Risk Ranking of Curves on New Zealand State Highways for Skid Resistance Monitoring and Treatment

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ABSTRACT

Loss of control on bends remains the largest cause of crashes on the New Zealand (NZ) rural state highway system, with a large proportion of these (over 1100pa) occurring on wet roads.

Transit New Zealand's (Transit) skid resistance specification requires higher skid resistance for curves with a radius of less than 250m (Category 2, IL 0.5). However international research indicates that high crash rates continue for curve radii up to approximately 450m to 600m radius. This is supported by the New Zealand Crash Database (CAS) that shows 88% of curve related loss of control or head-on injury crashes occurred on bends identified by New Zealand Police as moderate or easy radii curves.

Transit could increase the skid resistance requirements for all larger radii bends. However this would have obvious cost, material and maintenance implications. Furthermore, not all larger radii bends constitute a safety hazard. Instead Transit has elected to trial a process of assigning a risk ranking to all curves less than 500m radius and use this as a basis to review the skid resistance requirements.

The curve risk ranking is assigned based upon the difference between the approach speed and the curve speed. These speeds have been calculated from the high speed geometric data collected during the annual SCRIM surveys. High risk curves are where the approach speed is ≥ 15 km/h above the curve speed; medium risk 5 to 14 km/h above the curve speed; and low risk being when the approach speed is less than 5 km/h above the curve speed. A validation exercise undertaken over a sample of state highways, comprising 400 curves with over 1000 related crashes, indicated that the high risk curves had a 62% higher crash frequency than the medium and low risk curves.

The curve risk ratings of all curves have been provided to the network managers requesting that they review high risk curves taking account of local features, crash record, traffic flows etc, and modify the IL's accordingly. Similarly they have been encouraged to review the IL's of the low risk curves and give consideration to lowering the IL's if appropriate. The curve risk rating also has wider applications and may be used when reviewing signage, delineation, seal width, superelevation, and clearzones for higher risk curves.

1. BACKGROUND

1.1 CRASH RISK ON CURVES

It is well recognised that crash risk on curves decreases as the curve radius increases. This is demonstrated by various crash risk curves shown in Figure 1. However whilst the "heel" of the curve typically occurs between 200 - 400m radius, the crash rate does not plateau until around 450 to 600m.

