A road safety risk prediction methodology for low volume rural roads

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Abstract

The roads of New Zealand's Eastern Bay of Plenty region have relatively low vehicle volumes and experience a number of rural road safety issues, including inappropriate speed, the use of drugs and alcohol, low levels of restraint use and young/inexperienced drivers. Over half of all rural crashes are loss-of-control crashes on curves. Due to low network traffic volumes, crashes tend to be sporadic and difficult to predict using risk assessment techniques that rely on crash histories.

This paper introduces 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 1500km 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 in New Zealand or Australia. 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 (Ministry of Transport, 2010). This Strategy adopts a safe system approach to road safety focused on creating safe roads, safe speeds, safe vehicles and safe road use. These four safe system pillars need to come together if the New Zealand Government's vision for road safety is to be achieved.

Safe system signature projects are identified in the Safer Journeys Action Plan 2013-2015 (New Zealand Transport Agency [NZTA], 2013) 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.

The Eastern Bay of Plenty 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 inappropriate speed, use of alcohol/drugs, poor restraint use and inexperienced drivers. The scope of the project includes rural State highways and local roads. Most Eastern Bay of Plenty roads are low volume remote roads, where crashes tend to be sporadic and difficult to predict using reactive crash prediction models. Therefore a new approach to assessing road risk, independent of crash history, was required.

Abley Transportation Consultants was commissioned by the New Zealand Transport Agency (the Transport Agency) to develop a risk prediction model and mapping interface "SignatureNET" to support the delivery of this signature project. This included building a vehicle speed model to identify high risk curves, assessing road risk using the urban KiwiRAP risk mapping methodology (Brodie et al., 2013), and applying rural road risk prediction models.

Methodology

Many rural road crashes in Eastern Bay of Plenty occur on curves (57.9% of all fatal and serious rural road crashes 2004-2013) (NZTA, 2014). Due to the remote nature of the region's roads, fatal and serious crashes tend to occur on parts of the network where high-severity
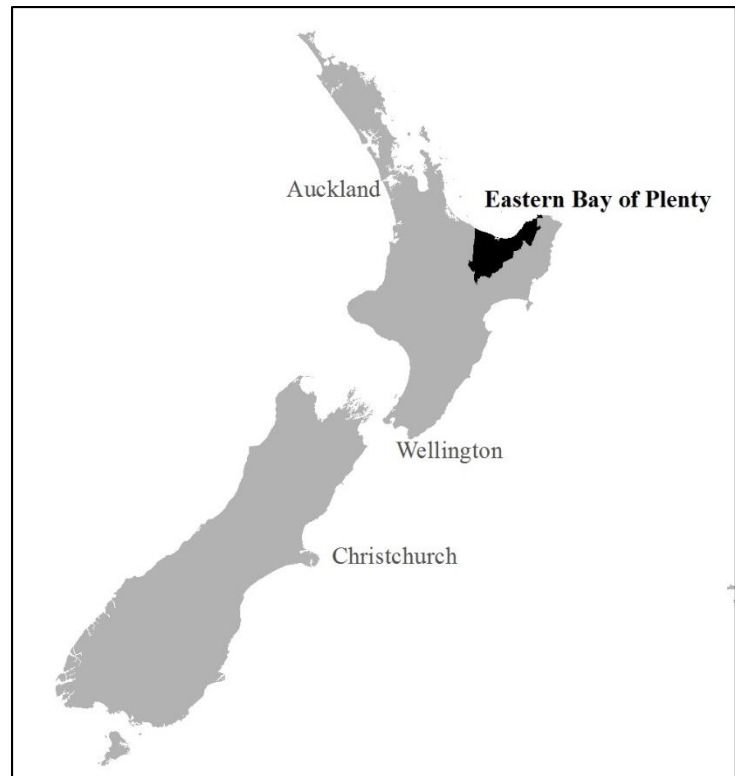
Figure 1. Eastern Bay of Plenty locality map

crashes have not occurred in the recent past. In these areas, relying on crash history alone to predict where future crashes will occur is unreliable. A new methodology that could identify and assess the risk of all the curves on the network that was independent of crash history was developed.

The Austroads (2009) operating speed model for rural roads provides a procedure for calculating speeds along road sections based on the geometric features of the road. Using calculated speeds and horizontal curve radii, the model allows users to assess the design limit of curves.

