Peer Reviewed Papers

Modelling and Analysis of Crash Densities for Karangahake Gorge, New Zealand

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Abstract

An 18 km length of New Zealand state highway located in tortuous terrain that displayed a poor safety level (11 injury crashes per year) was selected to trial the “safety improvement potential” approach to safety management of roads. This approach involves comparing the actual safety level over a section of road with the average safety level estimated from a crash prediction model.

This paper presents the results of applying a crash prediction model specifically developed for the New Zealand state highway network to analyse the safety performance of the 18 km route. The Poisson regression model is believed to be one of the first to successfully relate crash rates to road geometry and road condition. Therefore, the relative effectiveness of various engineering based countermeasures to bring about an improvement in the current safety level was also able to be assessed. The countermeasures investigated included realignment, high friction surfacing and road smoothing. It was determined from the modelling studies that a more consistent level of crash risk throughout the 18 km route could be achieved through either increasing friction levels or increasing the radius of the horizontal curves at specific locations.

Key Words: crash risk modelling, road surface condition, road geometry

1 Introduction

Transit New Zealand’s safety programme has, for the most part, been reactive, eliminating crash “grey-spots” and “black-spots” across New Zealand’s state highway network. However, there are now indications that the rate of road safety improvement is levelling off because the “grey-spot/black-spot” improvement process can be viewed as a screening exercise; as the analysis progresses, the number of sites progressively decreases because problem areas become less obvious. For example, between 1981 and 1985, 46% of reported injury crashes occurred at sites with 3 or more crashes per annum, whereas between 2000 and 2004 this percentage has dropped to 35%.

To continue to make gains in the safety level of state highways, the approach of “safety improvement potential” is being advocated whereby the actual safety level over a road section is compared with the average safety level estimated from a crash prediction model. This approach is seen as a more accurate method for identifying road safety problems as it reduces selection biases related to the random nature of crashes.

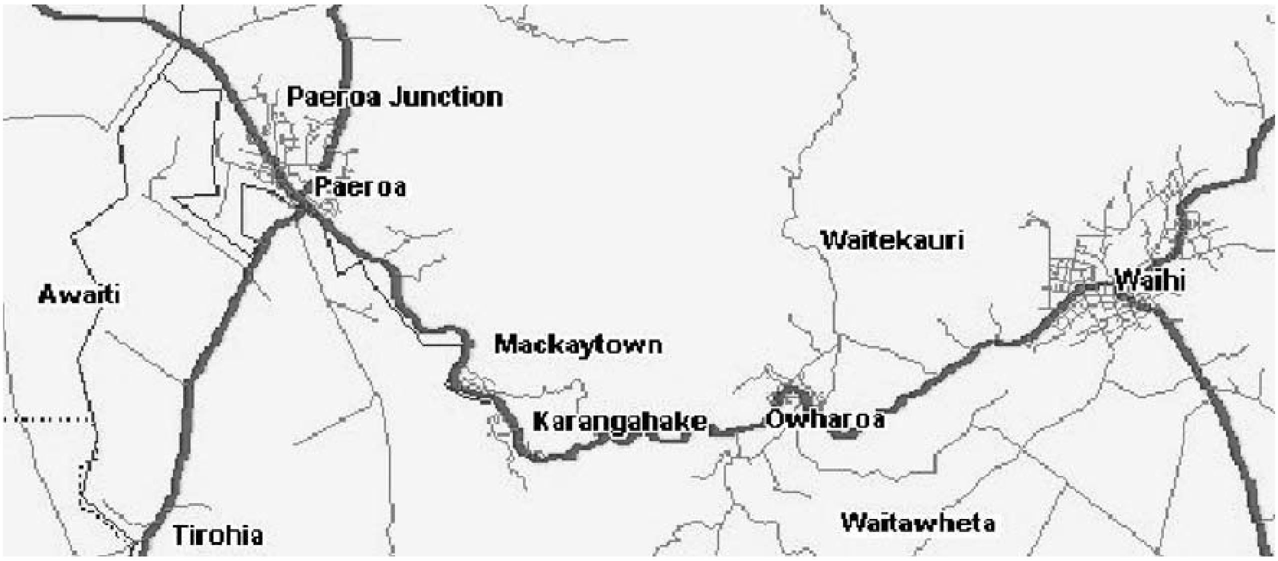
A crash prediction model has been developed that allows proactive identification of engineering-related safety deficiencies on New Zealand’s state highway network (1). The model itself and an example application are presented in the appendix to this paper for ready reference.

