CLASSIFYING HORIZONTAL CURVES AND CRASH RISKS

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Abstract

Poor geometric design of horizontal curves can result in particular sites leading to high crash rates. Past researchers have developed models to predict crash rates. These models consider various factors, such as the minimum radius of the curve, but do not consider how the radius of the curve changes throughout its length. This research seeks to establish an automated process to identify curve types and to observe if there is a particular curve type that leads to a higher or lower crash rate when compared with other types of horizontal curves. High speed data surveys, which are conducted annually across the state highway network, provide the geometric data as inputs for this automated process.

The identified curve types were transition curves, circular curves, reverse curves, broken back curves and spiral curves. No significant difference in crash rates was found between these curve types when analysing crash statistics for the past ten years on the New Zealand state highway network in the Waikato, Bay of Plenty and Hawkes Bay regions. Curve types were then analysed using other factors such as annual daily traffic, minimum radius and approach speed which determined that there was no discernible difference between the curve type classes.

1. Introduction

1.1 Background

Loss of control and head-on crashes on New Zealand state highways are one of the most common forms of road crashes. Head-on crashes account for 23 percent of all fatal crashes, meanwhile loss of control contributes to 40 percent of all fatal crashes in New Zealand (SaferJourneys 2013). In addition to this, 56 percent of the total crashes on New Zealand’s State Highway occur on horizontal curves (Charlton, de Pont 2007). New Zealand’s State Highway network in comparison to many developed countries consists of a very curvilinear alignment with many horizontal curves of various curve types. Certain types of classification of horizontal curves such as ‘broken back’ curves are expected to have a higher crash risk as it is difficult for road users to ‘read’ and ‘perceive’ the different curve elements as they drive through the curve.

During the last decade there has been significant research carried out on assessing the crash risks on rural two lane roads in New Zealand. Crash research in New Zealand utilises road condition and crash data stored in a database called CAS (Crash Analysis System). Most of the crash research in New Zealand has focused on assessing crash risks based on factors such as superelevation, minimum radius of horizontal curves, skid resistance (assessed via the SCRIM process), alignment, Average Daily Traffic (ADT), and rutting as affecting crashes on horizontal curves. However the majority of research has not focused on classifying horizontal curves based on their types and if these types would adversely affect crash rates.

1.2 Curve Classification Types

There are a number of horizontal curve type elements that make up the New Zealand State Highway network. This research considered reverse curves, transitional spiral, circular curve,
broken back, transitional Spiral-Circular-Spiral (SCS) curve; each of which will be discussed in the following sections.

1.2.1 Reverse Curve
The *Austroads 2010 Geometric Design* Guide defines the reverse curve as a section of road containing two curves that turn in the opposite direction while having a common tangent point at the start and end of the transition curves. The 2005 NZTA *State Highway Geometric Design Manual* states that reverse curves can introduce problems in achieving a suitable superelevation rotation rate, and therefore a spiral or straight should be provided in between reverse curves to allow for, the time taken to steer through the curves and the development of the superelevation length. The NZTA manual also states that reverse curves should only be used as a last resort because of high yaw forces, which are developed at the tangent points, that can especially result in truck instability.

1.2.2 Transitional Spiral
Transition spiral curves are commonly used to join straight sections of the road to a circular section. A planned transition helps to provide a smooth alignment when transitioning from straight to circular (NZTA 2005). Furthermore, transition spiral curves are based on the mathematical spiral which provides a constant change in vehicle acceleration in the spiral (Austroads Ltd. 2010a).

![Mathematical Spiral](image)

*Figure 1-Mathematical Spiral (Austroads Ltd. 2010a)*

1.2.3 Circular Curve
Circular curves are simple curves which have a constant radius. These curves are commonly found as a component of the typical Spiral-Circle-Spiral curves.