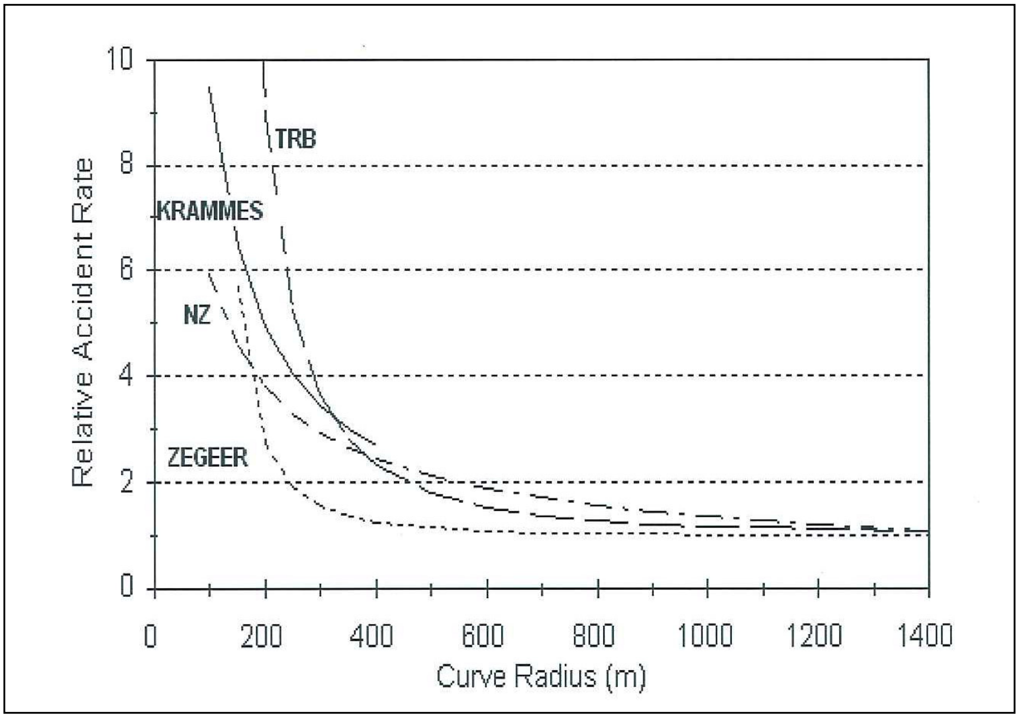

Figure 1: Relative Crash Rate Versus Curve Radius
Source: McLean 1996 *[1]

It is also widely accepted that crash risk decreases with an increase in skid resistance, particularly on single carriageway non-event highways (refer Figure 2).

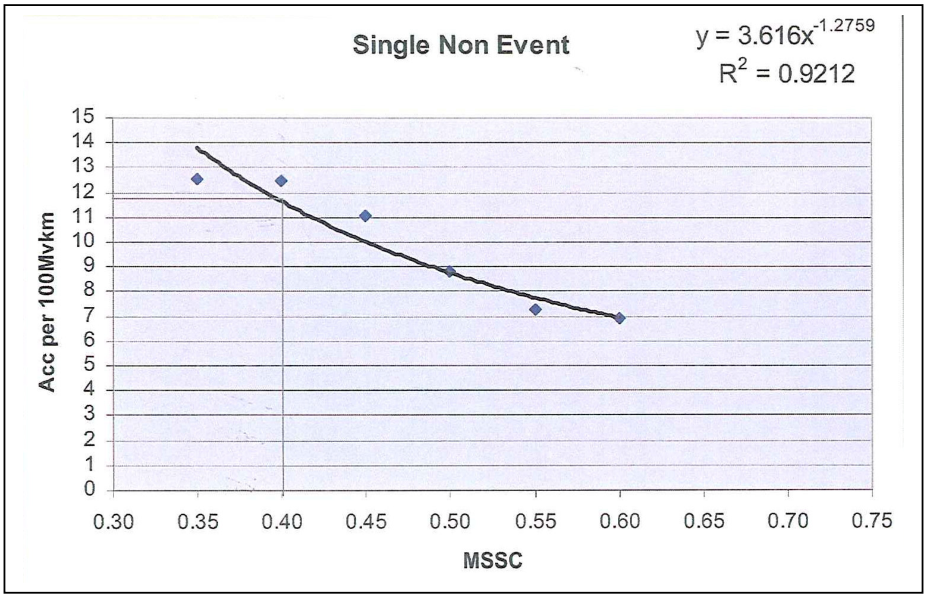

Figure 2: Relationship Between Accident Rate and Surface Friction (MSSC is Mean Summer Skid Co-efficent)
Source: International Surface Friction: Roads and Runways Conference, Christchurch 2005

These two relationships are captured in the three dimensional graph, Figure 3.

This indicates that there are significant safety benefits to be gained from increasing the skid resistance on all curve radii, but particularly below approximately 500m radius.

