Establishment of a Curve Deficiency Classification System in Determining a Risk Management Approach for Addressing Skid Resistance on a Network Level

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ABSTRACT

Skid resistance on road surfaces is a significant safety measure and is considered as one of the major factors in crash reduction in New Zealand. It is known from previous research that a strong relationship does exist between crash rate and the level of skid resistance. However poor skid resistance is never the sole cause of a crash. Other factors such as driver behaviour, speed and road geometrical shortcomings are contributors to the occurrence of crashes.

Frequent re-sealing of the road surface is required to maintain skid resistance and to meet the levels of surface friction specified by Road Controlling Authorities. However, the current regime for simply maintaining the asset does not appear to be supplying the safety outcomes expected and is expected to create an on-going maintenance problem for these authorities due to the behaviour and performance of multiple bituminous seals. A more holistic approach towards effective skid resistance management is required, one that focuses on crash risk rather than on meeting a skid resistance target.

It is known that the majority of crashes occurs on curves. This investigation focuses on all curves on the Transit Northland Network and aims to identify those sites that may be expected to have a high crash risk, even if there have been relatively few crashes to date simply due to the random nature of crashes on a network with relatively low traffic flows.

A process is developed whereby curves on a road network can be classified by their friction demand. This classification is based on the geometric characteristics (design speed) and the desired free speed for the particular speed environment in which the site lies. All curves were classified according to a three-category deficiency scale – Low, Medium or High. Following this process, crashes on deficient curves were investigated in order to establish a curve risk measure for implementation into a cost effective maintenance strategy on curves. Results presented in this report are the first attempt to compare curve deficiency with crashes. The expected social cost of crashes per vehicle entering a curve is adopted as the most appropriate measure of the level of curve risk. As no clear match exists between the expected cost per curve and the actual cost of crashes at each curve, it is envisaged that some combination of the expected social cost and the actual cost per deficient curve may produce a better tool in defining a risk measure for curves.

The outcome of this process may be imported into a risk management approach that would allow the optimisation of the type of mitigation measure or treatment required for each deficient curve.

1. INTRODUCTION

During 1999 Transit New Zealand (Transit) has made a radical shift in the way skid resistance is managed on its State Highway Network. These changes included amongst others, an annual survey of the friction and macro texture of the road surface. Interim standards were developed that specified Investigatory Levels for five site categories in terms of the Mean Summer SCRIM Coefficient (MSSC). Further research continued to determine whether the standards in terms of crash risk were valid for New Zealand and furthermore economically justifiable. The latest version of TNZ T10 : 2002 includes Threshold Levels which indicate the level at which immediate action is required to improve the skid resistance levels. Identifying potential poor wet-skidding sites and treating these as a matter of priority became part of the Transit business process resulting in these criteria being adopted as Key Performance Measures (KPM) on Performance Specified Maintenance Contracts (PSMC).

In combination with a number of other safety related initiatives, skid resistance management has resulted in a significant reduction of Loss of Control crashes on State Highways over the past five years (Wilson et al 2004). In terms of the above skid categorisation, much emphasis is placed on curves in higher speed environments (e.g. Site Category 2). It is also acknowledged that skid resistance remains one of the many parameters that determine the level of safety on higher risk areas of the network, especially on curves. Other factors like road geometry, driver behaviour and vehicle speed also contribute towards crash risk on curves. It is thus realised that skid resistance is a significant safety aspect in the management of a roading network but should not be considered in isolation during maintenance planning of such network.

On some roading networks, a substantial portion of the network consists of Site Category 2 curves. For example on Transit’s Northland Network, Site Category 2 curves account for an equivalent road length of 206 km. The generally low polished stone values (PSV) of the locally available aggregates in Northland combined with the volumes of heavy vehicles and often tortuous alignment, result in rapid polishing of the road surface aggregates and consequential loss of micro-texture, a key component of skid resistance. As a result the MSSC values in Northland deteriorate more rapidly than in many other parts of New Zealand. This is particularly the case for short sections of curves where tyre slip and therefore stone polishing is maximised.