![Circle Curve](image)

*Figure 2-Circle Curve (NZTA 2005)*

Broken Back Curves
A broken back curve is a curve turning in the same direction but joined by a short length of straight, or two small radii curves connected together by a large radii curve (Austroads Ltd. 2010a). Broken back curves pose high safety problems as it is often difficult to develop the correct superelevation for both curves, and it is very difficult to produce a visually pleasing vertical alignment for the edge of the road pavements (NZTA 2005).

![Figure 3-Broken Back Curves (Austroads Ltd. 2010a)](image)

1.2.4 Transitional SCS Curve
Transitional SCS curves are the most common curve type on the State Highway network of New Zealand. The transition spiral provides a length of road in which steering adjustments can be made by the driver before reaching the circular arc which is located between the two transition spirals (NZTA 2005).

![Figure 4-Typical Transition SCS Curve (NZTA 2005)](image)

2. Objectives
The objectives of the this research project was to investigate the effects of different types of horizontal curves on crash risks on selected rural two lane roads in New Zealand. A secondary objective was to determine the relationship of different variables which may affect crash rates on horizontal curves such as, ADT, super elevation, vertical grade, driveline issues and approach speed to the crashes in the specific types of horizontal curves.

The research considered the geometric data for State Highways in East Waikato, West Waikato, Central Waikato, Bay of Plenty East, Bay of Plenty West, and Napier. These regions were chosen due to the frequency of horizontal curves that exist in these areas.

Geometric and crash data was extracted from two databases, RAMM (Road Assessment and Maintenance Management system) and CAS (Crash Analysis System). RAMM contains all road condition data on the majority of state highways in New Zealand and CAS contains the crash data on these state highways. Due to the statistically random nature of crashes and variables which may affect crashes in horizontal curves, the research included statistical analysis to determine the
correlation between variables such as super elevation, approach speed and ADT, and crash rates on the different types of horizontal curves.

3. Methodology

3.1 Data Acquisition

Road skid resistance and surface geometry surveying is carried out annually on the majority of the New Zealand State Highway with the use of SCRIM vehicles. These SCRIM vehicles are owned and operated by WDM Limited, and are used to obtain high speed data for NZTA. SCRIM stands for Sideway force Coefficient Routine Investigation Machine. The SCRIM vehicles consists of a SCRIM wheel unit that measures skid resistance under wet conditions, a high speed laser unit to measure rutting and roughness, and a unit which contains an accelerometer and GPS to measure alignment data and GPS coordinates of the truck location.

The SCRIM vehicle obtains data in 10 or 20m sections depending on the type of data. That data measured in 10m sections includes the alignment data which contains curvature, gradient, crossfall, and the skid resistance of each wheel path under wet conditions. Data collected in the 20m increments includes the roughness of each wheel path measured by the international roughness index (IRI), and the rutting of each wheel path. All data collected by the SCRIM vehicle are locationally referenced to the New Zealand map grid by a differential GPS unit in the vehicle.

Crash data is recorded by the New Zealand Police using a Traffic Crash Report (TCR). Where a certain crash has occurred on the State Highway, the reporting police officer will fill out a report stating the type of crash, the location of the crash and how the crash occurred. The TCR data is then uploaded onto the NZTA's Crash Analysis System (CAS), and this database is then used as a basis for acquiring crash data in New Zealand.

3.2 Data Algorithm

For this research, Microsoft Excel was used for editing and coding the RAMM database to identify the different classifications of horizontal curves on the state highway network. The GPS and curvature data were the most important data in the RAMM geometry files for identifying horizontal curves on the state highway network. The “Curvature” of each geometric element is quantified using the radius of the curve and the GPS coordinates in RAMM are measured with respect to the NZ Map Grid coordinate system.

As to the curvature data in RAMM, a negative value of curvature indicates that the direction of the road is turning right, while a positive curvature indicates a left turn. Using the curvature data, the rate of change of curvature with respect to distance along the road was calculated for every 10m section of the data. This was carried out using the central differentiation method taking the difference between the cell below and above a selected 10m curvature value, then dividing it by 20m. For example below, the red highlighted section is the rate of change calculated by taking the difference between the blue highlighted sections and dividing by 20.