The road and traffic data required as input to the model are all found in Transit New Zealand’s Road Assessment and Maintenance Management (RAMM) state highway database and comprise absolute gradient, horizontal curvature, lane roughness, skid resistance, friction demand site category as defined in Transit New Zealand’s T/10 specification (2), traffic flow (ADT), urban/rural classification and Transit New Zealand administration region. As this Poisson regression based model uses 2nd or 3rd order polynomial functions of these variables to allow for the observed non-linear responses, the model can be incorporated in existing road asset management systems.

The model has been derived from 1997-2002 data that pertains to the entire 22,000 lane-km of the New Zealand state highway network. While the model cannot be expected to apply absolutely everywhere on the network, it does appear to reflect the actual crash data remarkably well.

To illustrate the potential use of the model to analyse the safety performance of the state highway network and to guide safety initiatives, an 18.2 km length of State Highway (SH) 2 between Paeroa and Waihi (RS 73/0.648 and RS 73/18.836) was selected because of its current poor safety level of 10.8 injury crashes per year. This section of SH2 has a “rural” classification and includes the Karangahake Gorge (refer Figure 1).

Figure 1: 18 km section of State Highway 2 investigated, Paeroa to Waihi



This paper summarises the findings of the comparative study of modelled and actual crash densities over a 5 year period from 2000 to 2004. The crash densities were calculated over two length intervals, 0.5 km and 3 km, in an attempt to guide safety initiatives by:

- detecting where there are significant discrepancies between actual and modelled crash densities;
- identifying 0.5 and 3 km road sections that stand out as having significantly higher crash densities than adjoining sections;
- establishing whether or not crash numbers for the entire 18.2 km length of SH2 of interest are significantly higher than would be expected for state highways with comparable road surface condition and road geometry;
- determining where along the 18.2 km length each of the following interventions is likely to be effective in reducing crash numbers: curve realignment; surface treatment to improve skid resistance; and surface treatment to improve ride quality (i.e. reduce

Review of Total Injury Crash Numbers

2.1 Validation of Model Predictions

In applying the model, a check as to its general validity was made by comparing "all" and wet road (abbreviated to "wet") reported injury crashes in Land Transport New Zealand's (formerly LTSA) crash analysis system (CAS) for the five year period 2000 to 2004.

A comparison of modelled and actual "all" and "wet" injury crash numbers occurring over the entire 18.2 km length of SH2 of interest (RS 73/0.64 and RS 73/18.81) is provided in Table 1 on a yearly and 5 year mean basis.

With reference to Table 1, there is reasonable agreement between predicted and observed "all" injury crash numbers when the 5 year mean values are considered. However, "wet" injury crashes are underestimated by the model by about a factor of two.

The main reason for this is that the criteria for classifying a crash as "wet" covers a wider range than in the original analysis. When one does the analysis with the data from the original analysis covering the years 1997-2002, the actual number of

Table 1: Comparison of Model Derived and Actual Crash Numbers

Analysis Period	Number of Injury Crashes					
	All		Dry		Wet	
	Model	Actual	Model	Actual	Model	Actual
2000	12.1	9	8.8	4	3.3	5
2001	12.0	3	8.8	1	3.2	2
2002	12.2	12	8.8	1	3.4	11
2003	12.4	15	9.0	5	3.4	10
2004	12.5	15	9.0	7	3.5	8
5 Year Mean (2000-04)	12.2	10.8	8.9	3.6	3.4	7.2

Derived from subtracting "wet" injury crashes from "all" injury crashes

crashes is larger than the predicted number but not by an amount that is statistically significant.