Frequent re-surfacing will maintain the necessary levels of skid resistance. Road surface dressings involve single size aggregates embedded in bitumen. Although the aggregate size changes over a series of re-surfacings, the resulting build-up of seal layers lacks the mechanical interlock of a dense aggregate grading and contains excess bitumen which moves towards the road surface. The result is a pavement that is prone to excessive bleeding, flushing and shoving, and one which presents Transit with on-going maintenance or reconstruction costs. In addition to the poor performance of these resurfacing strategies on high skid demand curves, it also contributes towards the depletion of natural sources of high Polishing Stone Value (PSV) surfacing aggregates.

This situation is particularly evident on the Northland Network with the relatively high number of Site Category 2 curves and a shortage in high PSV aggregates. It was therefore decided to follow a more holistic view in developing a risk based approach to determine the most appropriate maintenance strategy for each curve. This suggests that the current TNZ T/10 investigatory criteria remain unchanged while other factors that contribute to crash risk be recognised in the formulation of a maintenance option for a particular curve. Other factors or causes may include:

- Insufficient sight distance to the curve may be such that drivers have insufficient time to adjust their speed to the level that may allow them to negotiate the curve safely;
- The curve may be deceptive in that it appears on approach to be of a larger radius than it actually is, or the curve tightens part way through;
- The super-elevation may vary through the curve or be out of phase with the horizontal curvature of the rest of the alignment;
- The expected value of road-tyre friction may not be present due to low skid resistance, loose material or surface contamination.

So while a curve that is out of context with the surrounding speed environment will have a higher risk of loss of control, the level of risk may be further increased if the curve is deficient in other ways. Also, having lost control, the risk of a crash occurring (rather than coming to rest without injury or damage) will be related to the width of sealed pavement available for recovery and the clear zone beyond the edge of seal.

The likelihood and consequence of loss of control crashes on curves are therefore functions of a number of variables, only some of which are readily quantifiable. The challenge is therefore to find a balance between the crash risk on a particular curve and the cost effective maintenance treatment associated with that risk. This paper explains the development of the risk approach in managing low skid curves more efficiently.

2. STUDY OBJECTIVE

The current regime for simply maintaining the asset, does not appear to be supplying the safety outcomes expected, and is expected to create an on-going maintenance problem for Transit New Zealand.

One approach would be to establish crash risk on the basis of the historical crash records. This would focus attention on those sites with a significant crash history. However, given the generally low traffic volumes that occur on much of the Northland network, such a reactive approach may not deliver the greatest benefit.

A more proactive approach would be to identify those sites that may be expected to have a high crash risk, even if there have been relatively few crashes to date simply due to the random nature of crashes.

The objective of this study is to investigate crashes on curves, in order to establish a risk based criteria for a more cost effective maintenance strategy based on the approach outlined in Figure 2-1below.

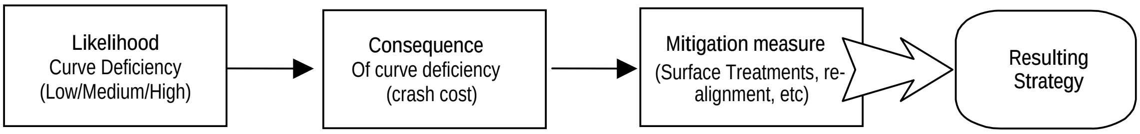

Figure 2-1 : Risk model approach

The expected outcome is the development of a number or measure that reflects the risk associated with a particular curve and which may be used to prioritise curves for maintenance. This number or measure should represent a combination of both the likelihood of a crash on a particular curve and the consequence of such a crash. The most appropriate measure would be the expected social cost of crashes per vehicle entering a particular curve expressed as cents per unit of vehicles.

This investigation is a first attempt at comparing curve deficiency with crashes.

3. CURVE DEFICIENCY CLASSIFICATION

Previous researchers (Matthews and Barnes, 1988; Jackett, 1992 and Koorey and Tate, 1997) have all identified that the crash risk on a particular curve is a function, among other things, of the speed at which a vehicle enters the curve and the design speed of that curve. It has been shown that crash rates increase significantly where the difference between the expected operating speed and the safe operating speed under design conditions is large (>15km/h). Simply, the crash rate on a 200m radius curve with a design speed of 80km/h will be far less (approximately 50% less) when such a curve is located on an alignment where the 85th percentile approach speed is 80km/h, than when the approach speed is 100km/h.