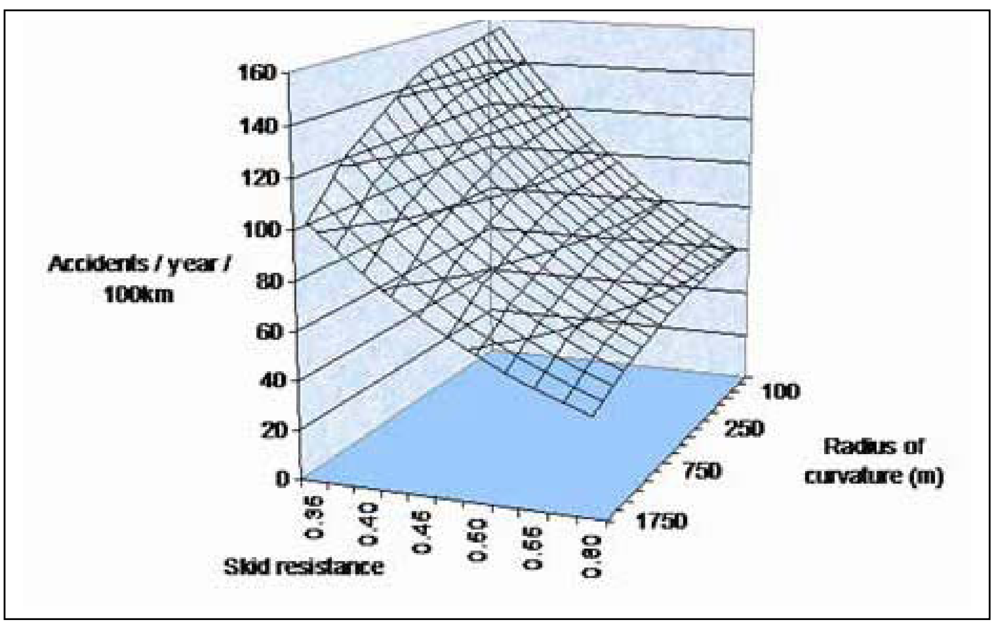

Figure 3: Relationship Between Skid Resistance, Radius and Accident Rate
Source: Sinhal et al, 2007*[2]

1.2 SKID RESISTANCE POLICY IN NEW ZEALAND

The New Zealand state highway network of approximately 11,000km is presently managed by a Crown Entity Transit New Zealand (Transit). It is primarily a rural two laned arterial road network connecting major population centres.

The state highway network has a skid resistance policy based around annual surveys by a Sideways Force Coefficient Routine Investigation Machine (SCRIM) and the results compared against a specification of Investigatory (IL) and Threshold (TL) levels. The T10 specification (2002)[*3] has five site categories similar to the old UK HD/94 standard.

Bends are effectively only covered by Site Category 2, which specifies an IL of 0.5 and a TL of 0.4 for curves with a radius < 250m. All curves with a radii ≥ 250m are deemed to be "*event free where no other geometrical constraint, or situations where vehicles may be required to brake suddenly, may influence the skid resistance requirements*" (Transit New Zealand , 2002)

The T10 specification does allow for the IL to be increased by between 0.05 to 0.1 for isolated curves, negative superelevation, or sites with a history of crashes. Investigatory Levels can also be lowered on uphill gradients and sites with low traffic volumes. However, experience has shown that in practice IL's are rarely modified.

The T10 specification requires all sites be inspected and prioritised for future maintenance when the skid resistance falls below the IL. When the skid resistance falls below the TL the sites must be investigated and the appropriate treatment designed and programmed as soon as practical. An "exception" report is produced, almost immediately following SCRIM survey that identifies sites of where the skid resistance falls below the TL.

In practice, the policy results in curves below 250m radius only being immediately investigated and treated when the skid resistance falls below the TL of 0.4 and curves greater than 250m radius only being immediately treated when the skid resistance falls below the TL of 0.3.

1.3 NEW ZEALAND CRASH SCENE

Crashes on bends, in the rural environment, is the single greatest crash problem in New Zealand. In 2006, there were 2,800 loss of control or head-on crashes on bends on the New Zealand state highway network, of which 76 resulted in fatalities. This is 45% of all rural state highway fatal crashes. Almost half (48%) of the bend crashes occur on wet or icy roads.

An examination of the New Zealand crash database (CAS) reveals that only a small percentage (12%) of the bend crashes resulting in injury occur on curves that have been classified by the New Zealand Police as "severe" curves, with the vast majority occurring on "moderate" or "easy" bends (refer Figure 4).

