Crash risk relationships for improved road safety management

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PD Cenek, Opus International Consultants Ltd, Lower Hutt
RB Davies, Statistics Research Associates Ltd, Wellington
RJ Henderson, Opus International Consultants Ltd, Lower Hutt

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NZ Transport Agency
Private Bag 6995, Wellington 6141, New Zealand
Telephone 64 4 894 5400; facsimile 64 4 894 6100
research@nzta.govt.nz
www.nzta.govt.nz

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Abbreviations and acronyms

ADT	average daily traffic (vehicles per day)
CAS	Crash Analysis System (refer to www.transport.govt.nz/research/crashanalysissystem(cas)/)
CR	crash rate (crashes per 100 million vehicle kilometres travelled) – also known as 'personal crash risk'
GPS	global positioning system
IRI	International Roughness Index (mm/km) (refer to www.umtri.umich.edu/erd/roughness)
LRS	location referencing system (refer to www.nzta.govt.nz/resources/location-ref-management-sys-manual/index.html)
LTSA	Land Transport Safety Authority
NZTA	New Zealand Transport Agency
PSI	present serviceability index
RAMM	road assessment and maintenance management system
RS	reference station
SC	SCRIM coefficient
SCRIM	Sideway-force Coefficient Routine Investigation Machine – a machine that provides a routine method of measuring skid resistance of roads under wet conditions
SCRIM+	As for SCRIM, plus additional instrumentation to measure roughness, rutting, cross-slope, gradient, horizontal curvature and GPS
SCRM	Simplified Crash Rate Model
v-km	vehicle-kilometres
vkt	vehicle kilometres travelled

Contents

Executive summary

In this research project, which was undertaken between July 2002 and April 2012, an attempt was made to develop a statistical crash prediction model for application to rural New Zealand state highways by combining detailed road geometry, road surface condition, carriageway characteristics and crash data information. Such a statistical modelling exercise was made possible because high-speed surveys generating simultaneously measured road condition and road geometry data for the entire 22,000lane-km of New Zealand's state highway network have been undertaken annually since 1997.

The following four road crash subsets covering the 5-year period 1997 to 2002 were investigated:

- all reported injury and fatal crashes
- selected injury and fatal crashes for loss-of-control events
- reported injury and fatal crashes in wet conditions
- selected injury and fatal crashes in wet conditions.

One- and two-way tables and Poisson regression modelling were employed to identify critical variables and their relationship with crash risk. Horizontal curvature, traffic flow, skid resistance and, to a lesser extent, lane roughness were critical variables common to all investigated crash subsets.

The resulting Poisson regression model appeared to work in a reasonably satisfactory way and produced results that, for the most part, made sense. Curvature, for example, had a strong effect on crash rate, as expected. There was also a strong correlation between skid resistance and crash rate, and a weaker effect for lane roughness and crash rate. This, however, was a retrospective analysis (as opposed to a designed experiment), meaning it was not possible to be sure that the predictor variables used in the regression analysis were really the ones affecting the crash rates. In particular, it is likely that average daily traffic is a general indicator of road quality and that this led to the observed drop in crash rate as average daily traffic increased.

The simplified model in its current form was shown to be sufficiently robust for the following four applications:

1. to improve understanding of the factors affecting crash risk and the relative importance of different factors
2. to improve the management of the state highway network by estimating the effect of changes in standards for curvature, skid resistance and roughness on crash numbers
3. 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
4. to help evaluate the effect of an actual change in road construction or management policy in an NZTA administration region by comparing observed and predicted crash numbers.

Key recommendations for future work arising from the research are as follows:

- Extend the analysis to territorial local authority (TLA) arterial and collector roads for which there is CAS crash data and corresponding SCRIM+ road geometry and road condition data.

- Separate out the effect of moderate (5–10%) gradients, as in the present model these have been combined with T/10 skid site category 3 (ie down gradients of 5–10%, approaches to road junctions, and motorway junction areas including on/off ramps) effects.
- Incorporate crash severity by exploring the relationships between fatal and serious crashes and all injury crashes. The present model does not account for crash severity.
- Differentiate between one-vehicle and multivehicle crashes.
- Investigate possible interactions between selected predictor variables (these being cross-fall, shoulder width, lane width, and texture) by comparing crash rate relationships derived for state highway networks, which have well-developed design and maintenance standards, with those derived for less regulated TLA arterial roads. In the existing model these variables show up as insignificant or barely significant, which is counter to international findings. This result has been attributed to the high conformance with NZTA geometric and maintenance standards.
- Investigate the effect of sudden changes in road characteristics, particularly curves immediately following a long straight.
- Trial an improved statistical method for handling the observed non-Poisson variances.

These proposed refinements will extend the present model's usefulness for guiding safety initiatives and providing economic justifications.

Abstract

This report presents the results of a first attempt to combine detailed road geometry, road surface condition, carriageway characteristics and crash data information to develop a statistical crash prediction model for application to rural New Zealand state highways. Such a study was made possible because high-speed surveys generating simultaneously measured road condition and road geometry data for the entire 22,000lane-km of New Zealand's state highway network have been undertaken annually since 1997.

Four road crash subsets were investigated: all reported injury and fatal crashes; selected injury and fatal crashes for loss-of-control events; reported injury and fatal crashes in wet conditions; and selected injury and fatal crashes in wet conditions.

One- and two-way tables and Poisson regression modelling were employed to identify critical variables and their relationship with crash risk. Horizontal curvature, traffic flow, skid resistance and, to a lesser extent, lane roughness were critical variables common to all investigated crash subsets. The resulting Poisson regression model uses 2nd- or 3rd-order polynomial functions of critical variables to allow for observed non-linear responses, enabling the model to be incorporated into existing road asset management systems. A comparison of observed and predicted crash numbers shows that the model can provide estimates of crash numbers to sufficient accuracy for safety management purposes.

1 Introduction

The ability to reliably predict crash rates is very important for road network safety management. Accurate prediction can help identify hazardous locations, locations requiring treatment, and locations where crash rate anomalies warrant further examination. The aim of this research, which was undertaken between July 2002 and April 2012, was to develop a model that combined detailed information on road geometry, road surface conditions, carriageway characteristics and crashes, and which would then generate crash estimates of sufficient accuracy for safety management purposes.

Since 1997, the NZ Transport Agency (NZTA, formerly Transit New Zealand) has annually surveyed the entire sealed length (22,000lane-km) of New Zealand's state highway network for road condition (roughness, rutting, texture and skid resistance) and geometry (horizontal curvature, cross-fall and gradient). The NZTA also maintains traffic flow estimates to quantify traffic demands on the network. Traffic-monitoring sites are distributed throughout the network. Most sites are counted between one and three times annually, with key sites counted continuously. Traffic flows are typically estimated from individual counts over one-week periods. In addition, fatal and injury road crash data is maintained by the NZTA through its crash analysis system (CAS), and includes details of location, time, distance, drivers, casualties, circumstances and causes.

These data sources, when combined, enable statistical modelling techniques to match the crash rate with road characteristics. Such an analysis allows a broad-brush approach to the entire state highway network, which is in contrast to studies of individual sites, eg black-spot sites. Generally, crash rates in New Zealand are too low to allow consistent conclusions to be drawn about the relationship between road characteristics and road crashes from before-and-after treatment comparisons at individual crash sites.

By using data from the whole state highway network, the analysis presented in this report in effect combines the data from individual potential crash sites, including those where there were no crashes, and so provides estimates of crash risk that can be used with a degree of confidence to evaluate the cost-effectiveness of road geometry- and road condition-related safety interventions. However, such an analysis cannot take into account all the special features of each section of road (eg specific hazards) and so it provides only an average estimate of crash risk.

This report summarises the results of two analyses of state highway data for the period 1997 to 2002. The first analysis utilised one-way and two-way tables to provide a preliminary indication of which road condition and road geometry factors affect crash rates. The second analysis involved Poisson regression modelling to better identify key predictor variables, and how these influence crash rates.

The report is structured as follows:

- Section 2 provides an overview of crash risk models for rural two-lane roads current at the time the research was undertaken, which was the two-year period 2002–2004.
- Section 3 covers the database created for the statistical modelling.
- Section 4 presents the one-way and two-way tables used to identify the likely factors affecting crash rates and their various interactions.
- The resulting Poisson regression model, an example calculation to illustrate how the model can be applied to estimate the expected crash rate for any 10m segment of a lane of rural state highway, and a comparison of fitted and observed crashes are presented in section 5.

- Section 6 demonstrates, through various practical examples, how the model can be used to gauge the effect of interventions, such as curve easing and high-friction surfacings, on the safety of the motoring public. The concept of 'safety improvement potential' is also introduced.
- The principal findings of the research and associated recommendations are given in section 7.
- Key references are listed in section 8.

The research presented in this report has been exposed internationally through two refereed papers:

- *The effect of skid resistance and texture on crash risk*, presented at the 1st International Conference on Surface Friction of Roads and Runways, Christchurch, NZ, 1–4 May 2005 (www.saferroads.org.uk/2005-conference.asp)
- *Modelling and analysis of crash densities for Karangahake Gorge, New Zealand*, presented at the 2006 Australasian Road Safety Research, Policing and Education Conference, Surfers Paradise, Australia, 25–27 October 2006 (www.rsconference.com/roadsafety/detail/617).

The reader should note that this report, which documents the origins of injury crash risk modelling on rural New Zealand state highways, was prepared as a companion report to *NZ Transport Agency research report 477*, Modelling crash risk on the New Zealand state highway network (March 2012).

Full details on the background and derivation of the complex and simplified statistical crash prediction models described in this report can be downloaded from www.robertnz.net/pdf/crashrisk8.pdf, which was last accessed on 6 June 2012.

2 Review of existing crash risk models

2.1 Focus of review

The overall aim of crash risk models is to reduce crash rates through the targeted allocation of resources to appropriate road maintenance and road design improvements. This review focused on pre-2004 literature that investigated factors that significantly influenced crash risk on rural two-lane roads. Other studies, such as those that considered urban crashes, intersection crashes, or multilane highway crashes, were not considered. A review of post-2004 literature on crash risk modelling is provided in Cenek et al (2012).

