing and analysing the distribution of calculated Collective Risk values of corridors in Auckland, Tauranga, Christchurch and Dunedin. The objective of the threshold setting was to attain the iRAP vision of targeting the highest risk 10% of roads where typically 50% of crashes occur.

Thresholds were initially developed as fixed values, independent of corridor length and speed environment. However, this approach resulted in a bias towards shorter corridors in low speed environments being more commonly identified as high risk while fewer longer corridors in higher speed environments were identified classified high risk. To address this bias, different thresholds were developed for urban and rural speed environments.

The rural thresholds were developed by transforming the fatal and serious crash thresholds presented in the New Zealand Transport Agency’s High-Risk Rural Roads Guide to estimated DS_i casualty equivalents per kilometre. These thresholds vary as a function of corridor length and are best defined by a negative power equation. Similar equations were then fitted to urban data and thresholds set to achieve the iRAP targeting vision. The agreed corridor risk thresholds are shown in **Figure B**.

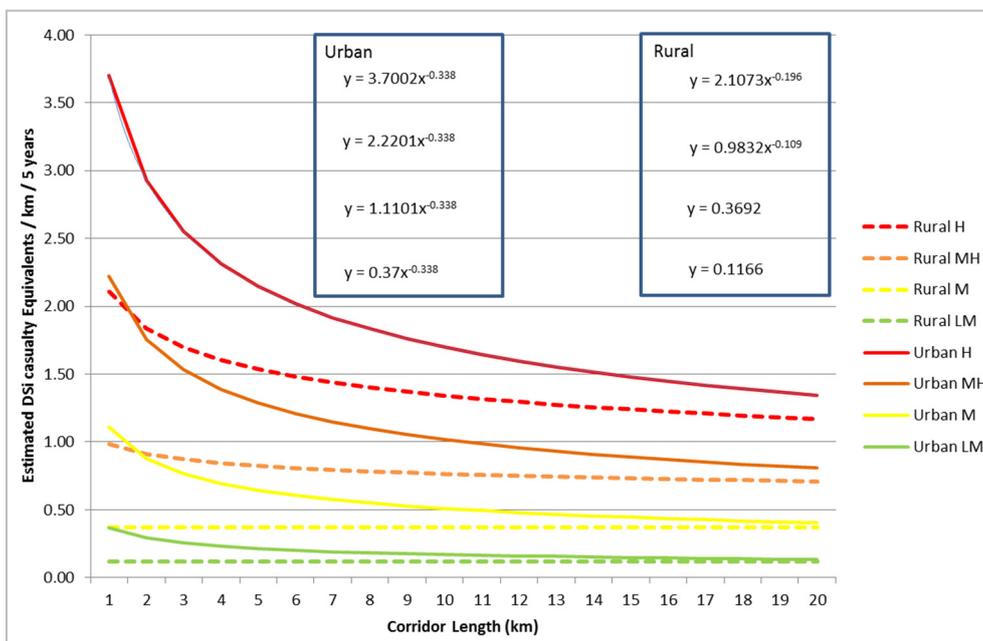


Figure B - Urban KiwiRAP & Rural Corridor Risk Thresholds based on Estimated DS_i Casualty Equivalents

The enhanced thresholds provided a more equitable comparison between corridors of different lengths and in different speed environments.

6. URBAN KIWRAP RISK MAPPING RESULTS

Collective Risk statistics for the networks of the four participating regions in the Urban KiwiRAP project are presented in **Table 2** and **Table 3** for intersections and corridors respectively.

Table 2 - Intersection Collective Risk Profile Statistics

Region	Number (Proportion) of High-Risk Intersections	Number (Proportion) of Injury Crashes
Auckland	271 (1.6%)	2,094 (22.8%)
Tauranga	17 (1.0%)	114 (18.8%)
Christchurch	81 (1.5%)	792 (24.9%)
Dunedin	32 (1.1%)	246 (19.7%)

Table 3 - Corridor Collective Risk Profile Statistics

Region	Length in km (Proportion) of network that is High-Risk	Number (Proportion) of Injury Crashes
Auckland	752 km (9.2%)	7,398 (48.9%)
Tauranga	46 km (6.9%)	289 (30.3%)
Christchurch	166 km (6.7%)	2,044 (46.8%)
Dunedin	77 km (3.9%)	695 (35.9%)

Table 2 shows that the thresholds in the High-Risk Intersection Guide result in less than 2% of all intersections within these regions being classified as high-risk. However, these intersections account for 18 to 25% of all intersection injury crashes.

Table 3 shows that the Urban KiwiRAP corridor thresholds are well-aligned with the iRAP vision of identifying the worst 10% of roads based on risk where 50% of the risk exists.