With 1500 km of rural road, manually assessing the risk of each curve in the Eastern Bay of Plenty 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 (Harris & Durdin, 2015). This methodology is discussed, in brief, below.

Curve identification

The first step in speed modelling methodology is to identify curves using a high quality road centreline and a methodology adapted from Cenek et al. (2011). The spatial road dataset used in this methodology closely matched the actual centreline of the road. Using GIS linear referencing tools, the road centreline was divided into 10m sections and the rolling 30m average radius calculated for each arc section.

Discrete curve sections were extracted by combining road segments where:

(a)   the radius was less than 800m;

(b)   at least one 10m section had a radius of 500m or less; and

(c)   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. The calculated curve radii represents a mid-road curvature value (rather than separate curve radii values for each lane or direction), noting that there are no divided carriageway roads in the Eastern Bay of Plenty region.

Speed modelling

The Austroads (2009) 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 a similar radii, their speeds stabilise to a level they feel comfortable with (Austroads, 2009). Section operating speeds for single, isolated curves were also calculated.

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

(a)   *Acceleration* on straights longer than 200m, or on curves where the approach speed is less than the operating speed of the curve.

(b)   *Speed maintenance* on straights less than 200m, or where the speed falls within the section operating speed range.

(c)   *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) (Figures 2 and 3). Extrapolation of values was required to estimate some acceleration and deceleration outputs, including acceleration for straights longer than 1000m (Figure 2) and deceleration where curve approach speeds are less than 60 km/h (Figure 3).