2.1.1 American studies

Most of the crash risk studies examined as part of this review analysed crash risks on US roads. The conclusions reached in these papers, and the relative importance of identified risk factors, do not necessarily translate to New Zealand conditions, for the following reasons:

1. The bulk of studies investigated multilane highways.
2. These studies frequently limited their focus to the exit/entry routes to main multilane highways.
3. Road sections were divided into segments, often based on geometrical features, for analysis. In the studies reviewed, these segments could be kilometres long – considerably longer than the 200m segments (considered more representative of the typical length of safety-related interventions) used by Cenek et al (1997) for a New Zealand study.

2.2 Analysis methods

A wide variety of statistical techniques can be used to model crash rate contributing factors. The challenges in choosing a good analytical technique and building a model that targets maintenance and improvement programmes include:

- insufficient crash data (ie too few crashes for statistically robust analysis)
- inaccurate or incomplete crash data (ie crash data not accurately recorded)
- highly correlated road geometry variables (eg curve radius and cross-slope)
- inaccurate road geometry data (particularly spatial location)
- inaccurate or insufficient road condition data.

The reviewed studies employed a variety of modelling techniques, including:

- one-way and two-way tables, eg Wanty et al (1995), Cenek et al (1997), Cairney et al (2000)
- Poisson Regression, eg Wanty et al (1995), Cenek et al (1997)
- hierarchical tree-based regression (HTBR), eg Karlaftis et al (2002)
- Chi-square logistic regression, eg Cairney et al (2000)

- Empirical Bayes-based procedures, eg Persaud et al (1999), Persaud et al (2000), Hanley et al (2000):

  Persaud et al (1999) detailed the refinement of an empirical Bayes procedure that allows sites to be ranked for potential safety improvements. The method sought to identify sites for possible safety treatment, and then to assess the expected safety of the site after improvement.

  The underlying principle was to target improvement works in a more cost-effective manner and to avoid expensive site inspections. In a later study, Persaud et al (2000) restricted their attention to the identification of hazardous curves, also through the use of an empirical Bayes procedure.

  Hanley et al (2000) focused on five accident reduction factors (ARFs), and calculated the priority of safety improvement programmes using Bayesian statistics. This was achieved by comparing before and after crash rates.

- Box-Cox methods, eg Gaudry et al (2000):

  Gaudry et al (2000) compared results generated by the DRAG model (DRAG = 'demand for road use, accidents and their gravity') and outlined the so-called 'Box-Cox' methodology that underpins the model. This study was largely irrelevant to our work, as the dependent variables did not include road geometry or surface condition. (The dependent variables considered were limited to the likes of climate, economy, reasons for travel, and fuel prices.)

- Fuzzy-logic, eg Xiao et al (2000):

  Xiao et al (2000) described a fuzzy-logic model for predicting wet-pavement crashes. They reported that the model was a better predictor of wet-pavement crash rates than conventional probabilistic non-linear regression models. Xiao et al concluded that more-complete data was needed to fine-tune the model, and that further model refinements were required.

2.3 Road geometry

The effect of road geometry on crash rates has been extensively studied. Representative literature is summarised below.

2.3.1 Vertical curvature and grade

The influence of grade and rate of change of grade (vertical curvature) on crash rates has been studied extensively by both Cenek et al (1997) and Cairney et al (2000). Cenek et al reported that crash rates are higher for downhill rather than uphill grades, and that crash rates increase for extremes of grade. Neither of these observations was replicated in the Cairney et al study, which attributed differences between the results to section definition disparities. Cenek et al used a uniform section length of 200m with the possibility of varying grade, while Cairney used sections of largely uniform grade and curvature.

Lamm et al (1988) made similar findings to the Cenek et al (ibid) research, noting that crash rates increase for extremes of grade. Lamm et al attributed this to differences in vehicle speeds as grade increases – particularly on uphill slopes, where non-homogeneity of traffic flow would result from heavily laden trucks having lower speeds than passenger vehicles.

2.3.2 Horizontal curvature (1/radius)

The effect of horizontal curvature (the inverse of curve radius) on crash rates has received much attention in the literature, and is well-accepted as the most significant road geometry parameter with respect to crash rates.

According to Cairney et al (2000) and Persaud et al (2000), the highest crash rates occur at small-radius bends. Lamm et al (1988) reported a similar trend, and commented that curve radius is the single best variable for predicting crash rates. Al-Masaeid (1997) showed that crash numbers along a section of road correlate with the number of curves of 5 degrees, or greater, that that section contains. Interestingly, however, only single-vehicle and total crash rates – rather than the multiple-vehicle crash rates – were found to be affected. Choueiri et al (1994) also considered this phenomenon, and added that crash rates are influenced by whether or not strings of curves have similar curve radii. Hauer (1999) concluded that crash rates depend not only upon curve radius but also on a curve's length.

2.3.3 Cross-fall

The effect of cross-fall (also called cross-slope or super-elevation) on crash rates has been studied by various authors. Lamm et al (2000) reported that it is difficult to distinguish between the effects of curve radius, advisory speed and cross-fall on crash rates, as all three are highly correlated. In a before-and-after study of the effects of road modifications, Hanley et al (2000) concluded that the effect of cross-fall on crash rates is not statistically significant. Hanley et al also noted that few road modification works altered curve cross-fall in isolation from curve radius. Wanty et al (1995) used cross-fall in their analysis, but found that it was not statistically significant in predicting crash rates when compared with average horizontal curvature and variances in horizontal curvature. In a similar study, Cairney et al (2000) measured cross-fall as a geometry variable, but did not later present it in correlation with crash rates. Although not explicitly stated, this was presumably due to the high degree of correlation between horizontal curvature and cross-fall.

2.4 Road surface condition

While considerable research effort has explored the effects of road geometry on crash rates, much less work has been done on the effects of road surface condition – skid resistance being an exception. This is probably due to three factors:

1. a decision to focus attention on arguably more significant factors such as road geometry (especially curve radius) and traffic flow (eg ADT)
2. difficulties in attributing crash risk to road condition in the presence of other contributing variables – for example, a skidding crash will generally show dependence not only on pavement skid numbers but also on curve radius, weather conditions and vehicle speed
3. the lack of comprehensive data on road surface conditions.

The opportunity to analyse the effect of road surface condition variables on crash rates in New Zealand has arisen recently, with the annual high-speed state highway data surveys now including this data in addition to road geometry. (The earlier New Zealand study described by Cenek et al (1997) and Wanty et al (1995) used survey data that included only road geometry data. No road condition variables were available at that time.)

2.4.1 Texture

None of the literature reviewed for this study considered the effects of pavement microtexture or macrotexture on crash rates. Only Wanty et al (1995) mentioned this potentially important relationship, stating that their crash model required expansion to include a number of additional factors, including pavement texture characteristics.

2.4.2 Skid resistance

A number of authors addressed the effect of skid resistance on crash rates, and the following findings are now generally accepted:

1. High-skid-number pavements reduce wet-pavement crash rates (Cleveland 1987, Cairney 1997).
2. The ratio of wet-pavement to dry-pavement crashes correlates well with skid numbers (Rizenbergs et al 1977).
3. Resurfacing alone does not necessarily reduce wet-pavement crash rates unless the skid number is increased (Cleveland 1987).

Properly accounting for variables such as road geometry, weather, vehicle speed and ADT is a common difficulty in attributing crashes to a deficient skid number, as these variables are also likely to influence wet-pavement crash rates (Rizenbergs et al 1977, Cairney 1997). In addition, determining skid numbers is frequently problematic as skid numbers vary seasonally, and are often only measured at a single lane on multilane roads (Cairney 1997). The seasonal effect can, however, be addressed to some extent by using an average skid number calculated over a multiyear interval – eg three years.

In analysing crashes where skid number is thought to be a contributing factor, the ratio of wet-pavement to dry-pavement crashes should be considered. The proportion of wet days for a site should also be determined, as this will vary with location and will therefore influence wet-pavement crash rates (Cleveland 1987).

Cairney (1997) comprehensively discussed the effects of skid resistance on crash rates, and examined the targeting of road maintenance and road design intervention for skid resistance improvement. According to Cairney, programmes can use one of three approaches:

1. a reactive programme based on the frequency of wet-weather crashes
2. a proactive programme based on surveys of skid resistance made with devices such as the Sideway-force Coefficient Routine Investigation Machine (SCRIM)
3. a modelling approach based on demand for braking (braking demand is a function of traffic flow, geometry, speed and gradient).

2.4.3 Roughness

Of the literature reviewed, only two papers considered the effects of road roughness on crash rates:

- Cleveland (1987) considered the effects of pavement resurfacing on crash frequency and severity for rural highways in the US. His work was based on the literature of others, which focused on crash rates before and after resurfacing. Only long segments of pavement resurfacing were considered, rather than shorter resurfacing of crash-prone areas such as bends and intersections. The evidence presented was inconclusive, with one study reporting an increased crash rate on rougher roads (low PSI), while other studies reported increases in the dry-pavement crash rate after resurfacing. This latter observation is perhaps counterintuitive, but has been attributed to an increase in driver speed over the new smoother surface, which does not necessarily have a significantly higher skid resistance.
- Al-Masaeid (1997) addressed the effects of pavement condition, road geometry and roadside conditions by analysing the crash rate for 1130km of rural two-lane road in Jordan. His results showed that while the total crash rate is independent of roughness, the single-vehicle crash rate reduces with increasing roughness and the multiple-vehicle crash rate increases with increasing roughness. It was concluded that the single-vehicle crash rate reduces with roughness because speeds are reduced,

while the multiple-vehicle crash rate increases due to variations in vehicle path and speed over rougher roads.

2.4.4 Rutting

Al-Masaeid (1997) considered rut depth as a possible contributor to crashes on rural roads. His thinking was that rutting might increase the risk of hydroplaning crashes. Analysis indicated, however, that rut depth was not correlated to crash rate. No other studies that deal with the effect of rutting on crash rates were found.

In analysing the effect of rutting, it is probably important to consider the types of vehicles involved. Motorcycle crash rates, for example, may well be more influenced by surface roughness and rutting than heavier vehicles.

2.4.5 Other road surface condition measures

Other pavement condition indicators were available, including shoving, scabbing, potholing, cracking and flushing. These indicators were not considered here, because they were either considered to not be significant or because their effect was already included in other measures (eg flushing is reflected in texture measurements).

2.5 Crash data

Crash data can often be inaccurate. This is due to the difficulty that authorities face in determining crash cause/s and the sequence of events, and the variable accuracy with which gathered data is recorded. It is not uncommon, for example, for crashes to be attributed to the wrong curve.