Given the finite resources available to improve road safety, it is imperative that road safety investigations and investments are targeted at the highest risk parts of the network to maximise the likelihood that projects will deliver the greatest road safety benefits. The results of the Urban KiwiRAP risk mapping help identify sites where targeted safety improvements are likely to be most successful at preventing deaths and serious injuries from occurring in the future.

7. STAR RATING TRIAL

The second stage of the Urban KiwiRAP programme is to extend star rating to local roads using the iRAP V3 model. As with risk mapping (the first stage in the Urban KiwiRAP programme), the focus of this trial is on urban networks but also includes local rural roads within the four Road Controlling Authorities taking part in the trial.

This initial trial includes almost 3,000km of roads in Auckland, Tauranga, Christchurch and Dunedin, and it has now been expanded to include a further five clusters of small and mid-sized local authorities. This extension is expected to bring the proportion of national urban road Deaths and Serious Injuries (DSIs) covered by the trial to almost 80%.

7.1 What is Star Rating?

Star Rating involves an assessment and allocation of a star rating from 1 star (poor) through to 5 stars (excellent) along a road corridor, based on the road and roadside features that are present. Star Rating relies on identified deficiencies in road infrastructure rather than crash history, to rate the safety potential of roads.

The Star Rating is assessed using a model which has risk factors for each road feature based on international literature and crash statistics.

The Star Ratings provide a quantitative measure of the safety provision of the road infrastructure and roadside environment. It is a wholly proactive approach to road safety that is expected to reduce deaths and injuries through targeted investment based on risk.

7.2 Background to Star Rating in New Zealand

In 2010 the first New Zealand Star Rating results were published using a specially developed KiwiRAP Star Rating model for more than 10,000km of the rural state highway network.

Analysis of these results gave an excellent relationship between the KiwiRAP star ratings and injury crash rates (**Figure C**), which gave confidence that the model accurately replicated the impact of road infrastructure on safety, and that therefore the infrastructure improvements derived from KiwiRAP would achieve the expected benefits. As such, KiwiRAP has since been embedded into a wide range of policies and guides, and is being used as a key network performance monitoring tool.

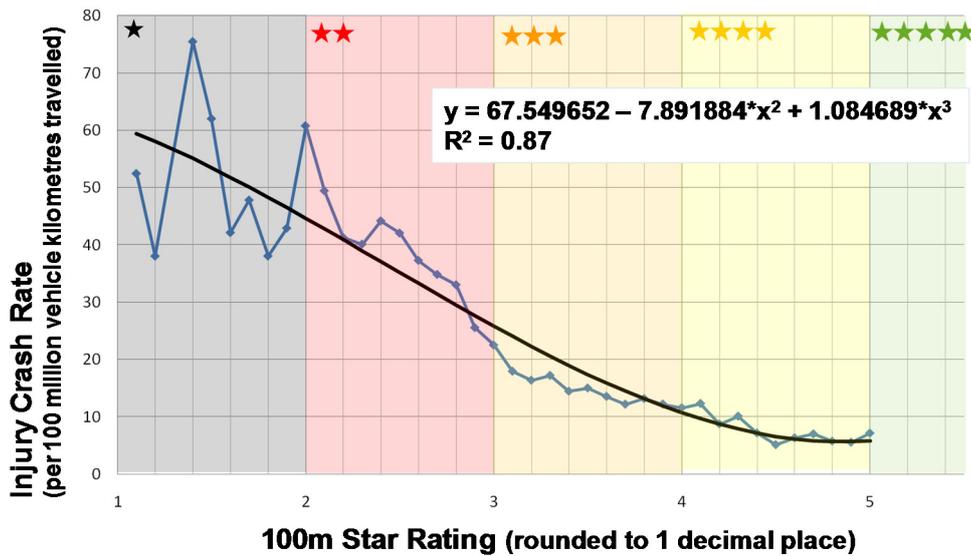


Figure C - Correlation between KiwiRAP Star Rating and Injury Crash Rate [4]

Since the release of the 2010 KiwiRAP star rating results the iRAP star rating model has been developed and updated incorporating a number of improvements, including innovations from the rural KiwiRAP star rating model. As the iRAP model is used by almost all of the eighty or so Road Assessment Programme countries, and applies to both urban and rural roads, it was the natural choice for the Urban KiwiRAP trial.

7.3 iRAP V3 Model

The latest iRAP model (Version 3) comprises four road user models for car occupants, motorcycles, bicyclists and pedestrians.

Each iRAP V3 road user model is based on the main crash types that account for road deaths and serious injuries, as shown in **Table 4**.

Table 4 - Crash Types Included in the iRAP V3 Star Rating Models

Vehicle Occupants	Motorcyclists	Bicyclists	Pedestrians
<ul style="list-style-type: none"> Run-off road Head-on Intersections and property access points 	<ul style="list-style-type: none"> Run-off road Head-on Intersections and property access points Moving along the road 	<ul style="list-style-type: none"> Travelling along road Intersections Run-off road 	<ul style="list-style-type: none"> Walking along road Crossing road

The model works by summing the scores from each of the crash types, where each Crash Type Score uses the same general form, as shown in the formula.