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 3). Curves where no deceleration is modelled are also considered to be 'within limit'.
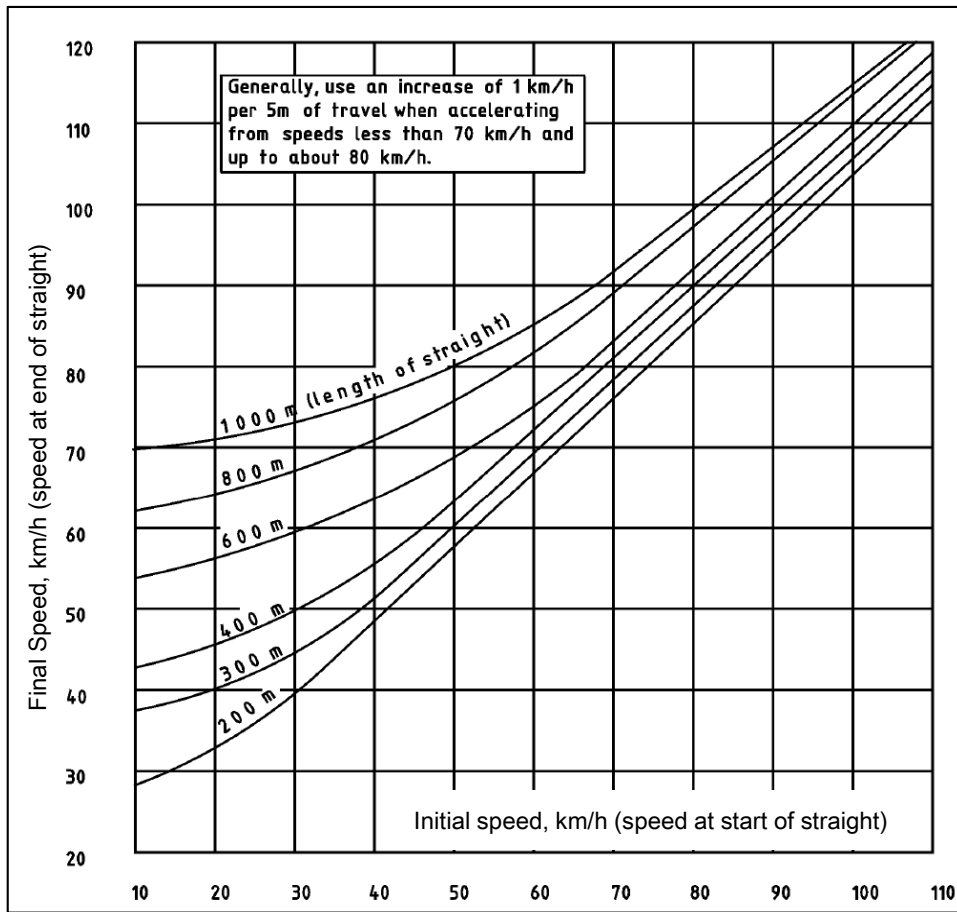
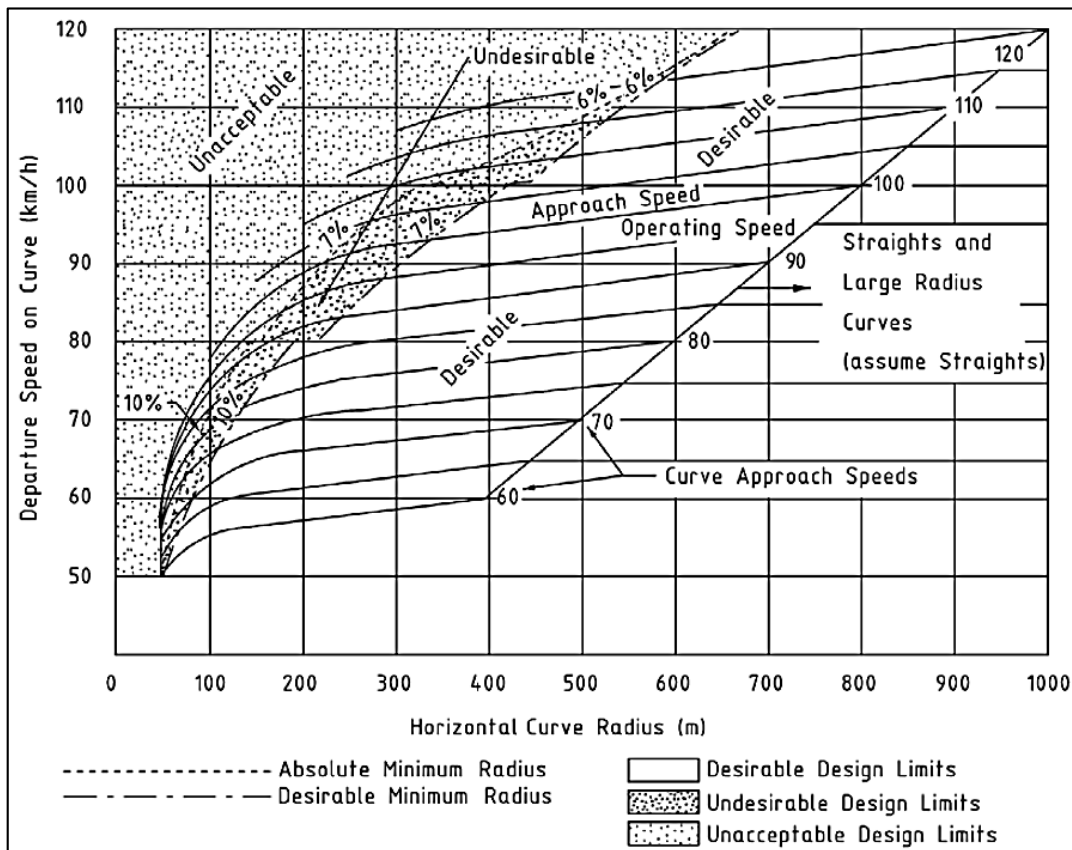*Figure 2. Acceleration on straights (source: Austroads, 2009)*