In a table such as this, the standard errors of the model's predictions will generally be much smaller than the variability in the crash numbers so estimates of goodness of fit can be based on the Poisson variability of the crash numbers.

2.2 Trend Analysis

Comparing the yearly crash numbers given in Table 1, the model predictions of "all" injury crashes shows a gradual upward trend in crash numbers (i.e. 0.1 crashes per year) over the 5 year analysis period from 12 to 12.5 crashes per year. This gradual upward trend is mirrored in the "wet" injury crashes. Therefore, the ratio of predicted dry road to wet road injury crashes remains fairly constant at about 2.6 i.e. there are 2.6 times as many dry road crashes as wet road crashes.

In contrast, the actual crash numbers vary substantially between years with a noticeable drop to only 3 "all" injury crashes in 2001. Since 2001 there has been an increasing trend, which seems to plateau at about 15 "all" injury crashes. There is similar substantial variation in the number of "wet" injury crashes. However, in neither case is there sufficient data to draw any conclusions about trends.

2.3 Relative Safety Performance of Analysed Route

There is close agreement between the modelled and actual 5 year mean values of "all" injury crashes, which correspond to 12.2 and 10.8 crashes respectively. Because the model has been derived from data for the entire state highway network, its estimates of injury crash numbers represent those that can be expected on average over the network. As a consequence, it can be inferred that the likelihood of having a crash on SH2 between Paeroa and Waihi (i.e. Karangahake Gorge) is no more nor no less than other sections of the state highway network that display similar road and traffic characteristics. However, actual crash numbers are dominated by crashes that occur under wet conditions. Therefore, a very effective crash reduction initiative would be to target interventions that will improve the wet weather performance of this section of SH2. One such intervention could be to reduce the depth of surface water through attention to drainage path length, surface slope and texture depth.

3 Comparison of Actual and Modelled Crash Densities

3.1 Analysis Period

Because of the random nature of road crashes, the choice of the analysis time period may have a significant impact on the accuracy and reliability of the safety assessment. Overly long periods may introduce biases in the analysis when current conditions differ from those prevailing when the crashes occurred. Overly short periods reduce the number of crashes considered and the statistical accuracy.

The accepted minimum analysis period is 3 years (3). For this safety assessment, an extended analysis period of 5 years, spanning 2000 to 2004, was chosen as figure 2 shows very little inter-year variation in the predicted crash densities over this period implying that road related factors affecting crash occurrence have remained relatively stable. Accordingly, comparisons of modelled and actual yearly crash densities used for detecting where actual crash densities are much higher (black spots) or lower (white spots) than expected for the measured road condition and geometry are based on 5 year mean crash densities.

These comparisons have been confined to "all" injury crashes on the grounds that the accuracy and reliability of the safety assessment will be better than for "wet" injury crashes as a consequence of there being more crashes on which to base the assessment.

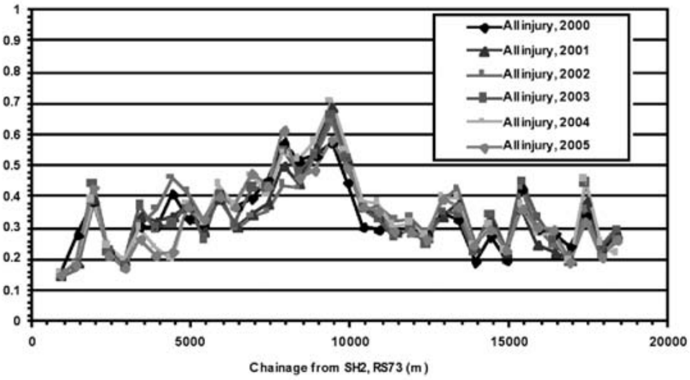


Figure 2: Temporal and spatial distribution of predicted "all" injury crash densities based on 0.5 km analysis length

3.2 Comparison of 0.5 km "All" Injury Crash Densities

Figure 3 graphically shows the level of agreement between modelled and actual average yearly crash densities across both increasing and decreasing lanes of SH2 between Paeroa and Waihi. The agreement is generally as close as one could expect.

