

that includes the Institute of Transportation Engineers (ITE), AAA, the Insurance Institute for Highway Safety (IIHS) and American Society of Civil Engineers (ASCE) is advocating for roads in developing countries to be built to a minimum 3-star safety standard for all road users [15].

The moral and economic case for scaling-up investment in safe infrastructure is compelling. As we approach the Second Global High-Level Conference on Road Safety, we have an unprecedented opportunity to build on the growing momentum; to tackle the road crash epidemic; and leave a legacy of safe travel for future generations.

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Developing a curve risk prediction model for a safe system signature project

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Abstract

The Safer Journeys Action Plan 2013-2015 identifies safe system signature projects as a strategic action to achieve the Safer Journeys vision. The rural roads of New Zealand's Eastern Bay of Plenty (EBoP) region were identified as an area where a signature project has the potential to make demonstrable advances in reducing road trauma for all road users.

This paper describes a new risk prediction methodology that identifies high-risk curves independent of crash history. Using geospatial data and innovative analysis techniques, existing methodologies for identifying curves and calculating vehicle operating speeds were modelled and automated to undertake a network-wide assessment of high risk curves.

The new methodology extracted and classified almost 7000 curves across 1,500km of road network. When compared to the location of loss-of-control crashes, it was found that 66.6% of crashes occurred on 20.3% of curves classified as 'high risk' in at least one direction. These results have been shared with road controlling authorities and will support prioritised road safety improvements targeting high risk curves.

This methodology is the first network screening tool that has been specifically developed to address road safety risk in low volume rural areas. The methodology demonstrates how existing research into vehicle operating speed behaviour can be applied to identify high risk road elements and support targeted improvements that have the potential to significantly reduce road safety risk.

Introduction

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 [4]. 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.

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.

Safe system signature projects are identified in the Safer Journeys Action Plan 2013-2015 [6] as exemplar projects that adopt a complete safe system approach to road safety. Safe systems signature projects provide a platform for trialling innovative approaches and treatments across the four safe system pillars.

Identifying the need

The Eastern Bay of Plenty (EBoP) region (Figure 1) was identified as a candidate for a safe systems signature project as it is a region with significant rural road safety issues; particularly speed, use of alcohol/drugs, poor restraint use and inexperienced drivers. Most EBoP roads are low volume remote roads with a very high proportion of rural road crashes occurring on curves - 57.9% of all fatal and serious rural road crashes 2004-2013 [8].

Due to the remote nature of the region's roads, fatal and serious crashes tend to occur sporadically on parts of the network where high-severity crashes have not occurred in the recent past. In these areas, relying on crash history alone is not a robust method of predicting where future crashes are likely to occur. Because of this, a new methodology that could assess and identify all high-risk curves on the network independent of crash history was required.

Existing methodologies, including Urban KiwiRAP [2] and the predictive risk models presented in the New Zealand



Figure 1. Eastern Bay of Plenty locality map

Transport Agency's Economic Evaluation Manual, are useful for highlighting safety issues along corridors and at intersections, but they do not identify the risk of individual geometric elements of the road's design that may be a contributing factor for these types of crashes. Similarly, the Star Rating of roads produced following iRAP protocols provides a strong basis for assessing the underlying safety of a section of road based on built features. However, calculation of Star Rating is manually intensive and is carried out on selected corridors – not an entire network.

Austrroads operating speed model

The Austrroads (2009) operating speed model for rural roads provides a procedure for calculating speeds along road sections based on the geometric features of the road, taking into account the typical behaviour of drivers and vehicles on higher speed rural roads. Using road geometry, the speed model includes figures for modelling acceleration along straights, deceleration through curves, and the identification of curve design limits based on approach speeds and curve radii.

The Austrroads model is used by road designers to estimate operating speeds on relatively short, discrete corridors of highway. The model requires designers to assess the overall terrain and curvature class of the corridor, identify all the curves (including curve radii) and measure the distance between them. Corridors must be manually divided into discrete operating speed sections with minimum and maximum operating speeds. Speed behaviour is modelled in both directions as either:

- Acceleration on straights, or curves where the approach speed is less than the operating speed.