Figure 3. Deceleration on curves and design limits (source: Austroads, 2009)
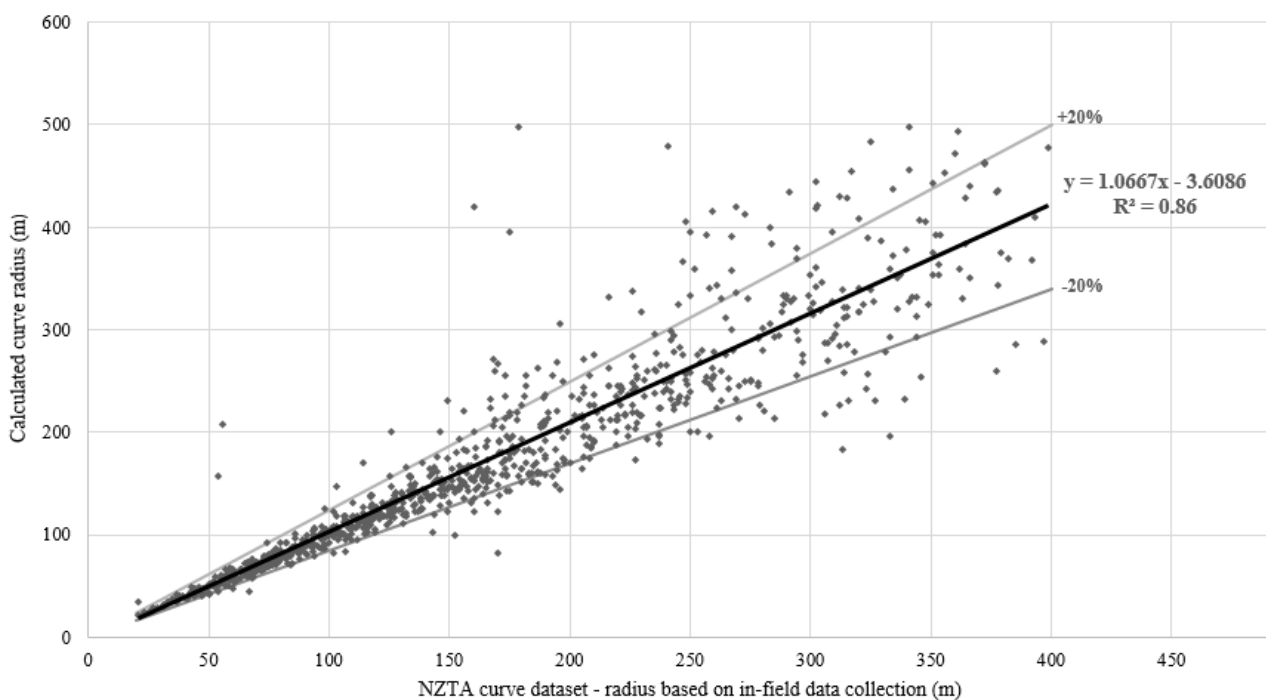
Results

The curve identification methodology recognised 6,985 curves across the Eastern Bay of Plenty region. Each curve was classified by design limit (in both directions) according to the Austroads speed model (Figure 3). The number of curves identified by category are displayed in Table 1. 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 1. 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%

Because the curve identification methodology developed for this project was a new and untested, the results were compared against an existing Transport Agency curve dataset for the state highway network in the Eastern Bay of Plenty. The state highway curve dataset is based on horizontal curvature data collected in the field as part of the Transport Agency's annual high speed surveys (Cenek et al., 2011).

The new methodology identified the location of 96.8% of curves in the state highway dataset, with a visible correlation between curve radii values (Figure 4). The two datasets met the assumptions required for linear regression, with 82% of calculated curve radii values within 20% of the Transport Agency's curve radii values. The degree of scatter between the two datasets, particularly for large-radius curves, is primarily attributed to the different collection methods. The state highway dataset is collected in-field using lane-based radii, whereas the operating speed model methodology relies on radii values calculated from the centreline. Extreme outlier values are more likely to reflect errors in the geometry and topology of road centreline dataset.

Figure 4. Comparison of calculated curve radii against NZTA out-of-context dataset