One possible point of difference is the 0.5 km length located at RS 73/17.14 – 17.64. While this might be simply a chance occurrence, the higher crash rate may indicate an additional risk at this point not properly captured by the model, or it might be due to higher traffic in the vicinity of Waihi that is not captured by the ADT data.

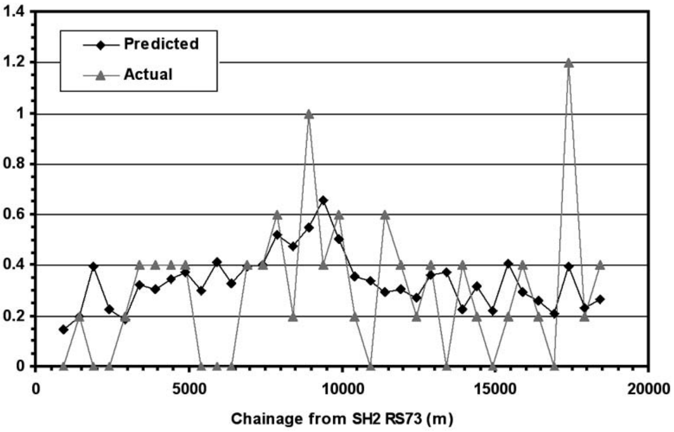


Figure 3: Spatial distribution of modelled and actual "all" injury average yearly crash densities based on 0.5 km analysis length for the period 2000 – 2004

3.3 Comparison of 3 km "All" Injury Crash Densities

Figure 4 is the same as Figure 3 except that the analysis length has been increased from 0.5 km to 3 km. The 6 fold increase in analysis length results in a significant improvement in the level of agreement between modelled and actual crash densities. There is only one location where the observed yearly crash density per 3 km is clearly greater than predicted (2.4 cf. 1.7). This 3 km length is located at the very end of the section of SH2 of interest i.e. RS 73/15.64 -18.64. At this location, factors other than road condition or road geometry, such as roadside encroachment and traffic operation, should be investigated to determine the cause of the higher than expected crash density.

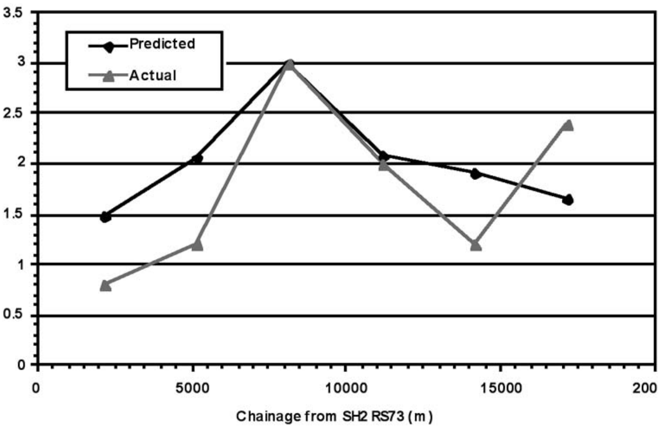


Figure 4: Spatial distribution of modelled and actual "all" injury average yearly crash densities based on 3 km analysis length for the period 2000 – 2004

Figure 4 also highlights a peak crash density of 3 and this occurs over the 3 km length located at RS 73/6.64 – 9.64. As the modelled and actual crash density distributions are in perfect agreement with regard to the location and magnitude of the maximum crash density, there appears to be scope to reduce the maximum by 1 crash per year to the yearly average value of 2 injury crashes per 3 km through appropriate attention to road condition and road geometry.