Thielman and Griffith (1999) attempted to improve the accuracy and consistency of on-scene crash recording by supplying police with pen-based computers running fuzzy-logic software. The software consisted of three expert systems:

1 seat belt use

2 vehicle damage rating

3 roadside barriers (type and point of impact).

At the time the paper was published, the study was still in its pilot stage, although the results of initial in-field trials were encouraging.

Wanty et al (1995) commented further on the problems of crash recording, and noted the difficulty of confidently attributing a crash to a particular site. Attempts to correlate RGDAS[1] road geometry data with TAR[2] crash data were reported. Part of the problem was attributed to the RGDAS geometry data having insufficient location information, with no GPS being used.

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[1] RGDAS – ARRB's road geometry data acquisition system

[2] TAR – traffic accident reports

2.6 Other parameters

Aside from the information obtained from data stored in the RAMM database, there appeared to be a number of other factors that could influence crash rates – for example:

- stock on the road due to poorly fenced paddocks
- stock effluent on the road
- wildlife on the road that could become road kill (eg rabbits, possums, pukeko, depending on the type and amount of surrounding vegetation).

2.7 Conclusions

Of the literature reviewed, the most comprehensive and useful approaches appeared to be those reported by Cenek et al (1997) and Cairney et al (2000). This was largely because both studies had available to them detailed road and crash data for substantial lengths of highway. This information was also available for the present study.

3 Database preparation

3.1 Road characteristics

The annual survey of road condition and road geometry over the 6-year period from 1997 to 2002 was performed by SCRIM$^+$, a truck-based multifunctional road-monitoring device. Texture (MPD[3], mm), skid resistance (SCRIM coefficient), gradient (%), horizontal curvature (radius, m) and cross-fall (%) were each recorded over 10m intervals, whereas roughness (IRI[4], m/km) and rut depth (mm) were recorded over 20m intervals.

The 10m data was used as the basis for linking the other datasets used in generating the base file for analysis. This required matching the data from both sides of the road, as the left (increasing) lane and the right (decreasing) lane of a two-lane carriageway were surveyed separately. Multilane roads were automatically excluded from the analysis.

Table 3.1 tabulates the number of 10m state highway segments over each year of the analysis period for which road condition and road geometry data was available. These 10m segments cover both rural and urban areas.

Table 3.1 Number of 10m road segments surveyed with SCRIM$^+$

Nominal survey year	Survey period	No. of 10m segments	
		Left (increasing) lane	Right (decreasing) lane
1997	March–May 1997	992,649	994,692
1998	March–May 1998	1,019,740	1,019,371
1999	December 1998–March 1999	1,031,110	1,025,371
2000	December 1999–May 2000	1,046,583	1,040,801
2001	December 2000–March 2001	1,055,997	1,056,202
2002	November 2001–March 2002	1,061,474	1,062,054

With reference to table 3.1, the nominal survey year was used for linking road condition and road geometry data with the CAS crash data. Although it might have been preferable to use the road condition/road geometry data closest to each crash date, to allow for any intervening maintenance activity, this would have added substantially to the complexity of managing the data and the likelihood of error.

3.2 Crash data

The crash data was extracted from the NZTA’s CAS database in October 2003, and included all reported injury (including fatal) crashes in rural and urban areas over the 6-year period 1997–2002. The statistical analyses were applied to each of the four crash dataset subsets tabulated in table 3.2. The relevant vehicle movement codes, as used by the LTSA (Land Transport Safety Authority) for crash-investigation-monitoring analysis, are summarised in table 3.3.

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[3] MPD – mean profile depth (refer to ASTM E1845 – 09)

[4] IRI – International Roughness Index (mm/km) (refer to www.umtri.umich.edu/erd/roughness)

Table 3.2 Description of crash dataset subsets

Group	Criteria
All	All injury and fatal crashes
Selected	All injury and fatal crashes with LTSA vehicle movement code being one of A, B, C, D or F
We	All injury and fatal crashes with the road wet field being W or the cause code[a] being 801 or 901 (skidding/loss of control crashes)
Wet & selected	Satisfying both the wet and the selected criteria

a) Pertains to coding used in CAS to describe factors that contributed to the crash.

Table 3.3 Description of vehicle movement codes

Movement type	Description
A	Overtaking and lane-change
B	Head-on
C	Lost-control or off-road (straight roads)
D	Cornering
F	Rear-end

Table 3.4 shows the number of crashes (including those on multilane carriageways) that were able to be located and the percentage they represented of all crashes recorded on the state highway network. The reasons why only about 75% of crashes could be located include:

- insufficient data about the location
- location data did not correspond to a valid section of state highway
- location not surveyed by SCRIM$^+$.

With reference to table 3.4, there appears to have been a marked improvement in the recording of crash locations on the state highway network between 1997 and 2002.

Table 3.4 Located road crash numbers, by year

Year	Crash subsets			
	All	Selected	Wet	Wet & selected
1997	2159 (66%)[a]	1443 (68%)	550 (66%)	415 (68%)
1998	2112 (70%)	1418 (71%)	444 (66%)	343 (68%)
1999	2222 (72%)	1609 (77%)	551 (73%)	444 (77%)
2000	2115 (74%)	1552 (79%)	418 (77%)	340 (81%)
2001	2452 (76%)	1770 (80%)	494 (73%)	377(76%)
2002	3034 (86%)	2166 (91%)	603 (84%)	460 (89%)
Total	**14,094 (74%)**	**9958 (78%)**	**3060 (73%)**	**2379 (76%)**

a) Pertains to corresponding percentage of all crashes of that type recorded on the state highway network.

3.3 Linking of crash data to road information

The original intention was to use crash data from the accident table contained within the NZTA's road maintenance and management system (RAMM) database. This automatically links to road condition data also held in RAMM via the NZTA's 'route position' location referencing system (LRS), which is distance-based. Route positions provide a unique address for each location on the state highway network and are measured in increasing direction from the preceding reference station (RS). Along state highways, RSs are located at approximately 16km intervals.

A comparison of all reported injury (including fatal) crash records in the RAMM accident table for the period 1997–2002 with those held in the Ministry of Transport's CAS, however, showed a significant discrepancy in record numbers. This was attributed to time delays in entering crash records in the RAMM database, and difficulties in locating crashes in terms of NZTA's LRS. Therefore, because of the need to use as large a crash database as possible, a decision was made to use the crash data held in CAS. This approach required the development of a procedure to link the spatially referenced crash data to the linearly referenced state highway data.

The following procedure was adopted to systematically link crash data with road condition, road geometry and traffic data from RAMM:

- Crash map coordinates, in terms of XY geocoding, were calculated by CAS from crash reports supplied by the New Zealand Police.
- These coordinates were matched to state highway centreline segments as recorded in the Critchlow Associates Ltd (www.critchlow.co.nz) database.
- The centreline segments, in turn, were converted to a route position (RP). This operation was also automatically performed within CAS.

Although Critchlow Associates Ltd annually rebuilds links between centreline data and RAMM, mismatches may occur due to changes to the NZTA's LRS over the year and between years because of road construction and reconstruction work. Consequently, CAS-derived geocoordinates were also matched to the nearest centreline point from the NZTA's centreline database. The NZTA's centreline data is automatically linked to the LRS, and is more accurate than Critchlow's data because winding sections are not as simplified. For example, using Critchlow's centreline database, the derived location of RPs can be up to 300m in error (1% error) in the 30km section through the Manawatu Gorge.

A comparison of the LRS location of 18,172 crashes showed good agreement between both methods (a correlation of about 70%), resulting in LTSA/Critchlow-derived route positions being used for these crashes. For the remaining 30%, LTSA/Critchlow-derived route positions were appropriately updated using the NZTA centreline data to reflect changes such as new RS numbers. Where possible, road features listed in the police crash reports were used in addition to geocoordinates, to assist in locating the crashes.

This time-consuming exercise highlighted the benefits of using spatial methods (ie GPS) for location referencing, to allow easier integration of crash and state highway data.

4 Statistical analysis: one- and two-way tables

4.1 Classification of data

To identify the likely factors affecting crash rates, segments of the state highway network were divided into categories using one or two road characteristics, with the average crash rate for each category calculated from the corresponding crash number and road length totals. The road condition and road geometry parameters considered were the average of both increasing and decreasing lanes.

The resulting one- and two-way tables are useful for identifying trends, but can be misleading for the following reasons:

- They do not take account of errors in locating crashes.
- Observed crash rate variations may be due to a variable related to, but not included in, the relevant table.

In addition, calculated crash rates may be subject to substantial statistical error whenever the number of crashes is less than 25.

4.2 One-way tables

The following tables were generated for the 'All crashes' dataset.

Table 4.1 indicates that crash rates increase as traffic volumes decrease. This is as expected because the quality of a road reflects average daily traffic (ADT), with lower ADT suggesting more challenging roads. These roads typically have narrower lanes and more tortuous alignments, which in turn often lead to a relatively high crash rate.

Table 4.1 Classification by average daily traffic (ADT) – all crashes

ADT range	Road length (km)	Number of crashes 1997–2002	Total traffic exposure (10^6 v-km[a])	Crash rate (crashes per 10^8vkt[b])
ADT < 200	68	14	26	55
200 ≤ ADT < 500	650	111	517	21
500 ≤ ADT < 1000	2103	862	3268	26
1000 ≤ ADT < 2000	2646	1817	8323	22
2000 ≤ ADT < 5000	2538	3374	18,144	19
5000 ≤ ADT < 10,000	1485	3672	21,548	17
10,000 ≤ ADT < 20,000	503	2329	14,941	16
20,000 ≤ ADT < 50,000	109	660	5579	12
ADT ≥ 50,000	0	0	158	0

a) v-km – vehicle kilometres

b) vkt – vehicle kilometres travelled

Table 4.2 shows that crash rates increase as horizontal curvature decreases. The smallest curvature grouping, however, is likely to include intersections, so the much higher crash rate observed for curves with less than 100m radius may result from other hazards apart from the curve itself.