<table>
<thead>
<tr>
<th>Curvature</th>
<th>dr/dx</th>
</tr>
</thead>
<tbody>
<tr>
<td>7519</td>
<td>375.95</td>
</tr>
<tr>
<td>7519</td>
<td>-125.95</td>
</tr>
<tr>
<td>5000</td>
<td>-125.95</td>
</tr>
</tbody>
</table>

*Figure 5-Rate of change of curvature calculation*
Once the rate of change of curvature with respect to distance has been calculated for every 10m section of the RAMM database, three main rules were created in order to identify horizontal curves. These rules included:

- Curvature > 2000 = Straight Section
- Curvature < 2000 AND Rate of Change of Curvature > 10 = Transition Section
- Curvature < 2000 AND Rate of Change of Curvature < 10 = Circular section

Once these rules were created, the algorithm would then assign every transitional and circular section as a curve and assign straight sections as zeroes in the event identifier column.

<table>
<thead>
<tr>
<th>Type</th>
<th>Event Identifier</th>
</tr>
</thead>
<tbody>
<tr>
<td>STRAIGHT</td>
<td>0</td>
</tr>
<tr>
<td>TRANSITION</td>
<td>CURVE</td>
</tr>
<tr>
<td>TRANSITION</td>
<td>CURVE</td>
</tr>
<tr>
<td>TRANSITION</td>
<td>CURVE</td>
</tr>
<tr>
<td>CIRCLE</td>
<td>CURVE</td>
</tr>
<tr>
<td>CIRCLE</td>
<td>CURVE</td>
</tr>
<tr>
<td>CIRCLE</td>
<td>CURVE</td>
</tr>
<tr>
<td>CIRCLE</td>
<td>CURVE</td>
</tr>
<tr>
<td>CIRCLE</td>
<td>CURVE</td>
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<tr>
<td>CIRCLE</td>
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<td>CURVE</td>
</tr>
<tr>
<td>CIRCLE</td>
<td>CURVE</td>
</tr>
<tr>
<td>TRANSITION</td>
<td>CURVE</td>
</tr>
<tr>
<td>TRANSITION</td>
<td>CURVE</td>
</tr>
<tr>
<td>TRANSITION</td>
<td>CURVE</td>
</tr>
<tr>
<td>STRAIGHT</td>
<td>0</td>
</tr>
<tr>
<td>STRAIGHT</td>
<td>0</td>
</tr>
</tbody>
</table>

*Figure 6-Section type and curve identifier algorithm*

### 3.3 Classifying Horizontal Curves Types

Using counters to count the number of straight, transition and circle sections, the horizontal curves were then classified into respective curve classification types. Circular horizontal curves were identified by counting the number of circular sections, and if the number of circular sections equalled the number of curved sections counted, then the curve was then classified as a circular curve.

Reverse horizontal curves were identified by curve counts where there was also a change in direction of the curvature values. The algorithm was programmed to include straight sections into the reverse group curve as long as the straight section did not consecutively exceed 60 meters.

Broken Back curves were identified by the algorithm by straight sections in a curve event with no change of direction, which did not exceed 50 meters.

Pure Transitional spiral curves were those curves that were identified with the number of transition event counts being the same as its curve event counts.
Transitional curves were those known to be the typical SCS curves and these were identified in the algorithm as curves that were not reverse curves, not broken back curves and not circular curves.

3.4 Predictor Variable Data in RAMM
In the RAMM geometry files, a number of predictor variable data can be extracted and tailored to suit the investigation carried out during the crash statistical analysis stage. From the curvature data, the algorithm was programmed to extract the minimum radius of any curve by taking the smallest value of curvature for any group of curve events. The algorithm also extracted the deflection angle of curves. This was carried out by calculating the bearing angle of the start and end of each curve group event from the GPS coordinates in the RAMM files, then subtracting the difference in bearing angles from the start and end positions of the curve to get the final total deflection of the curve.

