Crash Rates at Rural Intersections April 2007

Report for Road Safety Trust

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Abstract

Over recent years there has been an increase in rural lifestyle subdivisions that require direct access from high-speed rural roads. Transit NZ and other road controlling authorities are concerned with the impact such subdivisions will have on the safety of the rural road network. A significant number of rural crashes occur at intersections. The crash prediction models developed for priority junctions in this research (between 2004 and 2006) can be used to predict the effect on intersection safety of new development in rural areas. Making such predictions is difficult at present due to the relatively low crash histories observed at most sites, particularly when focused on specific crash types and road deficiencies such as poor visibility and high speeds.

As traffic volumes grow on the rural road network and four-laning becomes necessary along many road sections, many of the priority-controlled intersections that provide local access to communities are reaching capacity or have safety problems. Little research is currently available in New Zealand to assess the safety implications of the various improvement options, including grade separation, roundabout control and signalised control. The crash prediction models developed in this research project, along with severity ratios (e.g. fatal/serious/minor), for signalised and roundabout controlled intersections in high-speed areas, can assist in assessing the likely impact on safety of proposed intersection improvements.

Executive summary

Over recent years accident prediction models have been developed for low-speed (50km/h) urban intersections with various forms of control. Very little attention has been given to developing models at rural and high-speed intersections. In this study, crash prediction models have been developed for 1) rural priority controlled T-junctions and crossroads, 2) high-speed roundabouts, and 3) high-speed traffic signals. The priority and roundabout controlled intersections are spread throughout New Zealand with the majority in the North Island. Traffic signal sites come from New Zealand and Melbourne, Australia.

The crash prediction models for each major crash type at each intersection type have a number of predictor variables. The 'preferred model' for each crash type was determined using the Bayesian Information Criterion (BIC). Model variables include conflicting flow movements and non-flow variables, such as right turn bay. Models were typically of the following form:

$$A = b_0 x_1^{b_1} x_2^{b_2} \text{ ,}$$

where A is the annual mean number of crashes, x_n is the average daily flow of vehicles, and the b_n are the model coefficients.

Non-flow variable values were collected in the field for the priority-controlled intersections. Non-flow data was not available for the high-speed roundabouts and traffic signals. The non-flow variables examined at priority junctions were: form of control (stop or give-way), presence of right-turn bays, sight distance, and speed on the through road. Where a non-flow variable has two possible values, the models have an exponential term, as shown below:

$$A = b_0 x_1^{b_1} x_2^{b_2} e^{\pm b_3}$$

When such models were used, multiplicative factors were used in place of $e^{\pm b_3}$ in the final model form. The parameters for the preferred models are given in Table 1. The full set of models developed in the research can be found in Appendix B.

Table 1: Conflicting Flow Models at Rural and High-Speed Intersections

Model Description	Model Form #	Goodness of Fit
Priority T-junctions		
1. Crossing – vehicles turning	$A_{RMTP1} = 5.29\times10^{-6} \times q_1^{1.33} \times q_5^{0.15} \times (V_D)^{0.33}$	Yes
2. Right turning and following vehicle	$A_{RMTP2} = 5.29\times10^{-27} \times q_3^{0.46} \times q_4^{0.67} \times S_L^{11.0}$	Yes
3. Other – major road to right of minor road	$A_{RMTP3} = 1.59\times10^{-5} \times (q_5 + q_6)^{0.91}$	Yes

Model Description	Model Form #	Goodness of Fit
4. Other – major road to left of minor road	$A_{RMPT4} = 2.99\times10^{-4} \times (q_3 + q_4)^{0.51}$	Yes
5. Other – minor road	$A_{RMPT5} = 1.47\times10^{-2} \times (q_1 + q_2)^{-0.02}$	Yes
Priority cross-roads		
1. Crossing – major road	$A_{RMXP1} = 1.20\times10^{-4} \times q_2^{0.60} \times q_5^{0.40}$	Yes
2. Crossing – minor road	$A_{RMXP2} = 2.05\times10^{-4} \times q_2^{0.40} \times q_{11}^{0.44}$	Yes (marginal)
3. Right turn and following vehicle – major road	$A_{RMXP3} = 1.08\times10^{-6} \times q_4^{0.36} \times q_5^{1.08} \times \Phi_{RTB}$	Yes
4. Other – major road	$A_{RMXP4} = 1.14\times10^{-4} \times (q_4 + q_5 + q_6)^{0.76}$	Yes
5. Other – minor road	$A_{RMXP5} = 3.44\times10^{-3} \times (q_1 + q_2 + q_3)^{0.27}$	No
Signalised T-junctions		
1. Right-turn against	$A_{RATT1} = 7.76\times10^{-2} \times q_2^{0.41} \times q_5^{-1.20} \times f_{VIC}$	Yes (marginal)
2. Rear-end – major road	$A_{RATT2} = 2.28\times10^{-2} \times Q_{Major}^{0.29} \times f_{VIC}$	Yes
3. Crossing – vehicle turning	$A_{RATT3} = 3.18\times10^{-2} \times q_1^{0.12} \times f_{VIC}$	Yes (marginal)
4. Loss-of-control – major road	$A_{RATT4} = 5.77\times10^{-3} \times Q_{Major}^{0.32} \times f_{VIC}$	Yes
5. Other – major road	$A_{RATT5} = 1.82\times10^{-3} \times Q_{Major}^{0.37} \times f_{VIC}$	No
6. Other – minor road	$A_{RATT6} = 1.40\times10^{-3} \times Q_{Minor}^{0.41} \times f_{VIC}$	Yes
Signalised cross-roads		
1. Crossing	$A_{RAXT1} = 6.82\times10^{-5} \times q_2^{0.31} \times q_{11}^{0.35} \times f_{VIC}$	Yes
2. Right-turn against	$A_{RAXT2} = 2.17\times10^{-2} \times q_2^{0.20} \times f_{VIC}$	Yes
3. Rear-end	$A_{RAXT3} = 4.16\times10^{-7} \times Q_e^{1.18} \times f_{VIC}$	Yes (marginal)
4. Loss-of-control	$A_{RAXT4} = 5.75\times10^{-5} \times Q_e^{0.70} \times f_{VIC}$	Yes
5. Others	$A_{RAXT5} = 1.04\times10^{-2} \times Q_e^{0.14} \times f_{VIC}$	Yes
Roundabouts		
By approach	$A_{RAAR1} = 218\times10^{-6} \times Q_{Approach}^{0.71}$	Yes

- for variable definition refer to body of text

Table 1 shows that some crash types at priority intersections are more influenced by speed and visibility than others and produced some unexpected results for some crash types. The best models for some crash types at T-junctions included speed and visibility deficiency, when compared to the Austroads Guidelines. These models indicated that high speeds, and visibilities less than those recommended by Austroads, result in higher crash rates.

Prediction models were also produced using the link flows, for situations where turning volume counts were unavailable to the research team (at roundabouts), and for

applications of the models when turning counts are not available. In the priority and traffic signal controlled models (product-of-link-flow models) the predictor variables are the two-way traffic volumes on each of the intersection crossing links. For crossroads the first variable (Q_{major}) is the highest of the link flows and Q_{minor} is the flow on the other intersection route. For T-junctions the first predictor variable is always the through road volume and the second is the stem volume, irrespective of the magnitude of the flows. For roundabouts the two-way approach flows were used for each arm of the intersection. The parameter values for each of these models are shown in Table 2. We recommend caution when using the product-of-link-flow models, as they do not provide as accurate a prediction of the accident rate as do the conflicting flow models, particularly when there are higher than normal right-turning volumes.

Table 2: Product-of-link-flow Models at Rural and High-Speed Intersections

Model Description	Model Form#	Goodness of Fit
Priority T-junctions	$A_{RATP0} = 8.85 \times 10^{-9} \times Q_{Major}^{0.20} \times Q_{Minor}^{0.54} \times V_D^{0.04} \times S_{85}^{2.40}$	Yes
Priority cross-roads	$A_{RAXP0} = 4.69 \times 10^{-11} \times Q_{Major}^{0.37} \times Q_{Minor}^{0.63} \times V_D^{0.09} \times S_{85}^{3.31}$	Yes
Traffic signals – T-junction	$A_{RATT0} = 5.10 \times 10^{-2} \times Q_{Major}^{0.37} \times Q_{Minor}^{-0.10}$	Yes
Traffic signals – cross-roads	$A_{RAXT0} = 3.79 \times 10^{-4} \times Q_{Major}^{0.52} \times Q_{Minor}^{0.19} \times f_{VIC}$	Yes
Roundabouts	$A_{RAAR0} = 218 \times 10^{-3} \times \left(Q_{App1}^{0.71} + Q_{App2}^{0.71} + Q_{App3}^{0.71} + Q_{App4}^{0.71}\right)$	Yes

- for variable definition refer to body of text

Models for high-speed signalised intersections indicate that there are generally higher reported injury crash rates in Victoria (Australia) than in New Zealand for a given level of traffic volume. This may be due to different reporting rates in New Zealand and Australia. This matter needs further research. It was also found that, although New Zealand has a slightly higher crash rate for fatal injuries than Victoria (Australia), the serious crash rate is more than double that in Victoria and New Zealand's crash rate is significantly higher for other injury crashes.

Goodness-of-fit statistics (scaled deviance) have been calculated for the 'preferred' model for each crash dataset. The majority of the models were found to be statistically significant to the 95% level of confidence, as shown in Tables 1 and 2. Confidence intervals were also produced for the 'preferred' models to show the flow ranges over which the predictions were most accurate. This varies according to the dataset depending on the flow ranges of intersections in the sample. Confidence intervals for a number of the models are shown in the body of the text.

1. Introduction

1.1 Background

Transport professionals are interested in the crash rate that can be expected at rural and urban high-speed intersections, for a number of reasons. Crash prediction models (CPMs) allow practitioners to predict the number of crashes at high-speed intersections if traffic volumes increase due to new traffic-generating developments, changes in the intersection form of control (to roundabouts or traffic signals) and if selected road features are altered (e.g. visibility and speed limits).

Land Transport New Zealand (formerly Transfund) has adopted the Weighted Accident Procedure (WAP) as an economic analysis method for calculating crash savings at sites with low or zero crash observations and for calculating accident costs at new sites. This procedure incorporates CPMs and came about because:

- Transport analysts expressed concerns that the former crash evaluation procedure did not adequately capture the crash costs at some sites that exhibited unsafe features, but have a relatively low historical crash rate (or have no crash record).
- Stakeholders were often critical of the 'reactive' procedures that require crashes to occur before remedial measures could be justified.
- There is strong support for more 'proactive' methods that can identify sites warranting (and justifying) treatment, irrespective of whether the crash history currently reflects the site's potential for crash occurrence.
- Bad publicity can occur when modifications to current sites or new site layouts (or forms of control) result in an unsafe intersection, particularly if crashes are severe or fatal. CPMs could be used to predict if the crash frequency (and severity) will increase.

Few models have been developed for rural (and high-speed urban) intersections. Rural intersections are particularly hazardous due to high operating speeds on one or more approaches. Many low-volume rural intersections are narrow and do not have the design features of more modern intersection layouts. There is also a concern that having traffic signals in high-speed areas will lead to high crash rates and more severe crashes.

Models have already been produced for low-speed urban intersections, and urban and rural links, mainly because traffic count data was readily available. Traffic count data is not generally available at rural intersections and such data had to be collected for this project.

The models for the priority intersections in this study incorporate data from sites from a variety of classes of rural roads throughout New Zealand and use data in the form of turning movement counts, observed speed, sight distance, geometric data and reported crashes from the Ministry of Transport's Crash Analysis System (CAS).

The number of high-speed and rural traffic signal sites in New Zealand (where at least two legs of the intersection have 80km/h or higher speed limits) is relatively low (up to 20 sites).

To develop good fitting models it is desirable to have large sample sets. To overcome this problem, high-speed traffic signal sites in Victoria, Australia were included in the dataset.

1.2 Objectives

The aim of the project is to develop crash prediction models for rural intersections in New Zealand. Models will be developed for specific crash types and total crashes at rural priority T-junctions, crossroads, and high-speed traffic signals and roundabouts.

1.3 Report Layout

This report is structured in four parts:

- Data collection methods for each intersection type (Section 2);
- National and site specific crash data for the main crash types (Section 3);
- Crash prediction modelling procedures (Section 4);
- Crash models for each intersection type (Sections 5 to 9); and
- Conclusions drawn from the project, recommendations for use of the research and areas requiring future research (Section 10).

The modelling section (Section 4) outlines the general modelling procedure, the various model forms developed, the selection of the preferred model using goodness-of-fit testing and the parameters of the preferred model forms.

Crash models have been developed for priority T-junctions, priority cross-roads, signalised t-junctions, signalised cross-roads and roundabouts. The majority of the Victorian traffic signal sites are within the Melbourne metropolitan area. At least one of the roads has a speed limit of 80km/h or above. Most of the New Zealand signalised and roundabout controlled intersections are on expressways or on the urban/rural boundary edge of a major population centre.

2. Data Collection

2.1 Introduction

The data which was collected for this project depended on the form of intersection being studied and included turning movement counts, approach speed, sight distance, geometric data and reported accidents (from the Ministry of Transport's Crash Analysis System, CAS) for priority intersections and a more limited amount of information for high-speed traffic signals and roundabouts.

2.2 Priority Intersections

2.2.1 Site Selection

The sample set was drawn for the New Zealand population of rural priority three- and four-legged intersections, which is extensive. Fifty of the existing T-junction sites were selected in a previous research study. These sites were located in the Canterbury, Bay of Plenty, Manawatu-Wanganui and Wellington regions. Additional data was collected at the 50 old sites, due to additional data collection requirements. New sites were selected in the Auckland, Waikato, Taranaki, Manawatu-Wanganui, Wellington and Canterbury Regions. For financial reasons, the majority of the new sites were located within 40 km of a Beca office. Table 2.1 shows the number of crossroads and T-junctions in each region.

Table 2.1 Intersection Locations

Region	Number of Sites	
	Crossroads	T-junctions
Auckland	16	15
Waikato	20	10
Bay of Plenty	-	20
Taranaki	23	9
Manawatu-Wanganui	2	10
Wellington	7	2
Canterbury	33	34
Total	**101**	**100**

Intersections were selected initially from desktop assessment of road maps. Research staff then visited each potential site to determine whether it was suitable for inclusion in the dataset. Site selection criteria included:

1. The major and minor arms of the intersections had to be sealed (this excludes many sites with very low volumes of traffic);
2. The angle of each arm of the intersection had to be between approximately 70° and 110°;
3. Crossroads could not have staggered side road arms or any treatment that required vehicles travelling from the side road to travel parallel to the major road at any stage;

4. The intersection was not permitted to have had any major layout changes in the last 5 years, nor to have had significant change in side-road land use in the same time period; and
5. The intersection was to have few or no raised islands (it was, however, permitted to have centrally-located islands on the side road).

2.2.2 Traffic Volumes

Once sites were selected, turning movement counts were collected. These were collected manually at each site for three hours, with one-hour counts in the morning and the evening, and the final count at around midday. Weekly, daily and hourly correction factors from the "*Guide to Estimation and Monitoring of Traffic Counting and Traffic Growth*" were used to estimate the AADT. The hourly factors were calculated from flow profiles for the different road types. The three road types used in this study were:

- Rural Strategic (a);
- Rural Strategic (b); and
- Rural Urban Fringe.

The factors for each road were selected based on the researchers' knowledge about each site. The distance to the nearest urban centre and whether the major road was on a State Highway were important issues to consider in selecting road type.

Both national and intersection crash data was extracted from the Ministry of Transport's Crash Analysis System (CAS). Intersection crashes were extracted for the period 1 January 1995 to 31 December 2004. Section 3 summarises both the national statistics and those for this sample of sites in this study.

2.2.3 Approach Speed

For each intersection, the speeds of vehicles on the major road approaching the intersection were measured using a speed gun as indicated in Figure 2.1 and Figure 2.2.

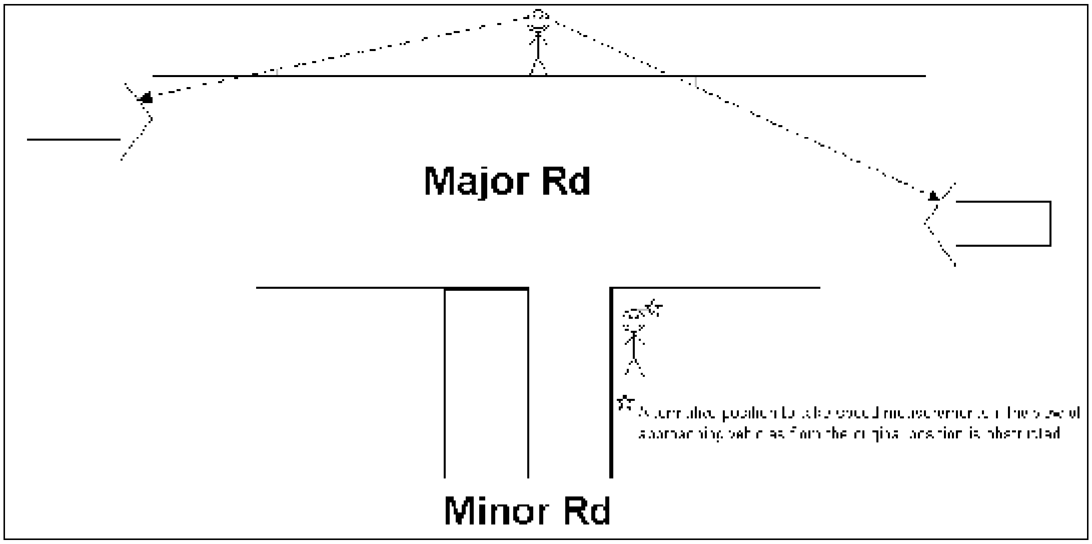

Figure 2.1: Speed Survey Location at Rural T-junctions

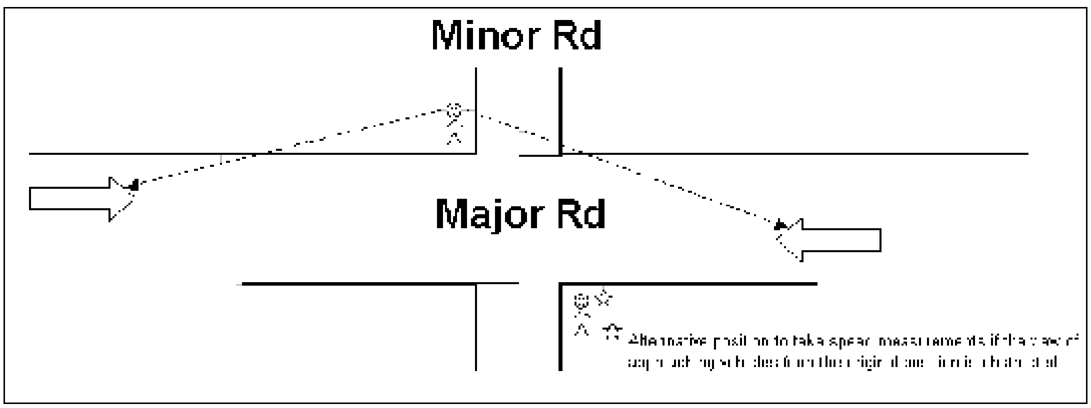

Figure 2.2: Speed Survey Location at Rural Crossroads

From the locations identified in Figure 2.1 and Figure 2.2 at least 30 speeds of vehicles approaching from both directions were recorded, a total of at least 60 speeds at each intersection.

Only the free speeds of light vehicles such as cars, station wagons, vans, SUVs and MPVs were recorded. The speeds of heavy vehicles, light vehicles towing trailers, following and turning vehicles were not recorded.

The following definitions for approach speed variables were used in the models:

S_L **mean speed of vehicles along major road approaching the intersection to the left of vehicles on the minor road;**

S_R **mean speed of vehicles along major road approaching the intersection to the right of vehicles on the minor road;**

S_{LSD} **standard deviation of vehicle speeds along major road approaching the intersection to the left of vehicles on the minor road;**

S_{RSD} standard deviation of vehicle speeds along major road approaching the intersection to the right of vehicles on the minor road.

2.2.4 Sight Distance

This involved measuring the sight distance from the side road using a laser range finder. The range finder was used to measure the distance in both directions from two locations on each minor road. These locations were 2 and 10 metres back from the limit lines along the side road (see Figure 2.3 and Figure 2.4).

The height that the site distance measure was taken from was approximately the driver's eye height of 1.05 m. A number of ranges were taken for each sight distance measurement until a typical value was established.

For the models developed in this study the sight distances used are the sight distances measured 2 metres back from the limit line.

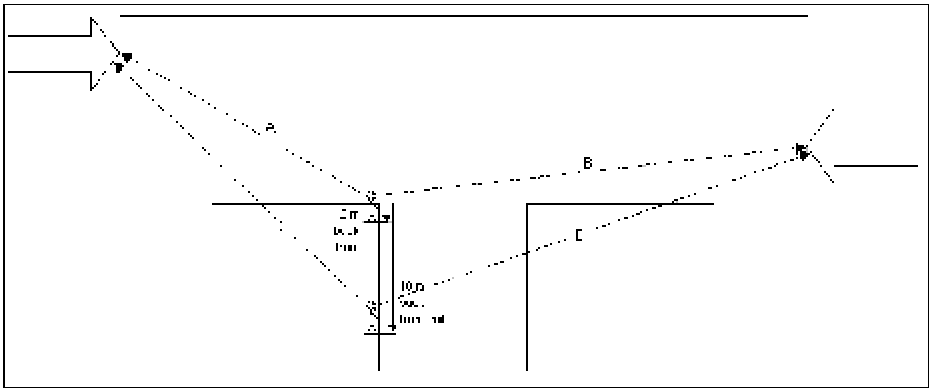

Figure 2.3: Sight Distance Measurements at Rural T-junctions

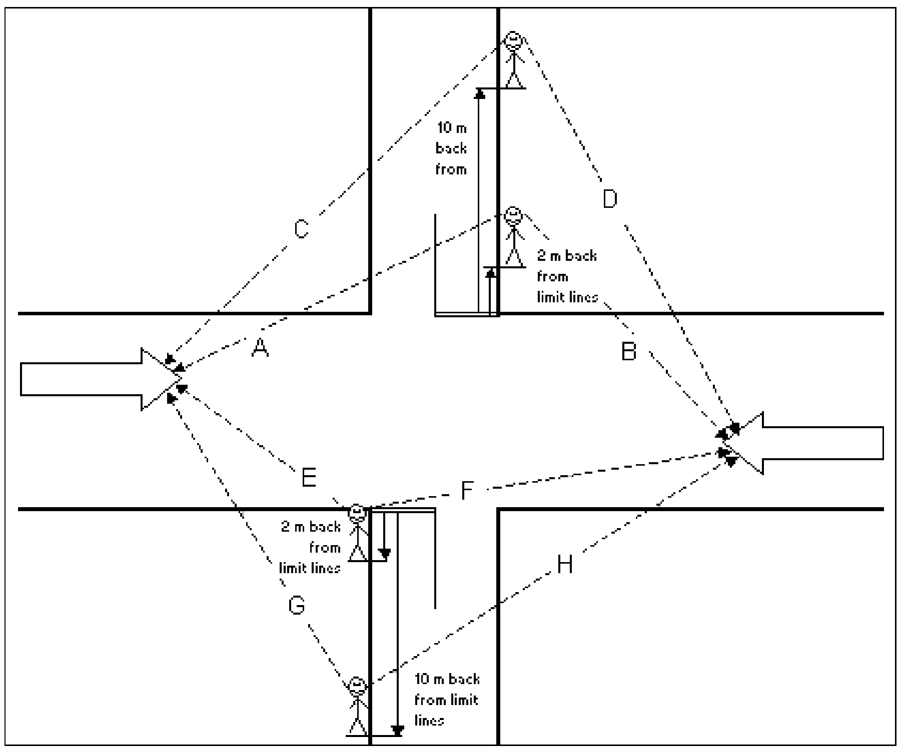

Figure 2.4: Sight Distance Measurements at Rural Crossroads

The following definitions for sight distance variables were used in the models:

V_L **sight distance from two metres back from vehicle at the limit lines on minor road to vehicles approaching from the left along major road;**

V_R **sight distance from two metres back from the limit lines on minor road to vehicles approaching from the right along major road;**

V_{LD} **sight distance deficiency to the left based on the difference between the available visibility and the minimum safe intersection sight distance (SISD) for the 85th percentile speed. The SISD is described in Austroads Part 5: Intersections at Grade. Where there is no deficiency a default deficiency of 1 metre has been used to enable modelling;**

V_{RD} sight distance deficiency to the right based on the difference between the available visibility and the minimum safe intersection sight distance (SISD) for the 85th percentile speed. Where there is no deficiency a default deficiency of 1 metre has been used to enable modelling; and

V_D total sight distance of deficiencies to the right and left.