On this basis an assessment of curves on Transit New Zealand's Northland network was undertaken, in which all curves were classified according to a three-category deficiency scale:

- **High** – the speed environment is more than 15 km/h higher than the design speed;
- **Medium** - the speed environment is more than 10 km/h higher and less than 15 km/h than the design speed;
- **Low** - the speed environment is more than 10 km/h higher than the design speed, but the super-elevation is high (>10%).

The Northland network has a total number of 1730 curves, which constitutes 39% (275km) of the entire network length measured along the centerline of the road. Some 49% (855) of these are classified as deficient in terms of the above deficiency scale. Figure 3-1 below illustrates the split in the number of deficient curves on the network for each deficiency level. Approximately 36% and 63% of all deficient curve sites are classified as having Medium and High deficiency levels respectively.

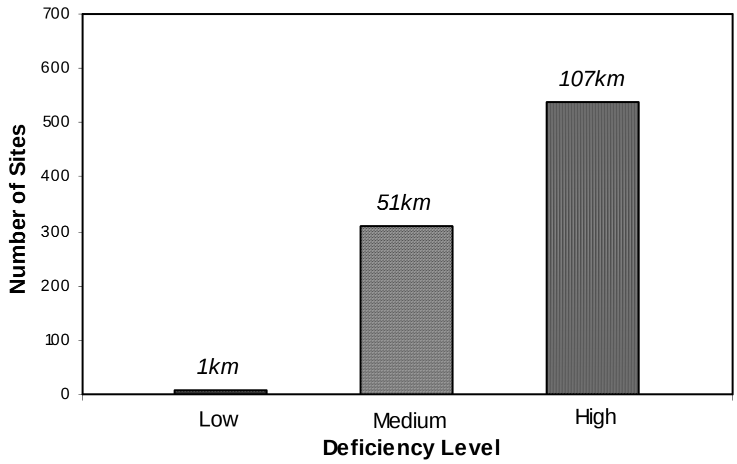

Figure 3-1 : Deficiency Classification Split

This assessment is based on the High Speed Data (HSD) collected in the annual SCRIM surveys (2003/2004) on the network. The actual design speed for each curve element was calculated by using the gradient, crossfall and radius of curvature values from the HSD and the design speed equation from the Transit New Zealand State Highway Geometric Design Manual (SHGDM). The speed environment for each curve was obtained from Highway Information Sheets and information from the network video. A field assessment of the speed environment values on curves was undertaken on a 64% sample of all curves on the network. This assessment comprised a drive-over on the relevant curves in order to verify curve approach speeds. The observed speed values have shown a good correlation with the speed values derived through the method described above.

Using the calculated design speed and observed speed environment of each curve, a curve deficiency plot was produced to highlight the deficient curves along a stretch of road as illustrated in Figure 3-2.