The results of the curve analysis were delivered through a mapping website ("SignatureNET"), which displayed the risk metrics alongside contextual road safety data including administrative boundaries and crash locations (Figure 5).
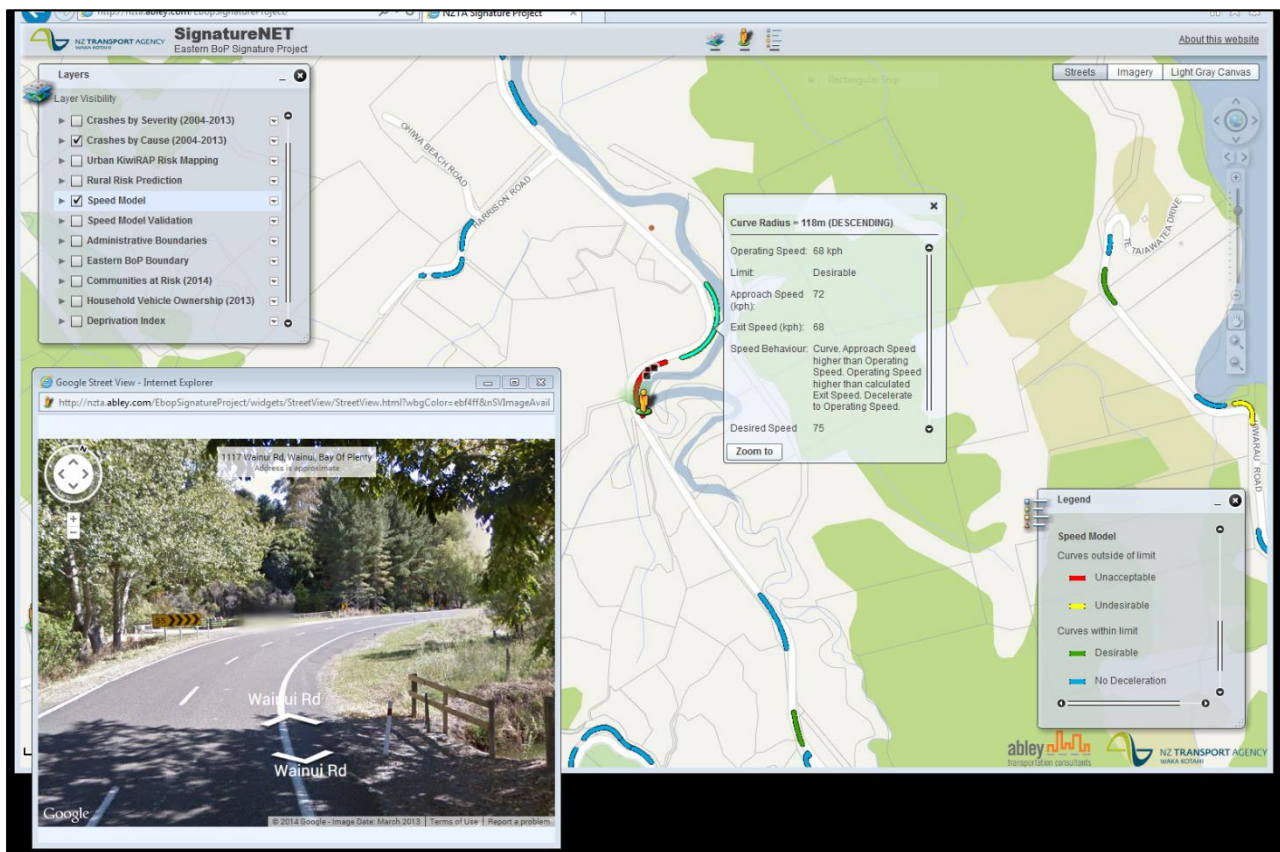
Figure 5. SignatureNET mapping website screenshot

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 this comparison, 10-years of crash data (2004-2013) was selected from New Zealand's Crash Analysis System (CAS) (NZTA, 2014a). For the purposes of this analysis, loss-of-control crashes were defined as those with movement code 'BF' (head on - lost control on curve), 'DA' (lost control turning right) or 'DB' (lost control turning left) in CAS (NZTA, 2014b).

In the 10-year period selected, there were 589 loss-of-control crashes on the curves categorised using the curve risk assessment methodology. The number and percentage of loss-of-control crashes by curve category are presented in Table 2.

Table 2. Eastern Bay of Plenty loss-of-control crashes by curve category

Curve Category	Total LOC Crashes	% 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 can target efforts on 20.3% of all curves where 66.6% of all loss-of-control crashes occur.

Further analysis and model validation

Since the first development of the operating speed model for the Eastern Bay of Plenty, the operating speed model has been applied to the Top of the South region of New Zealand - the area encompassed by the South Island local authority districts of Marlborough, Tasman and Nelson City. It includes some 3382 km of rural roads, which is much larger than the Eastern Bay of Plenty region (approximately 1500 km).

The operating speed model identified a total of 21,158 curves in the Top of the South region. The results of the curve classification are displayed in Table 5, showing that the proportion of curves in each classification in the Top of the South region mirrored the Eastern Bay of Plenty region (Table 3) very closely.