3.4 Comparison of Site Safety Level

Statistical procedures given in PIARC's Road Safety Manual (3) were used to calculate the safety level in terms of crash frequency (m) and the associated uncertainty in m at the 95% confidence interval for the entire 18.2 km length of SH 2 between RS 73/0.648 and RS 73/18.836.

From Table 1, the model gives a total of about 61 "all" injury crashes over the 5 year period 2000-2004 whereas only 54 "all" injury crashes were reported over the corresponding period. The resulting safety level statistics are summarised in Table 2. These statistics confirm that the model used is capable of providing safety level (m) estimates that are sufficiently reliable for safety management purposes.

Table 2: 95% Confidence Interval Safety Level Statistics for SH 2 RS 73/0.648 – 18.836

Crash Statistic	Derived from Model	Derived from Actual "All" Injury Crash Numbers
Crash Frequency, m (crashes/year)	12.2	10.8
Lower m value (crashes/year)	9.3	9.0
Upper m value (crashes/year)	15.7	12.9
Probability of exactly 10 crashes/year	78%	64%

4 Effectiveness of Engineering Based Countermeasures

4.1 Countermeasures Investigated

With reference to the various crash prediction model parameters listed in Table A1 of the Appendix, the only engineering based countermeasures available to produce a more constant level of crash risk over the 18.2 km length of SH2 between Paeroa and Waihi are to:

- reduce lane-roughness to provide improved tyre-to-road contact;
- increase the radius of curves to reduce required friction and speed variations along the route;
- increase the level of skid resistance to provide greater margins of safety for braking and cornering manoeuvres.

As the cost of these countermeasures can be very high, particularly in the case of increasing the radius of a curve, their relative effectiveness in reducing crashes was determined by applying the crash prediction model to the 2005 (latest) RAMM road condition and road geometry data to obtain baseline crash numbers. The values of lane-roughness, horizontal curvature and skid resistance were then factored in turn to produce a 25% improvement in each of these parameters (i.e. horizontal curvature and skid resistance values were scaled by 1.25 whereas lane roughness was scaled by 0.75 and expected crash numbers recalculated).

4.2Predicted Changes in Crash Numbers

The effect of each countermeasure on site safety level is summarised in Table 3. Increased skid resistance is shown to be clearly the most effective approach for ameliorating "all" injury crashes over the section of SH2 of interest.

Figures 5 and 6 show spatially the resulting absolute and relative change in "all" injury crash numbers per 3 km respectively.

Table 3: Change in Expected "All" Injury Crashes over the Analysed Route (SH2, RS 73/0.648 – 18.836)

Scenario	Number of "all" injury crashes	Reduction in "all' injury crash numbers		
		Total Length	per 0.5 km	per 3 km
2005 baseline	11.93	-	-	-
25% increase in horizontal curvature	10.64	1.29	0.036	0.22
25% increase in skid resistance level	9.68	2.25	0.063	0.38
25% decrease in lane roughness	11. 64	0.29	0.008	0.05

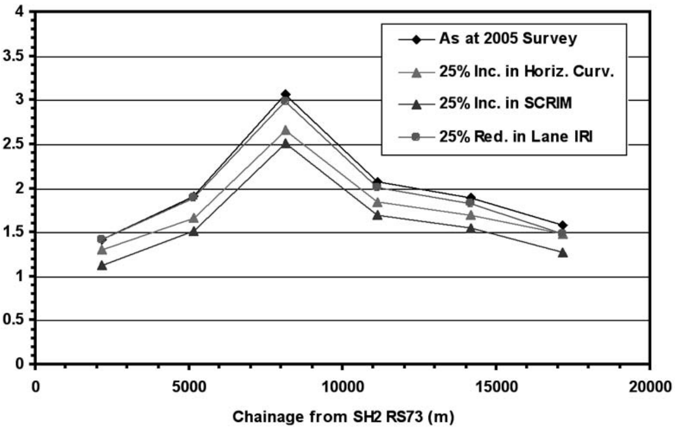


Figure 5: Predicted impact of different countermeasures on "all" injury crash densities –3 km analysis length