Table 4.2 **Classification by horizontal curvature – all crashes**

Horizontal curvature, R (m), range	Road length (km)	Number of crashes 1997–2002	Total traffic exposure (10^6 v-km)	Crash rate (crashes per 10^8vkt)
$10 \le R < 100$	125	262	518	51
$100 \le R < 1000$	2845	4277	17,457	25
$1000 \le R <$ 10,000	5273	6290	39,620	16
10,000 $\le R <$ 100,000	1835	1973	14,663	13
$R \ge$ 100,000	20	28	179	16

NZTA's policy for skid resistance is largely contained within the T/10 Specification (Transit New Zealand 2002). This specification was introduced in 1998, and aims to standardise the risk of a wet-skid crash across the state highway network by assigning investigatory skid resistance levels for different site categories, which are related to different friction demands. A description of these site categories and associated investigatory levels are summarised in table 4.3.

Table 4.3 **T/10 skid site categories**

Site category	Description	Notes	Investigatory level (SC[a])
5[b]	Divided carriageway		0.35
4	Normal roads	Undivided carriageways only	0.4
3	Approaches to road junctions, gradient > 5%		0.45
2	Curve < 250m radius, gradient > 10%		0.5
1	Highest priority	Railway level crossings, approaches to roundabouts, traffic lights, pedestrian crossings and similar hazards	0.55

a) Scrim coefficient.

b) Not used in analysis.

Table 4.4 shows the effect of skid resistance level on crash rates. An increase in crash rates for lower values of wet-road skid resistance is indicated, as measured in terms of SCRIM coefficient (SC). However, a one-way table such as table 4.4 is likely to underestimate the effect of skid resistance on crash rates, because surfaces displaying greater skid resistance are typically used as a safety measure on more hazardous road sections.

Table 4.4 Classification by pavement skid resistance – all crashes

SCRIM coefficient (SC)	Road length (km)	Number of crashes 1997–2002	Total traffic exposure (10^6 v-km)	Crash rate (crashes per 10^8vkt)
SC < 0.3	18	40	150	27
0.3 ≤ SC < 0.4	294	730	3125	23
0.4 ≤ SC < 0.5	2610	5144	28,048	18
0.5 ≤ SC < 0.6	4953	5421	32,649	17
0.6 ≤ SC < 0.7	2046	1287	7637	17
SC ≥ 0.7	116	62	372	17

Table 4.5 shows the effect of T/10 site category on crash rates and indicates that crash rates are much higher for T/10 site category 1 (roundabouts, railway crossings, etc) than for site category 4 (normal) locations. Crash rates for site category 1 locations may, however, be underestimated where a road segment has different skid site categories between one (entry) side of the intersection or crossing and the other (exit) side.

Table 4.5 Classification by T/10 skid site category – all crashes

T/10 skid site category	Road length (km)	Number of crashes 1997–2002	Total traffic exposure (10^6 v-km)	Crash rate (crashes per 10^8vkt)
4	7275	6980	52,625	13
3	1264	2935	11,165	26
2	1448	2237	6875	33
1	77	493	1004	49

4.3 Two-way tables

When the classifying variables are considered two at a time (eg in two-way tables), crash numbers are much smaller than in the one-way tables, resulting in a substantial amount of statistical fluctuation. Therefore, in tables 4.6–4.9, crash rates are bolded when the corresponding observed number of crashes is at least 25, to signify that there can be a degree of confidence in the crash rate tabulated.

Table 4.6 indicates that crash rates increase as the radius of curvature decreases, and that there is some increase in crash rates as ADT decreases (although less than shown in table 4.1). This implies that some of the apparent effect of ADT on crash rates is reduced when road curvature is allowed for.

Table 4.6 Crash rate by horizontal curvature and ADT – all crashes

Horizontal curvature, R (m)	Crashes per 10^8vkt					
	ADT range (1000 vehicles per day)					
	ADT<1	1≤ADT<2	2≤ADT<5	5≤ADT<10	10≤ADT<20	ADT≥20
10 ≤ R < 100	**53**	**54**	**51**	**48**	**54**	**33**
100 ≤ R < 1000	**35**	**29**	**26**	24	20	13
1000 ≤ R < 10,000	22	19	16	16	15	11
10,000 ≤ R < 100,000	16	15	14	13	13	11
R ≥ 100,000	**100**	12	12	16	15	0

Table 4.7 shows that within each range of SCRIM coefficient values, crash rates increase as the T/10 skid site category decreases, and for each T/10 skid site category, crash rates increase as the level of skid resistance provided by a road surface decreases. The latter effect appears to be strongest for the lowest skid resistance grouping (SC < 0.3), although the accuracy of the calculated crash rate in this case is low because the number of crashes involved is very small (17 or less).

Table 4.7 Crash rate by T/10 site category and SCRIM coefficient – all crashes

T/10 skid site category	**Crashes per 10^8vkt**					
	SCRIM coefficient range					
	SC< 0.3	**0.3≤SC<0.4**	**0.4≤SC<0.5**	**0.5≤SC<0.6**	**0.6≤SC<0.7**	**SC≥0.7**
4	17	16	13	13	14	12
3	**44**	**29**	**27**	**26**	23	**32**
2	**62**	**39**	**33**	**31**	**31**	**33**
1	0	**44**	**52**	**47**	**47**	**40**

Table 4.8 investigates horizontal curvature and skid resistance as classifying variables. Here crash rates are shown to increase as the level of skid resistance decreases within each curvature range, or as the radius of curvature decreases within each skid resistance range.

Table 4.8 Crash rate by horizontal curvature and SCRIM coefficient – all crashes

Horizontal curvature, R (m)	**Crashes per 10^8 vkt**					
	SCRIM coefficient range					
	SC< 0.3	**0.3≤SC<0.4**	**0.4≤SC<0.5**	**0.5≤SC<0.6**	**0.6≤SC<0.7**	**SC≥0.7**
10 ≤ R < 100	**55**	**48**	**54**	**43**	**61**	**40**
100 ≤ R < 1000	**55**	**30**	**25**	23	23	24
1000 ≤ R < 10,000	13	19	16	15	15	14
10,000 ≤ R < 100,000	**32**	21	14	12	13	14
R ≥ 100,000	0	**26**	15	11	**39**	0

As with table 4.8, table 4.9 investigates horizontal curvature and skid resistance as classifying variables, although only for crashes occurring on wet roads. Figures for traffic exposure to wet roads were not available, meaning that crash rates were for wet road crashes in terms of total traffic. Consequently, the crash rates presented in table 4.9 are significantly smaller and display greater statistical error than those in table 4.8 because crash numbers are also smaller. The general form of the results in table 4.8 is the same as for table 4.8. However, as one might expect, the effect of skid resistance is much stronger for crashes occurring on wet roads.

Table 4.9 Crash rate by horizontal curvature and SCRIM coefficient – wet crashes

Horizontal curvature, R (m)	**Crashes per 10^8 vkt**					
	SCRIM coefficient range					
	SC<0.3	**0.3≤SC<0.4**	**0.4≤SC<0.5**	**0.5≤SC<0.6**	**0.6≤SC<0.7**	**SC≥0.7**
10 ≤ R < 100	**55**	17	11	14	5	0
100 ≤ R < 1000	19	11	7	5	5	5
1000 ≤ R < 10,000	1	5	4	3	2	1
10,000 ≤ R < 100,000	4	5	3	2	3	0
R ≥ 100,000	0	13	7	4	7	0

5 Statistical analysis: the model

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

$$Expected\ number\ of\ crashes\ per\ year = ADT.e^{L} \qquad \text{(Equation 5.1)}$$

Where:

ADT = the average daily traffic

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

- absolute gradient
- horizontal curvature
- cross-fall
- T/10 skid site category
- skid resistance (SCRIM coefficient)
- log10(ADT)
- year
- NZTA 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 (eg urban/rural road), or are the product of a coefficient multiplied by the value of the road characteristic (eg A x curvature). These values and coefficients were determined by fitting road data to the variables using the method of maximum likelihood.

Equation 5.1 above can be converted to an equation for crash rate (number of crashes per 10^{8}vkt) by multiplying by the factor $10^{8}/(ADT.365.Road\ Length)$. Crash data was analysed over 10m sections, giving a road length of 10^{-2}km. Therefore, substituting equation 5.1 gives the crash rate as:

$$Crash\ rate\ (crashes\ per\ 10^{8}vkt) = ADT.e^{L}\ x\ 10^{8}/(ADT.365.10^{-2})$$

This simplifies to:

$$Crash\,rate = \frac{10^{10}}{365} \times e^{L} \quad \text{(Equation 5.2)}$$

A number of analyses were carried out on the different data subsets, comprising 'All crashes', 'Selected crashes' (excluding crashes such as merging and pedestrian crashes), 'Wet-road crashes', and 'Selected wet-road crashes' (ie crashes only on wet roads, excluding crashes such as merging and pedestrian crashes). While crash rate models were developed for each of these datasets, only the 'All crashes' model is discussed in detail below. However, model coefficients for the 'Selected crashes', 'Wet-road crashes', and 'Selected wet-road crashes' analyses are given in table 5.2.

Analysis of the 'All crashes' data resulted in two models being developed. The first was a complex model that used spline curves to fit the variables. These curves are illustrated in figures 5.1–5.11 and provide a good appreciation of how the various road characteristics considered affect crash rates. However, difficulties associated with applying the spline curves within a spreadsheet precluded the model's widespread use, and so a simplified model was developed that used polynomial curves instead to fit the data. This simplified model gave coefficients that are relatively straightforward to apply, and these are presented in section 5.2.

5.1 Predicted crash rates from complex model

A number of variables were used to form the exponent L for the complex crash rate model, and these are listed in table 5.1 to illustrate the influence of each variable on the crash rate. The other variables in each graph were held constant, with each taking the default values given in table 5.1. The error bounds shown in each plot correspond to a 95% confidence interval.

Table 5.1 Default graphing values for variables used in the complex model (figures 5.1–5.11)

Variable	Value
year	2002
region	R1
urban_rural	R
skid_site	4
curvature	5000
ADT	1000
gradient	0
SCRIM	0.5
log10_iri	0.3
rut_depth	3
cway_width	12
texture	1.5
lanes_category	two-lane
irr_width	R
cross_fall	0

Figure 5.6 is difficult to interpret because upward and downward gradients cannot be distinguished. Otherwise the plotted graphs show expected trends, although the crash rate relationships shown in

figures 5.9–5.11probably arise from random error and so do not show the true effect of rut depth, carriageway width and texture respectively.