However, one problem with this method was that most reverse curves would have unexpected deflection angles due to the fact that the start and end of the reverse curve positions will not give the true deflection angle of the reverse curve as it is essentially two curves in two different directions. One option considered to address this problem was to split the reverse curve into left-hand and right-hand turn sections then find the deflection angle for each section. This method returned cumulative deflection angles that were unrealistically high; therefore comparison between this curve type and other curves types would be meaningless. Therefore it was decided to exclude any reverse curves from the deflection angle calculations.

Crossfall and gradient data were also extracted for each horizontal curve. The crossfall and gradient were separately averaged for their positive and negative values for each curve. This was done to avoid erroneous averaging where certain curves have a mixture of positive and negative values, such as for reverse curves having positive and negative crossfall.

3.5 Data Verification
Data verification was very important as there must be proof that the algorithm was identifying curve classification types correctly. The GPS coordinates in RAMM are known to have occasional errors in them as the GPS equipment used in the SCRIM trucks may briefly lose signal, such as in mountainous areas, causing the GPS to undergo linear extrapolation until it regains signal.

As a quick way to verify the data, the start and end GPS positions of each curve can be plotted on aerial photographs to get an accurate aerial view without having to go on-site to physically check and verify the algorithms.

### Figure 7-GPS coordinates and curve start end positions

<table>
<thead>
<tr>
<th>Northing</th>
<th>Easting</th>
<th>Updated Curve event identifier</th>
<th>Transition tester</th>
</tr>
</thead>
<tbody>
<tr>
<td>6367820.6</td>
<td>2827620.9</td>
<td>CURVE</td>
<td></td>
</tr>
<tr>
<td>...</td>
<td>...</td>
<td>...</td>
<td></td>
</tr>
<tr>
<td>...</td>
<td>...</td>
<td>...</td>
<td></td>
</tr>
<tr>
<td>6367798.1</td>
<td>2827951.2</td>
<td>CURVE</td>
<td>Transition</td>
</tr>
</tbody>
</table>
3.6 MATLAB

Once the data was verified, a MATLAB (analysis software) code was used to extract data from the RAMM, crash, out of context and carriageway data files as inputs. The key parameters that the MATLAB code extracted from these four files were:

- Region
- Curve classification type
- Start and end chainage curve length
- Start and end Road ID of the curve
- Total crash number in the curve
- Urban and rural section
- ADT, approach speed, curve navigating speed, minimum radius, superelevation, gradient and deflection angle.

The MATLAB code created a 2D matrix array that stored information read in from the input files. After initially opening up the RAMM geometry file followed by the crash data, carriageway and out of context curve data, the code looped through the RAMM geometry file, reading the curve classification types of each curve from the RAMM excel curve algorithm output and then storing it in the matrix. A secondary analysis loop was then initiated which looped through the RAMM again, this time files reading and writing the chainage lengths, road ID, and predictor variable data into the matrix.

The crash data also needed to be read and written into the matrix. The crash data that was used for this project was extracted from CAS and put into a format very similar to the RAMM geometry excel files (refer to Figure 9).

<table>
<thead>
<tr>
<th>CAS Location</th>
<th>No. Fatal Injuries</th>
<th>No. Severe Injuries</th>
<th>No. Minor Injuries</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>155</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>195</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>265</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>295</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Figure 9-Crashes and associated locations

It was noted that the Police TCRs can sometimes not be very accurate in pin-pointing the exact location of the crashes. A crash that may have occurred in a horizontal curve may be reported wrongly in the TCR as a crash on a straight.

One typical scenario of this is when a vehicle approaches a curve at a very high speed and loses control sliding into a straight section. Here the crash should be reported as a loss of
control crash in the curve but may actually be recorded on the straight where the vehicle has ended up.

The MATLAB code looped through the crash data file and assigned all crashes to a curve while allowing a tolerance of crashes which have a chainage of +100m ahead of the curve’s end chainage. This allows for the problem of the TCR misreporting the crash locations and also allows for a larger sample size of crashes to analyse.