2.2.5 Intersection Data

During the site surveys the following intersection data was collected:

- Intersection control type (whether stop or give-way controlled or uncontrolled);
- Presence of central island on side road arms;
- Presence of flag or full lighting;
- Presence of advanced intersection signage on both major and minor roads;
- The lane configuration, including right-turn bays, left-turn acceleration bays and left-turning deceleration bays;
- Subjective assessment of lane widths on both major and minor roads;
- Subjective assessment of visibility from minor road approaches;
- Orientation of intersection; and
- Presence of chevron boards at T-junctions.

2.3 Traffic Signals

2.3.1 Site Selection

The number of high-speed traffic signal sites (where at least two legs of the intersection are 80km/h or higher) in New Zealand is relatively low. To develop good fitting models it is desirable to have large sample sets. Given that a large sample size is not available in New Zealand it was decided to develop covariate models using data from sites in Victoria, Australia, where there are a number of such sites and readily available data. This covariate analysis also allows us to make a direct comparison of crash frequency at an intersection level between the two countries.

Sites were excluded from the dataset where turning movement counts were not available or where the intersection had been upgraded after 2001.

Table 2.2 shows the number of sites in New Zealand or Melbourne that met these criteria and had data available for them. As the number of signalised seagull intersections was small these were not analysed further in this study.

Table 2.2 Numbers of High Speed Signalised Intersections in Study

	New Zealand	Melbourne	Total
Crossroads	4	24	28
T-Junctions	8	7	15
Seagull	3	0	3

2.3.2 Traffic Volumes

Turning movement counts at signalised intersections are often available from the signal controller. Some controllers do not have the facility to produce these easily and were therefore excluded from the study. Collecting data using this method has both limitations and benefits relative to collecting turning movements manually. The main benefit of collecting data form controllers is that counts can be collected over a longer duration. The disadvantages include:

- Errors introduced due to the method of counting vehicles using inductive loops;
- Not being able to determine the number of vehicles performing each movement from shared lanes; and
- In most cases slip lanes are not monitored so the controllers cannot count left-turning vehicles.

A number of the two-way link volumes were calculated from the detector counts. These were then compared to link volumes from tube counts, which compared favourably, and it is believed that errors in counting vehicles using signal controllers may be associated mainly with older controllers.

Where slip lanes or shared through and left lanes were present, left-turn volumes were assumed to be equal to the right-turn movement in the opposite direction. This assumption is not ideal and is a disadvantage of using counts from signal controllers.

2.4 Roundabouts

2.4.1 Site Selection

There are few rural roundabouts in New Zealand. Of the roundabouts that do exist there are a number with only one arm having a speed limit of 80 km/h or higher. There are also a number of high-speed roundabouts incorporated into motorway and expressway interchanges where arms are often one way. Both these types of roundabout were excluded from the study.

Likewise, sites that had been installed after 2001 were excluded due to limited crash histories, as too were roundabouts where there had been a significant change in traffic volumes over the crash period. This occurred, for example, when a link was added to an expressway.

Using these criteria 17 roundabouts with four arms and four roundabouts with three arms were selected across the country.

2.4.2 Traffic Volumes

A major issue with rural roundabouts is that turning movement data is generally unavailable. This is due to the following factors:

- **Turning movement data is not collected electronically as it is with traffic signals;**
- **Manual turning movement counts are difficult and labour intensive at roundabouts and especially at high-volume roundabouts; and**
- **The majority of rural roundabouts are Transit controlled and Transit does not have a program for collecting turning movement counts at roundabouts.**

Because of the lack of turning movement counts at rural roundabouts (counts were only obtained for six roundabouts), link volumes were used to calculate the major and minor link volumes for use in crash prediction models. These link volumes were obtained from four sources:

- **Manipulating turning movement counts;**
- **Link counts from Transit NZ;**
- **Link counts from TLAs; and**
- **The Ministry of Transport's Crash Analysis System (CAS) (both link counts and estimates).**

3. Crashes at Rural Intersections

3.1 Introduction

This section investigates crash severity and crash types at high speed (speed limit >70 km/h):

- Priority T-junctions
- Priority Crossroads
- Signalised T-junctions
- Signalised Crossroads; and
- Roundabouts.

3.2 Priority T-junctions

3.2.1 Crash Types Nationally

Crash data was extracted from CAS for all crashes at rural T-junctions in New Zealand for the period 2000-2004 inclusive. Figure 3.1 shows the severity of reported crashes at rural T-junctions in this period. Figure 3.2 shows the number of 'fatal and injury' crashes and non-injury crashes for each crash type. For an explanation of crash types refer to Appendix A.

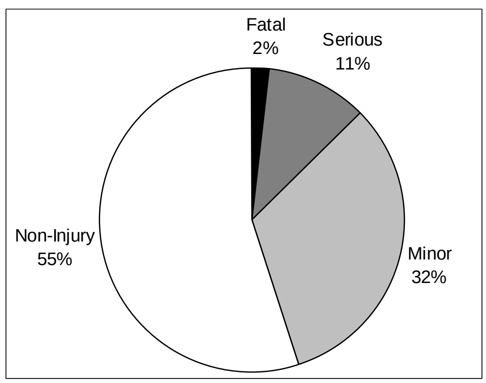

Figure 3.1 Severity of Reported Crashes at Rural T-junctions (Nationally 2000-2004)

Figure 3.1 shows that the majority of reported crashes at rural T-junctions are non-injury. This differs from the situation at rural crossroads (see Figure 3.) where the majority are injury accidents (54%).

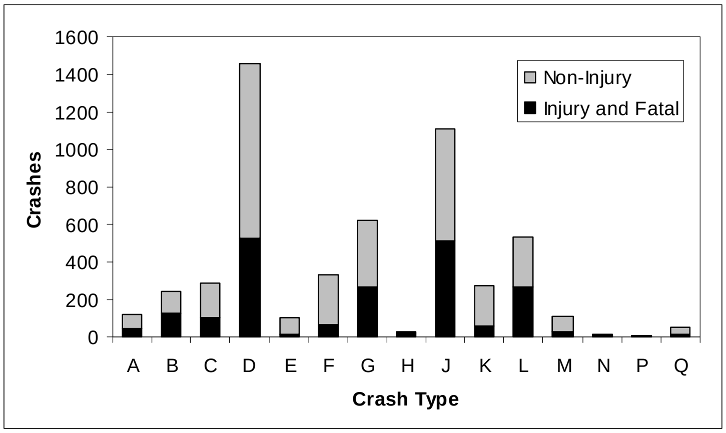

Figure 3.2 Reported Crashes at Rural T-junctions by Crash Type (Nationally 2000-2004)

3.2.2 Crash Types at Study Sites

Crash data was extracted from CAS for all crashes that occurred at crossroads in the sample set. The major crash types for the major road, are shown, along with crash severity, in Figure 3.3.

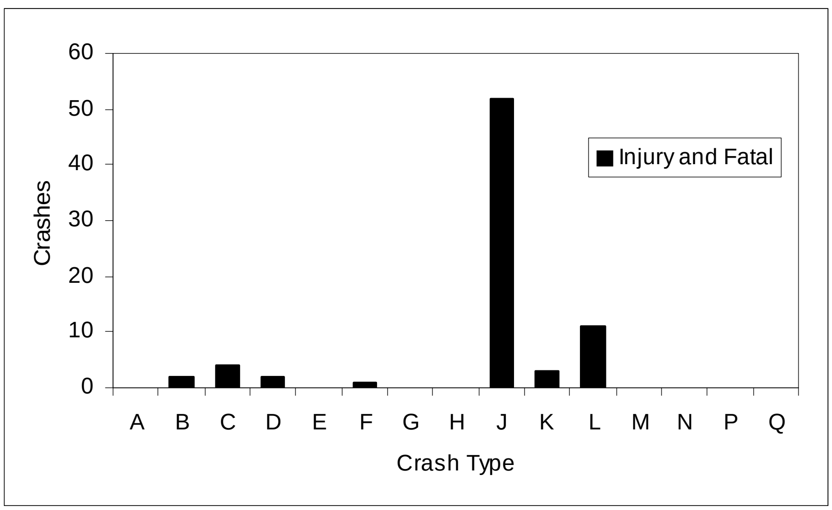

Figure 3.3 Reported Injury and Fatal Crashes on the Major Road (Sites in Study 1995-2004)

Figure 3.3 shows similar major crash types to those that occur nationally (in Figure 3.2). The exception is the proportion of Type D (cornering) crashes, which is lower in the sample set.

3.2.3 Main Crash Types to be Modelled

To produce data-sets with sufficient crash observations it has been necessary to aggregate the crash types into more general categories as described below and shown in Figure 3.4:

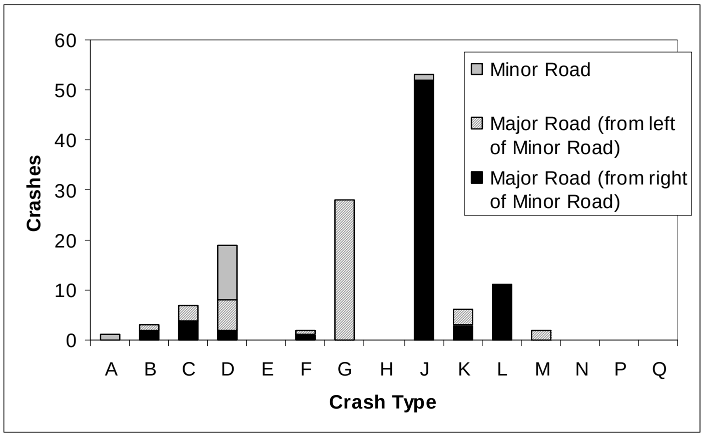

Figure 3.4 Reported Injury and Fatal Crashes by study crash types (Sites in Study 1995-2004)

- **Crossing – Vehicle Turning (Major Road approach to right of Minor Road) – crashes of Type JA where a vehicle travelling through the intersection collides with a vehicle turning right out of the minor road;**
- **Right Turner and Following Vehicle (Major Road approach to left of Minor Road) – crashes of type GC, GD and GE where a vehicle turning right from the major road collides with a vehicle that approached the intersection from the same direction;**
- **Other (Major Road approach to right of Minor Road) – crashes of all types other than those outlined above that occur on the major road approach to the right of the minor road approach;**
- **Other (Major Road approach to left of Minor Road) – crashes of all types other than those outlined above that occur on the major road approach to the left of the minor road approach;**
- **Other (Minor Road) – crashes of all types that occur on the minor road approach.**

3.3 Priority Crossroads

3.3.1 Crash Types Nationally

Crash data was extracted from CAS for all crashes at rural crossroads during 2000-2004 inclusive. Figure 3.5 shows the severity of reported crashes at rural crossroads in this period. Figure 3.6 shows the number of 'fatal and injury' crashes and non-injury crashes for each crash type. For an explanation of crash types refer to Appendix A.

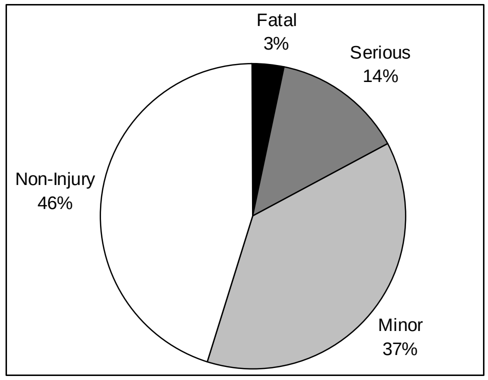

Figure 3.5: Severity of Reported Crashes at Rural Crossroads (Nationally 2000-2004)

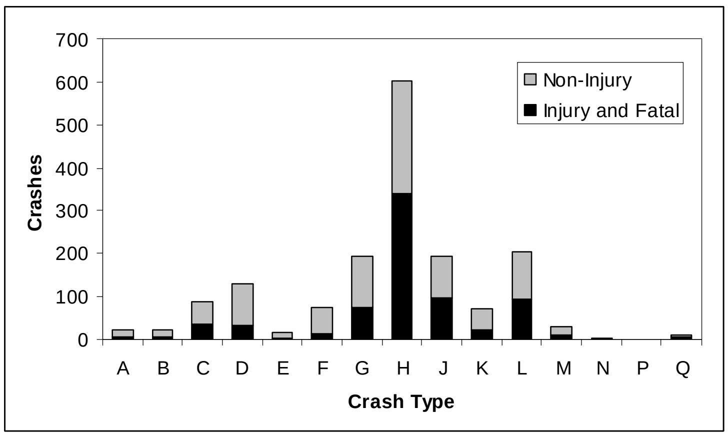

Figure 3.6: Reported Crashes at Rural Crossroads by Crash Type (Nationally 2000-2004)

3.3.2 Crash Types at Study Sites

Crash data was extracted from CAS for all crashes that occurred at crossroads in the sample set. The major crash types for the sample set are shown in Figure 3.7 and Figure 3.8, which consider crashes on the major and minor roads (road that is controlled). Overall 67% of injury and fatal accidents occurred on the major road. It should be noted however that, for the most common crash type H (crossing – no turns), the coded crash road depends on what side the vehicle was hit on. The road coded is always the road on which the vehicle was hit from the right-hand side.

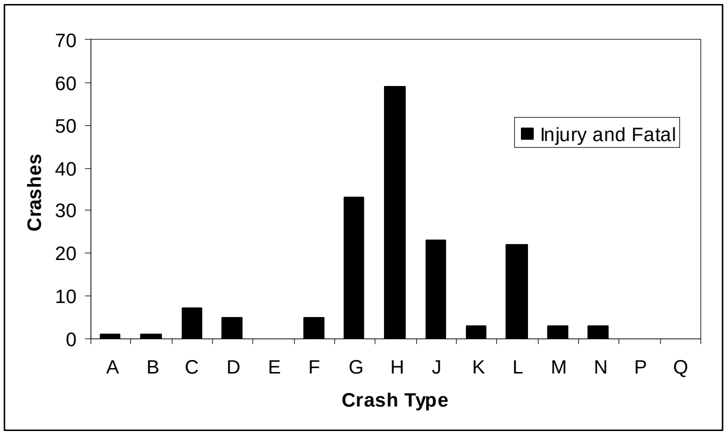

Figure 3.7: Reported Injury and Fatal Crashes on the Major Road (Sites in Study 1995-2004)

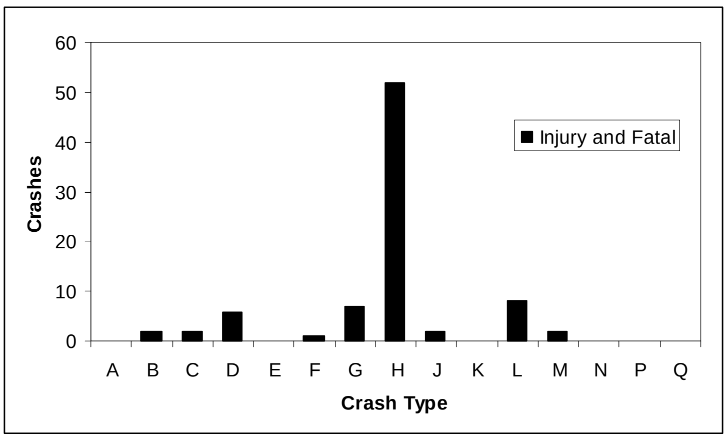

Figure 3.8: Reported Injury and Fatal Crashes on the Minor Road (Sites in Study 1995-2004)

Figure 3.7 and Figure 3.8 show similar major crash types to those that occur nationally (in Figure 3.6).

3.3.3 Main Crash Types to be Modelled

To produce data-sets with sufficient crash observations we have to aggregate the crash types into groups again, as follows:

- **Crossing (Major Road) – crashes of type HA where a vehicle travelling through the intersection on the major road is hit from the right by a vehicle travelling through the intersection along the minor road;**
- **Crossing (Minor Road) – crashes of type HA where a vehicle travelling through the intersection on the minor road is hit from the right by a vehicle travelling through the intersection along the major road;**
- **Right Turning and Following Vehicle (Major Road) – crashes of type GC, GD and GE where a vehicle turning right from the major road collides with a vehicle that approached the intersection from the same direction;**

- **Other (Major Road) – crashes of all types other than those outlined above that occur on the major road; and**
- **Other (Minor Road) – crashes of all types other than those outlined above that occur on the minor road.**

3.4 Signalised T-Junctions

3.4.1 Crash Types Nationally

Figure 3.9 and Figure 3.10 show the proportion of crashes of each type at low-speed and high-speed signalised T-junctions respectively. As for signalised crossroads, the proportion of rear-end crashes is greater for high-speed sites, with a consequent decrease in the proportions of other crash types. For high-speed signalised T-junctions this reduction is in the proportion of right-turn-against crashes(LB).

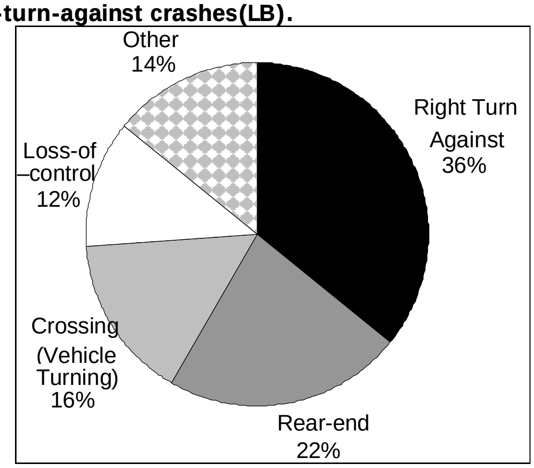

Figure 3.9 Injury Crash Types for Low-speed Signalised T-junctions

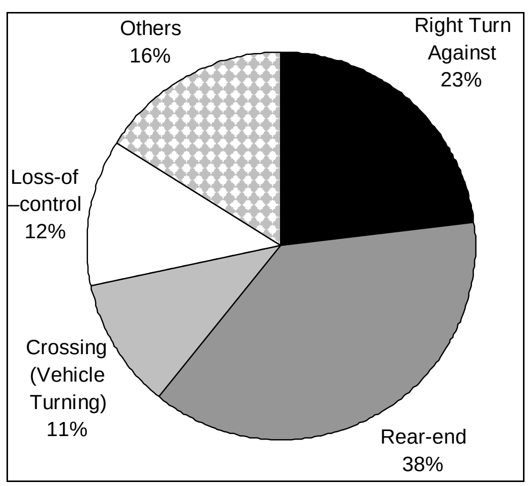

Figure 3.10 Injury Crash Types for High-speed Signalised T-junctions

The severity of crashes at high-speed T-junctions is also higher for rear-end injury crashes, with 25% of reported rear-end crashes resulting in injury, as opposed to 13% for those at

urban sites. Table 3.1 shows that overall 28% of all crashes at high-speed sites involve injury whereas the equivalent figure is 17% for urban sites.

Table 3.1 Percentage of Reported Crashes that Involve Injury

Crash Type	Crash Code	Urban	High-Speed
Right Turn Against	LB	26%	36%
Rear-end	FA to FE	13%	25%
Crossing (Vehicle Turning)	JA	23%	53%
Loss of control	C and D	17%	20%
Others		10%	29%
Total		17%	28%

3.4.2 Relationship between Crashes and Traffic Volume

Minor and major road traffic volumes at the high-speed signalised T-junctions in New Zealand were compared with those from Melbourne. Figure 3.11 shows that the New Zealand sites typically have lower traffic volumes than those around Melbourne. It also shows that there is a spread of sites of varying traffic volumes recorded on the minor and major arm approaches.

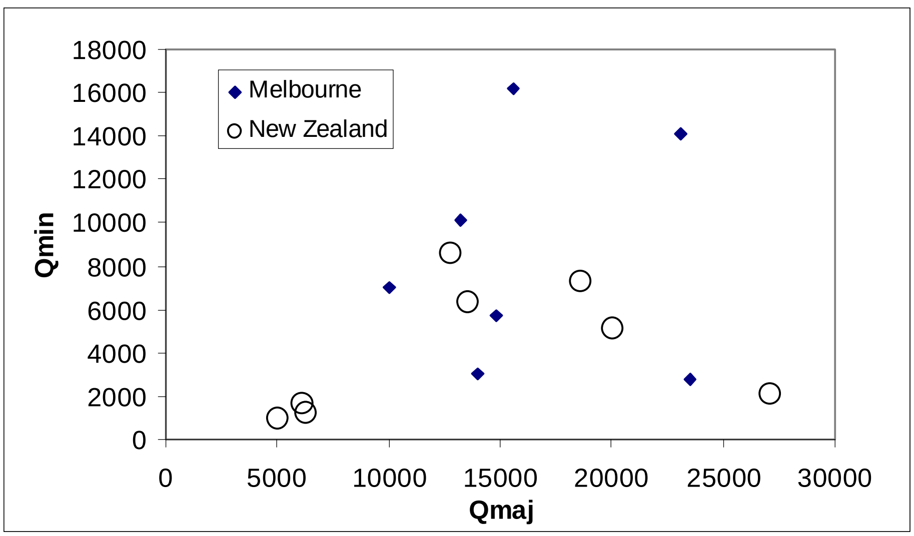

Figure 3.11 Comparison of Major and Minor Flows at High Speed Signalised T-junctions

Figure 3.12 shows a weak relationship between crashes and traffic volume for signalised T-junctions. It also shows that, in general, the number of reported injury crashes at the Melbourne sites is higher than that at the New Zealand sites.

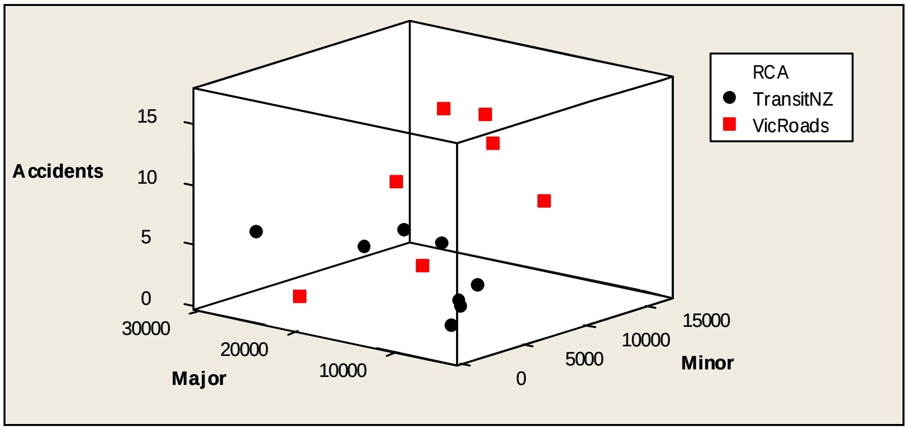

Figure 3.12 Relationship Between Crashes and Traffic Volumes at Signalised T-junctions

To determine potential reasons for the difference in the number of reported crashes between Victoria and New Zealand a brief Internet search was carried out on reporting rates in these two locations. No statistics were found for Victoria on this topic; reporting rate information is available in New Zealand.

3.5 Signalised Crossroads

3.5.1 Crash Types Nationally

Figure 3.13 and Figure 3.14 show the proportion of crashes of each type at low-speed (50 and 60km/h) and high-speed signalised crossroads, respectively.