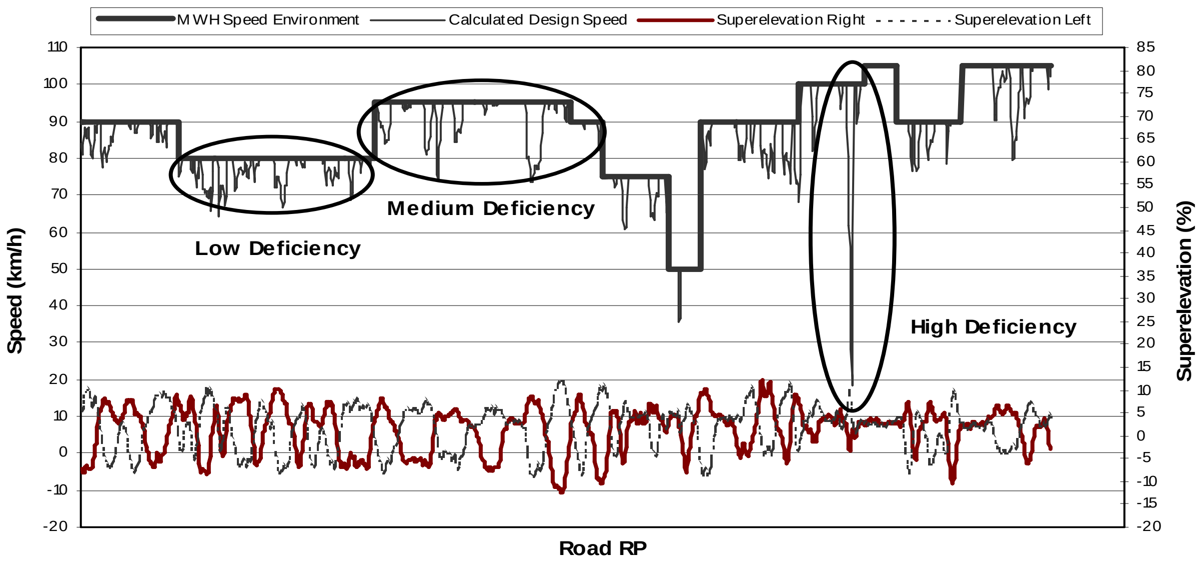

Figure 3-2: Curve Deficiency Plot

4. CRASHES ON CURVES

4.1 CRASH OVERVIEW

During the fifteen year period 1989 to 2003 inclusive a total of 3,607 non-intersection crashes have occurred on the rural state highways of the Northland network on curves where the speed limit is greater than 70 km/h. When only injury type crashes are considered, some 42% of injury crashes involved at least one fatal or serious injury. This is almost 30% higher than the average for all rural non-intersection injury crashes on state highways.

Loss of Control type crashes accounts for 75% of all crashes on the network. Of these:

- 7% involved a fatality (232);
- 15% involved at least one serious injury (484);
- 29% involved minor injury (988), and the remaining
- 49% were non-injury crashes (1,704).

The bulk of Loss of Control crashes occurred on curves as illustrated by Figure 4-1.

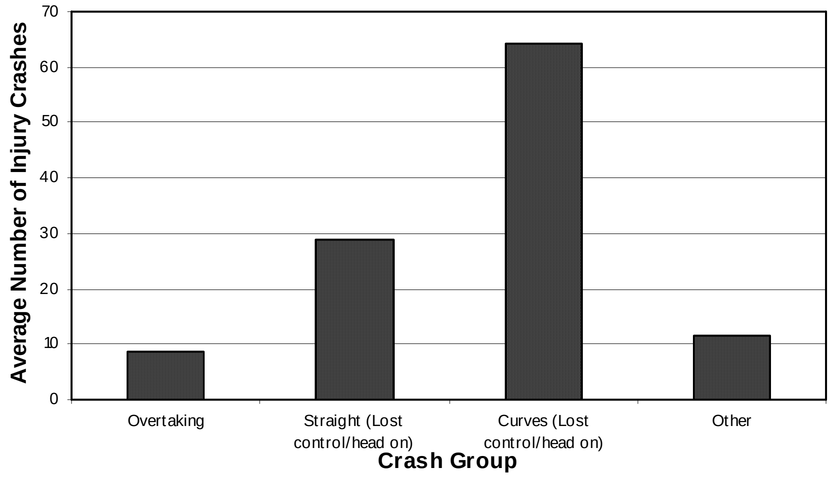

Figure 4-1 : Average number of Injury type Loss of Control Crashes per Crash Group

4.2 CRASHES AND CURVES

The road surface aggregates available locally in Northland have low polished stone values. Frequent re-sealing is required to maintain skid resistance to meet the KPM levels specified in PSMC002. This is expected to leave Transit with a long-term maintenance problem, particularly on curves where the loss of skid resistance is most pronounced and re-sealing of short sections of road is most frequent. Unfortunately, curve related crashes account for almost 57% of non-intersection injury crashes on the Northland State Highway network, far more than the average for all other state highways.

Under their current policy (TNZ T/10 2002), Transit seeks to manage safety on rural curves by specifying minimum levels of Mean Summer SCRIM Coefficient (MSSC) for:

- Skid Site Category 2 – Horizontal Curves of radius less than 250 m and
- Skid Site Category 4 – Undivided carriageways.

While the above specification has been based on international best practice and a smaller body of local research (Matthews and Barnes, 1988; Jackett 1992), a simple radius based criterion does not necessarily recognise the fact that much of Northland's road network is a product of "evolution" rather than design. Some sections of the network are particularly tortuous and the operating speeds are lower than may be expected.