Figure 5.1 Crash rate vs year

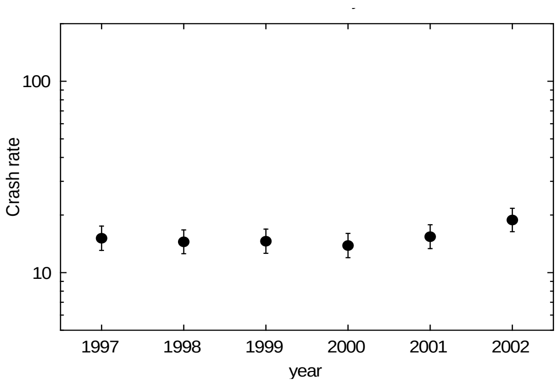


Figure 5.2 Crash rate vs NZTA region

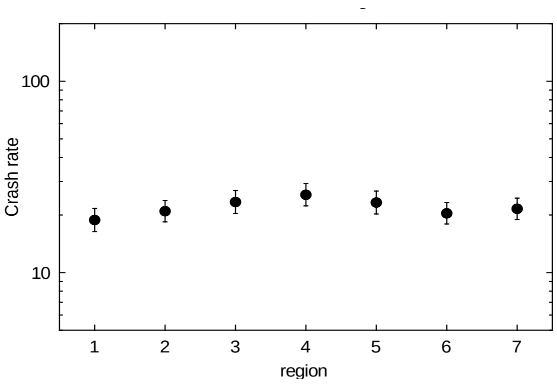


Figure 5.3 Crash rate vs T/10 skid site

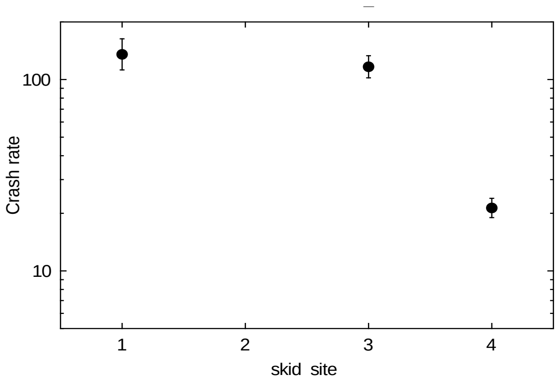


Figure 5.4 Crash rate vs curvature

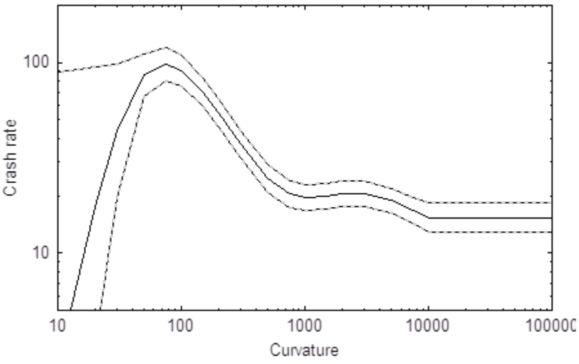


Figure 5.5 Crash rate vs ADT

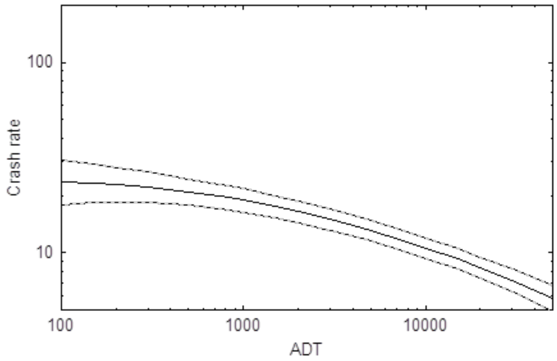


Figure 5.6 Crash vs gradient

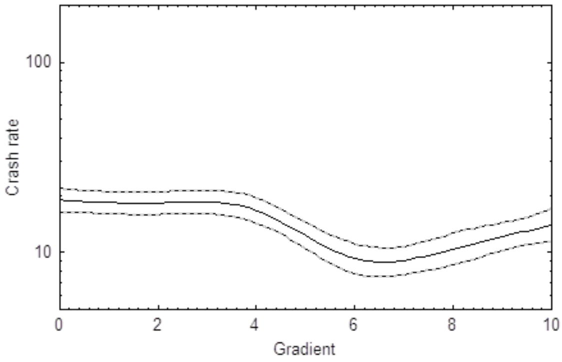


Figure 5.7 Crash rate vs SCRIM coefficient

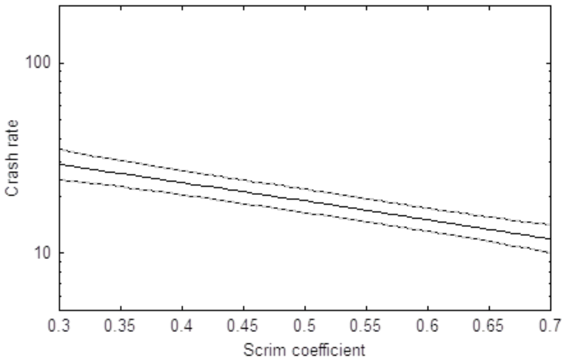


Figure 5.8 Crash rate vs log10(IRI)

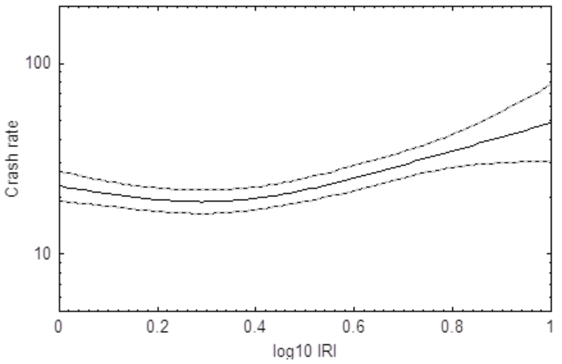


Figure 5.9 Crash rate vs rut depth

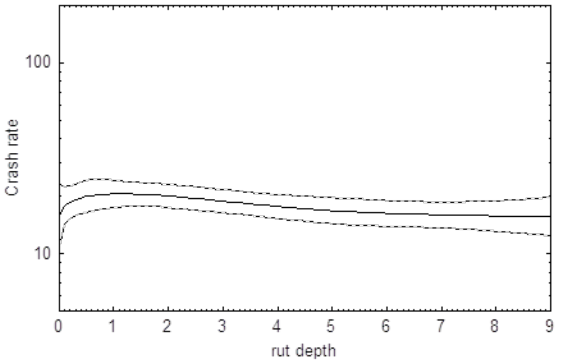


Figure 5.10 Crash rate vs carriageway width

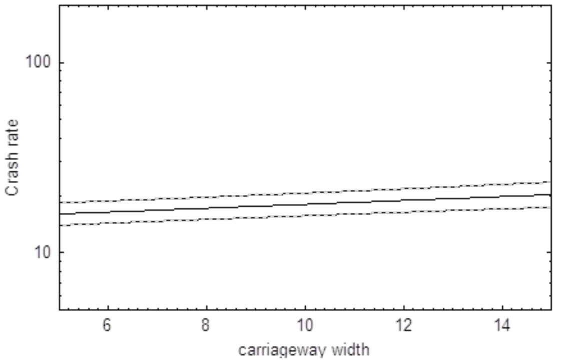
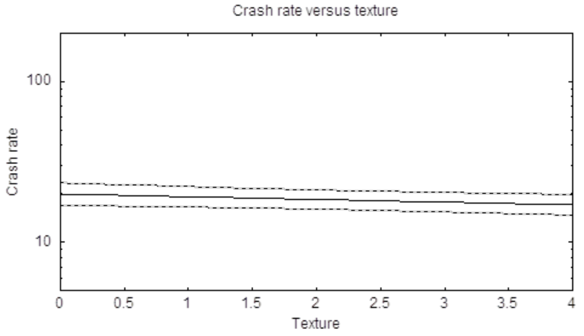


Figure 5.11 Crash rate vs texture



5.2 Simplified crash rate model

A simplified crash rate model was developed from the more complex model, to allow ease of use for a wide variety of users. The simplified model employed polynomial equations instead of the spline curves used in the complex model. While slightly less accurate than the spline representations, these polynomial equations were easily represented by a number of coefficients, which are given in table 5.2 below.

Limitations in the range of data available for the model fitting and the analysis method meant that the model was limited in its applications to the following parameter ranges:

year: 1997–2002 (beyond these years requires estimation of the yearly coefficient)

region: R1–R7 (= NZTA administration regions, where R1=Auckland, R2=Hamilton, R3=Napier, R4=Whanganui, 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: 100–10,000m radius (absolute value used, ie does not differentiate left- from right-hand curves). For radii outside this range, use 100m for values less than 100m, and 10,000m for values greater than 10,000m

ADT: average daily traffic, unlimited range of values

gradient: 4–10% (absolute value is used, and values less than 4% are set equal to 4%)

SCRIM: 0.3–0.7 SCRIM coefficient

IRI: 2.0–10.0IRI (m/km) lane roughness

The predicted crash rate was found by applying equation 5.2, in which L was first evaluated using table 5.2. L was the sum of the terms, which were calculated using the coefficients in table 5.2. Terms corresponding to *categorical variables* (ie year, region, urban_rural, skid_site) simply took the value of the corresponding coefficient in table 5.2, while terms associated with *continuous variables* (ie curvature, ADT, gradient, SCRIM coefficient and IRI) were found by multiplying the variable by the corresponding coefficient. An example calculation for determining the crash rate is given in section 5.3.