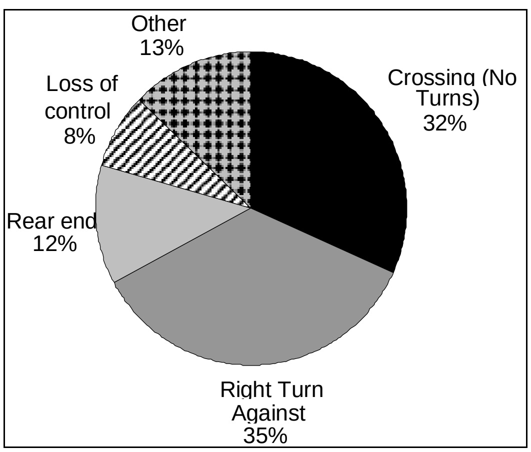

Figure 3.13 Injury Crash Types for Low-speed Signalised Crossroads

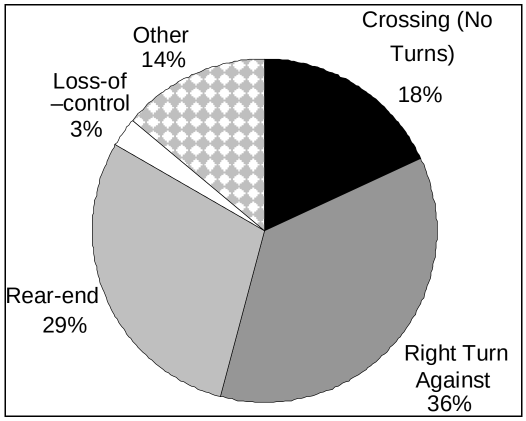

Figure 3.14 Injury Crash Types for High-speed Signalised Crossroads

Figure 3.13 and Figure 3.14 show that the proportion of crossing (HA) crashes is lower at high-speed signalised crossroads, while the proportion of rear-end crashes is higher. This may not indicate that the likelihood of rear-end crashes increases at high-speed traffic signals, but may instead reflect the increased severity of these crashes and hence their reporting as injury crashes. This is illustrated in Table 3.2, with rear-end injury crashes being 27% of reported rear-end crashes at high-speed sites, as opposed to 12% of those at low-speed sites. Overall injury crashes comprise 30% of all crashes at high-speed sites and 20% of those at low-speed sites.

Table 3.2 Percentage of Crashes that Involve Injury

Crash Type	Crash Code	Low-Speed	High-Speed
Crossing (No Turns)	HA	32%	42%
Right Turn Against	LB	23%	45%
Rear-end	FA to FE	12%	27%
Loss-of-control	C & D	23%	9%
Others		11%	26%
Total		20%	30%

3.5.2 Relationship between Crashes and Traffic Volume

Minor and major road traffic volumes at the high-speed signalised crossroads in New Zealand were compared with those from Melbourne. Figure 3.15 shows this comparison. It appears that the small number of New Zealand sites have typically lower traffic volumes than the sites around Melbourne.

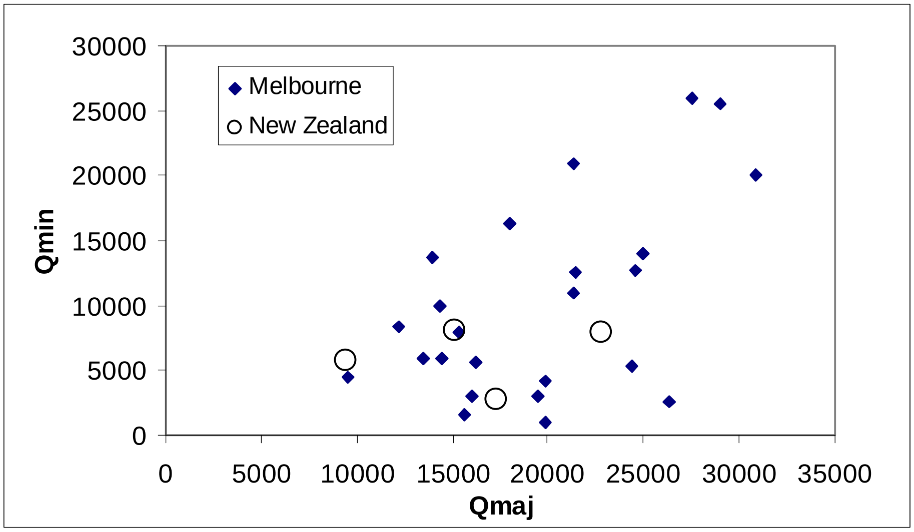

Figure 3.15 Comparison of Major and Minor Flows at High-speed Signalised Crossroads

Figure 3.16 shows a strong relationship between crashes and traffic volume for signalised crossroads. Again it appears that there are fewer injury crashes at the New Zealand sites than the Melbourne sites.

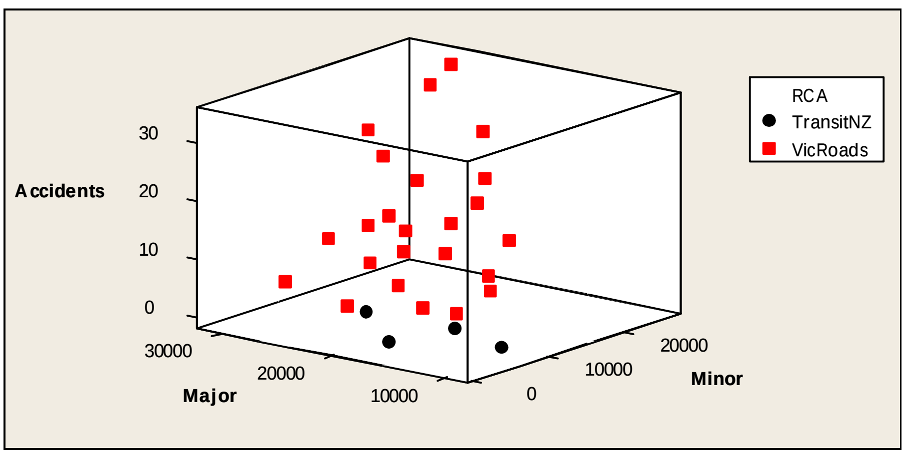

Figure 3.16 Relationship Between Crashes and Traffic Volumes at Signalised Crossroads

3.6 Roundabouts

3.6.1 Crash Types Nationally

Figure 3.17 and Figure 3.18 show the proportion of crashes of each type at urban-speed and high-speed roundabouts respectively. Unlike that for signalised intersections the proportion of rear-end crashes is not significantly higher at high-speed sites. The most common crash type at roundabouts, entering versus circulating, is lower in proportion at high-speed sites, but the proportion of loss-of-control type crashes is a lot higher.

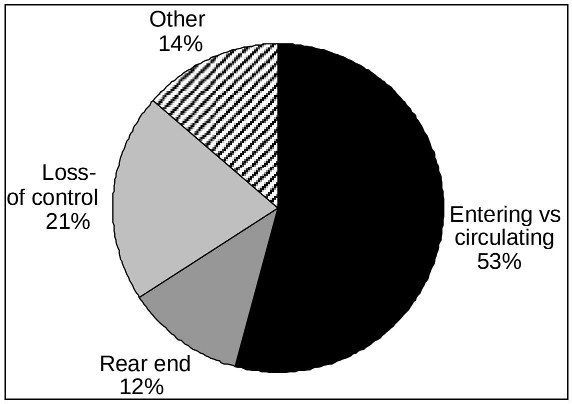

Figure 3.17 Injury Crash Types for Urban Roundabouts

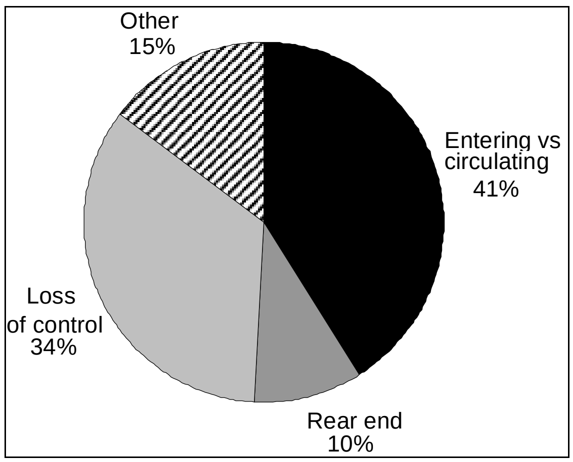

Figure 3.18 Injury Crash Types for High-speed Roundabouts

Table 3.3 shows that the percentage of injury crashes to all reported crashes is 14% at low speed roundabouts and 18% at high-speed sites. This is a smaller difference from that observed at the priority and signalised controlled intersections.

Table 3.3 Percentage of Reported Crashes that Involve Injury

Crash Type	Crash Code	Urban	High-Speed
Entering vs circulating	HA, LB, JA, MB, KA and KB	19%	26%
Rear end	FA to FD	9%	9%
Loss of control	C and D	19%	22%
Others		7%	12%
Total		14%	18%

3.6.2 Relationship between Crashes and Traffic Volume

Minor and major road traffic volumes at the rural four-arm roundabouts were compared with those at urban four-arm roundabouts from Turner (2000). Figure 3.19 shows that major and minor road flows are reasonably well correlated, especially for urban roundabouts. This is

potentially a result of the criteria under which roundabouts are typically installed. These 'criteria' typically require traffic volumes on the arms of the roundabout to be reasonably well balanced, for efficient operation, and the minor road volume to be sufficiently large to warrant delaying the major road traffic, when changing the layout from a priority-controlled intersection to a roundabout.

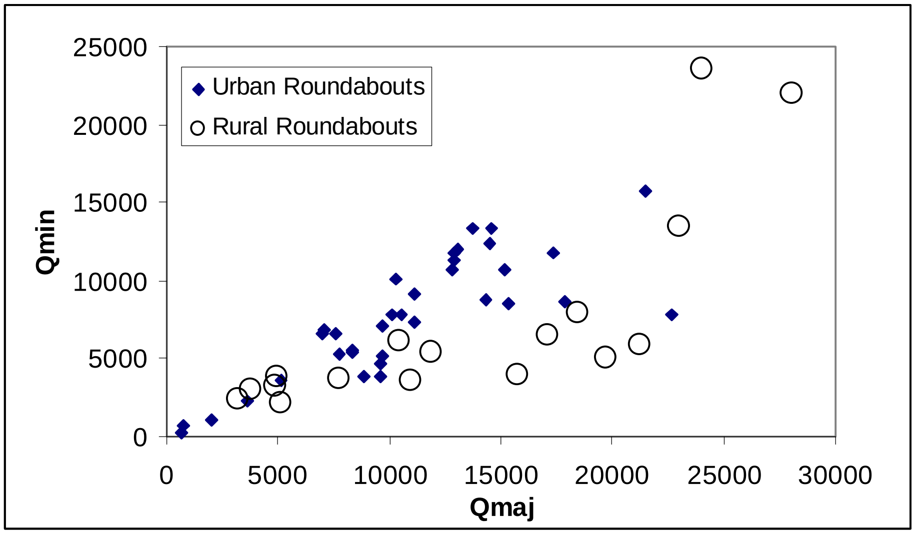

Figure 3.19 Comparison of Major and Minor Flows at Urban and Rural Roundabouts

To investigate the relationship between traffic volumes and crashes, Figure 3.20 was produced. This shows that the number of crashes increases with traffic volumes. It also shows that there is greater variability in the relationship for rural roundabouts, with a number of rural intersections with comparatively low minor road volumes having a low number of crashes. The variability in the relationship for rural roundabouts may also be indicative of the increased importance of roundabout design with increasing speeds.

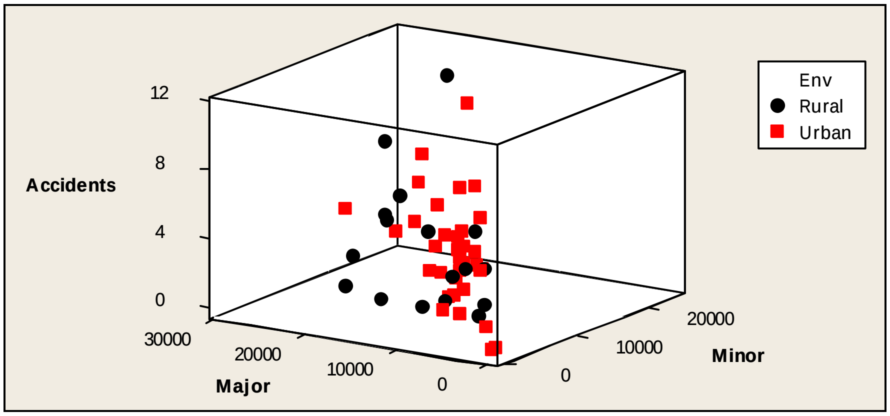

Figure 3.20 Relationship Between Crashes and Traffic Volumes at Roundabouts

4. Crash Prediction Modelling

4.1 Introduction

The aim of crash prediction modelling is to develop relationships between the mean number of crashes, traffic volumes, and non-flow predictor variables such as visibility and speed. The models are called generalised linear models and typically have a negative binomial or Poisson error structure. Generalised linear models were first introduced to modern road crash studies by Maycock & Hall (1984), and extensively developed in Hauer et al. (1989). These models were further developed and fitted using crash data and traffic counts in the New Zealand context for motor-vehicle-only crashes by Turner (1995).

This section outlines the modelling process used in this study, which is:

1. Trialling functional forms
2. Selecting models for goodness-of-fit testing;
3. Testing goodness of fit and selecting preferred models; and
4. Interpreting crash relationships and significance.

4.2 Functional Form

When crash prediction models were developed for conflicting flow variables only, only one model was generally developed for each crash type and the functional form of the crash model was assumed to be a power function as shown in Equation 4.1.

Equation 4.1 $$A = b_0 x_1^{b_1} x_2^{b_2}$$

However, non-flow variables can have different relationships to crashes from traffic volumes, requiring the testing of different model forms. The two functional forms for non-flow variables that are tested are power functions (Equation 4.2), and exponential functions (Equation 4.3).

Equation 4.2 $$A = b_0 x_1^{b_1}$$

Equation 4.3 $$A = b_0 e^{x_1 b_1}$$

where:

A is the annual mean number of crashes

x_1 is a continuous non-flow variable, and

b_0, and b_1 are model parameters.

Software has been developed in Minitab in order to fit such models (that is, to estimate the model coefficients); this can be readily done, however, in many other commercial packages such as GENSTAT, LIMDEP or SAS.

4.3 Adding Variables to the Models

Given the large number of possible variables for inclusion in the models for a particular crash type a criterion is needed to decide when the addition of a new variable is worthwhile; this balances the inevitable increase in the maximum likelihood (*L)* of the data against the addition of a new variable (where *p* is the number of variables included in the model and n is the total number of observations in the sample set). We chose to use the popular Bayesian Information Criterion (BIC). We stop adding variables when the BIC reaches its lowest point. The BIC is given by Equation 4.4.

Equation 4.4 $$\text{BIC} = (-2\ln(L) + p\ln(n))/n$$

The model with the lowest BIC is typically the preferred model. Addition of a new variable to a model generally provides an improved fit, though this may be slight and therefore not reduce the BIC. In Figure 4.1 the BIC values indicate that the parsimonious number of parameters is two. However, if analysts consider that the model with three parameters includes an important variable that the model with two parameters does not, they could justifiably select the model with three parameters, depending on the outcome of goodness-of-fit testing (see Section 4.1.3).

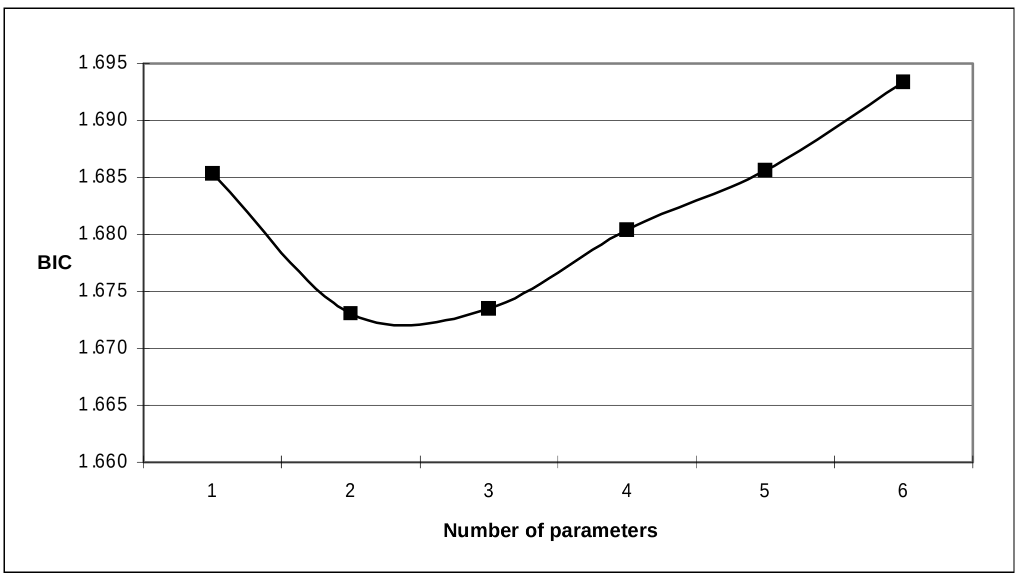

Figure 4.1 Bayesian Information Criterion (BIC)

Modelling every possible combination of variables to determine which has the lowest BIC would be time consuming and inefficient. The process used in this study is to introduce each non-flow variable to a model with the main flow variables. Many studies have shown that flow variables are generally more important predictor variables than non-flow variables. The variables that maximise the log-likelihood (and therefore minimise the BIC) are then added together to the flow-only model in a forward substitution process and the BIC calculated. This process is repeated for a number of variable combinations (but not all combinations), taking into account that some variables may be correlated as this is fairly common, particularly for layout/design variables.

Where variables are correlated, the 'best' two variables may not result in a better model. The correlation between different variables can be determined by examining the correlation matrix. The correlation matrix is a matrix of correlation coefficients between the variables used for modelling. Correlation coefficients indicate the strength and direction of a linear relationship between two random variables, where a value of one indicates a perfect positive correlation between two variables and a value of zero indicates statistical independence. Figure 4.2 illustrates an example of different values of linear correlation.

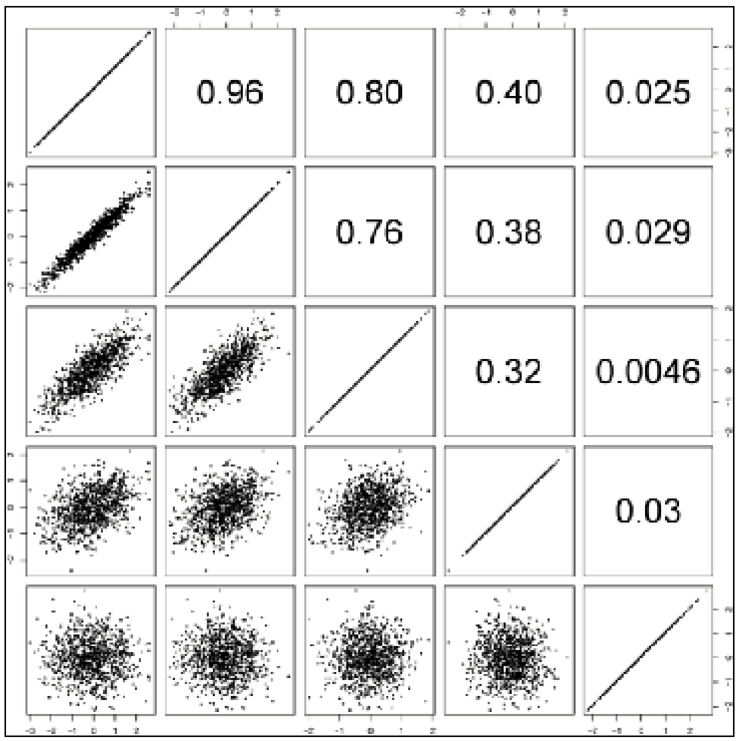

Figure 4.2 Example of Linear Correlation

4.4 Testing Goodness of Fit and Preferred Models

After the model with the lowest BIC has been obtained, the models are ranked in order of lowest (best) to highest (worst) BIC. A number of models are then selected for goodness-of-fit testing as, although the BIC provides us with models based on a parsimonious variable set and maximum likelihood, the models may still not fit the data well. Additionally, likelihood and goodness of fit are not directly related, meaning that the model with the best likelihood or BIC may not be the model with the best goodness of fit.

The models that are selected for goodness-of-fit testing are those that have a low BIC and have the variables that professional knowledge deems necessary. These 'necessary' variables are usually limited to the conflicting flow variables.

The usual methods for testing goodness of fit of generalised linear models involve using the test statistics; scaled deviance G^2 (twice the logarithm of the ratio of the likelihood of

the data under the larger model, to that under the smaller model) or Pearson's X^2 (the sum of squares of the standardised observations). These statistical tests are not accurate for testing goodness of fit of crash prediction models, except at an aggregate level (total crashes) at higher flow intersections where crash rates are relatively light. In most cases the models are being fitted to data with very low crash means, and this results in the "low mean value" problem. This problem was first pointed out by Maycock and Hall (1984).

In Wood (2002) a "grouping" method has been developed which overcomes the "low mean value" problem. The central idea is that sites are clustered and aggregate data from the clusters are then used to ensure that a grouped scaled deviance follows a chi-square distribution if the model fits well. Evidence of goodness of fit is provided by a *p*-value. If this value is less than 0.05, say, there is evidence at the 5% level that the model does not fit well. Software has been written in the form of Minitab macros in order to run this procedure.

Once the goodness of fit has been calculated for the models selected for goodness-of-fit testing the 'preferred' model is identified. This is the model that maximises the goodness of fit.

If the model fits poorly over a certain range of predictor variables (for example high or low volumes), this can be identified using the grouping technique by plotting predicted crashes against reported crashes. A poor fit is illustrated by a group that has different predicted and reported numbers of crashes (where the plotted point is furthest from the 45 degree line). The site features of approaches in any outlier groups can then be examined to determine where the model relationship may not apply.

4.5 Model Interpretation

4.5.1 Understanding Relationships

Once models have been developed, the relationship between crashes and predictor variables can be interpreted from the parameter values in most cases. However, caution should always be exercised in interpreting such relationships when there are multiple predictor variables, because two or more variables can be correlated (see Section 4.4).

When examining the relationships with non-flow variables it is important to determine whether they are significant. Significance of the model parameters is determined by examining the 95% confidence interval for the model parameter to identify if the relationship changes in trend over the range of the confidence interval. For example, a relationship may be significant if both the upper and lower limits of the confidence interval indicate that crashes increase with increases in the value of the predictor variable.

In the following sections guidance is given on interpreting crash relationships for:

- Power functions
- Exponential functions, and
- Covariates.

4.5.2 Power Functions

Equation 4.5 presents a model with a single variable (such as a flow or speed) with a power-function form. This section examines interpretation of the relationship between crashes and a predictor variable in a model of this type. The method can also be used to examine a single variable with a power function form in a multiple variable model.

Equation 4.5 $$A = b_0 x_1^{b_1}$$

where:

A	**is the annual mean number of crashes**
***x*₁** → x_1	**is a continuous flow or non-flow variable, and**
b_0 **and** b_1	**are model parameters.**

In this model form the parameter b_0 acts as a constant multiplicative value. If the number of reported injury crashes is not dependent on the value of predictor variable (x_1), the model parameter b_1 would be zero. In this situation the value of b_0 is equal to the mean number of crashes. The value of the parameter b_1 indicates the relationship that the predictor variable has (over its range) with crash occurrence. There are five types of relationship for this model form, as presented in Figure 4.3 and discussed in Table 4.1.

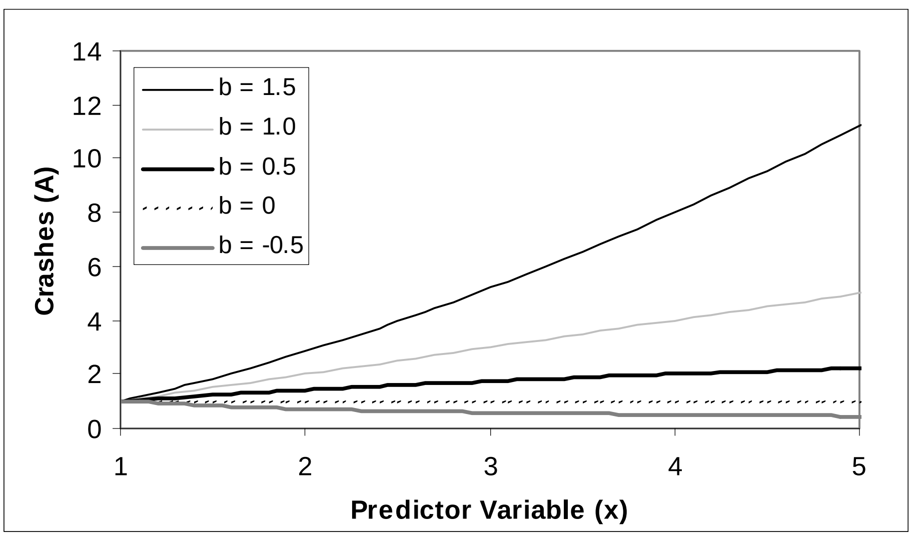

Figure 4.3 Relationship Between Crashes and Predictor Variable x for Different Values of Model Exponents (b_1)

Table 4.1 Relationship Between Predictor Variable and Crash Rate

Value of Exponent	Relationship with crash rate
bi > 1	For increasing values of the variable, the number of crashes will increase, at an increasing rate
bi = 1	For increasing values of the variable, the number of crashes will increase, at a constant (or linear) rate
0 < bi < 1	For increasing values of the variable, the number of crashes will increase, at a decreasing rate

Value of Exponent	Relationship with crash rate
bi = 0	There will be no change in the number of crashes with changes in the predictor variable
bi < 0	For increasing values of the variable, the number of crashes will decrease

Generally, models of this form have exponents between $b_i = 0$ and $b_i = 1$, with most flow variables having an exponent close to 0.5 (i.e. the square root of flow). In some situations, however, parameters have a value outside this range.