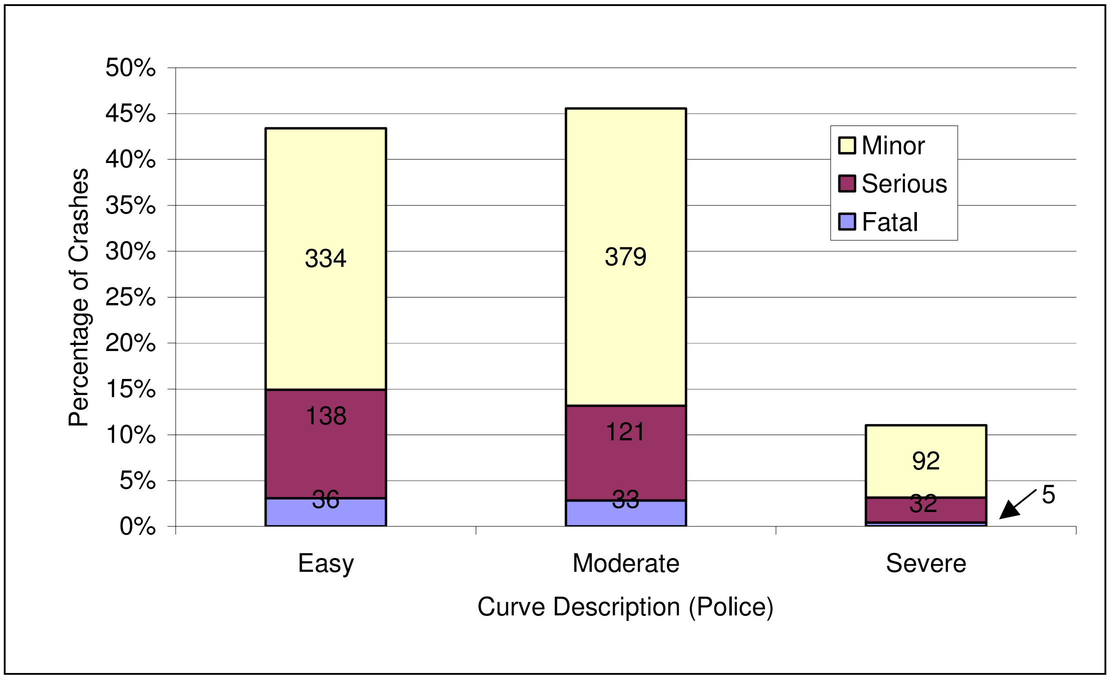

Figure 4: State Highway – Rural Loss of Control, Head-On (Bends) Injury
Source: Crash Analysis System (CAS)

There is little guidance or definition as to what constitutes severe, moderate and easy bends and relies on the opinion of the Police officer.

It is reasonable to assume that all severe bends and a proportion of moderate bends are below 250m radius, and at least half of the injury crashes, including the majority of fatal and serious crashes, occur on bends with a radius greater than 250m. Furthermore the crash reports indicate that approximately half of these occur on wet roads.

There may be a number of explanations for this including:

- These are less severe than moderate or easy curves on the state highway network.
- Severe curves are typically located on lower volume routes.
- The speeds on the tighter alignment routes and bends are lower and hence crash outcomes are less severe and possibly even less frequently reported.
- The higher skid resistance requirements on may also have had an effect on reducing the number of crashes on severe bends.

Irrespective, there appears to be the potential for significant safety benefits from addressing the safety on larger radii bends.

Finally, recent research in New Zealand (Tate and Turner, 2007*[4]) has also identified that irrespective of the design speeds of curves, vehicles are not slowing until the curve radii drops below 200 to 250m radius (refer Figure 5). Consequently although a 300m radius bend may be designed and superelevated for a design speed of 80km/h, operating speeds may actually be well above this.