- Speed maintenance on straights less than 200m, or where approach speeds fell within operating speed ranges.
- Deceleration on curves where the approach speed is higher than the operating speed.

The Austroads methodology includes figures for modelling acceleration based on the length of straight and the initial speed, and deceleration based on the curve approach speed and curve radius. The model requires users to manually read these figures, calculating the exit speeds for each curve or straight which is then the approach speed for the following element.

One of the outputs of the Austroads methodology is the identification of design limits for curves, which can be used as a proxy for curve risk when considered in conjunction with the approach speed. Curves are classified as one of the following, in ascending order of risk:

- Within limit (a driver could safely accelerate through this curve)
- Desirable
- Undesirable
- Unacceptable

With 1,500 km of rural road, manually assessing the risk of each curve in the EBoP region using the Austroads model would be time-consuming and cost-prohibitive. As the inputs to the Austroads operating speed model are available in a spatial format, the model was therefore automated using a new Geographic Information Systems (GIS) methodology. This included the development of GIS models that identify curves, predict vehicle operating speeds along road corridors, and assess curve risk using approach speeds and radius.

Automating the operating speed model

Data requirements

The analysis relied on a number of road and environmental datasets. The most important dataset was a high-quality road centreline sourced from a third-party data supplier. This dataset closely represented actual road alignment and could be used to accurately identify curves and calculate curve radii.

Other road datasets, including Road Assessment and Management (RAMM), were used to extract road characteristics including surface type, carriageway width and ADT. A digital elevation model (DEM) with 15 metre resolution from the University of Otago - National School of Surveying [9] was used to extract terrain using advanced analysis in GIS. Crash data from the Crash Analysis System (CAS) was used for risk mapping and speed model validation [8].

Data preparation

The first step in preparing the data for speed modelling was extracting the rural roads and identifying unique corridors that replicated unimpeded travel along a road corridor. Corridors could only be ‘broken’ where vehicles would be required to slow or stop at an intersection, or meet an urban boundary. The start speed for each road corridor was then estimated according to the start context (Table 1).

Table 1. Corridor start speeds by context

Corridor start context	Start speed
Intersection	20 km/h
Road end	20 km/h
Urban boundary	50 km/h
Outside the study area	Maximum speed (refer Table 2)

The maximum speed on any road was calculated as a function of curvature and terrain (Table 2). These values are based on the desired speeds in Austroads 2009 [1] – the maximum speed regarded as acceptable to most drivers for the particular environment.

Table 2. Maximum (desired) speed by curvature and terrain

		Terrain (and grade %)			
		Flat (< 2%)	Undulating (2-4%)	Hilly (5-7%)	Mountainous (>=8%)
Curvature	Straight	110 km/h	110 km/h	95 km/h	90 km/h
	Curved	110 km/h	100 km/h	95 km/h	90 km/h
	Winding	90 km/h	90 km/h	85 km/h	80 km/h
	Tortuous	75 km/h	75 km/h	75 km/h	70 km/h

Curvature data, measured as degrees of turn per kilometre, was provided by the Transport Agency with the centreline dataset. Terrain (flat, undulating, hilly, mountainous) was calculated using geospatial analysis and the digital elevation model. For each 10m of road, raw grade was calculated over 100m and an average grade calculated over 1000m.

Curve identification

Curves were identified by adapting the methodology in Cenek et al. [3]. Using GIS linear referencing tools, the road centreline was divided into 10m sections and the rolling 30m average radius calculated for each arc section, as demonstrated in Figure 2.