4.5.3 Exponential Functions

Equation 4.6 presents a model with a single variable (such as a flow or speed) with an exponential-function form. As with power functions the interpretation can also be used to examine a single variable in a multiple variable model.

Equation 4.6 $$A = b_0 e^{x_1 b_1}$$

where:

A	is the annual mean number of crashes
x_1	is a continuous flow or non-flow variable, and
b_0 and b_1	are model parameters.

The value of the parameter b_1 indicates the relationship that the predictor variable has (over its range) with crash occurrence. There are three types of relationship for this model form, as presented in Figure 4.4 and discussed in Table 4.2.

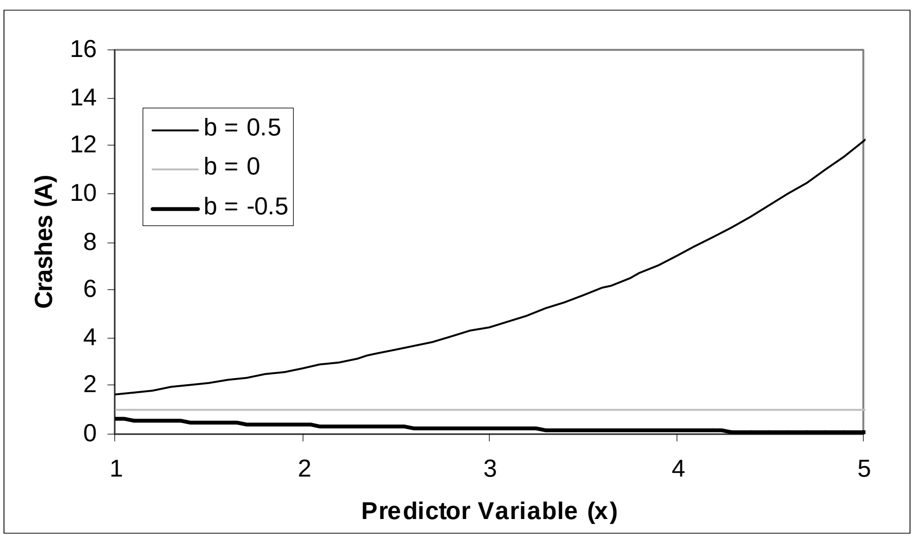

Figure 4.4 Relationship Between Crashes and Predictor Variable x for Different Values of Model Parameter (b_1)

Table 4.2 Relationship Between Predictor Variable and Crash Rate

Value of Parameter	Relationship with crash rate
$b_i > 0$	For increasing values of the variable, the number of crashes will

Value of Parameter	Relationship with crash rate
	increase, at a increasing rate
$b_i = 0$	There will be no change in the number of crashes with changes in the predictor variable
$b_i < 0$	For increasing values of the variable, the number of crashes will decrease at a decreasing rate

4.5.4 Covariates

In the modelling exercise covariates are different b_0 parameters for various features that are discrete variables with a small number of alternatives such as the presence of a right-turn bay at priority intersections. As all crash prediction models include multiplicative b_0 parameters regardless of the functional form of the predictor variables (Section 5.2), covariates can be applied to all models.

In this report, instead of having multiple b_0 values, a b_0 value is presented for the most common case (for example no right turn bay) and a multiplier for other situations (for example the presence of a right-turn bay). This multiplier factor indicates how much higher (or lower) the number of crashes is for sites with a particular value of the covariate.

5. Priority T-Junction Crash Models

The following sections present the crash prediction models developed for the major crash types at rural priority T-junctions. Each model is identified by a unique code as set out in Appendix D. A product of link flows model is also presented in Section 5.6, which can be used to predict the total number of crashes for which link volumes, but not turning movement counts, are available.

5.1 Crossing – Vehicle Turning (Major Road approach to right of Minor Road)

Models were developed for type JA crashes, where a vehicle travelling through the intersection (from the right of the minor road) collides with a vehicle turning right out of the minor road (see Figure 5.1).

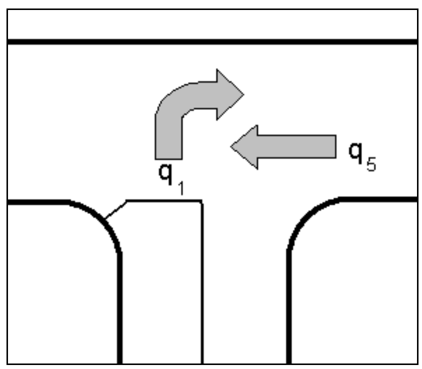

Figure 5.1 RMTP1 Crash Variables

The models were developed in accordance with the process outlined in Section 4. In this process 11 models were developed to explain this crash type. Appendix B outlines the predictor variables and the parameters of the models tested. Equation 5.1 presents the preferred model form, which includes both conflicting volumes and the sum of visibility deficiencies to the left and right. This model predicts all crashes of this type at the intersection.

Equation 5.1 $$A_{RMTP1} = 5.29 \times 10^{-6} \times q_1^{1.33} \times q_5^{0.15} \times (V_D)^{0.33}$$

where:

A_{RMTP1}	is the annual mean number of crossing – vehicle turning crashes
q_1	is right-turning flow from minor road
q_5	is major road through flow approaching from right of minor road, and
V_D	is the sum of the sight distance deficiency to the left and right, based on the difference between the available visibility and the minimum safe intersection sight distance (SISD) for the 85th percentile speed. The SISD is described in Austroads Part 5: Intersections at Grade. Where there is no deficiency a default deficiency of one metre has been used to enable modelling.

This model includes the sum of the visibility deficiency to the right and left and is statistically significant. The exponent of the sum of the visibility deficiency (V_{RD} + V_{LD}) is positive and indicates that, as the deficiency increases when compared with the Austroads guidelines, the number of crashes also increases.

Equation 4.1 has a p-value of 0.45, indicating a good fitting model. This can be illustrated by comparing the predicted mean number of crashes and the reported number of crashes for the "grouped" data as outlined in Wood (2002). Where a group has largely different predicted and reported numbers of crashes, the method provides the required evidence and points out where the poor fit occurs. If there is no evidence of poor fit this gives us valid grounds for increased confidence in the model. Figure 5.2 presents this comparison between reported and predicted crashes for the preferred model, indicating a generally good fit.

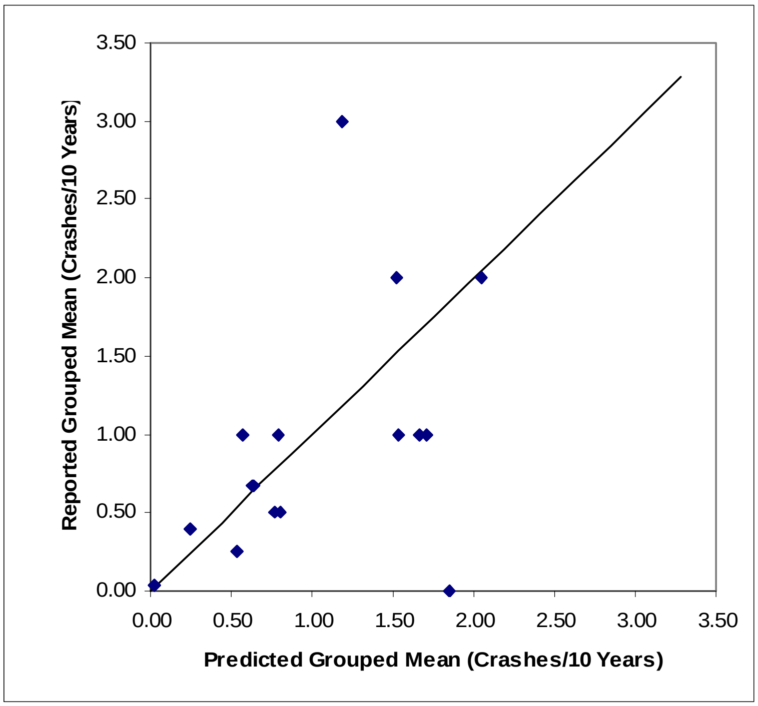

Figure 5.2 Relationship Between Predicted and Reported Crashes for A_{RMTP1} Model

A number of other models were developed in the modelling process. Apart from total visibility deficiency, the only other statistically significant non-flow variable was the visibility deficiency to traffic approaching from the right of the minor road. This relationship indicated that, as the visibility deficiency increases, the number of crashes also increases.

5.2 Right Turning and Following Vehicle (Major Road)

Models were developed for crashes of type GC, GD and GE, where a vehicle turning right from the major road is hit by a vehicle that approached the intersection from the same direction (see Figure 5.3).

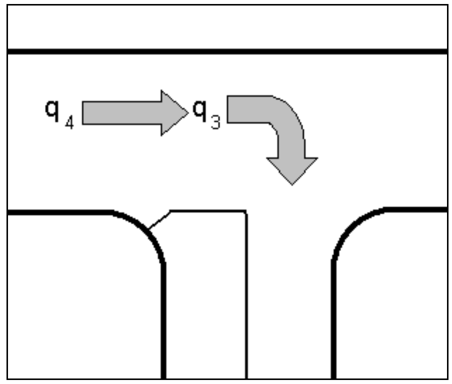

Figure 5.3 RMTP2 Crash Variables

The models were again developed in accordance with the process outlined in Section 4 and resulted in eight models to explain this crash type. Appendix B outlines the predictor variables and the parameters of the models tested. Equation 5.2 presents the preferred model that includes the conflicting flows. This model predicts all crashes of this type at the intersection.

Equation 5.2 $$A_{RMTP2} = 5.29 \times 10^{-27} \times q_3^{0.46} \times q_4^{0.67} \times S_L^{11.0}$$

where:

A_{RMTP2}	**is the annual mean number of right-turning and following vehicle crashes on the major road**
q_3	**is the flow of vehicles turning right from the major road**
q_4	**is the major road through flow approaching from the left of the minor road, and**
S_L	**is the mean speed of vehicles along the major road approaching the intersection to the left of vehicles on the minor road.**

The preferred model includes both conflicting flows and approach speed to left; this indicates a strong relationship between mean approach speed and the number of crashes of this type. To illustrate the relationship Figure 5.4 was produced showing a 3D scatter plot of crashes, right-turning vehicle flows and speed.

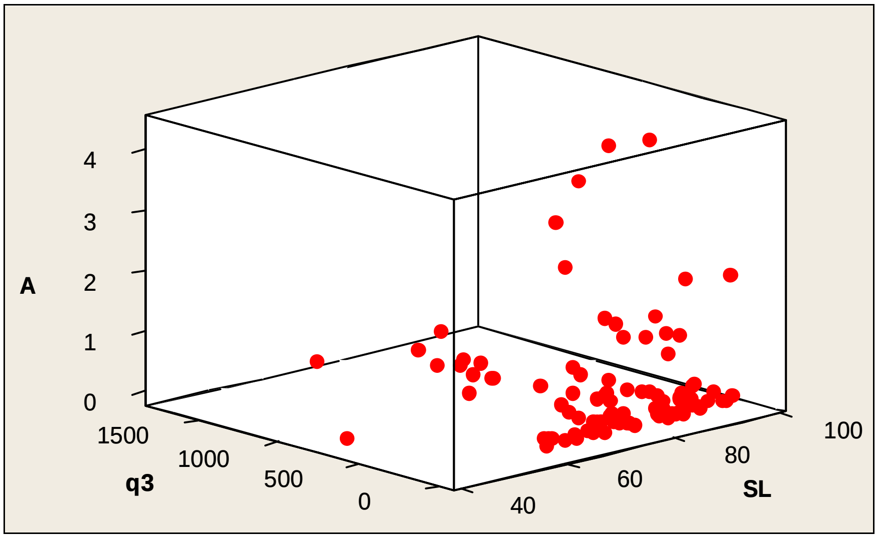

Figure 5.4 Relationship Between Crashes, Speed and Volume

The model has a p-value of 0.48 indicating a good fit. In the goodness-of-fit process intersections are grouped based on the predicted number of crashes. Figure 5.5 shows the relationship between the average reported number of crashes and the average predicted number of crashes in a ten-year period for each group of sites. This shows a good relationship between the numbers of reported and predicted crashes.

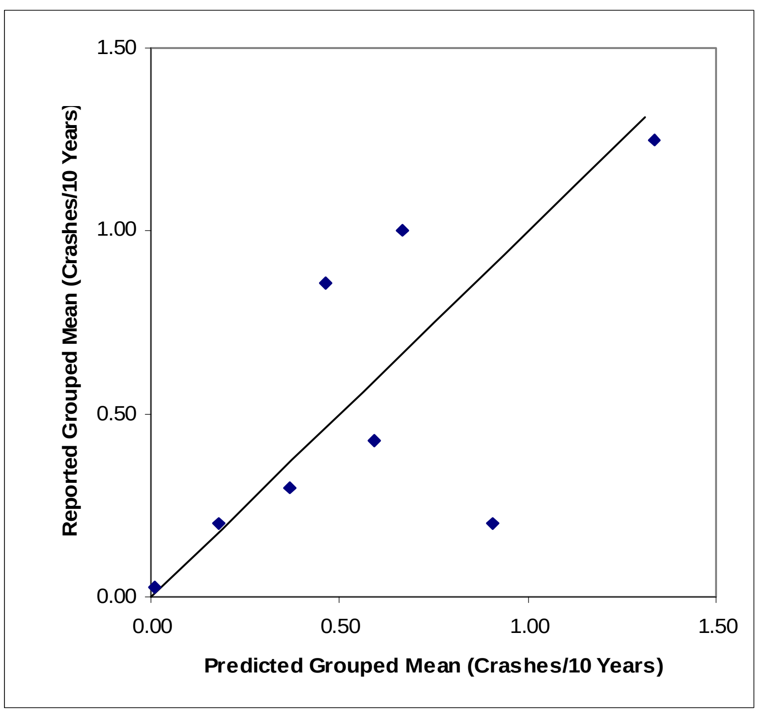

Figure 5.5 Relationship Between Predicted and Reported Crashes for A_{RMTP2} Model

A number of other models were developed in the modelling process. Apart from the mean speed of vehicles approaching the intersection to the left of vehicles on the minor

road, the next most important statistically significant non-flow variables and relationships were the visibility deficiency from the left of the minor road and the total visibility deficiency from the left and right combined. These relationships indicate that, as the visibility deficiency increases, the number of crashes also increases.

5.3 Other (Major Road approach to right of Minor Road)

Models were developed for 'other' crashes that occur on the major road approach to the right of the minor road (see Figure 5.6).

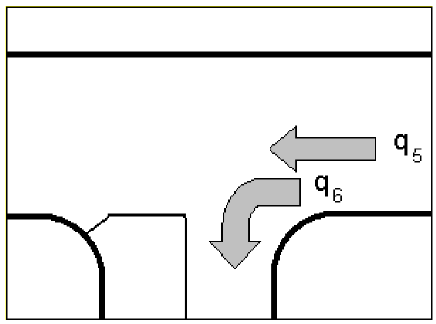

Figure 5.6 RMTP3 Crash Variables

The models were developed in accordance with the process outlined in Section 4 and resulted in three models to explain this crash type. Appendix B outlines the predictor variables and the parameters of the models tested. Equation 5.3 presents the preferred model that includes the approach flows. This model predicts all crashes of this type at this approach.

Equation 5.3 $$A_{RMTP3} = 1.59 \times 10^{-5} \times (q_5 + q_6)^{0.91}$$

where:

A_{RMTP3} **is the annual mean number of crashes on the major road approach to the right of the minor road;**

q_5 **is the major road through flow, and**

q_6 **is the flow of vehicles turning left from the major road approach.**

The preferred model for this crash type does not include non-flow variables, but is statistically significant with a p-value of 0.20. Figure 5.7 shows a good relationship between the numbers of reported and predicted crashes.

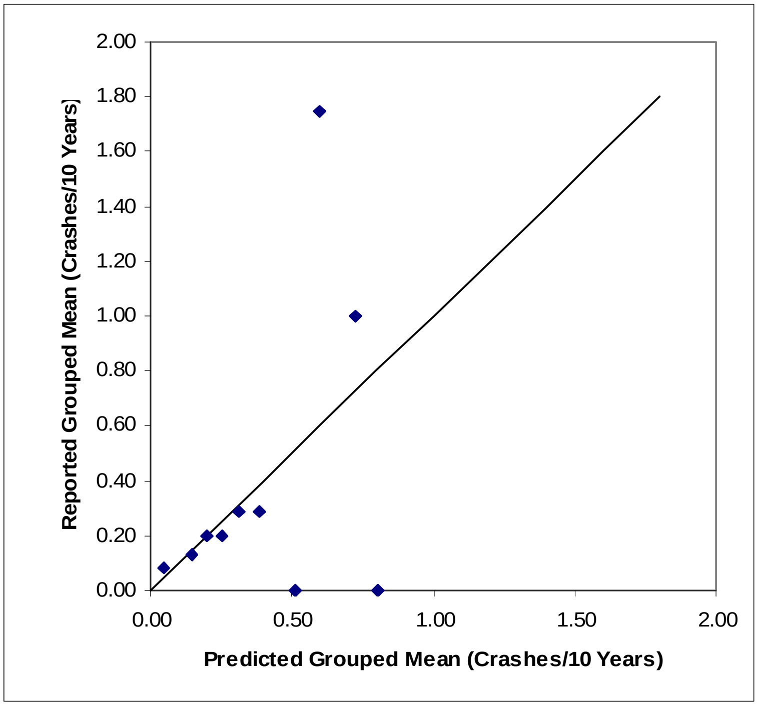

Figure 5.7 Relationship Between Predicted and Reported Crashes for A_{RMTP3} Model

For this crash type no significant relationships between non-flow predictor variables and crashes were identified.

5.4 Other (Major Road approach to left of Minor Road)

Four models were developed for crashes that occur on the major road approach to the left of the minor road, but excluding crashes between right-turning and following vehicles (Figure 5.8). Appendix B outlines the predictor variables and the parameters of the models tested.

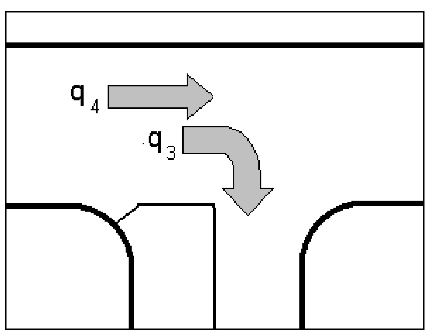

Figure 5.8 RMTP4 Crash Variables

Equation 5.4 presents the preferred model that includes the entering flow; it predicts all crashes of this type on this approach.

Equation 5.4 $$A_{RMPT4} = 2.99 \times 10^{-4} \times (q_3 + q_4)^{0.51}$$

where:

A_{RMPT4}	**is the annual mean number of crashes on the major road approach to the left of the minor road**
q_4	**is the major road through flow, and**
q_3	**is the flow of vehicles turning right from the major road approach.**

The preferred model for this crash type does not include non-flow variables, but is statistically significant with a p-value of 0.12. Figure 5.9 presents the comparison between the predicted and reported numbers of crashes for the preferred model. This indicates a generally good fit.

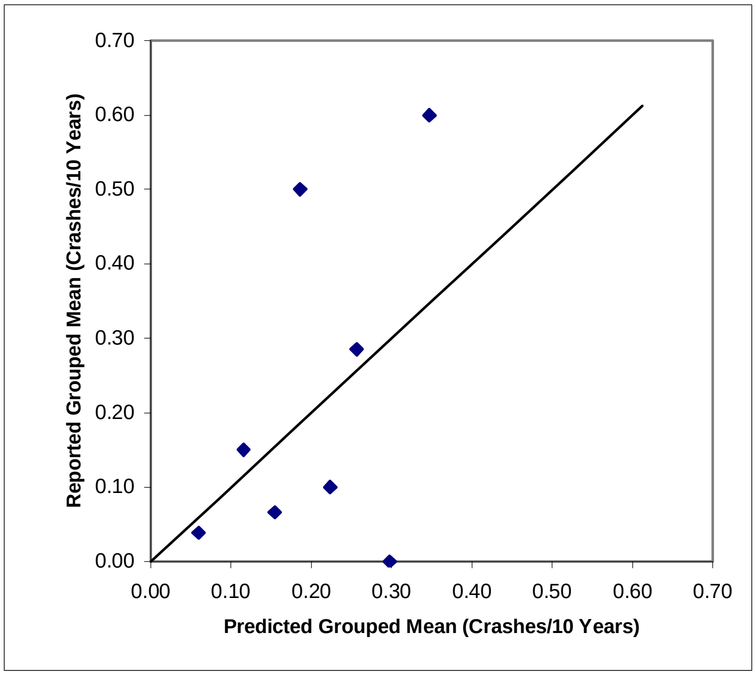

Figure 5.9 Relationship Between Predicted and Reported Crashes for A_{RMTP4} Model

A number of other models were developed in the modelling process. Apart from total visibility deficiency, the only other statistically-significant non-flow variable was the presence of a right-turn bay on the main road. This relationship indicated that more crashes occur with the presence of a right-turn bay.

It is possible that this counter-intuitive relationship is a result of using a ten-year crash history and not determining when the right-turn bay was installed. Therefore, sites which had been treated by installing right-turn bays may have 'before' period crashes included in the modelled crash history.

5.5 Other (Minor Road)

Models were developed for crashes of all types that occur on the minor road. The conflicting flow variables used in this model are shown in (Figure 5.10). Appendix B outlines the predictor variables and the parameters of the models tested.

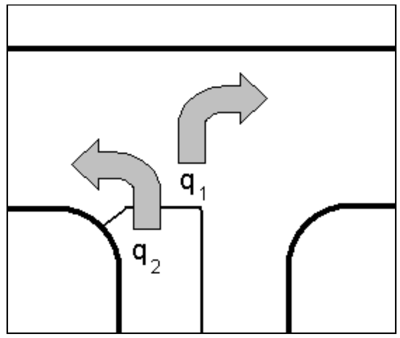

Figure 5.10 RMTP5 Crash Variables

Equation 5.5 presents the preferred model that includes the entering flow and number of entry lanes.

Equation 5.5 $$A_{RMPT5} = 1.47 \times 10^{-2} \times (q_1 + q_2)^{-0.02}$$

where:

A_{RMTP5} is the annual mean number of crashes for the minor road approach

q_1 is the flow of vehicles turning right from the minor road approach, and

q_2 is the flow of vehicles turning left from the minor road approach.

The preferred model includes an exponent of traffic volumes that is slightly negative for all models, indicating that crashes decrease with traffic volumes. This is likely to be a result of the small number of crashes in the sample set. The model for this crash type does not include non-flow variables, but is statistically significant with a p-value of 0.24. Figure 5.11 presents the comparison between the predicted and reported numbers of crashes for the preferred model. This plot is unique in that the predicted number of crashes does not vary while the reported number of crashes does. This is a result of the small exponent for flow which indicates that crashes do not vary with flow and are possibly influenced by other variables.

The lack of a strong relationship for this crash type is not surprising as the number of crashes of this type is small. This also explains why the model is statistically significant despite the obvious deficiencies in the model.