4.3 CRASH DATA

Using crash information obtained from the LTSA Crash Analysis System (CAS) database, the general patterns of crashes at deficient curves have been investigated and analysed with MWH's customised spreadsheets. From previous research it is known that Loss of Control-type crashes are related to geometric deficiencies on the road (Koorey et al 1997). This investigation therefore targets all Loss of Control crashes and includes all Head-on (Type B), Lost Control – straight roads (Type C) and Cornering (Type D) - type crashes that occurred within the site length in an effort to capture all crashes that were related to possible curve deficiency. The site length is depicted by the curve length plus 50 m either side. All pedestrian, junction, control and non-rural-type crashes within the site lengths were excluded from this assessment.

The five year analysis period from 1999 to 2003 inclusive was selected to capture the impact that Transit's Skid Resistance policy may have had on the network since implementation in 1999. During this period a total of 714 crashes were reported on curves, of which 40% were injury crashes. The distribution of target crashes on curves of the Northland Network is illustrated in Figure 4-2 below.

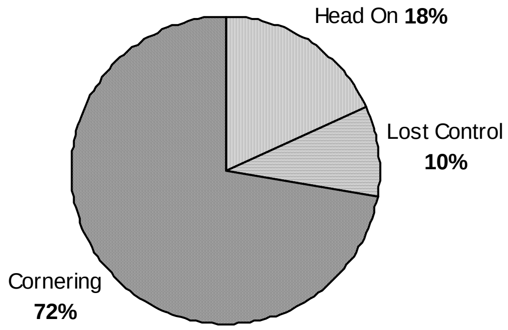

Figure 4-2 : Crash distribution of target crashes on Northland Network

The majority of curve crashes (72%) resulted from a loss of control during a cornering manouevre on a curve – crash movement Type D. Of these, almost 54% were of movement type DA (Loss control turning right). This can be attributed to the lack of traction for a vehicle losing control while turning right through a curve and veering off the surfaced road onto the gravel shoulder. A vehicle losing control while turning left through a curve can use the opposing lane to make a safe recovery. While the reason for such a manouevre may be as a result of a deficiency in the curve, it is not reflected in the crash statistics, especially on low volume roads.

Approximately 75% of all Head-on type crashes on curves were caused by vehicles losing control (Type BF) or swinging wide - straying across the centreline (Type BC) in a left turning curve. This manouevre is probably due to a driver overestimating the curve.

When target crashes on deficient curves were assessed, it was found that some 24% of all deficient curves on the network attracted crashes during the analysis period.

Table 4-1 lists the number of deficient curves per curve deficiency level and the number of curves on which crashes were recorded. These curves are referred to as crash curves in the following table. No crashes were recorded on curves with a *Low* deficiency level.

Table 4-1 : Crash Curves per Curve Deficiency

Curve Deficiency Level	Deficient Curves			Proportion of Injury Crashes
	Total	**Crash Curves**	**% of Total**	
Low	8	0	0%	0%
Medium	309	84	27%	11%
High	538	119	22%	16%
Total	**855**	**203**	**24%**	**28%**

The deficient curves on which crashes were recorded account for 28% of the 551 non-intersection injury crashes on the network during this period. Figure 4-3 illustrates the relationship between injury crashes and curve deficiency as a percentage of the total number of injury crashes that occurred on the network.