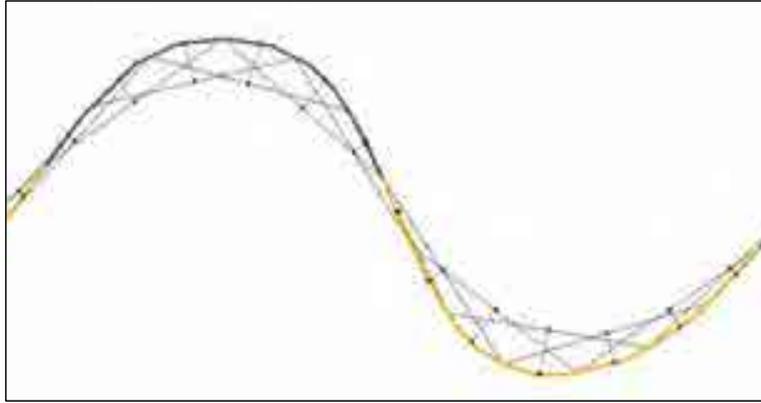


Figure 2: Example of curvature calculation

Discrete curve sections were extracted by combining road segments where:

- the radius was less than 800m;
- at least one 10m section had a radius of 500m or less; and
- the apex (direction) of the curve did not change.

Contiguous 10m sections of road that met these criteria were dissolved into a single curved segment, with the radius (m) of the curve defined as the minimum radius across all the sections that make up the curve.

Speed modelling

The Austroads 2009 guide [1] operating speed model predicts the operating (85th percentile) speed of cars travelling in each direction along a section of rural road. The model mimics the real-world behaviour of drivers based on a large number of car vehicle observations. As such, the model only applies to cars and cannot be used to predict the operating speeds of other types of vehicle.

Once curves had been identified (see above), each road corridor was divided sequentially into a series of curves with known radii, and straights with known lengths. Speeds were then modelled along the road centreline in both directions.

Sections of road with curves of a similar radius separated by short straights (less than or equal to 200m) were identified as discrete sections with an operating speed identified within a narrow range of values (minimum and maximum operating speeds). When drivers travel through a series of curves with similar radii, their speeds stabilise

to a level they feel comfortable with [1]. Section operating speeds for single, isolated curves were also calculated.

Working along the road corridor, speed behaviour was modelled as either:

- *Acceleration* – on straights longer than 200m, or on curves where the approach speed is less than the operating speed of the curve.
- *Speed maintenance* – on straights less than 200m, or where the speed falls within the section operating speed range.
- *Deceleration* – on curves where the approach speed is higher than the operating speed for the curve (or series of curves).

Rates of acceleration and deceleration were modelled using the methodology in Austroads 2009 [1] (Figures 4 and 5). Extrapolation of values was required to estimate some acceleration and deceleration outputs, including acceleration for straights longer than 1000m (Figure 3) and deceleration where curve approach speeds are less than 60 km/h (Figure 4).

The exit speed at the end of each curve or straight is applied as the approach speed for the following section of road. For each curve where deceleration is modelled, the design limit is identified as either out-of-context (unacceptable or undesirable) or within context (desirable) (Figure 4). Curves where no deceleration is modelled are also considered to be ‘within limit’.

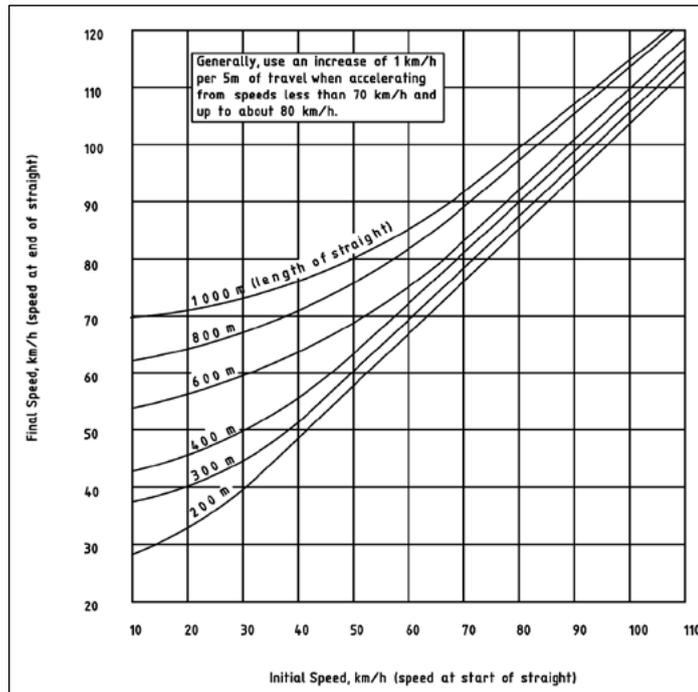


Figure 3: Acceleration on straights [1]