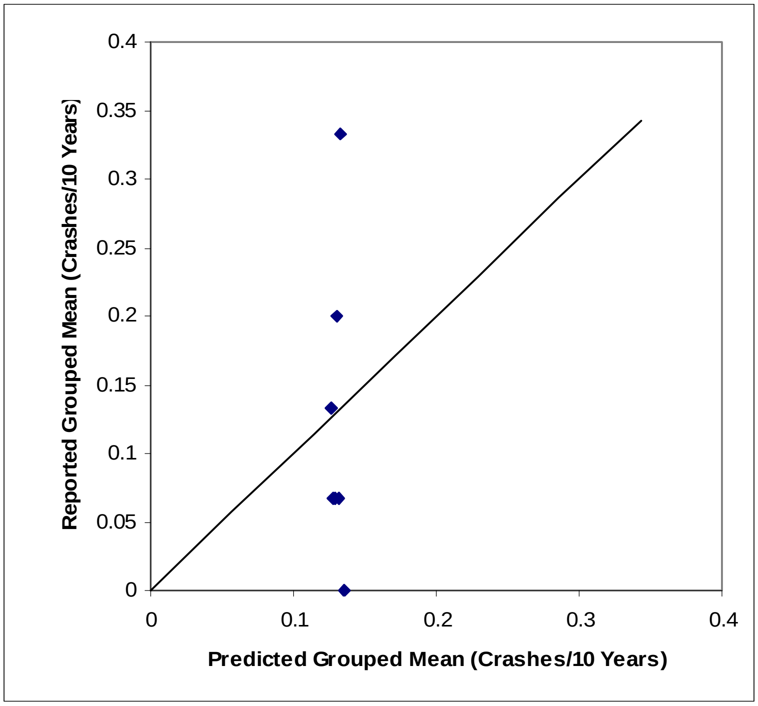

Figure 5.11 Relationship Between Predicted and Reported Crashes for A_{RMTP5} Model

5.6 Product of Link Model

The models in this section can be used to predict the total accident rate at a priority T-junction from the link (two-way) flows on each of the intersecting roads. This model should not be used when turning movement counts are available.

The models were developed in accordance with the process outlined in Section 4. Appendix B outlines the predictor variables and the parameters of the models developed. Equation 5.6 presents the preferred model form, which includes the two-way AADT on the major road and the stem, the total visibility deficiency and the average 85th percentile approach speed.

Equation 5.6 $$A_{RATP0} = 8.85\times10^{-9} \times Q_{Major}^{0.20} \times Q_{Minor}^{0.54} \times V_D^{0.04} \times S_{85}^{2.40}$$

where:

A_{RATP0}	*is the* annual number of all crashes occurring at an intersection
Q_{Major}	is the major road link flow
Q_{Minor}	is the minor (stem) road link flow
V_D	is the sum of sight distance deficiency in both directions when compared with Austroads SISD (if no deficiency this is 1 in the equation), and
S_{85}	is the average 85th percentile approach speed of both approaches on the main road.

The preferred model indicates that, as the visibility deficiency and 85th percentile speeds increase, so does the total number of crashes. Equation 5.6 has a p-value of 0.24,

indicating a good fitting model. This fit can be illustrated by comparing the predicted mean number of crashes and the reported number of crashes, as shown in Figure 5.12. Figure 5.12 differs from previous graphs of this type because the higher number of crashes results in smaller group sizes and a larger number of groups, using the Wood (2002) method.

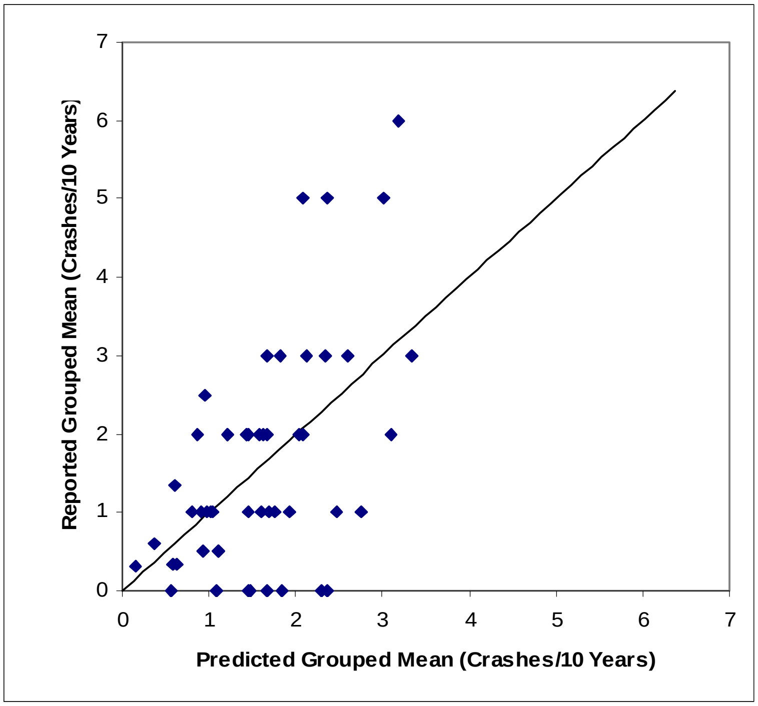

Figure 5.12 Relationship Between Predicted and Reported Crashes for A_{RMTP0} Model

Where the visibility deficiency and 85th percentile speed are unavailable, a 'flow-only' product-of-links model can be used. Equation 5.7 presents the flow-only product-of-links model.

Equation 5.7 $$A_{RATP0} = 4.24 \times 10^{-4} \times Q_{Major}^{0.18} \times Q_{Minor}^{0.57}$$

where:

A_{RATP0} is the annual number of all crashes occurring at an intersection

Q_{Major} is the Major road link flow, and

Q_{Minor} is the Minor (stem) road link flow.

5.7 Summary

The typical mean annual numbers of reported injury crashes for rural T-junctions can be calculated using the crash prediction models in Table 5.1. When turning movement counts are available, the number of accidents should be predicted by crash type and approach. The total number of crashes can then be predicted by summing the individual

predictions. The k-values can be used in the Weighted Accident Procedure (WAP) for economic analysis.

Table 5.1: Rural Priority T-junction Crash Prediction Models

Crash Types	Model	K value
Crossing – Vehicle turning (Major road approach to right of side road)	$A = 5.29\times10^{-6} \times q_1^{1.33}\times q_5^{0.15} \times V_D^{0.33}$	**8.1**
Right-turning and following vehicle (Major road approach to left of side road)	$A = 5.29\times10^{-27} \times q_3^{0.46}\times q_4^{0.67} \times S_L^{11.0}$	**0.2**
Other (Major road approach to right of side road)	$A = 1.59\times10^{-5} \times (q_5 + q_6)^{0.91}$	**1.0**
Other (Major road approach to left of side road)	$A = 2.99\times10^{-4} \times (q_3 + q_4)^{0.51}$	**3.0**
Other (Side road approach)	$A = 1.47\times10^{-2} \times (q_1 + q_2)^{-0.02}$	**0.6**

***K is the Gamma shape parameter for the negative binomial (NB) distribution.**

6. Priority Crossroad Crash Models

The following sections present the crash prediction models developed for the major crash types at rural priority crossroads. Each model is identified by a unique code as set out in Appendix D. A product-of-link flows model is also presented in Section 6.6, which can be used to predict the total number of crashes where link volumes, but not turning movement counts, are available.

6.1 Crossing (Major Road)

Models were developed for type HA crashes, where a vehicle travelling through the intersection on the major road is hit from the right by a vehicle travelling through the intersection along the minor road (Figure 6.1).

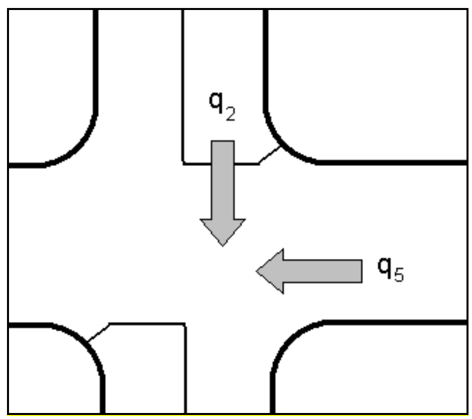

Figure 6.1 RMXP1 Crash Variables

The models were developed in accordance with the process outlined in Section 4. In this process 13 models were developed to explain this crash type. Appendix B outlines the predictor variables and the parameters of the models tested. Equation 6.1 presents the preferred model form, which includes both conflicting flows. For the total number of crashes of this type the model must be applied to both major road approaches, and the totals added together.

Equation 6.1 $$A_{RMXP1} = 1.20 \times 10^{-4} \times q_2^{0.60} \times q_5^{0.40}$$

where:

A_{RMXP1} is the annual mean number of crossing (major road) crashes

q_2 is the through flow from minor road,and

q_5 is the through flow from major road to left of minor road.

Equation 6.1 has a p-value of 0.22 indicating a good fitting model. This can be illustrated by comparing the predicted mean number of crashes and the reported number of crashes for the "grouped" data as outlined in Wood (2002). Where a group has largely different predicted and reported numbers of crashes, the method provides the required evidence and points out where the poor fit occurs. If there is no evidence of poor fit this gives us

valid grounds for increased confidence in the model. Figure 6.2 presents this comparison between reported and predicted crashes for the preferred model, indicating a generally good fit. However, on further investigation it appears to under-predict the number of crashes when the traffic volumes are very high.

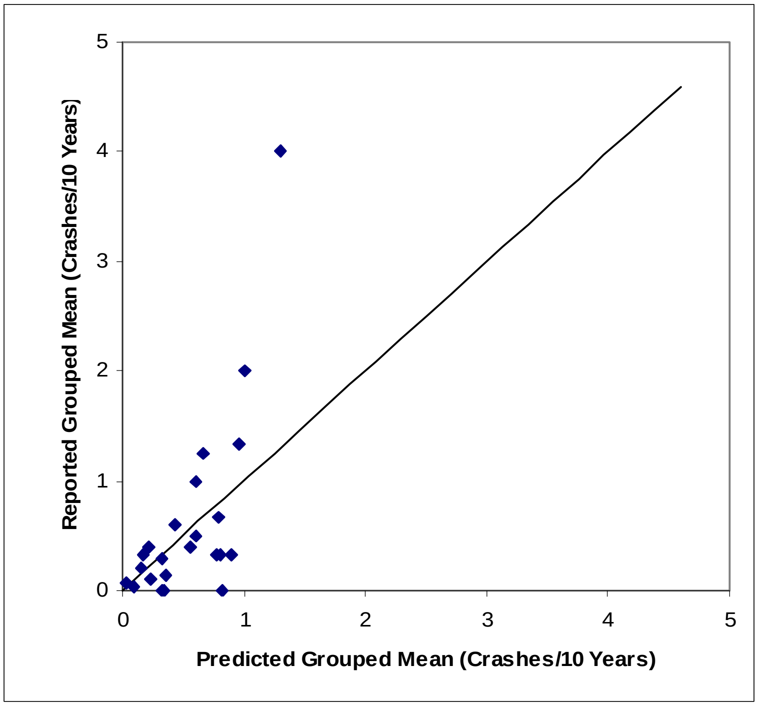

Figure 6.2 Relationship Between Predicted and Reported Crashes for A_{RMXP1} Model

A number of other models were developed in the modelling process. The only statistically significant non-flow variable was the standard deviation of the speed of traffic approaching from the left of the minor road. This relationship indicated that, as the variability in speed decreases, the number of crashes increases. This seemingly counter-intuitive result is discussed further in Section 6.2.

6.2 Crossing (Minor Road)

Crash prediction models were developed for type HA crashes, where a vehicle travelling through the intersection on the major road is hit from the left by a vehicle travelling through the intersection along the minor road (Figure 6.3). This crash type differs from 'Crossing (Minor Road)' in that the vehicle on the side road collides with a vehicle approaching the intersection from their right.

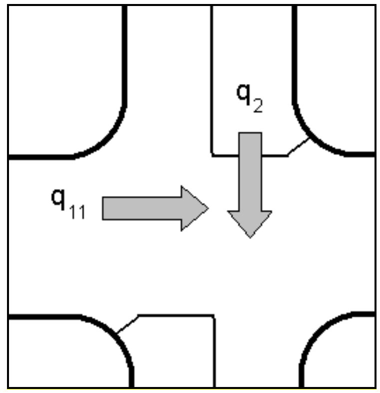

Figure 6.3 RMXP2 Crash Variables

Ten models were developed to explain this crash type. Appendix B outlines the predictor variables and the parameters of the models tested. Equation 6.2 presents the preferred model form, which includes both conflicting flows. For the total number of crashes of this type the model must be applied to both minor road approaches, and the totals added together.

Equation 6.2 $$A_{RMXP2} = 2.05 \times 10^{-4} \times q_2^{0.40} \times q_{11}^{0.44}$$

where:

A_{RMXP2}	**is the annual mean number of crossing (major road) crashes**
q_2	**is the through flow from minor road,and**
q_{11}	**is the through flow from major road to right of minor road.**

Equation 6.1 has a p-value of 0.07, indicating a statistically-significant model. The fit can be illustrated by comparing the predicted mean number of crashes and the reported number of crashes for the "grouped" data as shown in Figure 6.4. Figure 6.4 shows that this model is a reasonable fit.

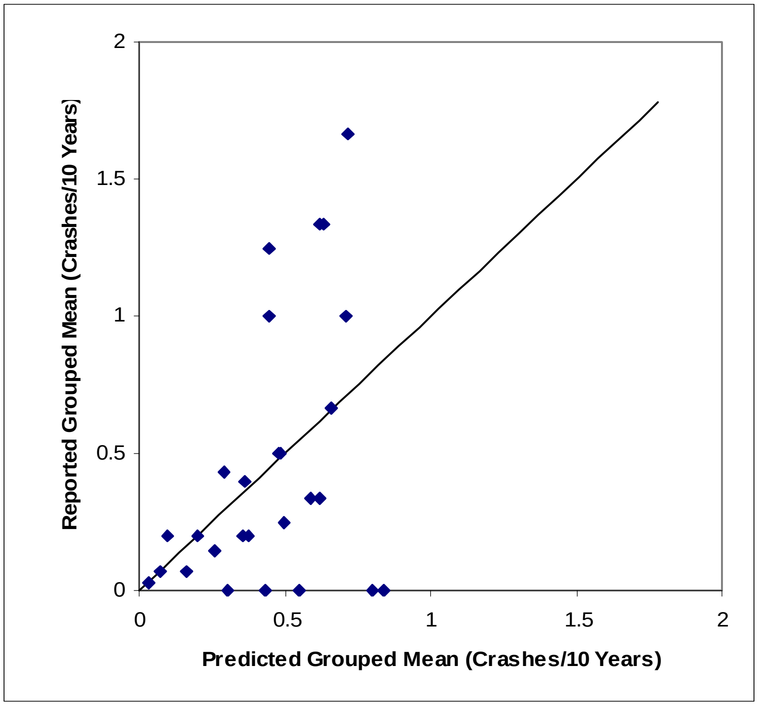

Figure 6.4 Relationship Between Predicted and Reported Crashes for A_{RMXP2} Model

A number of other models were developed in the modelling process, some of which included non-flow variables. The statistically-significant variables were:

- **The presence of a stop control at the intersection**
- **Whether the intersection was conspicuous when approaching from the side road, and**
- **The standard deviation of the speed of traffic approaching the side road from the right.**

These relationships indicate that more crashes occur with the presence of a Stop control, and when the intersection was deemed conspicuous. Both these results on first glance appear to be counter-intuitive; however, stop controls are often installed at high-crash sites so such sites can be expected to have a higher crash rate, [and sites with high conspicuously often occur at high speed sites?].

Crashes are expected to increase with decreasing variability in speed of traffic approaching from the right, which at first seems illogical.

Figure 6.5 below illustrates that variability in the traffic flow speed decreases with increasing major road traffic volumes. Therefore, crashes will increase with decreased variability in speed, which is just a reflection of increased major road traffic flow.

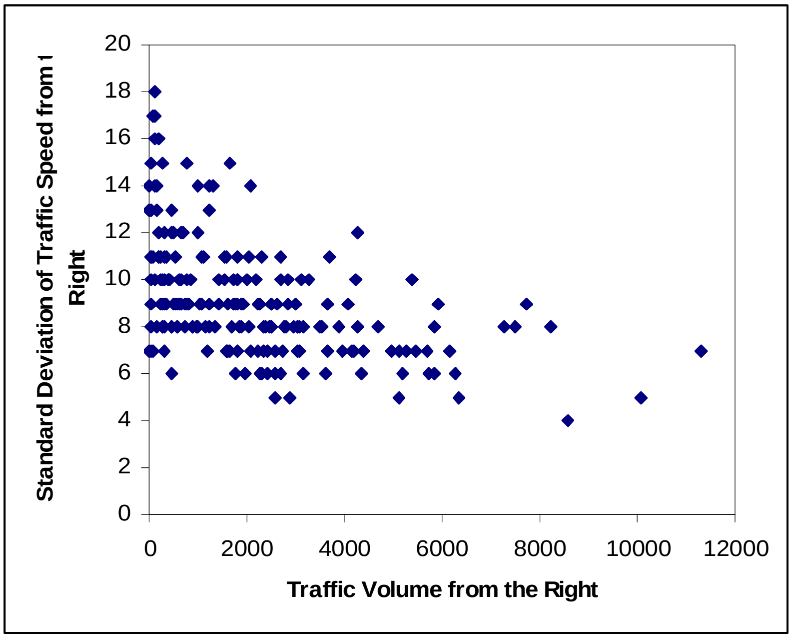

Figure 6.5 Correlation Between Variation in Traffic Speed and Traffic Volume Approaching from the Right

6.3 Right Turning and Following Vehicle (Major Road)

Models were developed for crashes of type GC, GD and GE, where a vehicle turning right from the major road is hit by a vehicle approaching the intersection from the same direction (Figure 6.6).

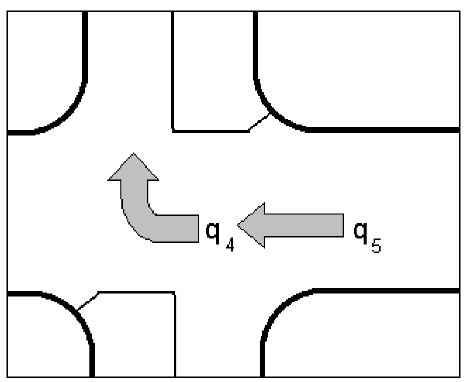

Figure 6.6 RMXP3 Crash Variables

The models were developed in accordance with the process outlined in Section 4. Equation 6.3 presents the preferred model that includes the conflicting flows. For the total number of crashes of this type the model must be applied to both major road approaches and the totals added together.

Equation 6.3 $$A_{RMXP3} = 1.08 \times 10^{-6} \times q_4^{0.36} \times q_5^{1.08} \times \Phi_{RTB}$$

where:

A_{RMXP3}	**is the annual mean number of right-turning and following vehicle crashes per major road approach**
q_4	**is the flow of vehicles turning right from the major road approach**
q_5	**is the major road through flow, and**
Φ_{RTB}	**is a multiplication factor of 0.22 if the approach incorporates a right-turn-bay (RTB).**

Equation 6.3 has a p-value of 0.28, indicating a good fitting model. The fit is illustrated in Figure 6.7.

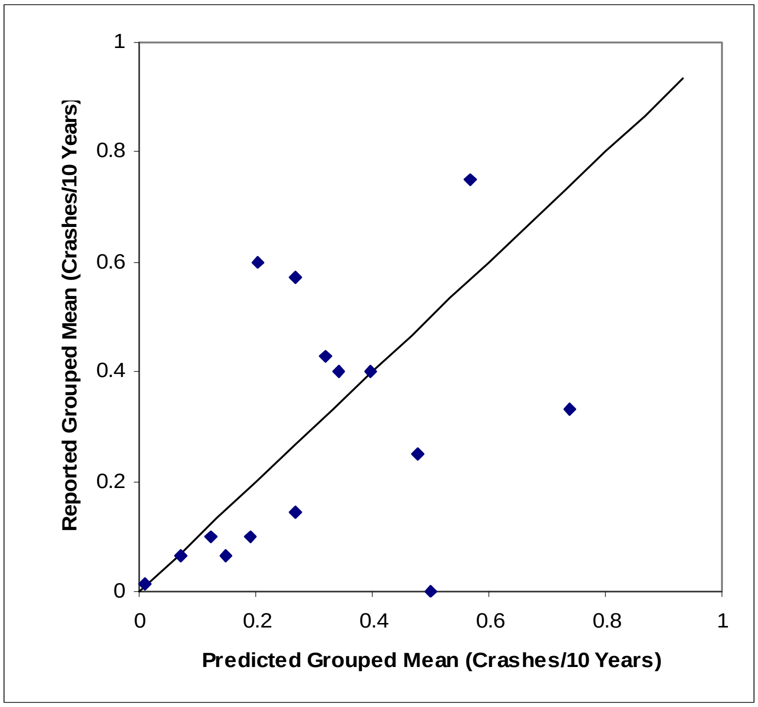

Figure 6.7 Relationship Between Predicted and Reported Crashes for A_{RMXP3} Model

A number of other models were developed in the modelling process, some of which included non-flow variables. The statistically significant non-flow variable is the presence of a right-turn bay. This relationship indicated that, with the presence of right-turn bays, the number of crashes decreases.

6.4 Other (Major Road)

Models were developed for those crash types occurring on the main road that are not covered in the RMXP1 (Crossing – Major Road) and RMXP3 (Right-turning and following vehicle) models. The models include the approach flow as shown in Figure 6.8.

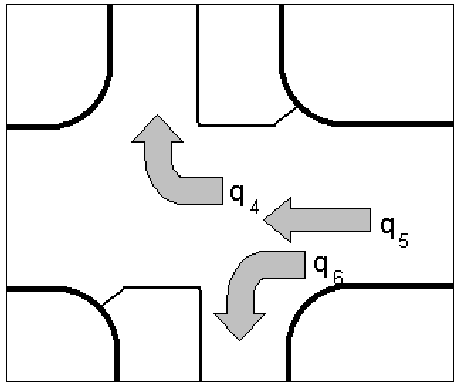

Figure 6.8 RMXP4 Crash Variables

Equation 6.4 presents the preferred model, which includes only the entry flow and no other variables. For the total number of 'other' on the major road the model must be applied to both major road approaches and the results added together.

Equation 6.4 $$A_{RMXP4} = 1.14 \times 10^{-4} \times (q_4 + q_5 + q_6)^{0.76}$$

where:

A_{RMXP4} is the annual mean number of 'other' crashes per major road approach

q_4 is the flow of vehicles turning right from the major road approach

q_5 is the major road through flow, and

q_6 is the flow of vehicles turning left from the major road approach.

Equation 6.4 has a p-value of 0.23 indicating a good fitting model. The fit is illustrated in Figure 6.9.

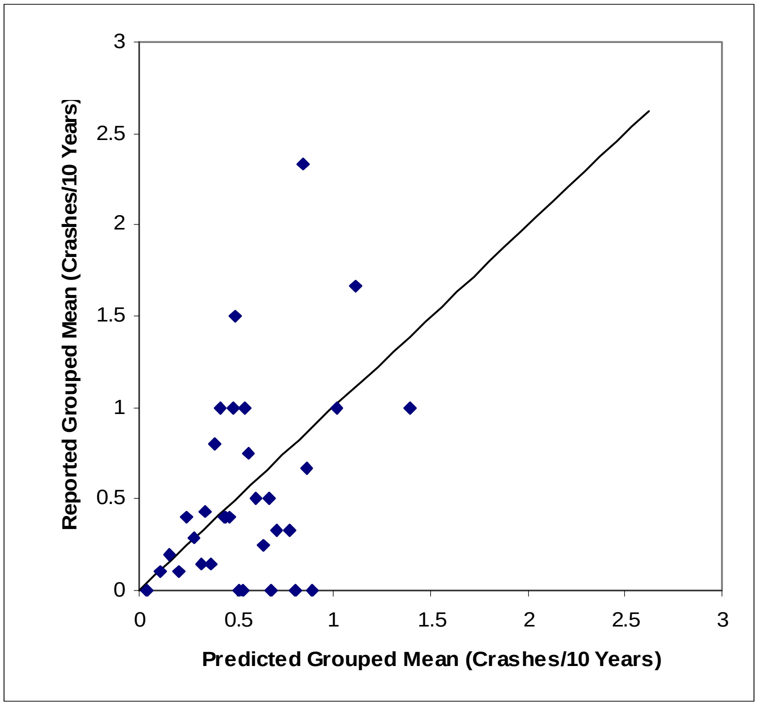

Figure 6.9 Relationship Between Predicted and Reported Crashes for A_{RMXP4} Model

For this crash type no other significant relationships between non-flow predictor variables and crashes were identified.