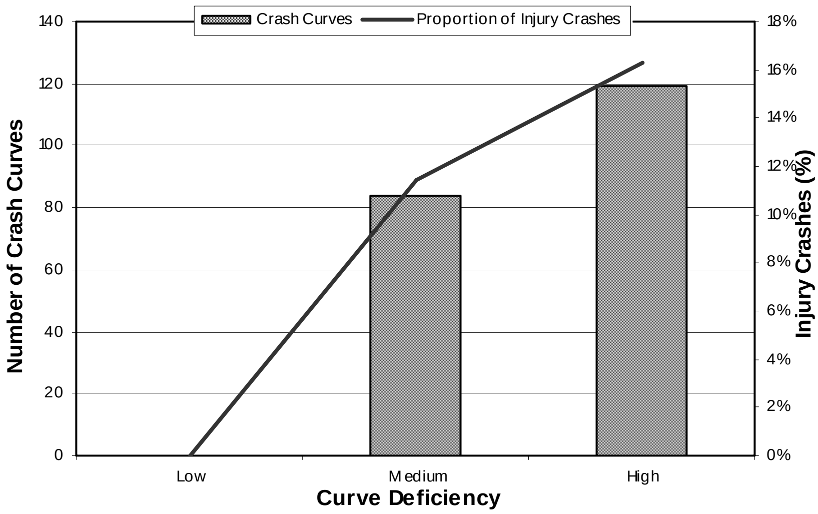

Figure 4-3 : Crashes on Deficient Curves

The percentage of injury crashes to the total number of crashes that occurred on curves over the five year period 1999 – 2003 are plotted against the crash severity classes for each curve deficiency category – refer to Figure 4-4.

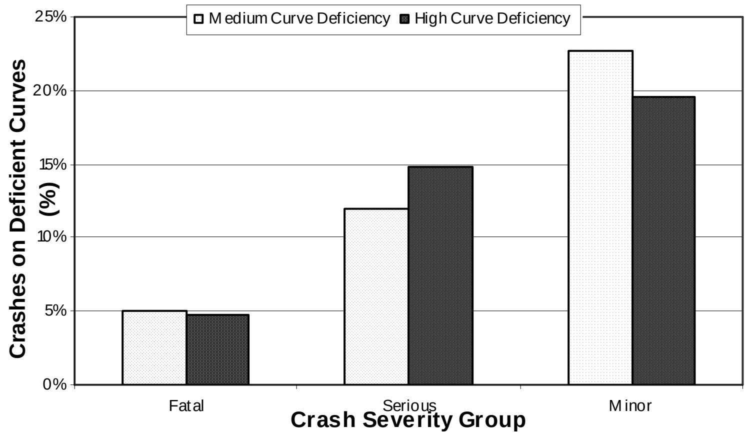

Figure 4-4 : Crash severity per Curve Deficiency

Crash severity changes between deficient curve categories and does not show a distinct relationship

4.4 CRASH RATE

The investigation into a possible relationship between deficient curves and historical crashes compared the number of reported injury-type crashes at each deficient curve with the deficiency level of that curve. In this assessment, the occurrence of a crash at a curve is considered to be an event that takes place on a particular site and therefore the length of the site is not considered in the calculation of the crash rate.

The crash rate of injury crashes at each curve is determined by dividing the number of target crashes that occurred during the assessment period by the number of vehicles that passed through the curve during the same period. Likewise, the crash rate for each deficient curve category was obtained by the following equation using traffic numbers and crash data for the period 1999 – 2003 inclusive:

$$Crash\ Rate = \frac{Total\ number\ of\ Injury\ Crashes\ per\ Deficient\ Curve\ Category}{Total\ number\ of\ vehicles\ entering\ these\ curves \times 365 / 10^8}$$

Figure 4-5 demonstrates the relationship between the crash rate and curve deficiency based on historical crash data. It would seem as if some relationship does exist between crash rate in a curve and the deficiency level of that curve.

Although the crash rate increases with curve deficiency, there is no firm relationship as no crashes were recorded on curves with a *Low* deficiency level for the 1999 – 2003 period. However, a rough assessment of the crash rate for the 15 year period 1989 – 2003 confirms the upward trend in crash rate with an increase in curve deficiency.

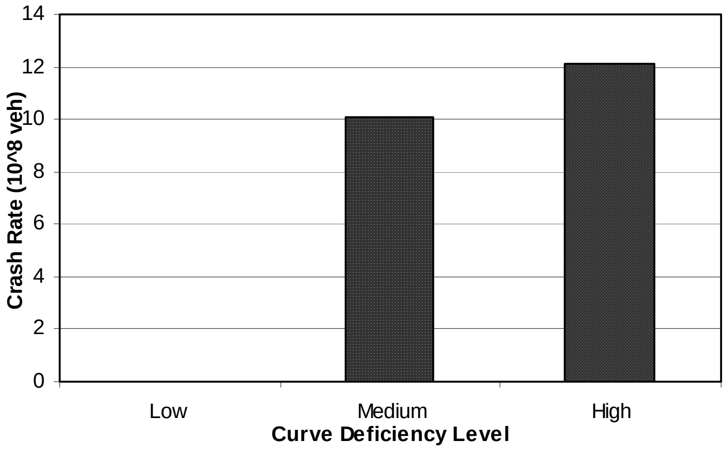

Figure 4-5 : Crash Rate (Injury Crashes) per Deficient Curve Category

When comparing the actual (annual average) number of crashes on a curve with the expected annual number using the crash rate derived above, large discrepancies occur for some curves on the network. This highlights the effect of geometric deficiencies on these curves not being accounted for in the model. The relatively low levels of traffic on the Northland Network are also likely to result in distortions of this kind.