With reference to these figures it can be seen that either increasing the level of skid resistance or increasing curve radius will have a similar effect in reducing the number of "all" injury crashes and that this effect extends over the entire 18.2 km length, though it is most pronounced over the 3 km length situated between RS 73/6.64 and RS 73/9.64. In contrast, smoothing (i.e. reducing lane roughness) is expected to produce only localised crash reductions at RS 73/6.64, RS 73/9.39, RS 73/16.39 and RS 73/17.39, though Figure 6 suggests that there is likely to be some safety benefit in reducing lane roughness of SH2 over the 11 km length between Karangahake and Waihi (i.e. RS 73/8.14 - 18.836).

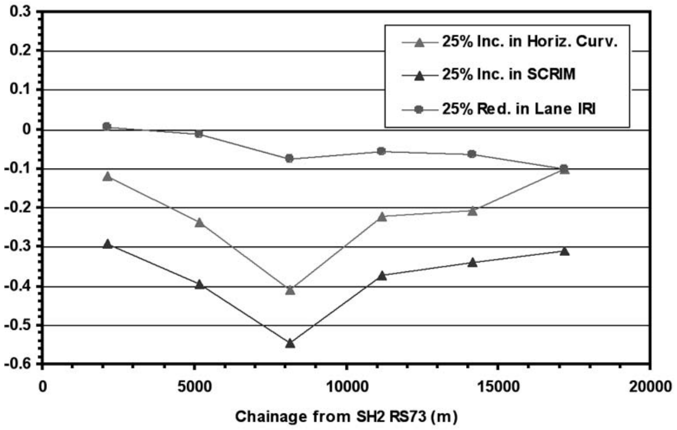


Figure 6: Predicted change in crash density relative to 2005 baseline resulting from adoption of various engineering related countermeasures – 3 km analysis length

Conclusions

1 The trial application has achieved its objective of demonstrating the value of the concept of potential for improvement at a route or road network level for guiding engineering-based road safety initiatives.

2 In determining the potential for improvement over a route, crash prediction models that account for the interactions between traffic, geometric, road condition and weather variables are required. Such models do not need to be overly complex, as it was shown that 2nd and 3rd order polynomials functions are adequate to allow for observed non-linear responses of the key variables.

3 The crash prediction model developed for specific application to New Zealand's sealed state highway network in its current form is sufficiently robust for the following four applications:

- To improve the understanding of the factors affecting crash risk and the relative importance of different factors.
- To improve the management of the highway network by estimating the effect on crash numbers of changes in standards for curvature, skid resistance and roughness.
- To identify black spot regions where, because of factors not included in the model, crash rates are much higher than predicted by the model. It may also be possible to detect white spots where crash rates are lower, although this is less likely to be successful.
- To use the model to help evaluate the effect of an actual change in road construction or management policy in a Transit New Zealand administration region by comparing the observed and predicted number of crashes.

References

1. Davies, R.B., Cenek, P.D and Henderson, R.J (2005): *The Effect of Skid Resistance and Texture on Crash Risk,* Paper presented at the International Conference on Surface Friction for Roads and Runways, Christchurch, NZ, 1-4 May 2005.
2. TNZ (2002): TNZ T/10, *Specification for Skid Resistance Investigation and Treatment Selection,* Transit New Zealand.
3. PIARC (2003) Road Safety Manual, PIARC Publication 13.03.B.