6.5 Other (Minor Road)

Models were developed for crashes that occurred on the minor road, but were not explained by the RMXP2 (Crossing – Minor Road) model. The models for this crash type used the approach flows as shown in Figure 6.10.

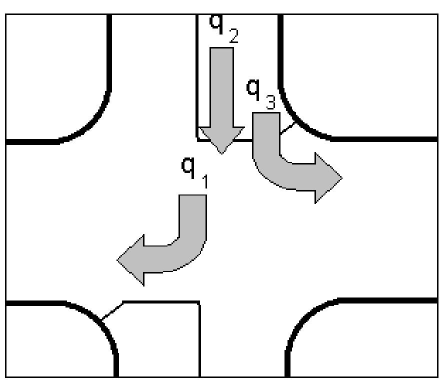

Figure 6.10 RMXP5 Crash Variables

Equation 6.5 presents the preferred model, which includes only the entry flow and no other variables. For the total number of 'other' on the minor road the model must be applied to both major road approaches and the results added together.

Equation 6.5 $$A_{RMXP5} = 3.44 \times 10^{-3} \times (q_1 + q_2 + q_3)^{0.27}$$

where:

A_{RMXP5}	is the annual mean number of 'other' crashes per minor road approach
q_1	is the flow of vehicles turning right from the minor road approach
q_2	is the minor road through flow
q_3	is the flow of vehicles turning left from the minor road approach, and
Φ_{STOP}	is a multiplication factor if the approach requires stop control.

Equation 6.5 has a p-value of 0.01 indicating that it is not statistically significant. This results from there being few crashes of this type. The fit is illustrated in Figure 6.11.

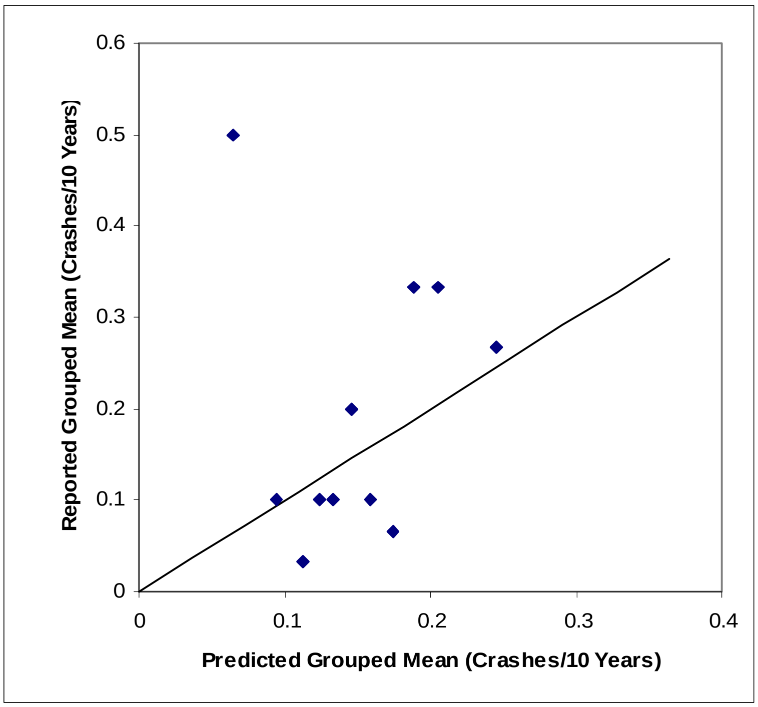

Figure 6.11 Relationship Between Predicted and Reported Crashes for A_{RMXP5} Model

For this crash type no other significant relationships between non-flow predictor variables and crashes were identified.

6.6 Product of Links

The models in this section can be used to predict the total accident rate at a priority crossroads from the link (two-way) flows on each of the intersecting roads. This model should not be used when turning movement counts are available.

The models were developed in accordance with the process outlined in Section 4. Appendix B outlines the predictor variables and the parameters of the models developed. Equation 6.6 presents the preferred model form, which includes the two-way AADT on the

major and minor roads, the total visibility deficiency and the average 85th percentile approach speed.

Equation 6.6 $$A_{RAXP0} = 4.69 \times 10^{-11} \times Q_{Major}^{0.37} \times Q_{Minor}^{0.63} \times V_D^{0.09} \times S_{85}^{3.31}$$

where:

- A_{RATP0} **is the annual number of all crashes occurring at an intersection**
- Q_{Major} **is the major road link flow**
- Q_{Minor} **is the minor road link flow** V_D **is the sum of sight distance deficiency in both directions on both minor roads when compared with Austroads SISD (if no deficiency this is 1 in the equation), and**
- S_{85} **is the average 85th percentile approach speed of both approaches on the major road.**

The preferred model indicates that, as the visibility deficiency and 85th percentile speeds increase, so does the total number of crashes. This model also indicates that lower speeds and good visibilities are more important for crossroads than for T-junctions, due to the higher exponents of these variables. Equation 6.6 has a p-value of 0.12, indicating a good fitting model. This fit can be illustrated by comparing the predicted mean number of crashes and the reported number of crashes, as shown in Figure 6.12**.** Figure 6.12 **differs from previous graphs of this type because the higher number of crashes results in smaller group sizes and a larger number of groups, using the Wood (2002) method.**

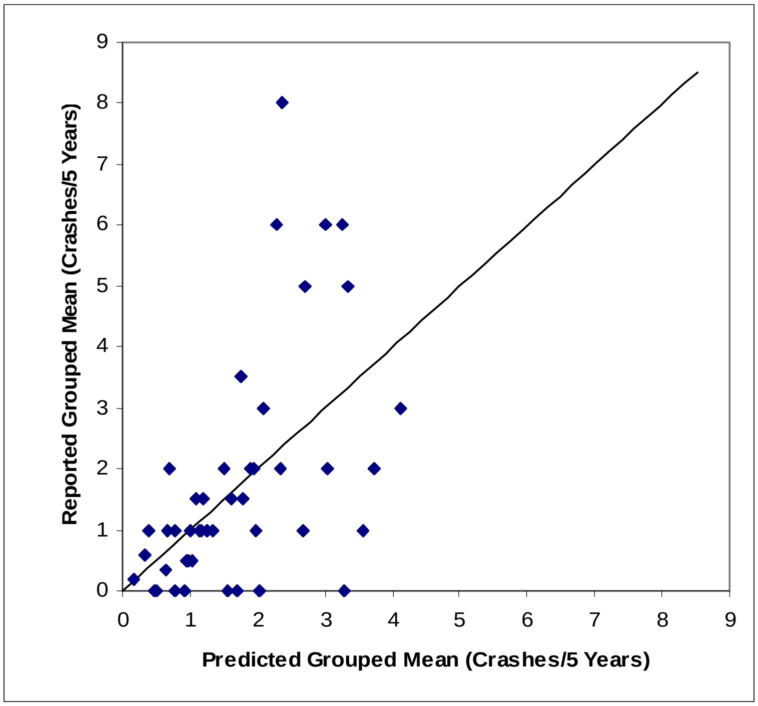

Figure 6.12 Relationship Between Predicted and Reported Crashes for A_{RMTP0} Model

Where the visibility deficiency and 85th percentile speed are unavailable a 'flow-only' product-of-links model can be used. Equation 6.7 presents the flow-only product-of-links model for total crashes at crossroads.

Equation 6.7 $$A_{RAXP0} = 4.21\times10^{-4} \times Q_{Major}^{0.39} \times Q_{Minor}^{0.50}$$

where:

A_{RATP0} is the annual number of all crashes occurring at an intersection

Q_{Major} is the major road link flow, and

Q_{Minor} is the minor road link flow.

6.7 Summary

The typical mean annual numbers of reported injury crashes for rural priority crossroads can be calculated using the crash prediction models in Table 6.1. When turning movement counts are available, the number of crashes should be predicted by crash type and approach. The total number of crashes can then be predicted by summing the individual predictions for the specified approaches. For example, to calculate the total number of crashes each model must be used twice (once for each approach of the specified type). The k-values can be used in the Weighted Accident Procedure (WAP) for economic analysis.

Table 6.1: Rural Priority Crossroad Crash Prediction Models

Accident Types	Model	K value
Crossing – hit from right (Major road approaches only)	$A = 1.15\times10^{-4} \times q_2^{0.60} \times q_5^{0.40}$	0.9
Crossing – hit from right (Minor road approaches only)	$A = 1.97\times10^{-4} \times q_2^{0.40} \times q_{11}^{0.44}$	2.0
Right turning and following vehicle (Major Road approaches only)	$A = 1.04\times10^{-6} \times q_4^{0.36} \times q_5^{1.08} \times \Phi_{RTB}$ $\Phi_{RTB} = 0.22$ (If right-turn bay present) $\Phi_{RTB} = 1.00$ (If right-turn bay absent)	2.6
Other (Major road approaches only)	$A = 1.09\times10^{-4} \times (q_4 + q_5 + q_6)^{0.76}$	1.1
Other (Minor road approaches only)	$A = 3.30\times10^{-3} \times (q_1 + q_2 + q_3)^{0.27}$	0.2

*K is the Gamma shape parameter for the negative binomial (NB) distribution.

7. Signalised T-junction Crash Models

The following sections present the crash prediction models developed for the major crash types at high-speed signalised T-junctions with speed limits of greater than 70 km/h on the main road. Each model is identified by a unique code as set out in Appendix D. A product-of-link flow model is also presented in Section 5.6, which can be used to predict the total number of crashes where link volumes, but not turning movement counts, are available.

7.1 Right-turn-against

Models were developed for type LB crashes, where a vehicle travelling through the intersection collides with a vehicle approaching from the opposite direction and turning right (see Figure 7.1). Appendix B outlines the predictor variables and the parameters of the models tested.

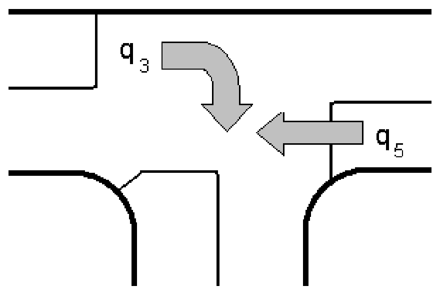

Figure 7.1 RATT1 Crash Variables

Equation 7.1 presents the preferred model that includes the conflicting flow variables. It predicts all crashes of this type at the intersection.

Equation 7.1

$$A_{RATT1} = 7.76 \times 10^{-2} \times q_2^{0.41} \times q_5^{-1.20} \times f_{VIC}$$

where:

A_{RATT1}	**is the annual mean number of crossing crashes at the intersection**
q_3	**is the flow of vehicles turning right into the side road**
q_5	**is the through flow from right of side road, and**
Φ_{VIC}	**is a multiplication factor if the intersection is located in Victoria, Australia (Φ_{VIC} =2.85).**

Equation 7.1 presents the preferred model which, like that for urban signalised T-junctions, has a negative exponent on the through movement flow. It is unclear why the negative exponent is larger than that for urban signalised intersections (-0.38), but it is suspected that this may be a result of different give-way rules between the two countries.

The preferred model is statistically significant with a p-value of 0.07. Figure 7.2 presents the comparison between the predicted and reported number of crashes for the preferred model. This indicates a generally good fit.

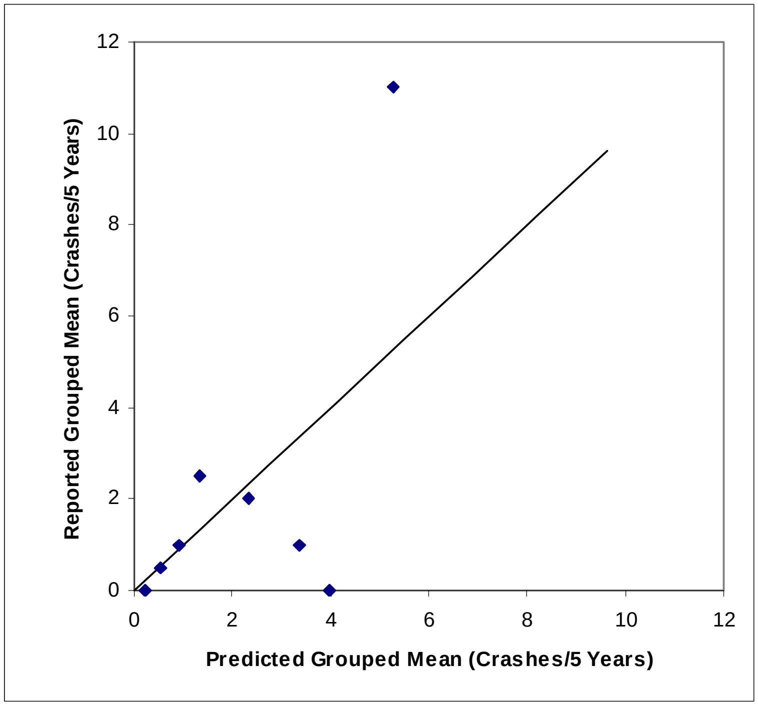

Figure 7.2 Relationship Between Predicted and Reported Crashes for A_{RATT1} Model

7.2 Rear-end (Major Road)

Models were developed for rear-end crash types FA to FE, where a vehicle approaching an intersection collides with the rear of a vehicle travelling in the same direction on one of the major road approaches. These models use the two-way link flow along the major road (see Figure 7.3). Appendix B outlines the predictor variables and the parameters of the models tested.

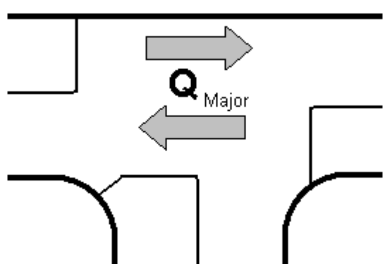

Figure 7.3 RATT2 Crash Variables

Equation 7.2 presents the preferred model that includes the two-way link volume on the major road. It predicts all crashes of this type on the major road (excludes rear-end crashes on the side road).

Equation 7.2

$$A_{RATT2} = 2.28 \times 10^{-2} \times Q_{Major}^{0.29} \times f_{VIC}$$

where:

A_{RATT2}	**is the annual mean number of rear-end crashes on the major road**
Q_{Major}	**is the two-way link flow along the major road (typically calculated as the average two-way flow of the major road links, not the sum of q_4 and q_5), and**
Φ_{VIC}	**is a multiplication factor if the intersection is located in Victoria (Φ_{VIC} =0.89).**

It is interesting that the multiplicative value for this crash type is less than one for intersections in Victoria. This is the only crash type for high-speed signalised crossroads and T-junctions where this occurs.

The preferred model is statistically significant with a p-value of 0.21. Figure 7.4 presents the comparison between the predicted and reported numbers of crashes for the preferred model. This indicates a generally good fit.

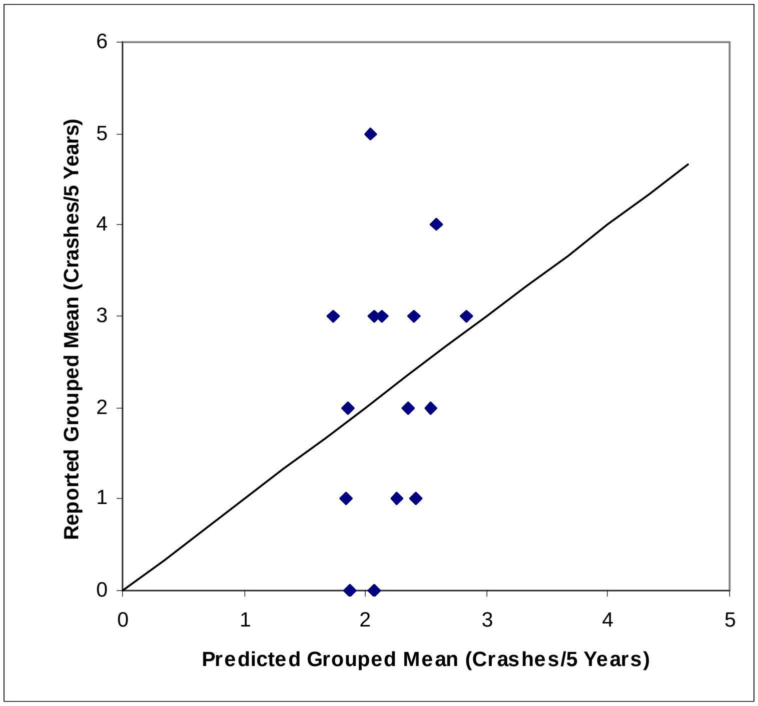

Figure 7.4 Relationship Between Predicted and Reported Crashes for A_{RATT2} Model

7.3 Crossing (Vehicle turning)

Models were developed for type JA crashes, where a vehicle turning right from the minor road collides with a vehicle travelling through from its right (see Figure 7.5). Appendix B outlines the predictor variables and the parameters of the models tested.

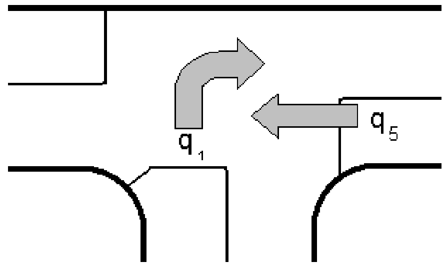

Figure 7.5 RATT3 Crash Variables

Equation 7.3 presents the preferred model. This does not include both conflicting flows. It predicts all crashes of this type at the intersection

Equation 7.3 $$A_{RATT2} = 3.18 \times 10^{-2} \times q_1^{0.12} \times f_{VIC}$$

where:

A_{RATT3} **is the annual mean number of crossing – vehicle turning crashes per intersection**

q_1 **is the right-turning flow from the minor road, and**

Φ_{VIC} **is a multiplication factor if the intersection is located in Victoria (Φ_{VIC} =1.67).**

The preferred model has the same form as the model for crashes of this type at urban signalised intersections and has similar exponents. It is statistically significant with a p-value of 0.10. Figure 7.6 presents the comparison between the predicted and reported numbers of crashes for the preferred model. This indicates a generally good fit.

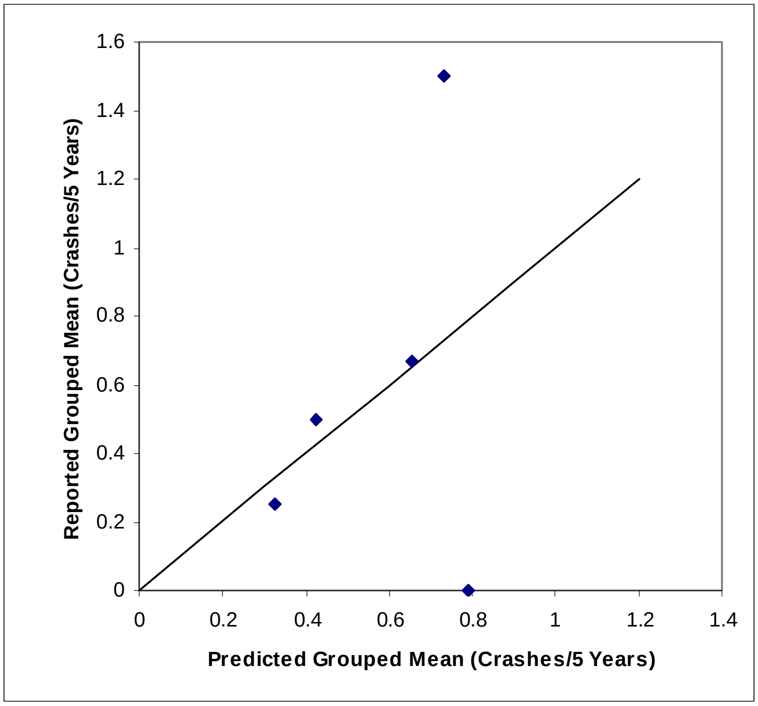

Figure 7.6 Relationship Between Predicted and Reported Crashes for A_{RATT3} Model

7.4 Loss-of-control (Major Road)

Models were developed for loss-of-control crash types C and D where a vehicle approaching an intersection loses control on one of the major road approaches. These models use the two-way link flow along the major road (see Figure 7.7). Appendix B outlines the predictor variables and the parameters of the models tested.

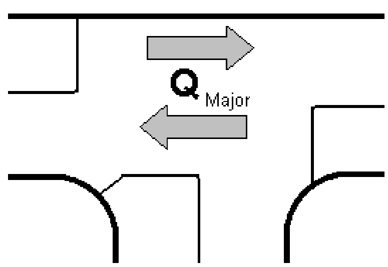

Figure 7.7 RATT4 Crash Variables

Equation 7.4 presents the preferred model that includes the two-way link volume on the major road. It predicts all crashes of this type on the major road (excludes loss-of-control crashes on the side road).

Equation 7.4

$$A_{RATT4} = 5.77 \times 10^{-3} \times Q_{Major}^{0.32} \times f_{VIC}$$

where:

A_{RATT2} **is the annual mean number of loss-of-control crashes on the major road**

Q_{Major}	is the two-way link flow along the major road (typically calculated as the average two-way flow of the major road links, not the sum of q_4 and q_5), and
Φ_{VIC}	is a multiplication factor if the intersection is located in Victoria ($\Phi_{VIC} = 1.06$).

The preferred model is statistically significant with a p-value of 0.22. Figure 7.8 presents the comparison between the predicted and reported numbers of crashes for the preferred model. This indicates a generally good fit.

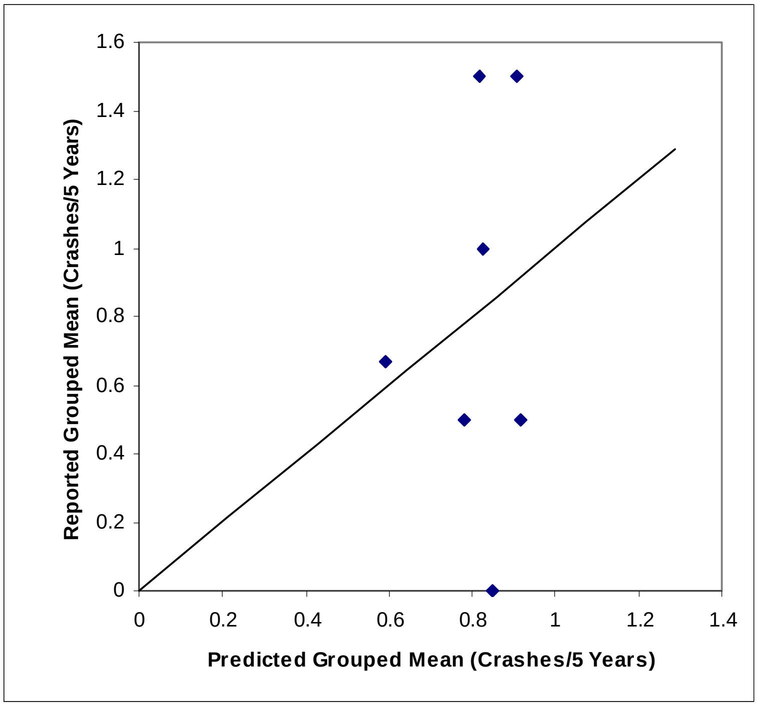

Figure 7.8 Relationship Between Predicted and Reported Crashes for A_{RATT4} Model

7.5 Other (Major Road)

Models were developed for crashes of other types that occur on the major road and not already covered by the preceding models. The models use two-way flow on the major road (Figure 7.9). Appendix B outlines the predictor variables and the parameters of the models tested.

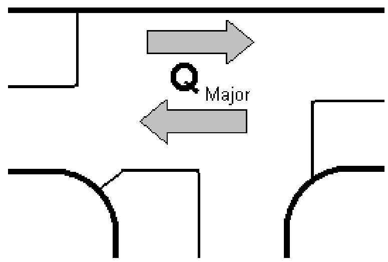

Figure 7.9 RATT5 Crash Variables

Equation 7.5 presents the preferred model that includes the two-way link volume on the major road. It predicts all 'other' crashes on the major road not predicted by the preceding models.

Equation 7.5 $$A_{RATT5} = 1.82 \times 10^{-3} \times Q_{Major}^{0.37} \times f_{VIC}$$

where:

A_{RATT5} **is the annual mean number of 'other' crashes on the major road**

Q_{Major} **is the two-way link flow along the major road (typically calculated as the average two-way flow of the major road links, not the sum of q_4 and q_5), and**

Φ_{VIC} **is a multiplication factor if the intersection is located in Victoria (Φ_{VIC} =2.81).**

This is the only preferred model for high-speed signalised T-junctions that is not statistically significant. For the sake of completeness this model is included in the summary and should be used in the calculation of the total number of crashes at an intersection. It should also be noted that crashes in this category only comprise 11% of the total crashes in the dataset. Figure 7.10 presents the comparison between the predicted and reported numbers of crashes for the preferred model.