Table 5.2 Coefficients for the simplified crash rate model

Parameter	All crashes		Selected crashes		Wet-road crashes		Selected wet-road crashes	
	Coeff.	Standard error	Coeff.	Standard error	Coeff.	Standard error	Coeff.	Standard error
Constant	2.095	1.76	-0.541	2.01	1.015	3.43	0.008	3.83
year: 1997	0.000		0.000		0.000		0.000	
year: 1998	-0.060	0.03	-0.049	0.04	-0.240	0.07	-0.216	0.08
year: 1999	-0.053	0.03	0.044	0.04	-0.027	0.06	0.059	0.07
year: 2000	-0.118	0.03	-0.014	0.04	-0.331	0.07	-0.240	0.08
year: 2001	0.000	0.03	0.089	0.04	-0.203	0.07	-0.175	0.08
year: 2002	0.198	0.03	0.278	0.04	-0.002	0.07	0.008	0.08
region: R1	0.000		0.000		0.000		0.000	
region: R2	0.108	0.03	0.074	0.04	0.192	0.07	0.188	0.08
region: R3	0.210	0.05	0.206	0.05	0.101	0.10	0.091	0.11
region: R4	0.306	0.04	0.260	0.04	0.565	0.08	0.537	0.09
region: R5	0.224	0.04	0.154	0.05	0.053	0.09	0.041	0.11
region: R6	0.105	0.04	0.090	0.05	0.146	0.09	0.161	0.10
region: R7	0.124	0.04	0.164	0.05	0.045	0.09	0.073	0.10
urban_rural: R	0.000		0.000		0.000		0.000	
urban_rural: U	-0.157	0.03	-0.416	0.04	-0.272	0.06	-0.595	0.09
skid_site: 4	0.000		0.000		0.000		0.000	
skid_site: 3	1.595	0.04	0.569	0.07	1.528	0.08	0.561	0.15
skid_site: 1	1.697	0.08	0.803	0.15	1.175	0.20	0.100	0.47
log10(|curvature|)	-5.360	0.29	-5.036	0.33	-7.426	0.57	-6.329	0.63
[log10(|curvature|)]^2	0.759	0.05	0.683	0.05	1.048	0.09	0.843	0.10
log10 (ADT)	0.707	0.31	1.129	0.37	2.380	0.71	2.516	0.80
[log10 (ADT)]^2	-0.173	0.04	-0.247	0.05	-0.401	0.10	-0.424	0.11
|gradient|	-2.598	0.70	-1.411	0.76	-2.913	1.33	-2.802	1.40
|gradient|^2	0.314	0.11	0.202	0.12	0.396	0.21	0.443	0.22
|gradient|^3	-0.012	0.01	-0.009	0.01	-0.017	0.01	-0.022	0.01
SCRIM-0.5	-1.637	0.16	-2.177	0.18	-3.551	0.33	-4.073	0.37
(SCRIM-0.5)^2	-0.090	1.30	1.790	1.47	3.344	2.48	6.220	2.60
log10 (iri)	-10.540	4.48	-18.556	5.96	-7.348	8.48	-17.379	11.50
[log10 (iri)]^2	19.219	8.48	31.537	11.39	10.916	15.65	29.938	21.84
[log10 (iri)]^3	-9.850	4.99	-15.504	6.77	-3.563	8.89	-14.644	12.92

5.3 Example calculation using the simplified model

The following example shows the procedure for calculating crash rate using the simplified ‘All crashes’ model presented in section 5.2.

First the exponent, L, was evaluated, as shown in table 5.3.

Table 5.3 Example application of simplified 'All crashes' crash rate model

Parameter	Parameter value	Calculation value	Corresponding coefficient[a]	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[b]	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)	10,000	4	0.707	2.828
$[\log10 (ADT)]^2$	10,000	16	-0.173	-2.768
|gradient|	0[c]	4	-2.598	-10.392
$\|gradient\|^2$	0[c]	16	0.314	5.024
$\|gradient\|^3$	0[c]	64	-0.012	-0.768
SCRIM-0.5	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
				Σ = - 13.937

a) Coefficients taken from table 5.2.

b) Skid_site category 2 has been combined with skid_site category 4.

c) Gradients between 0 and 4 default to a value of 4.

As the road condition and road geometry parameter values extracted from RAMM pertained to a 10m length of either the left (increasing) or right (decreasing) lane, the expected number of crashes predicted to occur over this length per year could be calculated from equation 5.1:

$$\begin{aligned} \textit{Crash density} &= (ADT/2).e^{L} \\ &= (10000/2).e^{-13.937} \\ &= 0.0044 \textit{ crashes per year per 10lane-m} \end{aligned}$$

The crash rate was calculated using equation 5.2:

$$\begin{aligned} \textit{Crash rate} &= (1010/365).e^{L} \\ &= (1010/365).e^{-13.937} \\ &= 24.3 \end{aligned}$$

A correction should be made for crashes that could not be located on the state highway network and were excluded from the analysis and model predictions. Table 3.4 gave the percentage of 86% for 'All crashes' that could be located in 2002. Therefore, multiplying the calculated crash rate by 100/86 gave the true crash rate in 2002:

$$\text{Crash rate} = 24.3 \times 100/86 = 28.2 \text{ crashes per } 10^8\text{vkt}$$

It is worth remembering that this value was derived from reported crashes and that the actual crash rate, including unreported crashes, would be higher.

5.4 Comparison of fitted and observed crashes

The fit of the 'All crashes' model is tested below by looking at the differences between measured and predicted crashes. The state highway network was divided up, using carriageway area and state highway number, to give 136 individual areas. The model was used to predict the number of crashes in each of these areas. Observed crash numbers are compared with the predicted numbers in figure 5.12 below.

Figure 5.12 Predicted vs observed crashes

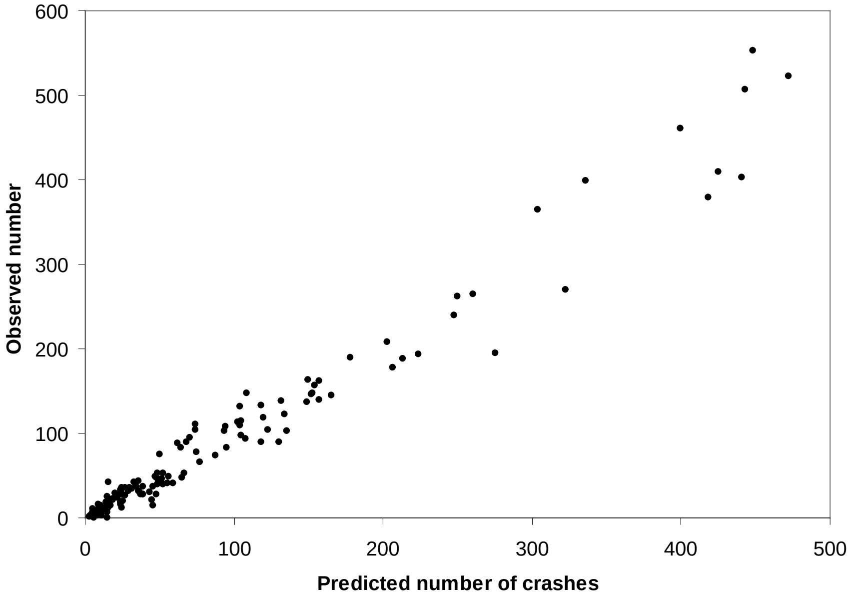
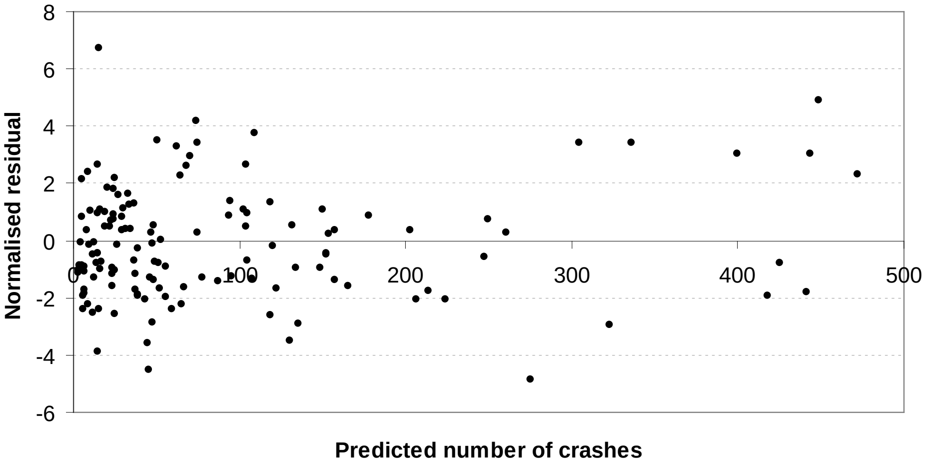


Figure 5.13 shows a plot of the residuals (ie the differences between the observed and predicted values), which have been normalised using equation 5.3.

$$residual = \frac{observed - predicted}{\sqrt{predicted}} \quad \text{(Equation 5.3)}$$

Figure 5.13 Normalised residual plot



For a perfect model fit, there ideally should be few normalised residuals that lie outside the range -2 to 2. With reference to figure 5.13, the actual range of residuals is more in the range –4 to 4, with a few outside this range, indicating that the model fits the data well, but not perfectly.

5.5 Check on the effect of skid resistance

A previous study (Cenek et al 2002) used paired crash site analysis to consider changes in crash numbers and road surface skid resistance at two different points in time for specific crash sites. That study found the 95% confidence interval for the crash rate reduction factor per 0.1 increase in SCRIM coefficient to be:

- (1.2, 1.7)[5] for a comparison of 1995 and 1998 data
- (1.1, 1.8) for a comparison of 1995 and 1999 data.

Application of the simplified model for the 'Wet selected crashes' data subset, with only a linear function of SCRIM coefficient, gave the 95% confidence interval for the crash rate reduction factor per 0.1 increase in SCRIM coefficient as (1.4, 1.7). Since this is in general agreement with the previous estimates, there can be a degree of confidence that estimates of crash rates provided by the simplified model will be sufficiently accurate for safety management purposes.

5.6 Interaction between gradient and skid site 3

Skid site 3 includes a gradient effect, so in this analysis, skid site 3 should have been separated into sites where there was a junction and sites where there was a gradient effect. The failure to do this probably accounts for the peculiar effects concerning gradient found in this analysis. The overall predictive power of the model should not have been greatly affected by this, but interpretation of the skid site and gradient effects have been confused.

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[5] This means that there is a 95% chance that a 0.1 increase in the SCRIM coefficient of a road surface will cause the crash rate to reduce by a factor of between 1.2 and 1.7.

6 Illustrative applications

The simplified crash rate model (SCRM) presented in section 5.2 allows the expected number of injury crashes to be calculated for any 10m lane segment of two-lane state highway from road condition, road geometry and traffic data stored in the NZTA's RAMM database. Therefore, the expected number of injury crashes over any length of road can be calculated by simply summing the 10m crash density estimates over both lanes for the length of interest. The longer the length, the better the agreement between the estimated and observed crash numbers is likely to be.

To demonstrate the possible role of the SCRM in quantifying the benefits of road safety improvement works, illustrative examples drawn from realignment and surface treatment projects are provided below. Actual and predicted 'before' and 'after' crash rates are compared wherever possible, to provide confirmation of the predictive ability of the SCRM.