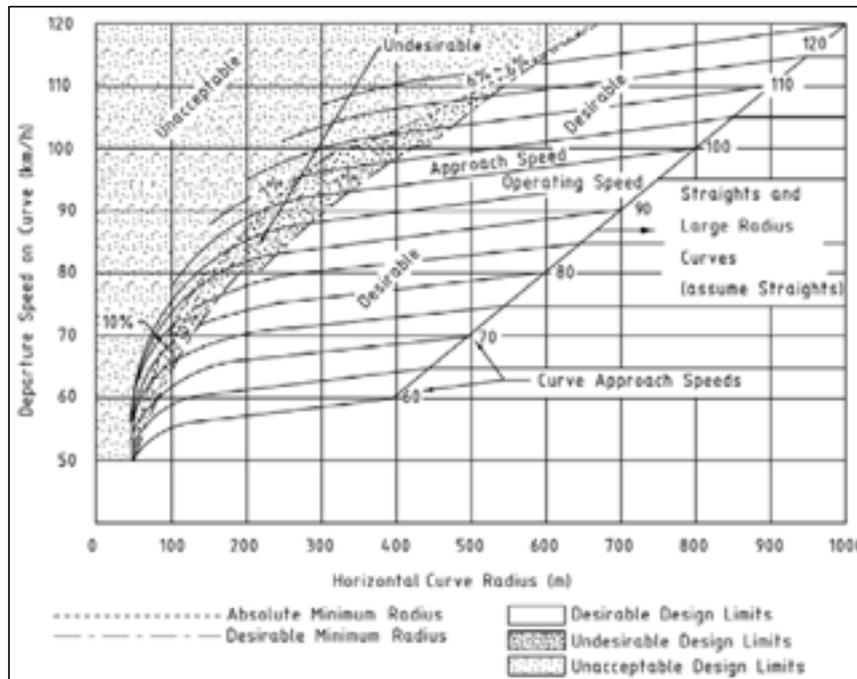


Figure 4: Deceleration on curves and design limits [1]

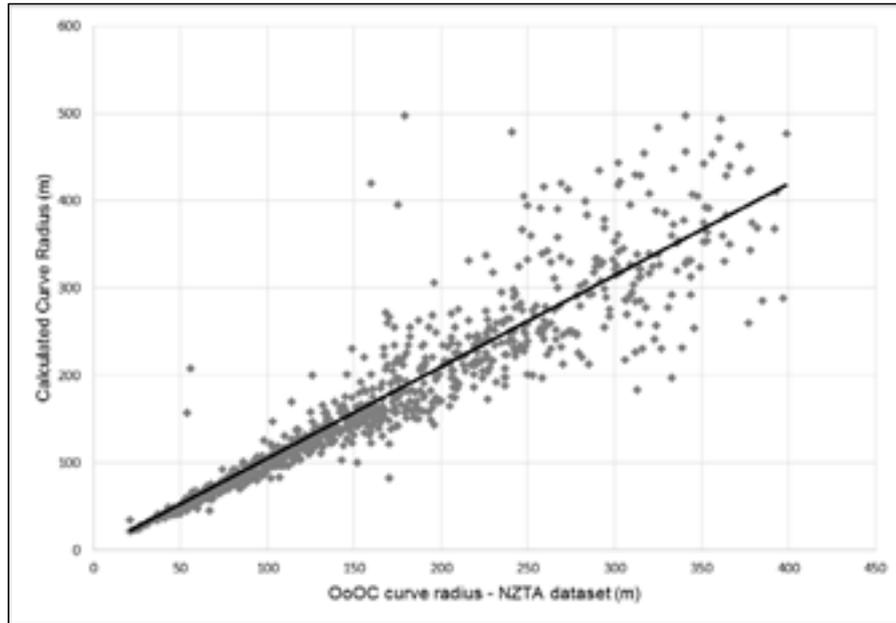


Figure 5: Comparison of calculated curve radii against NZTA out-of-context curve dataset

Calibration

Because the curve identification methodology developed for this project was new and untested, the results were compared against an existing New Zealand Transport Agency out-of-context curve dataset for the State Highway network in the Eastern Bay of Plenty region to assess the accuracy of the methodology.