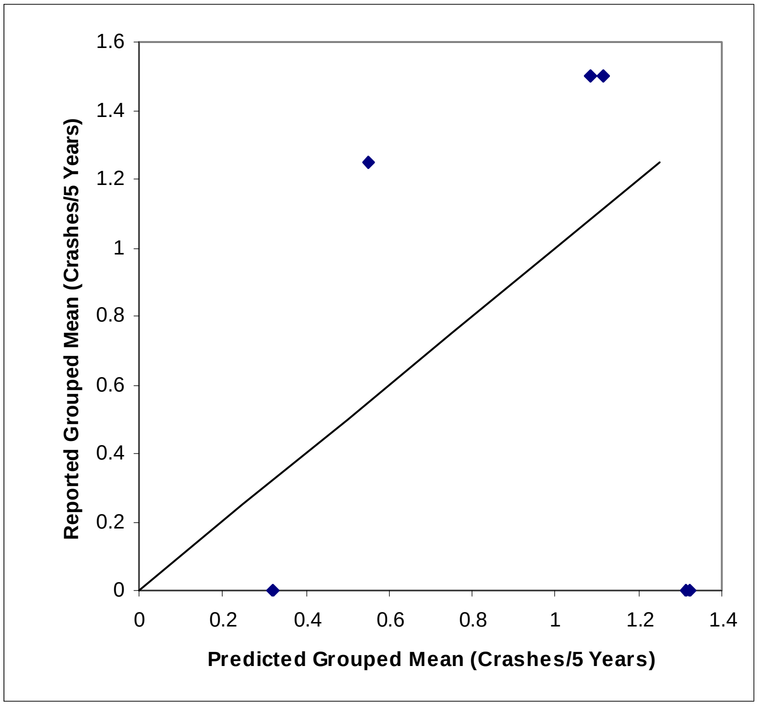

Figure 7.10 Relationship Between Predicted and Reported Crashes for A_{RATT5} Model

7.6 Other (Minor Road)

Models were developed for crashes of other types that occur on the minor road and not already covered by the preceding models. The models use two-way flow on the minor road (Figure 7.11). Appendix B outlines the predictor variables and the parameters of the models tested.

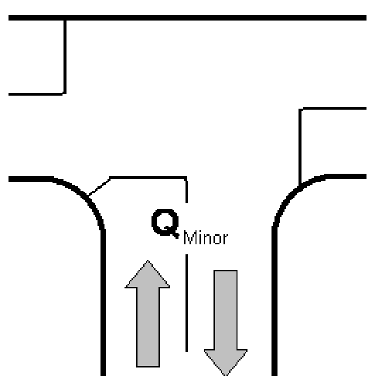

Figure 7.11 RATT6 Crash Variables

Equation 7.6 presents the preferred model that includes the two-way link volume on the minor road. It predicts all 'other' crashes on the major road not predicted by the preceding models.

Equation 7.6

$$A_{RATT6} = 1.40 \times 10^{-3} \times Q_{Minor}^{0.41} \times f_{VIC}$$

where:

A_{RATT6}	**is the annual mean number of 'other' crashes on the minor road**
Q_{Minor}	**is the two-way link flow along the minor road, and**
Φ_{VIC}	**is a multiplication factor if the intersection is located in Victoria (Φ_{VIC} =5.04).**

The preferred model is statistically significant with a p-value of 0.17. Figure 7.12 presents the comparison between the predicted and reported numbers of crashes for the preferred model. This indicates a generally good fit.

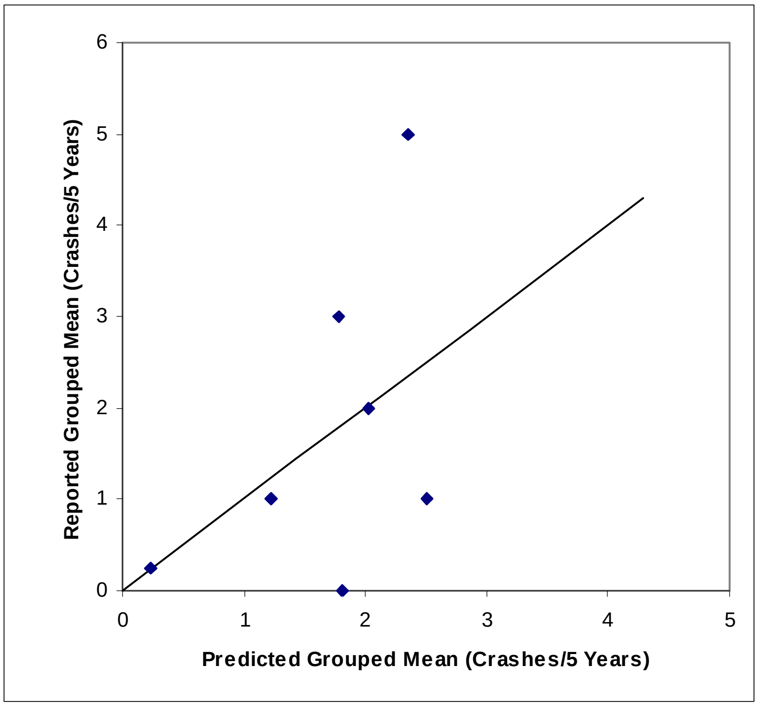

Figure 7.12 Relationship Between Predicted and Reported Crashes for A_{RATT6} Model

7.7 Product–of-Link Model

The models in this section can be used to predict the total crash rate at signalised T-junctions from the link (two-way) flows of the major and minor roads. The model should only be used in the absence of turning movement counts or turning volumes from a transport model. Where volumes on both link approaches are available, the two approach flows should be summed to calculate the link volume.

The models were developed in accordance with the process outlined in Section 4. Appendix B outlines the predictor variables and the parameters of the models developed. Equation 7.7 presents the preferred model form, which includes the two-way AADT on the major and minor roads.

Equation 7.7

$$A_{RATT0} = 5.10 \times 10^{-2} \times Q_{Major}^{0.37} \times Q_{Minor}^{-0.10}$$

where:

A_{RATT0}	is the annual number of all crashes occurring at an intersection
Q_{Major}	is the major road link flow, and
Q_{Minor}	is the minor road link flow.

Equation 7.7 has a p-value of 0.73, indicating a good fitting model. Due to the correlation between the major and minor flows, and the large difference in the number of crashes between New Zealand and Victoria, the modelled data included only New Zealand intersections. This is acceptable because fewer sites are required for developing product-of-link models than for models for individual crash types.

The fit of the model to the data can be illustrated by comparing the predicted mean number of crashes and the reported number of crashes, as shown in Figure 7.13.

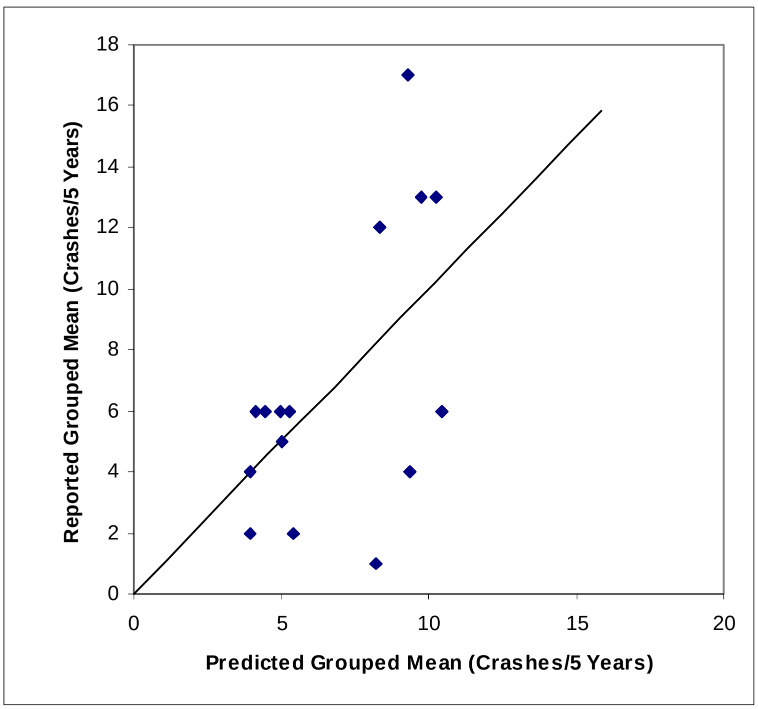

Figure 7.13 Relationship Between Predicted and Reported Crashes for A_{RATT0} Model

7.8 Summary

The typical mean annual numbers of reported injury crashes for high-speed signalised T-junctions in New Zealand can be calculated using the crash prediction models in Table 7.1. When turning movement counts are available, the number of crashes should be predicted by crash type and approach. The total number of crashes can then be predicted by summing the individual predictions for the specified roads. The k-values can be used in the Weighted Accident Procedure (WAP) for economic analysis.

Table 7.1: High-speed Signalised T-junction Crash Prediction Models

Accident Types	Model	K value*
Right-turn-against	$A_{RATT1} = 7.76 \times 10^{-2} \times q_2^{0.41} \times q_5^{-1.20}$	**2.3**
Rear-end (Major Road only)	$A_{RATT2} = 2.28 \times 10^{-2} \times Q_{Major}^{0.29}$	**-**
Crossing – Vehicle turning	$A_{RATT2} = 3.18 \times 10^{-2} \times q_1^{0.12}$	**-**
Loss-of-control (Major Road only)	$A_{RATT4} = 5.77 \times 10^{-3} \times Q_{Major}^{0.32}$	**-**
Other (Major Road only)	$A_{RATT5} = 1.82 \times 10^{-3} \times Q_{Major}^{0.37}$	**-**
Other (Minor Road only)	$A_{RATT6} = 1.40 \times 10^{-3} \times Q_{Minor}^{0.41}$	**8.0**

***K is the Gamma shape parameter for the negative binomial (NB) distribution.**

8. Signalised Crossroads Crash Models

The following sections present the crash prediction models developed for the major crash types at high-speed signalised crossroads with speed limits of greater than 70 km/h on the main road. Each model is identified by a unique code as set out in Appendix D. A product-of-link flow model is also presented in Section 5.6, which can be used to predict the total number of crashes where link volumes, but not turning movement counts, are available.

8.1 Crossing

Models were developed for type HA crashes, where a vehicle travelling through the intersection collides with another vehicle travelling through the intersection to its right. (see Figure 8.1). Appendix B outlines the predictor variables and the parameters of the models tested.

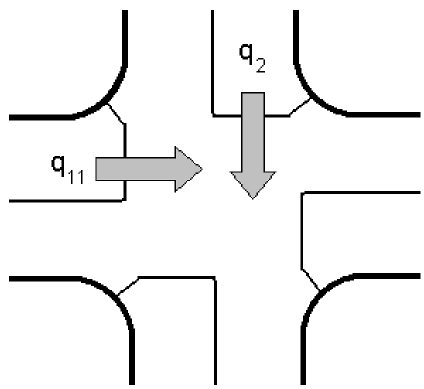

Figure 8.1 RAXT1 Crash Variables

Equation 8.1 presents the preferred model that includes the conflicting flow variables. To predict the total number of crashes of this type the model must be applied to all four approaches and the crashes added together.

Equation 8.1 $$A_{RAXT1} = 6.82 \times 10^{-5} \times q_2^{0.31} \times q_{11}^{0.35} \times f_{VIC}$$

where:

A_{RAXT1}	**is the annual mean number of crossing crashes per approach**
q_2	**is the through flow**
q_{11}	**is the through flow to right, and**
Φ_{VIC}	**is a multiplication factor if the intersection is located in Victoria (Φ_{VIC} =3.95).**

The preferred model is similar to that for crashes of this type at urban signalised intersections. It is statistically significant with a p-value of 0.55. Figure 8.2 presents the comparison between the predicted and reported numbers of crashes for the preferred model. This indicates a generally good fit.

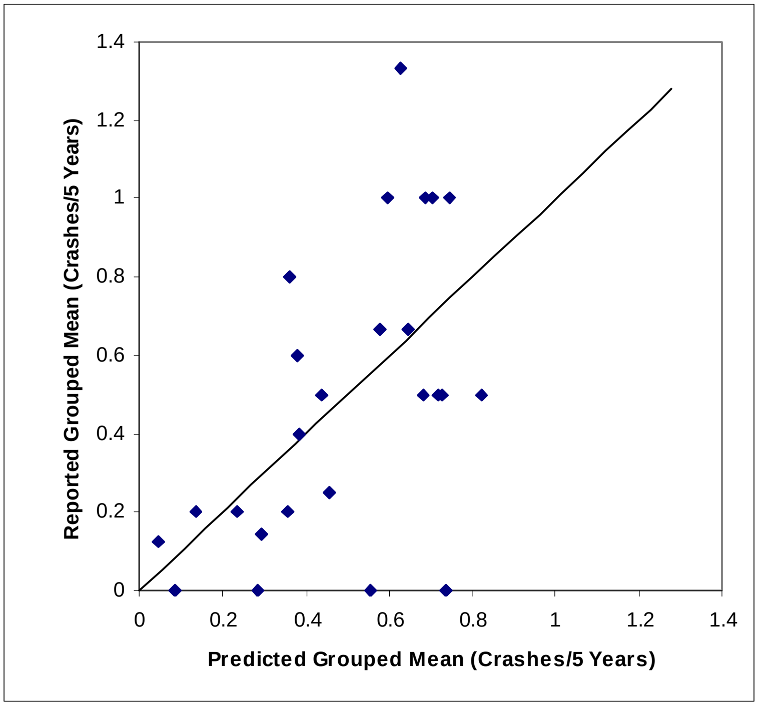

Figure 8.2 Relationship Between Predicted and Reported Crashes for A_{RAXT1} Model

8.2 Right-turn-against

Models were developed for type LB crashes, where a vehicle travelling through the intersection collides with a vehicle approaching from the opposite direction and turning right (see Figure 8.3).

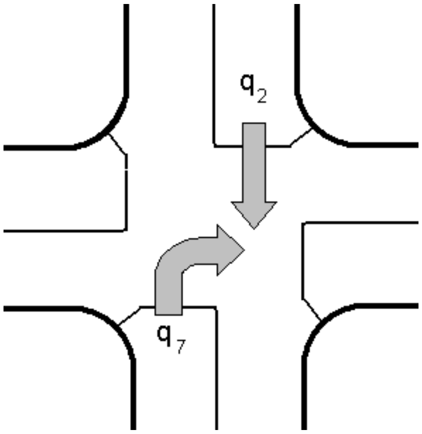

Figure 8.3 RAXT2 Crash Variables

Equation 8.2 presents the preferred model that includes the conflicting flow variables. To predict the total number of crashes of this type the model must be applied to all four approaches, and the crashes added together.

Equation 8.2 $$A_{RAXT2} = 2.17 \times 10^{-2} \times q_2^{0.20} \times f_{VIC}$$

where:

A_{RAXT2}	is the annual mean number of right-turn-against crashes per approach
q_2	is the through flow
q_7	is the opposing right-turning flow, and
Φ_{VIC}	is a multiplication factor if the intersection is located in Victoria (Φ_{VIC} =1.43).

This model differs substantially from that for urban signalised crossroads, possibly as a result of differences in signal phasing between the two datasets, with the majority of urban sites having no protected right turns. It is statistically significant with a p-value of 0.55. Figure 8.4 presents the comparison between the predicted and reported numbers of crashes for the preferred model. This indicates a generally good fit.

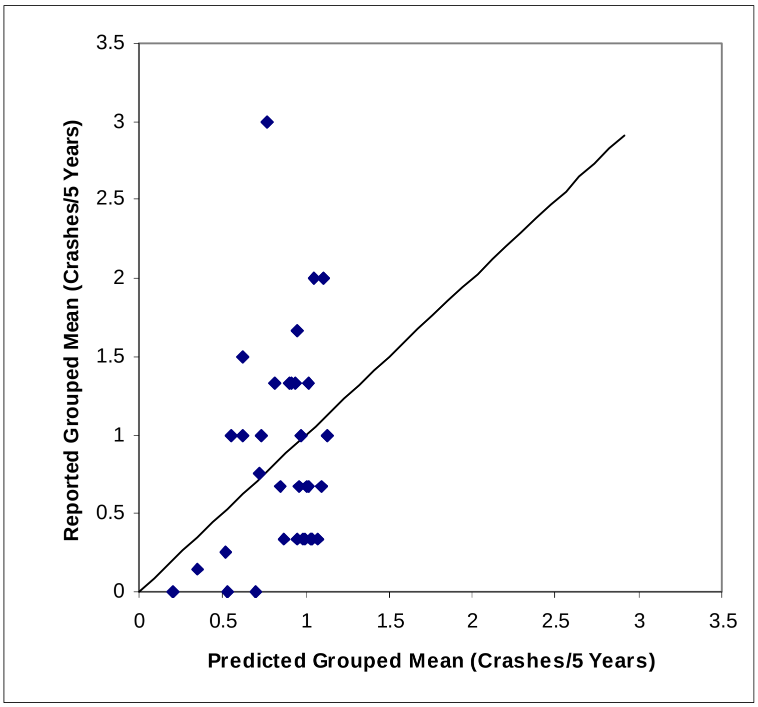

Figure 8.4 Relationship Between Predicted and Reported Crashes for A_{RAXT2} Model

8.3 Rear end

Models were developed for rear-end crash types FA to FE, where a vehicle approaching an intersection collides with the rear of a vehicle travelling in the same direction (see Figure 8.5). Unlike the rear-end model for high-speed signalised T-junctions, these models use the sum of all entering flows for each approach.

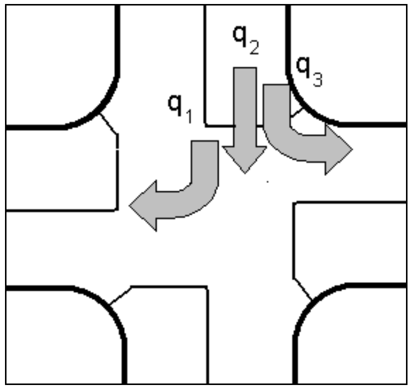

Figure 8.5 RAXT3 Crash Variables

Equation 8.3 presents the preferred model that includes the conflicting flows. To predict the total number of crashes of this type the model must be applied to all four approaches, and the crashes added together.

Equation 8.3

$$A_{RAXT3} = 4.16 \times 10^{-7} \times Q_e^{1.18} \times f_{VIC}$$

where:

A_{RAXT3}	**is the annual mean number of rear-end crashes per approach**
Q_e	**is the flow of vehicles approaching an intersection (q_1 + q_2 + q_3) from a single approach, and**
Φ_{VIC}	**is a multiplication factor if the intersection is located in Victoria (Φ_{VIC} =9.91).**

It is interesting that the multiplicative value for this crash type of 9.91 is so much higher for crashes in Victoria. The exponent for the through flow is greater than 1, which is similar to that for rear-end crashes at urban signalised crossroads.

The preferred model is statistically significant with a p-value of 0.08. Figure 8.6 presents the comparison between the predicted and reported numbers of crashes for the preferred model. This indicates a generally good fit.

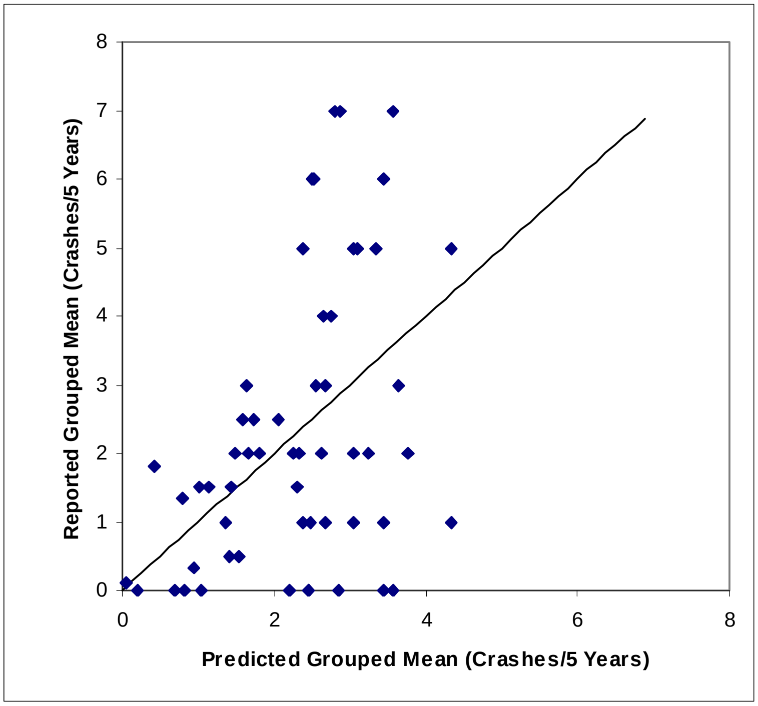

Figure 8.6 Relationship Between Predicted and Reported Crashes for A_{RAXT3} Model

8.4 Loss of Control

Models were developed for loss-of-control crash types C and D where vehicles approaching an intersection lose control (see Figure 8.7). Unlike the loss-of-control model for high-speed signalised T-junctions these models use the sum of all entering flows for each approach.

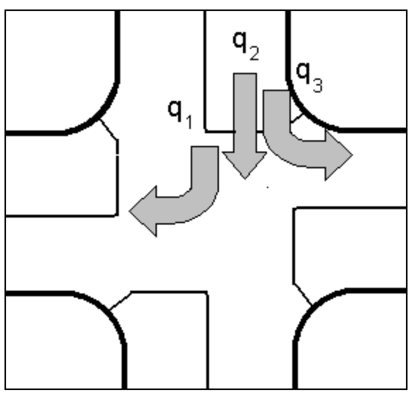

Figure 8.7 RAXT4 Crash Variables

Equation 8.4 presents the preferred model that includes the conflicting flows. To predict the total number of crashes of this type the model must be applied to all four approaches and the crashes added together.

Equation 8.4

$$A_{RAXT4} = 5.75 \times 10^{-5} \times Q_e^{0.70} \times f_{VIC}$$

where:

A_{RAXT4}	**is the annual mean number of loss of control crashes per approach**
Q_e	**is the flow of vehicles approaching an intersection (q_1 + q_2 + q_3) from a single approach, and**
Φ_{VIC}	**is a multiplication factor if the intersection is located in Victoria (Φ_{VIC} =1.15).**

The exponent for the entering flow in the preferred model is greater than that for urban signalised crossroads. The preferred model is statistically significant with a p-value of 0.20. Figure 8.8 presents the comparison between the predicted and reported numbers of crashes for the preferred model. This indicates a generally good fit.

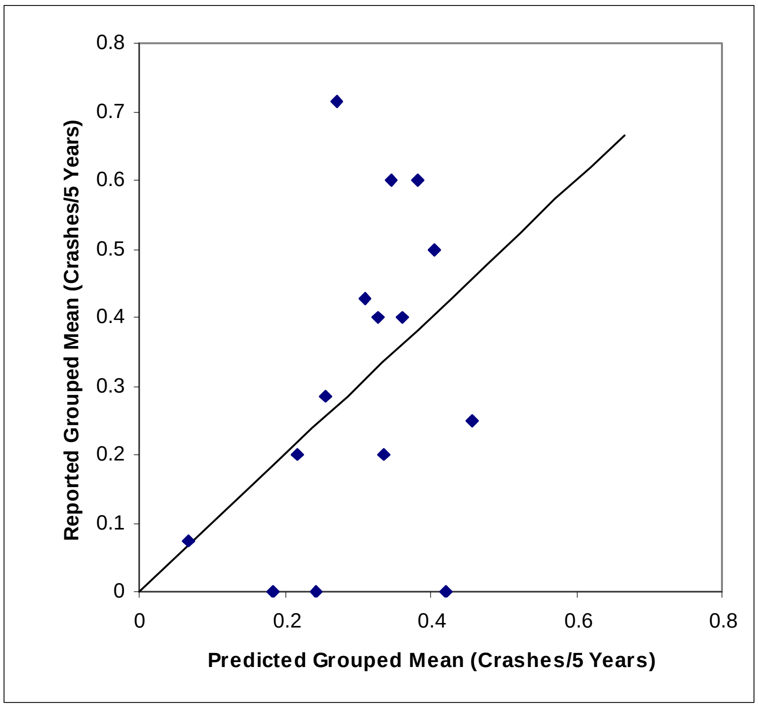

Figure 8.8 Relationship Between Predicted and Reported Crashes for A_{RAXT4} Model

8.5 Others

A model was developed to predict crashes of other types by approach, for crash types not already covered by the preceding models. The flow variable is the sum of entering flows for each approach as shown in Figure 8.9.