6.1 Curve realignment

6.1.1 Site selection

'Before' and 'after' injury crash rates from a selection of sites were used to validate the crash rates (CR) calculated using SCRM. CR in this context is the number of crashes where one or more persons are injured per 100 million vehicle kilometres travelled, commonly abbreviated to 10^8vkt.

Three sites that had high crash rates and had been treated by road realignment following a scheme assessment report (SAR) were used. All of the three sites had one or more curves eased (refer to figure 6.1 below) and at least five years post-improvement crash history.

The locations of the realignment and reseal sites and their traffic loadings are given in table 6.1.

Table 6.1 Realignment sites

Site name	Location (SH/RS/RP)	Completion date	Traffic	
			Before	After
Earthquake Flat	005/67/5.4-8.1	Mar 1997	5274 (1994) 18% HCV[a]	6700 (2010) 11% HCV
Tarukenga Curves	005/29/6.4-7.9	Jan 1995	3525 (1992) 13% HCV	5226 (2010) 12% HCV
Scowns Hill	003/321/6.5-7.7	May 1994	3041 (1989) 12% HCV	4135 (2010) 18% HCV

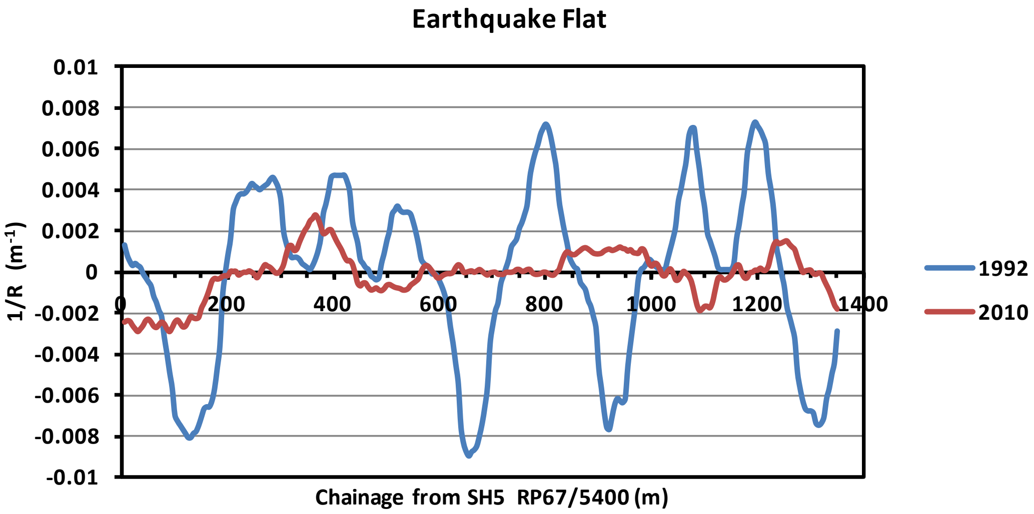
a) Heavy commercial vehicles

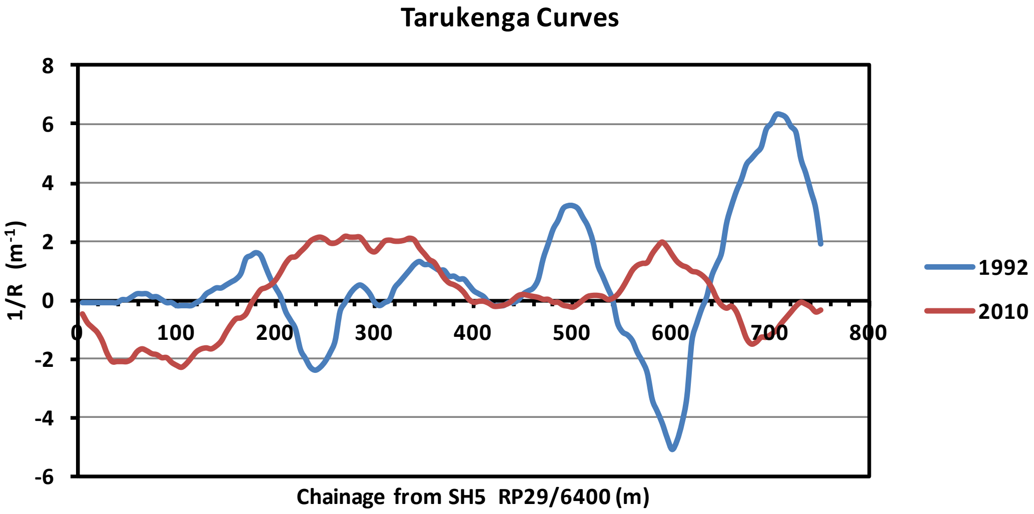
6.1.2 'Before' and 'after' crash rates

Table 6.2 compares the predicted 'before' and 'after' crash rates with those observed for the three case sites. In calculating the observed rates, all reported injury crashes over a 5-year period that ended two years prior to and two years after the realignment works were completed were averaged to obtain the 'before' and 'after' yearly average injury crash numbers respectively.

With reference to table 6.2, it can be seen that the SCRM underestimates 'before' crash rates and mostly overestimates 'after' crash rates, so that the resulting predicted reduction in crashes due to realignment works is understated by a factor of 2 to 6.

Figure 6.1 Before and after horizontal alignment for the three case sites





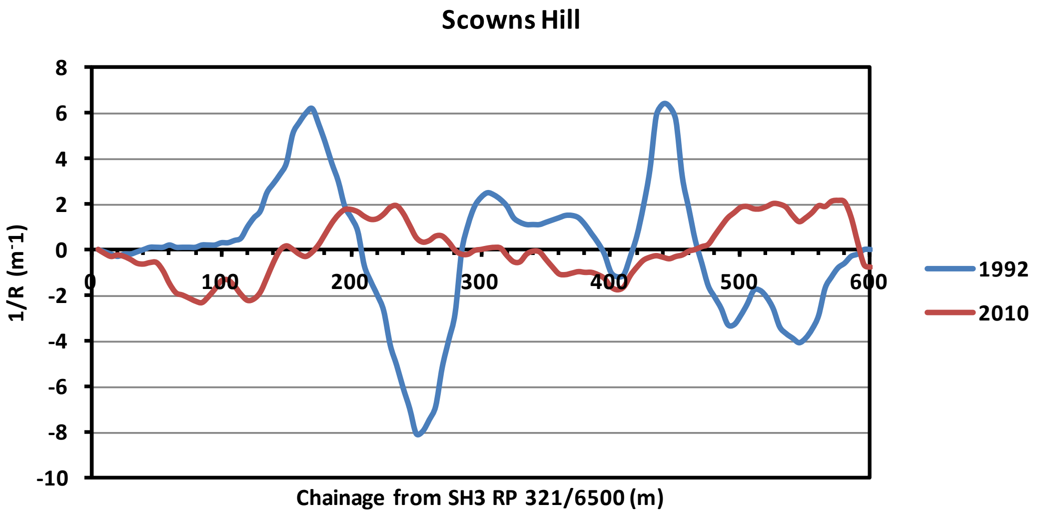


Table 6.2 Comparison of observed and predicted 'before' and 'after' crash rates

Case site	Crash rates (annual injury crashes per 10^8vkt)				Percentage reduction in injury crashes	
	Before realignment		After realignment			
	Observed	Predicted	Observed	Predicted	Observed	Predicted
Earthquake Flat	48.5 (1991–1995)	25.7	12.1 (1998–2003)	14.9	75%	42%
Tarukenga Curves	76.9 (1989–1993)	17.5	28.0 (1997–2001)	15.8	64%	10%
Scowns Hill	55.2 (1988–1992)	24.8	11.0 (1996–2000)	18.9	80%	24%

A possible explanation for the larger-than-desirable differences between observed and predicted crash rates for the three realignment case sites is that the SCRM does not take into account the difference between the approach speed and curve speed. Previous New Zealand research (Koorey and Tate 1997) identified that the risk and severity of crashes on curves were not only a function of absolute curve radius (as modelled in the SCRM), but also the difference between the approach speed and the curve speed. Furthermore, the crash rate was shown to increase significantly when the difference between the approach speed and curve speed exceeded 15km/h. This effect has been subsequently termed the 'out-of-context-curve' (OOCC) effect, and its impact on crash rates and incorporation in statistical crash rate models was investigated in Cenek et al (2012).

6.2 Safety improvement potential of a route

6.2.1 Concept of safety improvement potential

The state highway safety programme has, for the most part, been reactive, eliminating crash 'grey spots' and 'black spots'. However, 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 three or more crashes per annum, whereas between 2000 and 2004 this percentage had dropped to 35%.

To continue to make gains regarding the safety levels 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.

To illustrate the potential use of the model to analyse the safety performance of the state highway network and to guide safety initiatives, an 18.2km length of State Highway (SH) 2 between Paeroa and Waihi (RS 73/0.648 and RS 73/18.836) was selected because of its poor safety level of 10.8 injury crashes per year. This section of SH2 has a 'rural' classification and includes the Karangahake Gorge (see figure 6.2).

Figure 6.2 **18km section of SH2 investigated, Paeroa to Waihi**

6.2.2 Review of total injury crash numbers

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 CAS for the 5-year period 2000–2004.

A comparison of modelled and actual 'All' and 'Wet' injury crash numbers occurring over the entire 18.2km length of SH2 of interest (RS 73/0.64 and RS 73/18.81) is provided in table 6.3 on a yearly and 5-year-mean basis.

Table 6.3 Comparison of model-derived and actual crash numbers

Analysis period	Number of injury crashes					
	All		Dry[a]		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**

a) Derived from subtracting 'Wet' injury crashes from 'All' injury crashes.

With reference to table 6.3, 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 reasons for this are that the criteria for classifying a crash as 'Wet' covers a wider range than in the original statistical modelling exercise and, more importantly, the road in the Karangahake Gorge is shaded and wet for many more days per year than the average road.

Because the model was derived from data for the entire state highway network, its estimates of injury crash numbers represented those that could 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 (ie Karangahake Gorge) is neither more nor less than on 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.