The new methodology accurately identified the location of 96.8% of curves in the State Highway dataset, with a high correlation between curve radii values ($R^2 = 0.86$) (Figure 5).

The strong correlation between the automated operating speed model results and State Highway out-of-context dataset indicated that the new method developed for the signature project could be robustly applied to any road network regardless of the presence of comprehensive high-speed geometric data, including superelevation.

Results

The curve identification methodology recognised 6,985 curves across the EBoP region. Each curve was classified by design limit (in both directions) according to the Austroads operating speed model (Figure 4). The number of curves identified by category are displayed in Table 3. Where curves were classified differently in opposing directions, the worst (most out-of-context) classification has been applied. For example, a curve that is ‘undesirable’ in one direction but ‘within limit’ in the reverse direction would be categorised as ‘undesirable’.

Table 3: Eastern Bay of Plenty curve categorisation

Curve Category	Total Curves	% of all Curves
Unacceptable	600	8.6%
Undesirable	815	11.7%
Desirable	941	13.5%
Within Limit	4629	66.3%

Correlation between curve category and loss-of-control crashes

Further analysis was undertaken to identify the number and percentage of loss-of-control crashes by curve category. For the purposes of this analysis, loss-of-control crashes were defined as those with movement code ‘BF’, ‘DA’ or ‘DB’ in CAS. In the 10-year period from 2004 – 2013, there were 589 loss-of-control crashes on the curves identified. The number and percentage of loss-of-control crashes by curve category are presented in Table 4.

Table 4: Eastern Bay of Plenty loss-of-control crashes by curve category

Curve Category	Total Crashes	LOC	% of all LOC Crashes
Unacceptable	226		38.4%
Undesirable	166		28.2%
Desirable	64		10.9%
Within Limit	133		22.6%

The results show that two thirds (66.6%) of all loss-of-control crashes occur on out-of-context curves i.e. those identified as ‘unacceptable’ or ‘undesirable’. This is a particularly important finding as it means road controlling

authorities in the Eastern Bay of Plenty region could target efforts on 20.3% of all curves where 66.6% of all loss-of-control crashes occur. The relationship between curve category and loss-of-control crashes is shown in Figure 6.

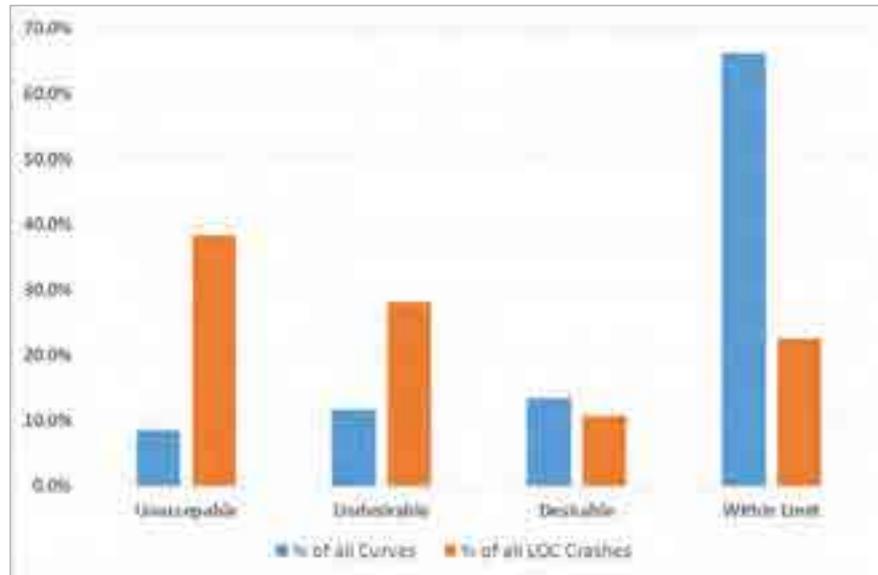


Figure 6: Curve category and loss-of-control crashes relationship

Further analysis of the number of loss-of-control crashes by curve category (Figure 7) demonstrates that curves rated ‘unacceptable’ or ‘undesirable’ in either direction have a higher incidence of loss-of-control crashes compared to