Appendix

A1 Model Form

A model, which relates a variety of road characteristics exponentially to crash risk, has been developed from a statistical analysis that investigated the dependency of observed crash rates to road condition and road geometry data acquired during annual surveys of the State Highway network. The analysis assumed that the crashes were statistically independent and the number of crashes that occur in each 10m road segment follow a Poisson distribution (of course, for most segments the number of crashes was zero). The fundamental form of the model is given below.

Expected number of crashes per year per 10 m = ADT.eL … (A1)

where: ADT = is the average daily traffic

L = is the weighted sum of the values of the various road characteristics such as:

- absolute gradient
- horizontal curvature
- T/10 skid-site category
- skid resistance (SCRIM Coefficient)
- lane roughness (IRI)
- log10(ADT)
- year
- TNZ administration region
- urban/rural classification

The exponent, L, is the sum of a number of variables that are either assigned values depending on the road characteristic (e.g. Urban / Rural road) or are the product of a coefficient multiplied by the value of the road characteristic (e.g. A x Curvature). These values and coefficients were determined by fitting the road data to the variables using the method of maximum likelihood.

The expected number of crashes per year equation given above can be converted to an equation for crash rate (number of crashes per 108 vehicle-km) by multiplying by the factor, 108/(ADT.365.Road Length). Crash data has been analysed over 10m sections, giving a road length of 10-2 km.

Therefore, substituting equation A1 gives the crash rate as:
crash rate (crashes per 108 vehicle.km)
= ADT.e^L x 10^8 = ADT.eL x 108/(ADT.365.10-2)

This simplifies to:

$$\text{crash rate } \frac{10^{10}}{365} e^{L} = \ldots \text{ (A2)}$$

The values and ranges of the parameters are as follows:

year:	1997 to 2002 (beyond these years requires estimation of the yearly coefficient)
region:	R1 to R7 (= TNZ Administration Regions, where: R1=Auckland, R2=Hamilton, R3=Napier, R4=Wanganui, R5=Wellington, R6=Christchurch and R7=Dunedin)
urban_rural:	U (urban) or R (rural)
skid_site:	T/10 site category 1, 3 or 4 (category 2 has been combined into category 4)
curvature:	100 to 10000m radius (absolute value used, i.e. does not differentiate left from right hand curves). For radii outside this range use 100m for values less than 100m and 10000m for values greater than 10000m
ADT:	average daily traffic, unlimited range of values
gradient:	4 to 10 (absolute value is used, and values less than 4 are set equal to 4)
SCRIM:	0.3 to 0.7 SCRIM Coefficient
IRI:	2.0 to 10.0 IRI (m/km) lane roughness

The predicted crash rate is found by applying equation A2, in which L is first evaluated using Table A1. L is the sum of various terms, which are calculated using the coefficients in Table A1. Terms corresponding to categorical variables (i.e. year, region, urban_rural, skid_site) simply take the value of the corresponding coefficient in Table A1, while terms associated with the continuous variables (i.e. curvature, ADT, gradient, SCRIM Coefficient and IRI) are found by multiplying the variable by the corresponding coefficient.

The model coefficients for the calculation of "all-injury" crashes (including fatals) and "wet" crashes (i.e. all injury and fatal crashes occurring on road surfaces considered to be in a wet condition) are given in Table A1.

The model allows the number of crashes expected to occur over a year on a specific 10 m section of state highway to be calculated. Estimates of yearly crash numbers over lengths greater than 10 m are obtained by summing the component 10 m estimates. Therefore, the calculation of the number of crashes per year expected over the 18.2 km of SH2 between RS 73/0.648 and RS 73/18.836 required the summation of 1,820 component estimates of yearly crash rate per 10 m.

The coefficients for gradient shown in Table A1 don't seem very sensible – more slope reduces crash risk. This is because of an interaction between gradient and the T/10 skid-site category 3 classification. This shouldn't have a serious impact on the predictive power of the model but needs to be rectified in the next upgrade of the model.

A2 Example Calculation

The following example shows the procedure for calculating the crash rate using the simplified 'All Crashes' model coefficients from Table A1. First the exponent, L is evaluated, as shown in Table A2.