Crash Type Score

$$= \text{Likelihood} \times \text{Severity} \times \text{Operating Speed} \times \text{External Flow Influence} \\ \times \text{Median Traversability}$$

Where:

- *Likelihood* refers to road attribute risk factors that account for the chance that a crash will be initiated
- *Severity* refers to road attribute risk factors that account for the severity of a crash
- *Operating Speed* refers to factors that account for the degree to which risk changes with speed
- *External Flow Influence* factors account for the degree to which a person's risk of being involved in a crash is a function of another person's use of the road
- *Median Traversability* factors account for the potential that an errant vehicle will cross a median (only applies to vehicle occupant and motorcyclist run-off road and head-on Crash Type Scores).

Values for over 60 road and roadside features are recorded. These features include alignment, terrain, lane and shoulder widths, roadside hazard severity and offset, road condition and skid resistance, delineation features, intersection features, bicycle, pedestrian and motorcyclist facilities and so on.

The star ratings are determined using data collected during road inspections, which have two parts:

1. Road surveys, which involve the collection of video of the road, location (GPS) and distance data.
2. Road coding, which involves using the road survey data to rate each road feature for every 100m section of road.

The features are coded, typically as categorical variables. For example, for the vehicle occupant run-off road Crash Type Score model the available sealed shoulder width is coded to one of four categories (0m to ≥ 2.4 m), with relative risks ranging from 0.77 to 1.0. These relative risks mean that the crash rate on roads with sealed shoulders greater than or equal to 2.4m is typically 0.77 times less than that on roads with no sealed shoulder.

These 100m scores are then combined and averaged over longer lengths (typically 1km for urban and 3km for rural) to generate the star ratings.

7.4 Urban KiwiRAP Star Rating Trial

The Urban KiwiRAP star rating trial is being undertaken in 2014 and 2015 for the initial four cities taking part. Roads were videoed in September and October 2014 and are being coded in early 2015 with star rating results expected in late 2015.

Following the production of star ratings using the iRAP V3 model, the results will be evaluated by doing comparisons to injury crash data and intuitive star rating. This will follow the same process as was used for the development of the rural KiwiRAP star rating model.

Based on the success of these initial results, further work may be undertaken to test and potentially modify the iRAP V3 model. As with the 2010 rural KiwiRAP star rating, this work would draw from existing New Zealand research, models and crash patterns to develop New Zealand based crash risk factors and weightings if required.

7.5 Star Rating Application and Benefits

KiwiRAP star rating on rural state highways has already realised many benefits, and with the development of Urban KiwiRAP these benefits will extend to New Zealand's local roads as well. KiwiRAP star rating is:

- Raising the profile of road safety and helping to grow public awareness with an easy to communicate star rating system. It lets the public know that not all roads are equal, and that different roads pose different levels of safety risk, enabling road users to drive to the road environment.
- Enabling better understanding of the deficiencies in road infrastructure features that increase crash risk.
- Allowing for star rating policies to be developed to ensure that roads meet minimum safety criteria. For example, the New Zealand Transport Agency has adopted a policy that all Roads of National Significance (RoNS) should be at least four star.
- Proactively and more accurately identifying and prioritising road safety investment to target resources to those routes and features where the greatest road safety gains can be achieved. Using the relationship between star ratings and injury crash rates, star ratings can predict casualty savings, enabling practitioners to quickly assess and compare projects based on their expected safety outcomes. In New Zealand this fast project assessment method has been used to develop a national state highway minor safety programme.
- KiwiRAP star ratings are influencing the types of treatments that will be implemented. This includes the use of more cost effective solutions that provide a greater safety benefit return, such as increased use of median and roadside barriers.
- This nationwide analysis together with trends in treatment types encourages work to be bundled into programmes, rather than undertaking safety projects on an individual basis. This has ensured that KiwiRAP is not only a useful tool and source of information for practitioners but it is an effective way of communicating with policy makers and politicians. This increasing support for road safety will hopefully see more funding put into safety related projects, and will ensure that increasing levels of safety are incorporated in all road designs.

8. IN CONCLUSION

The KiwiRAP programme has become a key tool in supporting the drive to achieve safer roads and roadsides which forms a cornerstone of the New Zealand road safety strategy 2010-2020, *Safer Journeys*. Resource targeting on high risk rural state highways has seen significant crash improvements and it is expected that future targeting of resources on urban roads based on star rating and risk mapping will continue to deliver such results, extending the benefits across the whole road network maximising the provision of safe travel.

9. REFERENCES

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