curves that are within context (‘desirable’ or ‘within limit’). This demonstrates that the relative risk of a rural curve is a function of the extent to which the curve is out-of-context with the approach speed.

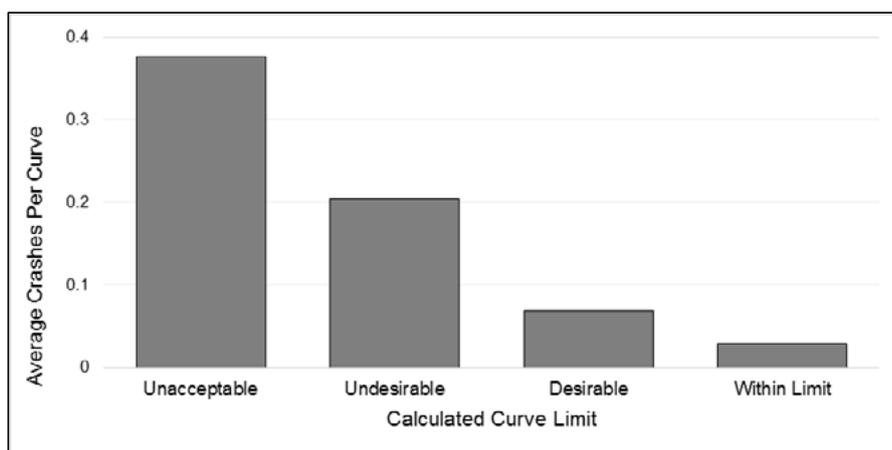


Figure 7: Loss-of-control crashes per curve by curve limit class

Output

The deliverable was a mapping website (“SignatureNET”) displaying the risk metrics generated from the analysis, as well as contextual road safety data including administrative boundaries, communities at risk [7], crashes (categorised

by crash severity and cause), and census statistics including deprivation and access to motor vehicles (Figure 8). The SignatureNET web viewer is available for all the signature project partners to access and query and features Google Streetview integration to allow users to view actual road conditions.