The exponent, L, is then used to calculate:

- Expected number of crashes per year per 10m =
- The crash rate in terms of 108 vehicle–kilometres travelled using equation A2 i.e.

$$\frac{10^{10}}{365}e^{L} = \frac{10^{10}}{365}e^{-13.937} = 24.3$$

Table A1: Coefficients for the Crash Prediction Model

Parameter	All Crashes		Wet Road Crashes	
	coefficient	standard error	coefficient	standard error
constant	2.095	1.76	1.015	3.43
year: 1997	0.000		0.000	
year: 1998	-0.060	0.03	-0.240	0.07
year: 1999	-0.053	0.03	-0.027	0.06
year: 2000	-0.118	0.03	-0.331	0.07
year: 2001	0.000	0.03	-0.203	0.07
year: 2002	0.198	0.03	-0.002	0.07
region: R1	0.000		0.000	
region: R2	0.108	0.03	0.192	0.07
region: R3	0.210	0.05	0.101	0.10
region: R4	0.306	0.04	0.565	0.08
region: R5	0.224	0.04	0.053	0.09
region: R6	0.105	0.04	0.146	0.09
region: R7	0.124	0.04	0.045	0.09
urban_rural: R	0.000		0.000	
urban_rural: U	-0.157	0.03	-0.272	0.06
skid_site: 4	0.000		0.000	
skid_site: 3	1.595	0.04	1.528	0.08
skid_site: 1	1.697	0.08	1.175	0.20
$\log_{10}(\lvert curvature \rvert)$	-5.360	0.29	-7.426	0.57
$[\log_{10}(\lvert curvature \rvert)]^2$	0.759	0.05	1.048	0.09
$\log_{10}(ADT)$	0.707	0.31	2.380	0.71
$[\log_{10}(ADT)]^2$	-0.173	0.04	-0.401	0.10
$\lvert gradient \rvert$	-2.598	0.70	-2.913	1.33
$\lvert gradient \rvert^2$	0.314	0.11	0.396	0.21
$\lvert gradient \rvert^3$	-0.012	0.01	-0.017	0.01
SCRIM - 0.5	-1.637	0.16	-3.551	0.33
$[(SCRIM-0.5)]^2$	-0.090	1.30	3.344	2.48
$\log_{10}(iri)$	-10.540	4.48	-7.348	8.48
$[\log_{10}(iri)]^2$	19.219	8.48	10.916	15.65
$[\log_{10}(iri)]^3$	-9.850	4.99	-3.563	8.89

Table A2: Example Application ‘All Crashes’ Crash Prediction Model

parameter	parameter value	calculation value	corresponding coefficient †	product (value x coefficient)
constant		1	2.095	2.095
year 2002	1	0.198	0.198	
region R2	1	0.108	0.108	
urban_rural	Rural	1	0.000	0.000
skid_site	4 *	1	0.000	0.000
log10(|curvature|)	300	2.477	-5.360	-13.277
[log10(|curvature|)]2	300	6.136	0.759	4.657
log10 (ADT)	10000	4	0.707	2.828
[log10 (ADT)]2	10000	16	-0.173	-2.768
|gradient|	0 **	4	-2.598	-10.392
|gradient|2	0 **	16	0.314	5.024
|gradient|3	0 **	64	-0.012	-0.768
(SCRIM-0.5)2	0.45	-0.05	-1.637	0.082
(SCRIM-0.5)2	0.45	0.0025	-0.090	0.000
log10 (iri)	3	0.477	-10.540	-5.029
[log10 (iri)]2	3	0.228	19.219	4.375
[log10 (iri)]3	3	0.109	-9.850	-1.070
				∑= -13.937 = L

Notes:

† coefficients taken from Table A1

* skid_site category 2 has been combined with skid _site category 4

**gradients between 0 and 4 default to a value of 4

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