Table 3. Top of the South curve categorisation

| Curve Category	Total Curves	% of all Curves
Unacceptable	1772	8.4%
Undesirable	2215	10.5%
Desirable	2345	11.8%
Within Limit	14826	70.1%

Analysis of loss-of-control crashes against curve category was also undertaken for the Top of the South region, identifying that 55.8% of all loss-of-control crashes occurred at 18.9% of curves identified as out-of-context ('unacceptable' or 'undesirable') (Table 4). This result is similar to the analysis of the Eastern Bay of Plenty region, although the correlation is not as pronounced.

Table 4. Top of the South loss-of-control crashes by curve category

Curve Category	Total LOC Crashes	% of all LOC Crashes
Unacceptable	360	32.3%
Undesirable	262	23.5%
Desirable	135	12.1%
Within Limit	359	32.2%

The Eastern Bay of Plenty and Top of the South data were combined so the relationship between curve categorisation and loss-of-control crashes could be better understood (Figure 6). This figure shows there is a strong relationship between curve category and loss-of-control crashes. The relationship indicates that focusing road safety improvement efforts on out-of-context curves is targeting to risk.
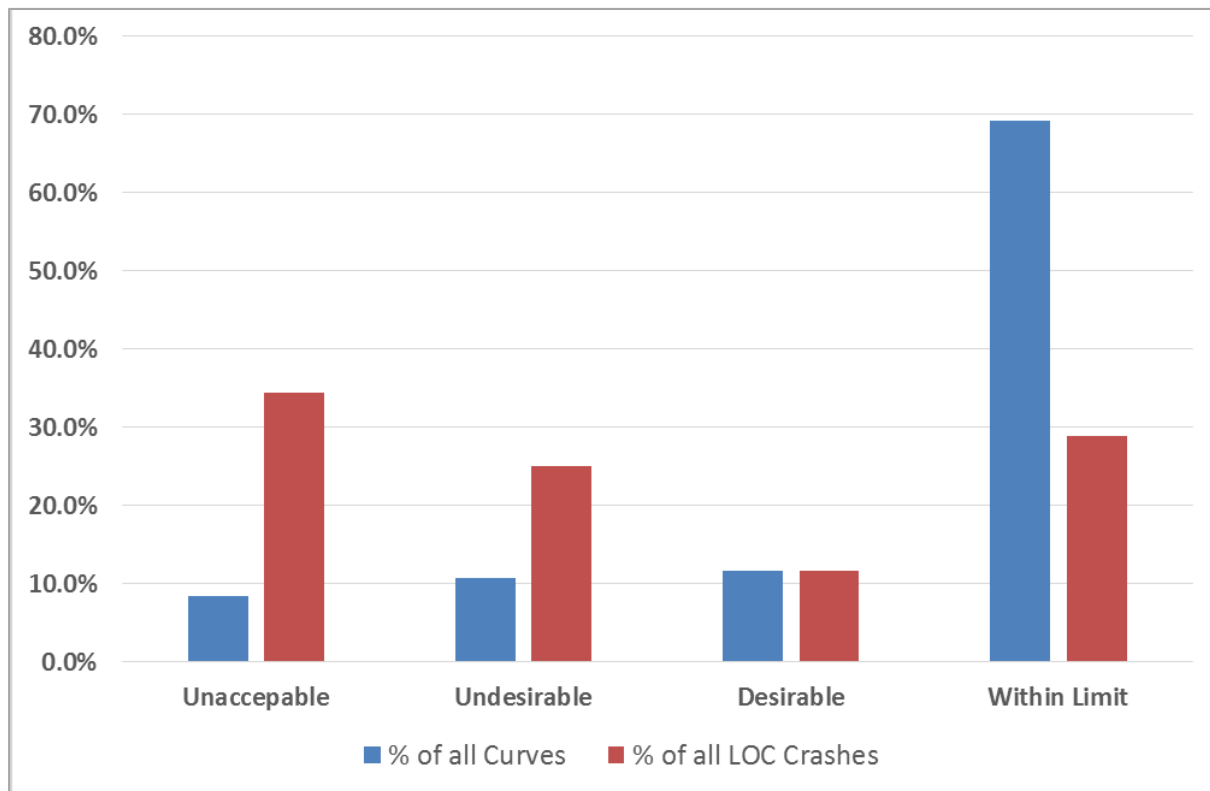
Figure 6. Graph demonstrating the relationship between curve category and the location of loss-of-control crashes

Discussion

The methodology presented in this paper has been well-received by all the agencies involved in the delivery of the Eastern Bay of Plenty safe systems signature project. The curve risk data and SignatureNET web viewer is now available to all the local road controlling authorities to assist them in identifying and prioritising road safety interventions targeting loss-of-control crashes on curves.