The crash rate calculated above presents a measure of the likelihood of a crash occurring at a deficient curve and completes the first step in the risk model illustrated in Figure 2-1.

5. RISK ASSOCIATED COST PER DEFICIENT CURVE CATEGORY

With the curve deficiency classification established and the crash rate per curve calculated, the next step was to investigate the expected cost of a crash occurring on a curve.

The social cost of crashes on the network was assessed as a means of identifying and rating curves for investigation and treatment. The cost of crashes in each curve was calculated by using the accident costs from the Transfund Project Evaluation Manual (TNZ 2004) - Table A6.12 for accidents in 100km/h speed limit areas.

The following approach is a first attempt at producing some information that will assist in the formulation of a risk model for prioritising curves, bearing in mind that the traffic volumes on the Northland Network are relatively low. This simple model uses the expected social cost of crashes for each curve under consideration to calculate a risk measure for each curve.

Using crash data for the period 1999 – 2003, the social cost is calculated for each curve deficiency category and brought into context with the traffic flow through all curves in that category :

$$Social\ Cost = \frac{Total\ social\ cost\ of\ crashes\ per\ Deficient\ Curve\ Category}{Total\ number\ of\ vehicles\ entering\ these\ curves}$$

Figure 5-1 illustrates the annual social cost (in cents) per vehicle entering the curve for each curve category.

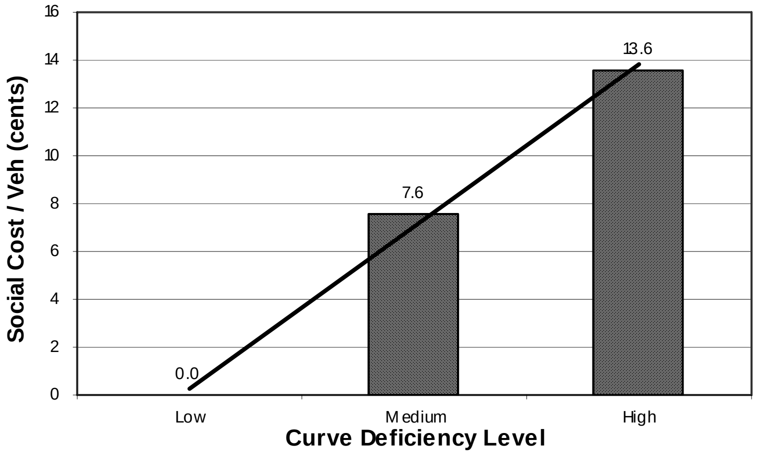

Figure 5-1 : Annual Social Cost per Deficient Curve Category

With this information it is possible to calculate a risk measure that reflects the level of risk associated with a particular curve *(C_i)* :

$$Risk\ Measure = S_D \times T_C$$

where:

S_D = Annual Social Cost per Curve Deficiency Category *(D)* of curve C_i (see below),

T_C = Annual Traffic Flow through curve C_i.

and:

Curve Deficiency Category ***D***	Social Cost / vehicle (cents) ***S***
Low	0.0
Medium	7.6
High	13.6

This approach yields the expected annual social cost of crashes at curve C_i.

A comparison between the expected cost per curve (as derived using the above equation) and the actual average cost of crashes at each curve does not yield a close match between the two data sets – refer to Figure 5-2 below.