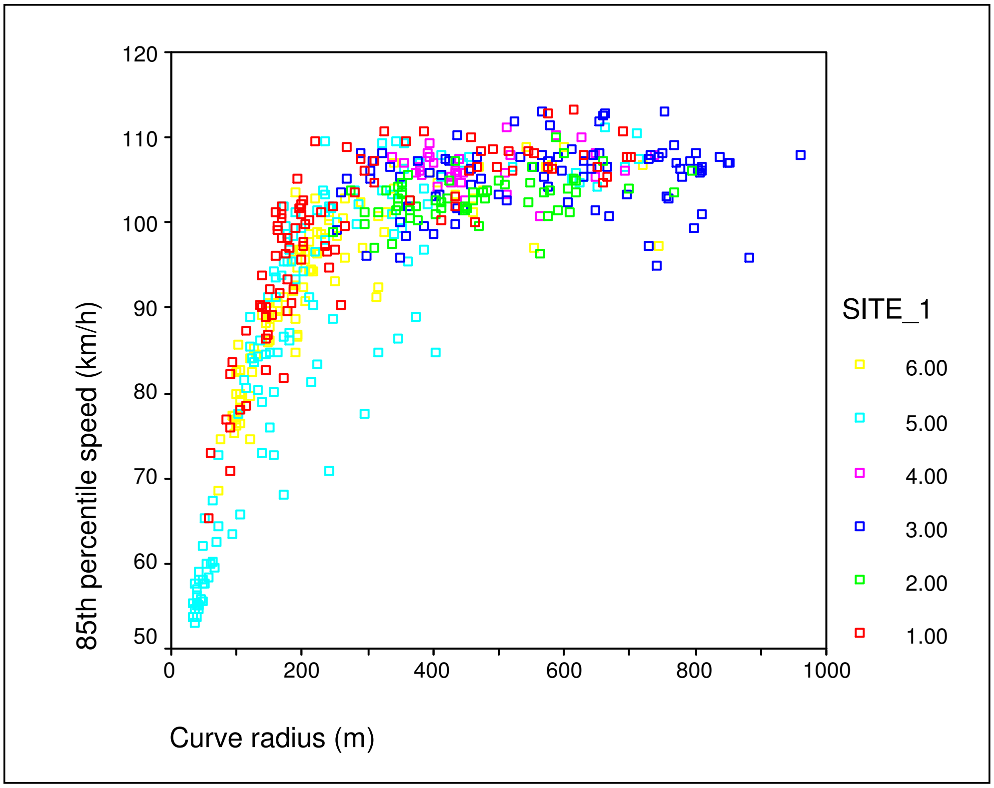

Figure 5: Relationship between Curve radius and 85th percentile negotiation speed
Source: Tate and Turner, 2007

2.0 TREATMENT STRATEGIES

2.1 INCREASING RADIUS RANGE FOR INCREASED IL

The need to extend the "bend" category from less than 250m radius, up to a less than 500m radius on single carriageways has been identified in Great Britain (Viner et al, 2005*[5]) and included in the revised 2004 specification (HD28/04 Site Category S2; IL 0.5 to 0.55).

A similar approach could be taken in New Zealand by increasing the radius in Site Category 2 from 250m to 500m. However the concerns with this approach include:

- Not all curves in the 250 – 500m radius range are a safety risk, particularly those in slower speed environments and curves between tighter radius curves.
- Increased demand on good quality, high polished stone value (PSV) aggregates.
- Increased frequency and cost of resealing.

Consequently an alternative approach was sought.

2.2 RISK RATING OF CURVES

Previous New Zealand research (Koorey and Tate, 1997*[6]) has also identified that the curve crash risk and severity is not only a function of absolute curve radius, but also the difference between the approach speed and the curve speed. It has been shown that the crash rate increases significantly when the difference between the approach speeds and the curve speeds exceed 15km/h. This was adopted by Theron et al*[7] in a study to identify the high, medium and low risk curves on the New Zealand Northland network.

Consequently the approach taken in New Zealand has been to broadly rate all state highway curves on the basis of their risk to identify high risk curves, particularly in the 250 to 500m radius range. The IL of these curves could then be modified upwards. Conversely, consideration could be given to lowering the IL of low risk curves.