Current applications

The curve assessment and automated operating speed model is currently being rolled-out across other locations in New Zealand.

Informing speed management decisions

The Transport Agency has developed a process for identifying parts of the state highway road network for speed management interventions based on road safety risk. Potential interventions include targeted enforcement, reducing speed limits, or upgrading parts of the road network to reduce the frequency and severity of crashes at current operating speeds. To determine and prioritise appropriate intervention strategies, the operating speed model was applied across the high speed state highway network to determine: (a) operating speeds under current speed limits; and (b) operating speeds under the identified safe and appropriate speed limits, noting that speed limit is a factor in determining the maximum (desired) speed of a road (Austroads, 2009; Harris & Durdin, 2015).

The different operating speeds are then being used to estimate the potential for death and serious injury (DSi) savings by using Nilsson's Power Model which connects changes in traffic speeds with

changes in road crashes at various levels of injury severity using a power relationship (Nilsson, as cited in Cameron & Elvik, 2008). Sections of state highway that exhibit little or no speed reduction are considered to be 'self-explaining' as the geometry and terrain of the road naturally prevents drivers from achieving higher speeds. Conversely sections with extreme differences when comparing the current operating speeds and the safe and appropriate operating speed are generally straight roads where enforcement or engineering improvements may be more appropriate, depending on potential DSi savings and the functional classification of the corridor.

Training safety practitioners

As noted earlier, the methodology has been extended to the Top of the South region in New Zealand for exercises in the annual Safe Systems Engineering Workshop.   The outputs were presented in a web viewer and combined with Urban KiwiRAP risk profiles for the region delivered as part of an Accident Compensation Corporation (ACC) funded road safety initiative. The web viewer was used as learning media to introduce Safe Systems Engineering Workshop attendees to the use of network screening tools to assist with the identification of road safety issues across the region. By considering different risk metrics alongside one another and in combination with crash data, practitioners were able to identify potential factors contributing to high-risk locations and formulate responses at a desktop level prior to physically investigating sites.

Limitations and future enhancements

The speed modelling and curve risk assessment methodology is of greatest value to road safety practitioners where it is used as a network screening tool. The methodology should be applied with care when considering individual curves. Site-specific factors such as roadside hazards should be taken into account when identifying or prioritising curve treatments. For this reason, the SignatureNET web viewer included aerial imagery basemaps, Google Street View and other contextual data to support users in undertaking desktop reviews.

During the development and roll-out of the methodology, a number of further enhancements were suggested and are being explored. These include:

(a)   Enhancing the speed model by exploring the relationship between curve risk category, road surface type, carriageway width and actual road safety performance.

(b)   Exploring the relationship between curve risk category, KiwiRAP star rating and the road safety performance of state highways.

(c)   Enhancing the speed model by comparing calculated operating speeds against known operating speeds, for example data collected using GPS devices.

(d)   Exploring the feasibility of using high-resolution elevation data collected using LiDAR, (if available) to calculate superelevation and vertical curvature and incorporate these factors into the curve risk assessment models.

Conclusion

The operating speed model and high risk curve assessment methodology demonstrate that innovative assessment methods and tools can be developed within a safe system signature project environment. Current applications of this methodology in New Zealand demonstrate the potential of this methodology in supporting the safe system philosophy, including the identification of high risk curves for targeted safety investigation and treatment (Eastern Bay of Plenty), supporting the development of the New Zealand Transport Agency's Speed Management Guide, and being used as training media for Safe Systems Engineering Workshops. The curve identification and analysis

techniques presented in this paper will be of particular interest to any road controlling authorities wanting to reduce loss-of-control crashes on rural roads.

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