6.2.3 Comparison of actual and modelled crash densities

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

The accepted minimum analysis period is three years (PIARC 2003). For this safety assessment, an extended analysis period of five years, spanning 2000–2004, was chosen. Accordingly, comparisons of modelled and actual yearly crash densities used for detecting where actual crash densities were much higher (black spots) or lower (white spots) than expected for the measured road condition and geometry were based on 5-year mean crash densities. These comparisons were confined to 'All' injury crashes on the grounds that the accuracy and reliability of the safety assessment would be better than for 'Wet' injury crashes, as a consequence of there being more crashes on which to base the assessment.

Figure 6.3 graphically shows the level of agreement between modelled and actual average yearly 0.5km 'All' injury 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 following 0.5km length: 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 that was not properly captured by the model, or it might be due to higher traffic in the vicinity of Waihi that was not captured by the ADT data.

Figure 6.3 Spatial distribution of modelled and actual 'All' injury average yearly crash densities based on 0.5km analysis length for the period 2000–2004

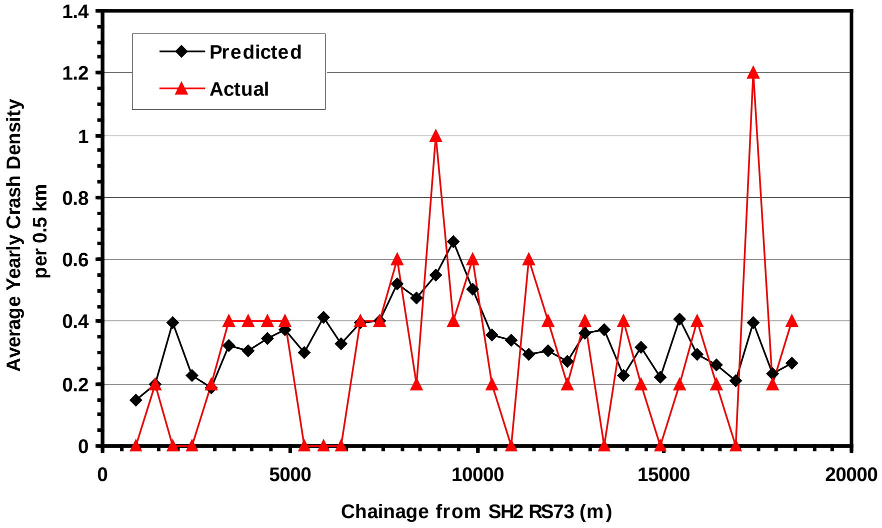


Figure 6.4 is the same as figure 6.3 except that the analysis length was increased from 0.5km to 3km. The six-fold increase in analysis length resulted in a significant improvement in the level of agreement between modelled and actual crash densities. There is only one location where the observed yearly crash density per 3km is clearly greater than predicted (2.4 cf. 1.7). This 3km length is located at the very end of the section of SH2 of interest ie 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 6.4 Spatial distribution of modelled and actual 'All' injury average yearly crash densities based on 3km analysis length for the period 2000–2004

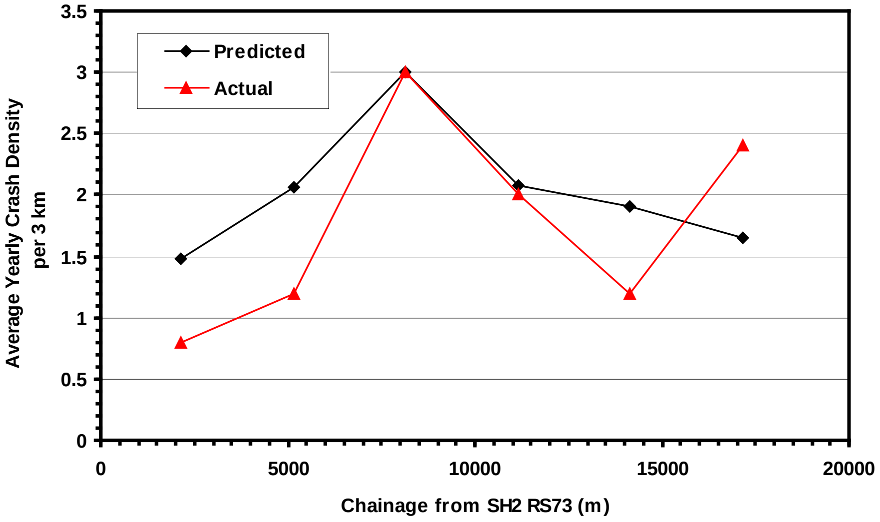


Figure 6.4 also highlights a peak crash density of 3, and this occurs over the 3km length located at RS 73/6.64 – 9.64. As the modelled and actual crash density distributions are in perfect agreement with regard to the location and magnitude of the maximum crash density, there appears to be scope to reduce the maximum by 1 crash per year to the yearly average value of 2 injury crashes per 3km, through appropriate attention to road condition and road geometry.

6.2.4 Relative effectiveness of engineering-based countermeasures

The engineering-based countermeasures available to produce a more constant level of crash risk over the 18.2km length of SH2 between Paeroa and Waihi that could be investigated using SCRM are limited to:

- reducing lane roughness to provide improved tyre-to-road contact
- easing the radius of curves to reduce the amount of friction required to safely negotiate the curve
- increasing 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 easing the radius of a curve, their relative effectiveness in reducing crashes was determined by applying the crash prediction model to the 2005 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 (ie horizontal curvature and skid resistance values were scaled by 1.25, lane roughness was scaled by 0.75, and expected crash numbers were recalculated).

The effect of each countermeasure on site safety level is summarised in table 6.4. Increased skid resistance is shown to be clearly the most effective approach for ameliorating ‘All’ injury crashes over the section of SH2 of interest.

Table 6.4 Change in expected ‘All’ injury crashes over the analysed route (SH2, RS 73/0.648 – 18.836)

Scenario	Number of ‘All’ injury crashes per year	Reduction in injury crashes	
		Crash numbers per year	As a percentage
2005 baseline	11.9	-	-
25% increase in horizontal curvature	10.6	1.3	10.8%
25% increase in skid resistance level	9.7	2.3	18.9%
25% decrease in lane roughness	11. 6	0.3	2.4%

6.3 Crash rates before and after new surface treatment

Loss-of-control crashes are expected to be reduced when a roadway is resealed, because the friction of the road surface is improved at this time. Detailed analysis of crash records at 76 resealed sites located on both urban and open roads (LTSA 1996) suggested that crashes declined overall by 39% following resealing. Specifically, open road loss-of-control crashes on straights declined by 32%, and on curves, by 42%.

To test the suitability of the SCRM to predict crash reductions after resurfacing, typical values for SCRIM skid resistance before and after resealing were input into the SCRM for straight and curved road sections.

Based on the T10 specification (Transit NZ 2002), a road surface will be programmed for priority treatment if it is at or below the specified threshold level (TL) pertaining to the site category. For road sections with a horizontal radius of curvature less than 250m, the TL equals 0.4 SCRIM coefficient (SC), corresponding to T10 site category 2, whereas for road sections with a horizontal radius of curvature equal to or greater than 250m, the TL equals 0.3SC, corresponding to T10 site category 4.

Annual skid resistance surveys of the entire sealed state highway network indicate road surfaces when new have a skid resistance level of around 0.65SC.

Table 6.5 tabulates SCRM estimates of all injury crash rates before and after resealing for a 3000ADT road, this being representative of traffic on regional state highways (NZTA 2010) for the following situations:

- a tight curve (150m horizontal radius of curvature)
- a medium curve (500m horizontal radius of curvature)
- a straight road section (3000m horizontal radius of curvature).

With reference to table 6.5, there is very good agreement between the SCRM estimates of crash reduction following resealing and those derived by the LTSA from a statistical analysis of the 52 open-road sites. This result provides a degree of confidence that the SCRM can adequately model the effects of resealing.

Table 6.5 Estimated reduction in crash rate due to resealing

	Tight curve (150m R)	**Moderate curve (500m R)**	**Straight (3000m R)**
Before reseal			
SCRIM skid resistance	0.4	0.3	0.3
Crash rate (injury crashes per 10^8vkt)	63.5	31.3	18.6
After reseal			
SCRIM skid resistance	0.65	0.65	0.65
Crash rate (injury crashes per 10^8vkt)	42.1	17.7	14.8
% reduction in crash rate	**34**	**44**	**20**

7 Conclusions

The Poisson regression model presented in this study appeared to work in a reasonably satisfactory way and produced results that, for the most part, made sense. Curvature, for example, had a strong effect on crash rate, as expected. There was also a strong correlation between skid resistance and crash rate, and a weaker effect for lane roughness and crash rate. This, however, was a retrospective analysis (as opposed to a designed experiment), meaning it was not possible to be sure that the predictor variables used in the regression analysis were really the ones affecting the crash rates. In particular, it was likely that ADT was a general indicator of road quality and that this was leading to the observed drop in crash rate as ADT increased.

The simplified model in its current form is sufficiently robust for the following four applications:

1. to improve understanding of the factors affecting crash risk and the relative importance of different factors
2. to improve the management of the state highway network by estimating the effect of changes in standards for curvature, skid resistance and roughness on crash numbers
3. 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
4. to help evaluate the effect of an actual change in road construction or management policy in an NZTA administration region by comparing observed and predicted crash numbers.

8 Recommendations

Key recommendations for future work arising from the research are as follows:

- Extend the analysis to territorial local authority (TLA) arterial and collector roads for which there is CAS crash data and corresponding SCRIM+ road geometry and road condition data.
- Separate out the effect of moderate (5–10%) gradients, as in the present model these have been combined with T/10 skid site category 3 (ie down gradients of 5–10%, approaches to road junctions, and motorway junction areas including on/off ramps) effects.
- Incorporate crash severity by exploring the relationships between fatal and serious crashes and all injury crashes. The present model does not account for crash severity.
- Differentiate between one-vehicle and multivehicle crashes.
- Investigate possible interactions between selected predictor variables (these being cross-fall, shoulder width, lane width, and texture) by comparing crash rate relationships derived for state highway networks, which have well-developed design and maintenance standards, with those derived for less regulated TLA arterial roads. In the existing model, these variables show up as insignificant or barely significant, which is counter to international findings. This result has been attributed to the high conformance with NZTA geometric and maintenance standards.
- Investigate the effect of sudden changes in road characteristics, particularly curves immediately following a long straight.
- Trial an improved statistical method for handling the observed non-Poisson variances.

These proposed refinements will extend the present model’s usefulness for guiding safety initiatives and providing economic justifications.

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