Tate and Turner (2007)*[4] tested a range of variables and amongst other things found a strong correlation between crashes and the difference between the approach speed over a 500m length and the minimum curve speed over a 30m length. The approach and curve speeds can be reasonably determined using the Rawlinson Formula, below.

$$AS_{RGDAS} = -\left(\frac{107.95}{H}\right) + \sqrt{\left(\frac{107.95}{H}\right)^2 + \left[\frac{127{,}000}{H}\right]\left[0.3 + \frac{X}{100}\right]}$$

where	AS_{RGDAS}	=	RGDAS Advisory Speed (km/h)
	X	=	% Crossfall (sign relative to curvature)
	H	=	Absolute Curvature (rad/km) = (1000m / R)

The Rawlinson formula had previously been identified by Wanty et al (1995)*[8] and as a means of determining the advisory speeds using the 1992 state highway high speed geometric data from RGDas, which gave gradient, radius and crossfall at 10m centres. Similar high speed geometric data is also available through the annual SCRIM vehicle surveys.

A software routine has now been developed and run across New Zealand's entire rural state highway network in both directions to calculate the advisory speed for every 10m section based upon the Rawlinsons formula. The radii and hence speeds were averaged over 30m to remove any short kinks. All curves greater than 30m in length and less than 500mR were identified and the average approach speed determined over the preceding 500m approach in each direction.

A diagrammatic representation of the curve speeds and approach speeds is shown in Figure 6.

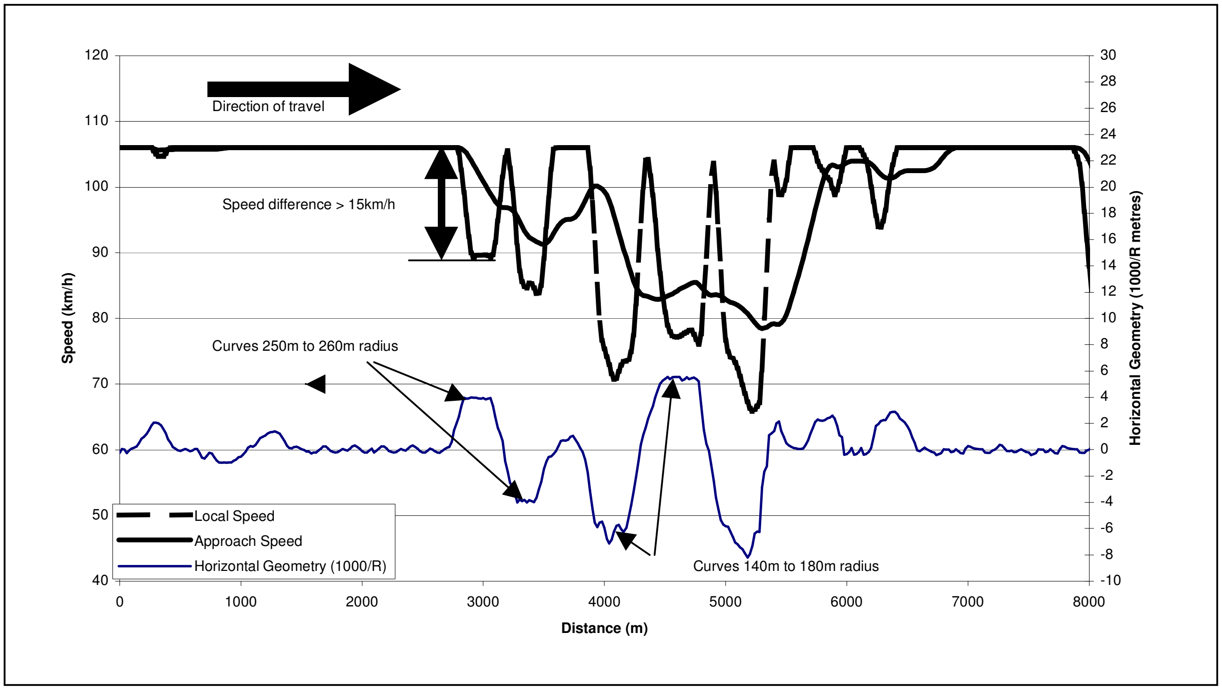

Figure 6: Diagrammatic Representation of Curve and Approach Speeds

Curves were then given a geometric rating on the following basis:

- High - These are the higher risk curves where the approach speed exceeds the curve speed by ≥ 15kph
- Low - These are the lower risk curves where the approach speed is less than 5kph above the curve speed
- Medium - All remaining curves are medium risk

The high risk category is further denoted two ways:

- High (+DG) – Where there is also a downhill approach greater than 5% gradient and hence the crash risk may be higher still.
- High (LSA) – Where there is a low approach speed (less than 70 km/h) and hence crash outcomes may be of lower severity.

2.3 VALIDATION

Two coarse validation exercises have been undertaken on the Waikato state highway network (in the , central North Island of New Zealand).

In the first, curves over a selection of state highways comprising of 400 curves and over 1000 curve crashes, were analysed and the curve ratings compared to the crash rates. The following relationships were found

- High risk curves ⇒ 3.56 crashes / curve/year?
- Medium risk curves ⇒ 2.23 crashes / curve/year?
- Low risk curves ⇒ 2.15 crashes / curve/year?

In the second exercise, the social cost of crashes were calculated for all curves throughout the Waikato network. The worst 300 curves with the highest social cost of crashes were analysed and the following relationship found:

- 76% of these curves were rated as high risk
- 18% were rated as medium risk
- 6% were rated as low risk

Consequently whilst the methodology may not be perfect, it is a reasonable broad brush approach at identifying the higher and lower risk curves for which modification of the skid resistance Investigation Levels should be considered.

2.4 IMPLEMENTATION AND REVIEWING THE INVESTIGATION LEVELS

Spreadsheet tables of all the curves, the curve radius, speed and approach speed, along with the risk rating were provided to the Network Managers requesting them review the Investigation Levels and treatments of the curves on the following basis.

a. High Risk Curves

   - Confirm that these are higher risk curves through field inspection.
   - Curves greater than 250m radius should be investigated and consideration given to raising the IL above 0.4 (say 0.45 or 0.5).
   - Curves less than 250m radius may not require special action for skid resistance as the Exception Report will have identified those curves with a Threshold Level (TL) less than 0.4.
   - Where there is also a downhill approach gradient greater than 5% (High (+DG)) the crash risk may be higher still and this should be considered in setting IL's and prioritising any treatment.
   - Where the approach speed is less than 70kph (Denoted: High (LSA) crash risk) the severity of a crash may be less and this should be considered in prioritising any treatment.

b. Low Risk Curves

   Where the curve risk is low, and the radius is less than 250m, the IL may be reduced (to say 0.45) provided investigation identifies that there is no relevant crash record on the curve or adjacent similar curves, the roadside environment is not hazardous, traffic volumes are relatively low, the curve is readable and it does not have a large deflection angle.

Treatment of the high risk curves were to be prioritised based upon the traffic volume, crash history and local environment features, such as roadside hazards.

Whilst this procedure was initially developed for skid resistance management, particularly for curves within the 250 to 500m radius range, the geometric risk ranking of curves has now been extended to other safety retrofit treatments such as sign posting and delineation improvements, seal widening, hazard removal, etc. Additional funds have been made available to address the highest risk curves over the next two to three years.

3.0 FUTURE DEVELOPMENT

Consideration is now being given to further development of the curve risk rating procedure.

Future developments are likely to include:

a. Identifying and fixing the curves locations by GPS coordinates.

b. Prioritisation of curves for treatment and modification of IL's on the following basis:

    - The difference between curve and approach speeds
    - Crash prediction modelling based upon the geometric elements and exposure (AADT)
    - The actual reported crash record

c. On the basis of the above, IL's will be set nationally for all curves based upon risk.

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