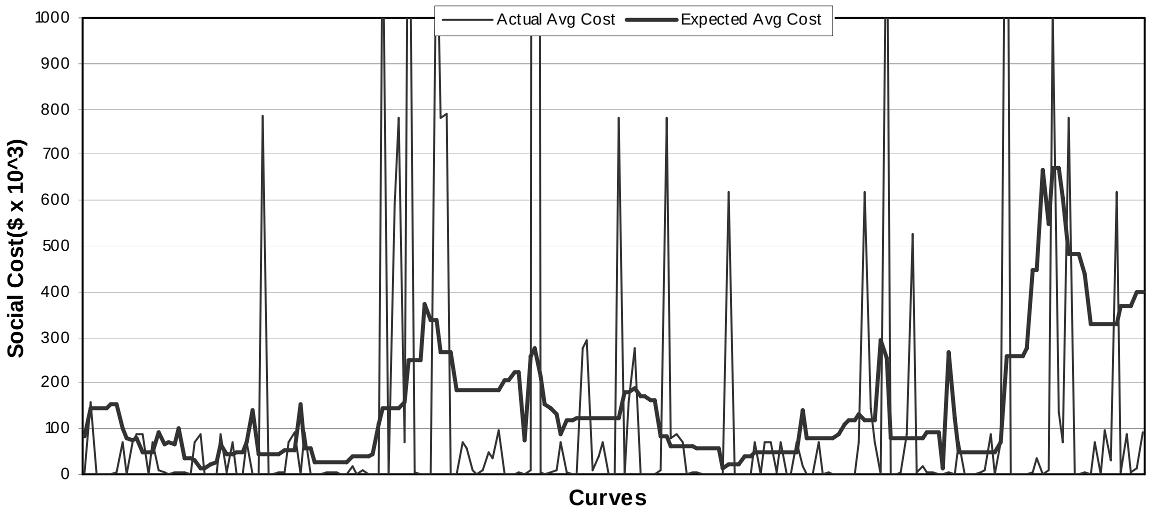

Figure 5-2 : Comparisson between Expected and Actual Cost per Curve

The expected cost calculated at the high cost curves appears to be lower than the actual cost. Likewise, the calculated cost for the low cost curves is higher than the actual cost. Some combination of the expected social cost and the actual cost per deficient curve may produce a better tool in defining a risk measure for curves.

This poor comparison may be due to a higher than expected crash rate on some curves due to geometric deficiencies not being accounted for in the model. Also the social cost per crash is greater due to possible hazardous features on the road not being accounted for.

The above-calculated social cost presents a measure of the consequence of a crash occurring at a deficient curve and completes the second step in the risk model illustrated in Figure 2-1.

6. SUMMARY

This investigation established a system whereby curves on a road network can be classified in terms of their deficiency level according to a three-category deficiency scale – *Low, Medium* or *High*. In addition to this classification system, a crash rate has been formulated for each deficient curve category.

As a means of prioritising curves for investigation and treatment purposes, the social cost of crashes on curves was assessed. The results presented are a first attempt at comparing curve deficiency with crash cost. However, the apparent poor comparison between expected and actual social cost per curve as demonstrated above, highlights the effect that other factors may have on the crash rate in a curve. Some of these are insufficient sight distance to the curve, deceptive curves which appear on approach to be of a larger radius than they actually are, varying curve radius and/or super-elevation, low skid resistance, loose material or surface contamination.

So while a curve that is out of context with the surrounding speed environment will have a higher risk of loss of control, the level of risk may be further increased if the curve is deficient in other ways. The likelihood and consequence of loss of control crashes on curves is therefore a function of a number of variables, only some of which are readily quantifiable.

With risk measure and consequential risk categories established, a range of mitigation strategies can be identified for each category. These strategies should be formulated in terms of their cost and the associated benefits of implementing each one. Strategies should also be assessed in terms of their risk reducing effect in a curve. These strategies may vary between a single treatment per strategy or a series of treatments within a strategy and should cater for the short, medium and long term application.

In order to improve the quality and usefulness of this approach, a number of enhancements were identified. These include

- a refinement of the curve deficiency classification system to include a continuous measure of the actual speed difference that the deficiency category is based on,
- calculation of approach speed on curves,
- adjustments for gradient,
- back-calculation of friction demand which can be compared to that supplied,
- the incorporation of deficient geometric elements within a curve, ie sudden change in crossfall or radius,
- assessment of the day and night-time crashes is required to rule out any delineation or marking effects and an assessment of the wet and dry proportion of crashes on curves.

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