Following this, the MATLAB code would then loop into the carriageway file which contained ADT data, and urban and rural classifications of the state highway. ADT data is given for each start and end state highway road sections. Finally, the MATLAB code processed the out of context curve data file which contained approach speed and curve navigating speed for the out of context curves with minimum radius less than 400m.

The final output file that MATLAB would produce was called the Combined Crash Output File. This file is the summary of the matrix which the MATLAB code writes all the data into. The combined crash output file (refer to Figure 10) contains the summary of each curve that the RAMM algorithm has picked up along with its associated length, crashes, start-end chainage and road ID, and its predictor variable data.
### Figure 10-Combined crash output file summary

<table>
<thead>
<tr>
<th>Name.Type</th>
<th>Length</th>
<th>Crash.number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reverse</td>
<td>280</td>
<td>1</td>
</tr>
<tr>
<td>Reverse</td>
<td>420</td>
<td>3</td>
</tr>
<tr>
<td>Reverse</td>
<td>260</td>
<td>2</td>
</tr>
<tr>
<td>Reverse</td>
<td>230</td>
<td>1</td>
</tr>
</tbody>
</table>

4. **Results**

Before conducting statistical analysis from the combined crash output file, preliminary data filtering was first carried out to avoid statistical misrepresentation for the crash data. A constraint with the crash data was that around 40-50% of the curves identified had zero crashes on them. Although zero crashes on a curve is valid data, to include these into the statistical analysis may cause excessive data skewing and misrepresentation of the trends. Intersection crashes were also filtered out for the purpose of this research because such crashes would be influenced at least in part by the intersection layout and not from the geometry of the curve. Furthermore, the crash data contained both urban and rural crashes, so urban crashes were filtered out in the combined crash output file.

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**Figure 11-Boxplot of curve crashes by curve classification type**

Figure 11 shows that the median number of crashes across the various curve classifications was broadly similar such that there is no significant difference between the different curve classification types and the number of crashes between each curve classification type. However, the spread of crash data for reverse curves were much higher than the other curve types.

It was found when comparing predictor variables that there was no statistical difference in terms of trends for each of the curve classification types. Therefore, when comparing the subsequent
analysis for the predictor variables, the overall number of crashes for all curve classification types was used.

![Figure 12-Scatterplot of number of curve crash vs. ADT](image)

*Figure 12-Scatterplot of number of curve crash vs. ADT*

The scatterplot shown in Figure 12 shows a high density of curve crashes where the State Highway’s ADT is below 5000 vehicles per day. The scatter of points implicates a less well defined relationship between crashes and traffic volume with a slight trend of crashes increasing as the ADT values drops.

![Figure 13- Scatterplot of number of curve crash vs. Minimum Radius](image)

*Figure 13- Scatterplot of number of curve crash vs. Minimum Radius*

When the number of curve related crashes is plotted against the minimum curve radius (refer Figure 13), as minimum radius decreases crash numbers increase. A high density of overlapping data can be seen below the 400m minimum radius mark.
The approach speed, and curve speed data in Figure 14 were derived from the approach speed research courtesy of Fergus Tate (NZTA). These approach and curve speeds only apply to curves with minimum radius below 400m. No significant trends can be seen from this plot, and scatter points away from the high density of overlap are highly random. Negative values in the difference in approach and curve speed, means that the approach speed going into the curve is slower than the speed at which the driver navigates the curve.

Figure 15 shows the relationship of the approaching spiral development length to the circular arc length ratio. Again, there are no obvious trends and the scatter is highly random.

5. Discussion

From the information above there is no significant, difference between the number of curve crashes and the curve classification types. By comparing the medians of crashes against different curve classifications for data which had curves with zero crashes filtered, and for data which had
curves with zero crashes included, the median would still turn out to be the same, indicating that there is no difference between the number of crashes and curve type classification.

Statistical analysis using t tests were carried out to test the difference in mean crash rates between different curve classifications and whether the crash data for different curve classification types were statistically significant.