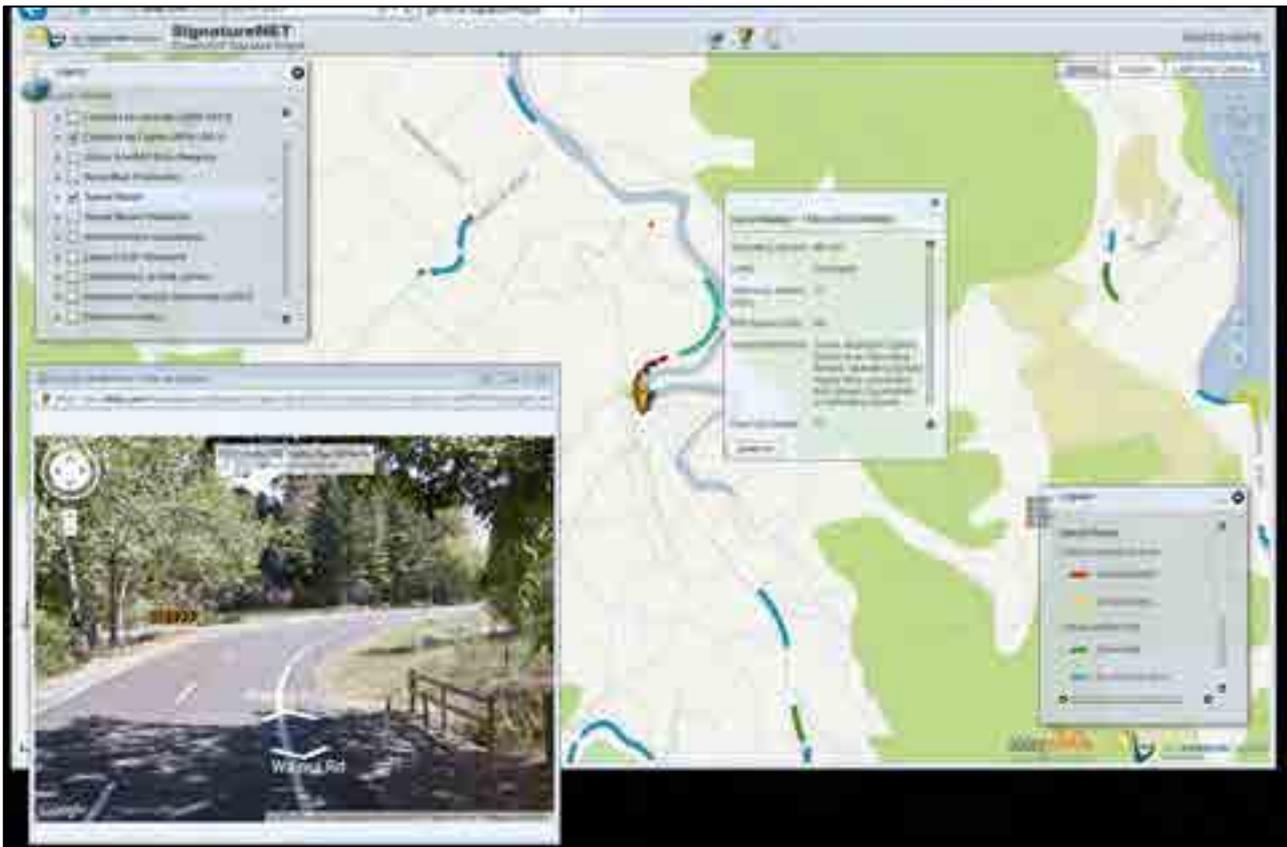


Figure 8: SignatureNET mapping website screenshot

Discussion and conclusion

SignatureNET and the new high risk curve assessment methodology demonstrate that innovative assessment methods and tools can be developed within a safe system signature project environment. Combining the speed and risk prediction models and related context data into a single mapping website has also provided the signature project partners with a tool to make well-informed road safety investment decisions. Both the SignatureNET website and underlying analysis can now be readily rolled-out across other regions using existing data and GIS methodologies.

The curve identification and analysis techniques presented in this paper will be of particular interest to road controlling authorities wanting to reduce loss-of-control crashes on rural roads. The output represents the first network screening tool that has been developed specifically to address the primary road safety risk in low volume rural areas in New Zealand – loss of control crashes on curves. As such, the model has the potential to benefit communities where road safety has been delivered in a largely reactive manner – which in low volume networks especially is usually a very ineffective way of deploying road safety funds.

The operating speed model provides a proactive approach of targeting to risk at a network-wide level. As a result,

road controlling authorities can now make better informed decisions about the use of their limited road safety funds in a more efficient manner. The tool is sufficiently sophisticated that curves may be considered out-of-context in one direction of travel, but not the other, thereby enabling road controlling authorities to treat specific approaches rather than both directions. This then enables limited road safety budgets to reach a greater number of high-risk locations within the region.

There is a wide range of potential applications of the outputs, ranging from low cost interventions to enhance delineation on high-risk curves e.g. edge marker posts, curve warning signs and chevrons, through to informing the potential for reductions in fatal and serious trauma if speed limits are reduced.

Further enhancements to the speed model and high-risk curve identification include:

- Enhancing the speed model by exploring the relationship between curve risk category, road surface and carriageway widths and actual road safety performance.
- Exploring the relationship between curve risk category, star rating and the road safety performance of State Highways

- Enhancing the speed model by comparing calculated operating speeds against known operating speeds, for example using data collected using GPS.

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