Interpreting the results from the t-test, indicated that when broken back curve crashes are compared with other classification of curve crashes, a low t value of 3.2 would arise. Low t-test values mean that the data being compared is not statistically significant. The t-test can effectively work on non-normal data as long as there are more than 50 samples. The low t-test values for broken back crashes exists because it was found that broken back curves rarely exist on the state highway network tested meaning that there is a low sample size of broken back crashes.

When transition curve crashes were compared to reverse curve crashes, a t-test value of 9.8 was found and this is considered a high value. It was found that reverse curve crashes have a higher mean than the transition crashes by 2 – 3 crashes. Broken back curves had just over 80 samples with 1 or more crashes, and the reverse and transition had well over 700 samples, hence the difference in t-test values when comparing the curve classification types. It was decided from this research that data would be analysed using only count frequency methods such as scatterplots due to the t-test value of the broken back crash classification giving a low or not statistically significant result.

Crash data is not normally distributed; therefore the mean does not equal the median. However for non-normal data the rule of thumb is to use the median rather than the mean.

In rural two lane roads, ADT values are often low causing the number of curve crashes vs. ADT to be highly overlapped at low values of ADT. From equation 3.1 in NZTA research report 477 by Cenek et al, it was expected that the number of crashes (frequency) would increase when the ADT increases, with a corresponding increase of head-on crashes on the curves, however this is not the case according to this research. Although there is a slight trend of crashes increasing when ADT decreases, there is too much scatter with the data, such that there are no significant statistical conclusions suggesting that curve crashes are not highly related to ADT.

With the trend in the number of curve crashes increasing with decreasing minimum radius, there was still a need to take into account of out of context curves combined with low minimum radius having an effect on curve crashes. Out of context curves are curves that drivers are not expecting, such as a curve in between two long straight sections. It is expected that odd curves with very low minimum radius would be a major factor with crashes increasing as the minimum radius drops below 400m. Therefore to conclude that minimum radius alone is a factor that influences curve crashes would not be entirely correct as other key factors such as odd curves combined with minimum radius would need to be looked at to determine what the real cause of curve crashes are. Unfortunately, comparing the odd out of context curve with general curves with low minimum radius in context with adjacent curves was not carried out due to the lack of time and resources. This comparison is recommended for future research.

No trends could be identified between curve crash numbers and difference in approach and curve navigation speed. The cluster of overlapping data was mostly in the 20-40km/h region. Log transformation of the data was carried out in order to convert the number of curve crashes and difference in speeds to normality, however high random scatter was still a large problem and no statistically significant trends could be identified.
5.1 Limitations
In order to gain a better understanding of the relationship of predictor variables on curve related crashes, advanced regression models could be undertaken to combine different predictor variables. Due to time constraints on this project this was unable to be undertaken.

6. Conclusions
The research undertaken attempted to identify horizontal curves within six North Island State Highway regions and crash data for each curve classification. The algorithm was verified using tools such as Google earth to plot the start and end coordinates.

From the statistical analysis conducted on the data, it was found that there was no difference between the number of curve related crashes and the type of curve. This has been verified by t-tests which proved that the sample size for the reverse curve and transition curve were large enough for accurate statistical analysis, however for the broken back curve crashes, the t-test value was too small for any in depth statistical analysis to be conducted. Therefore the research used traditional count frequency methods such as scatterplots and boxplots to graphically analyse any trends with the crashes and predictor variables.

From previous literature reviews, it was expected to see crashes on curves increasing as the ADT increases. However, this research showed no obvious trends between curve crashes and ADT. When minimum radius was used as a predictor variable against curve crashes, it was found that there was a trend, but not significantly correlated, of crashes increasing as the minimum radius drops below 400m. Crashes are multi-factored, highly random events so to conclude that one predictor variable such as minimum radius is a key factor in causing curve related crashes would not be sufficient as other factors such as out of context curves must also be taken into account.

7. Acknowledgements
The authors would like to give special thanks to the following people who aided and gave support in the completion of this research:
- Fergus Tate, NZTA
- Darren Newland, WDM NZ Ltd
- Don McKenzie, TDG
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