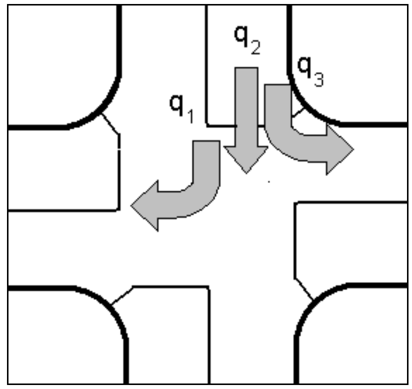

Figure 8.9 RAXT5 Crash Variables

Equation 8.5 presents the preferred model that includes the conflicting flows. To predict the total number of crashes of this type the model must be applied to all four approaches, and the crashes added together.

Equation 8.5 $$A_{RAXT5} = 1.04 \times 10^{-2} \times Q_e^{0.14} \times f_{VIC}$$

where:

A_{RAXT5}	**is the annual mean number of 'other' crashes per approach**
Q_e	**is the flow of vehicles approaching an intersection (q_1 + q_2 + q_3) from a single approach, and**
Φ_{VIC}	**is a multiplication factor if the intersection is located in Victoria (Φ_{VIC} = 4.44).**

This model is very similar to that developed for urban signalised crossroads. The model is statistically significant with a p-value of 0.35. Figure 8.10 presents the comparison between the predicted and reported numbers of crashes for the preferred model. This indicates a generally good fit.

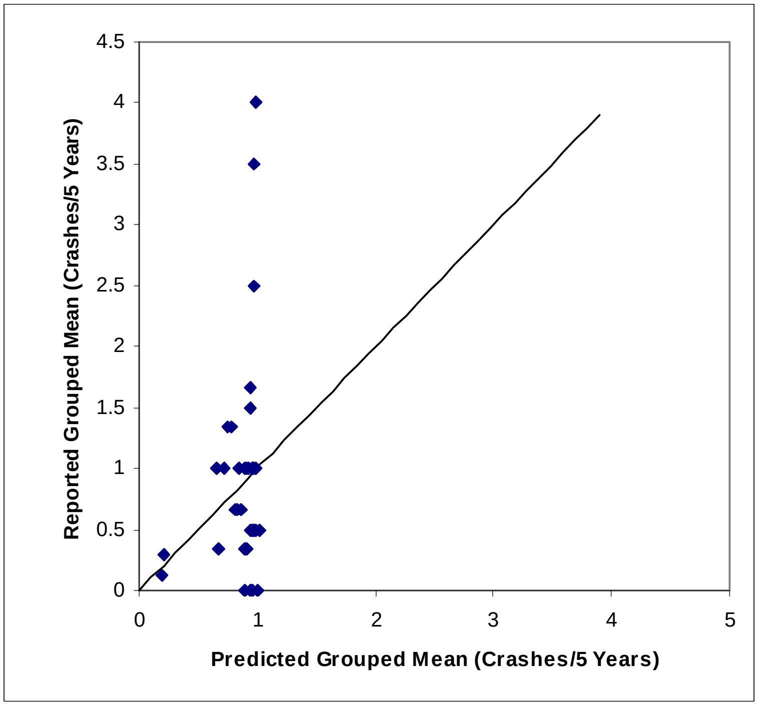

Figure 8.10 Relationship Between Predicted and Reported Crashes for A_{RAXT5} Model

8.6 Product-of-link Model

The models in this section can be used to predict the total crash rate at a four-arm signalised crossroads from the link (two-way) flows on each of the intersecting roads. These models should only be used in the absence of turning movement counts or turning volumes from a transport model. Where volumes on both link approaches are available, the two approach flows should be summed to calculate the link volume.

The models were developed in accordance with the process outlined in Section 4. Appendix B outlines the predictor variables and the parameters of the models developed. Equation 8.6 presents the preferred model form, which includes the two-way AADT on the major and minor roads.

Equation 8.6

$$A_{RAXT0} = 3.79 \times 10^{-4} \times Q_{Major}^{0.52} \times Q_{Minor}^{0.19} \times f_{VIC}$$

where:

A_{RATT0} is the annual number of all crashes occurring at an intersection

Q_{Major} is the major road link flow

Q_{Minor} is the minor road link flow, and

Φ_{VIC} is a multiplication factor if the intersection is located in Victoria (Φ_{VIC} =1.33).

The fit of the model to the data can be illustrated by comparing the predicted mean number of crashes and the reported number of crashes, as shown in Figure 8.11.

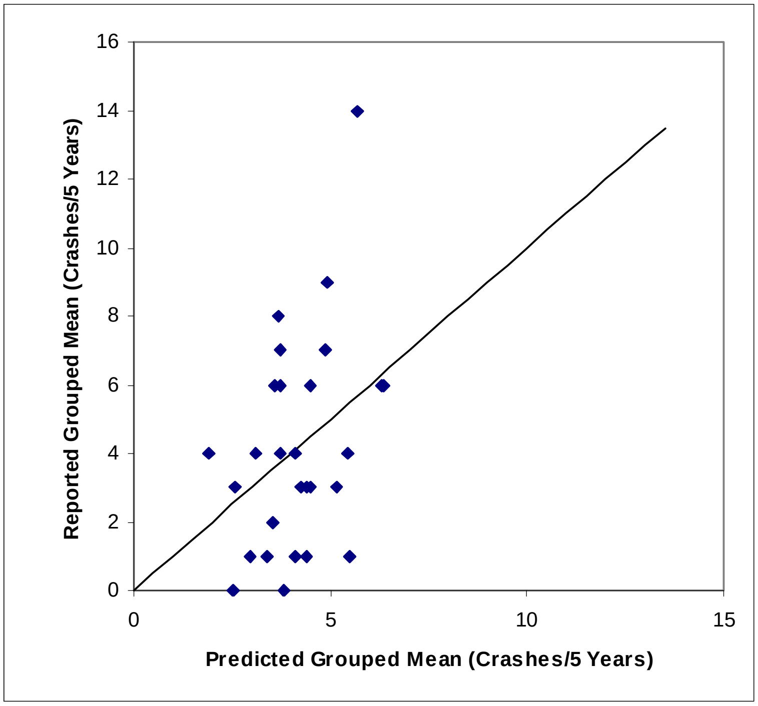

Figure 8.11 Relationship Between Predicted and Reported Crashes for A_{RAXT0} Model

8.7 Summary

The typical mean annual numbers of reported injury crashes for high-speed signalised crossroads in New Zealand can be calculated using the crash prediction models in Table 8.1. When turning movement counts are available, the number of crashes should be predicted by crash type and approach. The total number of crashes can then be predicted by summing the individual predictions for each of the four approaches. The k-values can be used in the Weighted Accident Procedure (WAP) for economic analysis.

Table 8.1: High-speed Signalised Crossroads Crash Prediction Models

Accident Types	Model (crashes per approach)	K value
Crossing	$A_{RAXT1} = 6.82 \times 10^{-5} \times q_2^{0.31} \times q_{11}^{0.35} \times f_{VIC}$	-
Right-turn-against	$A_{RAXT2} = 2.17 \times 10^{-2} \times q_2^{0.20} \times f_{VIC}$	0.9
Rear-end	$A_{RAXT3} = 4.16 \times 10^{-7} \times Q_e^{1.18} \times f_{VIC}$	1.7
Loss of Control	$A_{RAXT4} = 5.75 \times 10^{-5} \times Q_e^{0.70} \times f_{VIC}$	5.7
Others	$A_{RAXT5} = 1.04 \times 10^{-2} \times Q_e^{0.14} \times f_{VIC}$	1.7

***K is the Gamma shape parameter for the negative binomial (NB) distribution.**

9. Roundabout Crash Models

9.1 Product of Links

The models in this section can be used to predict the total number of crashes at high-speed roundabouts. Due to the absence of turning movement counts, no models for individual crash type models were developed.

The models were developed in accordance with the process outlined in Section 4. Appendix B outlines the predictor variables and the parameters of the models developed. Unlike other intersection crash types, the traditional 'product-of-link' models using major and minor flows were comparatively poorly fitting given the number of reported crashes. The exponents of the flow also seemed unreasonable due to the correlation between the major and minor flows.

For this reason, models were trialled that use the two-way approach volume to predict the number of crashes associated with an individual approach. Equation 9.1 presents the model for crashes per approach based on the two-way AADT.

Equation 9.1 $$A_{RAAR1} = 218 \times 10^{-6} \times Q_{Approach}^{0.71}$$

where:

A_{RARX1}	**is theannual number of all crashes occurring at an approach to the roundabout, and**
$Q_{Approach}$	**is the two-way approach flow.**

The fit of the model to the data can be illustrated by comparing the predicted mean number of crashes and the reported number of crashes, as shown in Figure 9.1.

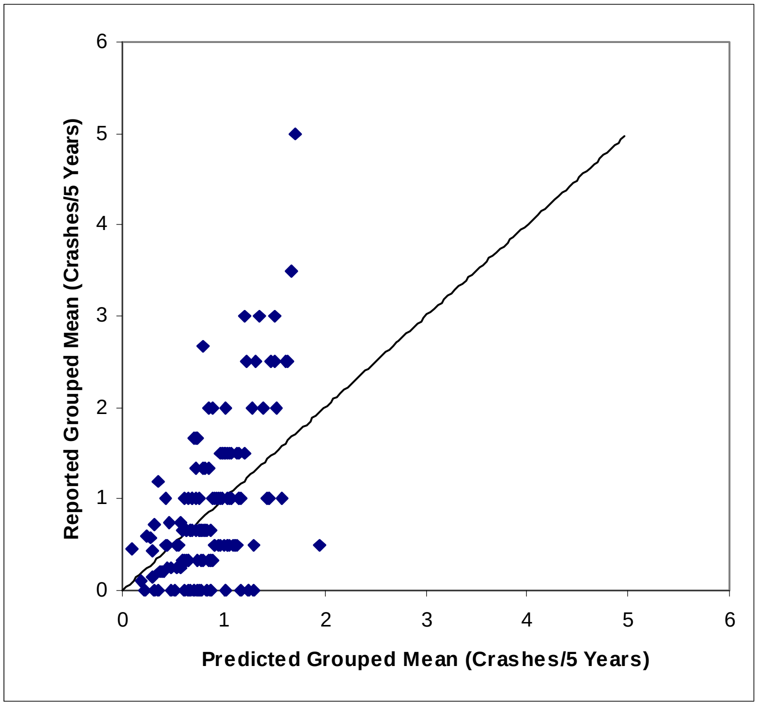

Figure 9.1 Relationship Between Predicted and Reported Crashes for A_{RAAR1} Model

To calculate the total number of crashes at an intersection the number of crashes per approach can be calculated and then added together. For the sake of completeness a simplified form of this calculation is presented in Equation 9.1.

Equation 9.1

$$A_{RAAR0} = 218 \times 10^{-3} \times \left(Q_{App1}^{0.71} + Q_{App2}^{0.71} + Q_{App3}^{0.71} + Q_{App4}^{0.71} \right)$$

where:

A_{RARX0} **is the annual number of all crashes occurring at the intersection, and**

$Q_{App\ i}$ **is the two-way approach flow for the specified approach.**

10. Conclusions

10.1 Summary

Crash occurrence at rural priority T-junctions and crossroads, high-speed signalised T-junctions and cross-roads, and rural roundabouts, have been investigated in this research report. Crash Prediction Models have been developed for the major crash types and the overall number of crashes (product-of-link flow models) for each control type. Both traffic flow and non-flow variables have been included in these models.

For priority controlled intersections the main findings of this research project are:

1. A greater percentage of total crossroad reported crashes (injury and non-injury) involve injury when compared with T-junctions. Hence, crash severity appears to be higher for crossroads compared with T-junctions.
2. The majority of injury crashes at crossroads are vehicle-crossing (HA) crashes. The most common injury crash type at T-junctions is Type JA.
3. A number of non-flow variables were found to be important for particular crash types, including form of control (stop or give-way), visibility deficiency, 85%ile speed on through road, and presence of right-turning bay.
4. The preferred model form for some of the crash models does not include both the conflicting flows, but only one flow. The preferred model form is selected using the Bayesian Information Criterion (BIC) test.
5. The goodness-of-fit testing indicates that the preferred model forms were significant for all five crash types at T-junctions, but only for three of the five crash types at crossroads.
6. The key model form varies for different crash types, with between one and three predictor variables significant for the various model forms.

For traffic signals and roundabouts the main findings of this research project are:

7. The proportion of rear-end crashes that involve injury at high-speed signalised intersections is almost double that at low-speed sites.
8. High-speed traffic signals have a higher proportion of injury crashes than low-speed traffic signals.
9. There is a high correlation between major and minor road volumes at high-speed signalised intersections and roundabouts.
10. Although New Zealand has a slightly higher crash rate for fatal injuries than Victoria (Australia), Victoria's serious crash rate is more than double New Zealand'sand Victoria's is also significantly higher for other injury crashes.
11. Some crash models had similar exponents to those for low-speed intersections, indicating that similar relationships with flow exists.
12. All crash models for signalised intersections, except those for rear-end crashes at T-junctions, had covariates for the Victorian intersections that were greater than 1. Of particular note is the occurrence of rear-end crashes, for which modelled rates are approximately 10 times greater in Victoria than in New Zealand. This indicates that, at an intersection level, there are far more reported injury crashes in Victoria

than in New Zealand. This may be a result of lower crash rates, lower reporting rates, or a combination of both, in New Zealand.

10.2 Recommendations

The following recommendations are made as a result of this research project:

1. Land Transport New Zealand should include the product-of-link models presented in this research in Appendix 6 of the Economic Evaluation Manual.
2. The base models for priority intersections should be used by Land Transport New Zealand for the Road Infrastructure Safety Assessment (RISA) project.
3. Transit NZ should consider including the models, perhaps product-of-flow models, in one of its manuals, possibly the State Highway Control Manual. The models could be used to assess the impact of additional traffic from developments at rural intersections, and for assessing the safety impact of upgrading rural intersections to traffic signals or roundabouts.

10.3 Areas for Future Research

The following areas should be considered in future research on this topic:

1. Obtain a larger sample size of high-speed signalised intersections to develop models based more on New Zealand conditions. For example there are a number of high-speed traffic signals in the Wellington region for which data on turning movement volumes are currently not available.
2. Collect turning movement counts at high-speed roundabouts to develop models for each crash type.
3. Collect approach speed data on each leg of the high-speed signals and roundabouts to investigate further the influence of speed. This will enable the effect of different operating speeds on crash occurrence to be assessed in more detail.
4. Collect data on other factors such as visibility, number of lanes, and surfacing, to investigate the impact of these attributes on predicted crash rates at signalised intersections and roundabouts.

11. References

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Appendix A – Crash Movement Codes

	TYPE	A	B	C	D	E	F	G	O
A	Overtaking and lane change								A OTHER
B	Head on								B OTHER
C	Lost control or off road (straight roads)								C OTHER
D	Cornering								D OTHER
E	Collision with obstruction								E OTHER
F	Rear end								F OTHER
G	Turning versus same direction								G OTHER
H	Crossing (no turns)								H OTHER
J	Crossing (vehicle turning)								J OTHER
K	Merging								K OTHER
L	Right turn against								L OTHER
M	Manoeuvring								M OTHER
N	Pedestrians crossing road								N OTHER
P	Pedestrians other								P OTHER
Q	Miscellaneous								Q OTHER

Appendix B - Crash Prediction Model Parameters

Introduction

This appendix outlines all the crash prediction models developed using the modelling procedure in Section 4. The model parameters are included in tables in the following section, by crash type, and have been sorted by their Bayesian Information Criterion (BIC). The preferred model, that is the model that maximises goodness of fit while having a parsimonious number of variables, is highlighted in bold.

To illustrate how the models can be reconstructed from their parameters, the parameters in Table A.1 will be reconstructed to form a model for predicting pedestrian crashes.

Table A.1 Example Parameters for Model Reconstruction

Predictor Variables	Parameters b_0	b_1	b_2	b_3	b_4	Multiplier Φ	Error Structure	BIC
P, $e^{(Qa/100)}$ Φ_{MEL}	3.84×10^{-4}	0.55	0.003			3.67	K = 1.8	0.889

The first stage is to write out the functional form of the model. Models always start with the b_0 parameter and then the multiplicative variables are added. If the variables listed are not exponents or multipliers (Φ) (for example P) they are in a power function form and have a model parameter as an exponent. If the variable is an exponent such as Qa/100 then the model parameter is a multiplier in the exponent. Finally, the multipliers (Φ) are added without any parameters, and the value in the table is the multiplier if the feature is present. The parameters are numbered by the corresponding location in the list of predictor variables. Using this process the functional form of the predictor variables in Table A.1 is shown in Equation A.1.

Equation A.1

$$A = b_0 \times P^{b_1} \times e^{b_2 \times (Q_q/100)} \times f_{MEL}$$

The next step is to add in the model parameters to the functional form as illustrated in Equation A.2.

Equation A.2

$$A = 3.84 \times 10^{-4} \times P^{0.55} \times e^{0.003 \times (Q_q/100)} \times f_{MEL}$$

Model Parameters

The following section outlines the model parameters for the seven crash types and total crashes.

Rural Priority T-Junction

Crossing – Vehicle Turning (Major Road approach to right of Minor Road)

Table A.2: RMTP1 Accident Prediction Equations

Predictor Variables	Parameters b_0	b_1	b_2	b_3	b_4	Multiplier Φ	Error Structure	BIC
Q_1, V_{RD}	1.64×10^{-5}	1.34		0.35			K=8.3	1.19
Q_1	1.29×10^{-4}	1.04					K=5.2	1.21
Q_1, Q_5, $(V_{RD}+V_{LD})$	5.29×10^{-6}	1.33	0.15	0.33			K=8.1	1.22
Q_1, Q_5, V_{RD}	7.08×10^{-6}	1.28	0.16	0.34			K=7.9	1.22
Q_1, V_R	1.06×10^{-2}	1.11		-0.87			K=6.2	1.23
Q_1, S_{RSD}	2.32×10^{-3}	0.99		-1.29			K=12	1.23
Q_1, S_R	1.47×10^{-9}	1.08		2.53			K=4.4	1.23
Q_1, Q_5	4.29×10^{-5}	0.97	0.19				K=5.2	1.24
Q_1, ϕ_{STOP}	1.01×10^{-4}	1.07				1.33	K=5.3	1.25
Q_1, Q_5, ϕ_{STOP}	3.91×10^{-5}	1.00	0.18			1.23	K=5.3	1.28
Q_5	4.67×10^{-4}		0.55				K=0.9	1.47

Table A.3: RMTP2 Accident Prediction Equations

Predictor Variables	Parameters b_0	b_1	b_2	b_3	b_4	Multiplier Φ	Error Structure	BIC
Q_3, S_L	1.79×10^{-21}	0.67		9.1			K=0.3	1.25
Q_3, Q_4, S_L	5.29×10^{-27}	0.46	0.67	11.0			K=0.4	1.27
Q_3	5.08×10^{-4}	0.71					K=0.2	1.29
Q_4	1.45×10^{-4}		0.68				K=0.2	1.29
Q_3, Q_4	2.89×10^{-5}	0.53	0.50				K=0.2	1.31
Q_3, S_{LSD}	4.75×10^{-3}	0.71		-1.12			K=0.2	1.32
Q_3, ϕ_{RTB}	3.25×10^{-4}	0.83				0.54	K=0.2	1.32
Q_3, Q_4, ϕ_{RTB}	8.13×10^{-6}	0.64	0.63			0.36	K=0.3	1.33

Table A.4: RMTP3 Accident Prediction Equations

Predictor Variables	Parameters b_0	b_1	b_2	b_3	b_4	Multiplier Φ	Error Structure	BIC
$(Q_5 + Q_6)$	1.59×10^{-5}	0.91					K=1.0	1.16
$(Q_5 + Q_6)$, S_{RSD}	3.54×10^{-8}	1.16	2.01				K=1.1	1.18
$(Q_5 + Q_6)$, S_R	5.42×10^{-6}	0.90	0.26				K=1.0	1.20

Table A.5: RMTP4 Accident Prediction Equations

Predictor Variables	Parameters B_0	b_1	b_2	b_3	b_4	Multiplier Φ	Error Structure	BIC
$(Q_3 + Q_4)$, ϕ_{RTB}	3.27×10^{-03}	0.09				5.11	K=7.6	0.97
$(Q_3 + Q_4)$	2.99×10^{-04}	0.51					K=3.0	0.99
$(Q_3 + Q_4)$, S_{LSD}	4.03×10^{-06}	0.70	1.36				K=3.5	1.02
$(Q_3 + Q_4)$, S_L	7.47×10^{-05}	0.50	0.33				K=3.3	1.03

Table A.6: RMTP5 Accident Prediction Equations

Predictor Variables	Parameters b_0	b_1	b_2	b_3	b_4	Multiplier Φ	Error Structure	BIC
(Q_1+Q_2)	1.47×10^{-02}	-0.02					K=0.7	0.91
(Q_1+Q_2), $\phi_{CHEVRON}$	1.33×10^{-02}	-0.04				1.60	K=0.6	0.94
(Q_1+Q_2), ϕ_{STOP}	1.49×10^{-02}	0.00				0.63	K=0.6	0.95
(Q_1+Q_2), $(V_{RD}+V_{LD})$	1.56×10^{-02}	-0.02	-0.07				K=0.6	0.95
(Q_1+Q_2), (V_L+V_R)	5.68×10^{-03}	-0.02	0.15				K=0.7	0.95

Table A.7: RMTP0 Accident Prediction Equations

Predictor Variables	Parameters b_0	b_1	b_2	b_3	b_4	Multiplier Φ	Error Structure	BIC
Q_{Major}, Q_{Minor}	4.24×10^{-04}	0.18	0.57				K=4.7	1.94
Q_{Major}, Q_{Minor}, $\phi_{WIDENING}$	6.39×10^{-04}	0.14	0.56			1.35	K=5.1	1.97
Q_{Major}, Q_{Minor}, $\%_{SIDE\ ROAD\ LEFT\ TURNERS}$	8.89×10^{-04}	0.26	0.42	-0.45			K=5.7	2.80
Q_{Major}, Q_{Minor}, $(V_{RD}+V_{LD})$	4.88×10^{-04}	0.24	0.48	0.08			K=8.4	2.79
Q_{Major}, Q_{Minor}, $(V_{RD}+V_{LD})$, $\%_{SIDE\ ROAD\ LEFT\ TURNERS}$	7.13×10^{-04}	0.26	0.45	0.11	-0.70		K=13.9	2.81
Q_{Major}, Q_{Minor}, $(V_{RD}+V_{LD})$, S_{85}	8.85×10^{-09}	0.20	0.54	0.04	2.40		K=9.6	2.80
Q_{Major}, Q_{Minor}, ϕ_{IDEAL}	6.53×10^{-04}	0.24	0.46			0.93	K=5.6	2.81
Q_{Major}, Q_{Minor}, $(V_{RD}+V_{LD})$, S_{85}, $\%_{LEFT\ VISIBILITY}$	1.11×10^{-08}	0.20	0.55	0.04	2.26		K=9.7	2.84

Rural Priority Crossroads

Table A.8: RMXP1 Accident Prediction Equations

Predictor Variables	Parameters b_0	b_1	b_2	b_3	b_4	Multiplier Φ	Error Structure	BIC
Q_2, Q_5	1.20×10^{-04}	0.60	0.40				K=0.9	1.25
Q_2, S_{LSD}	6.58×10^{-02}	0.67	-1.74				K=0.9	1.25
Q_2	2.24×10^{-03}	0.58					K=0.7	1.26

Predictor	Parameters					Multiplier	Error	BIC
Variables	b_0	b_1	b_2	b_3	b_4	Φ	Structure	
Q_2, Q_5, S_{LSD}	2.69×10^{-03}	0.64	0.26	-1.10			K=1.0	1.27
Q_2, Q_5, ϕ_{STOP}	1.22×10^{-04}	0.55	0.39			1.36	K=0.9	1.28
Q_2, Q_5, V_L	2.74×10^{-04}	0.60	0.39	-0.16			K=0.9	1.28
$Q_2, \phi_{CONSPICUOUS}$	1.85×10^{-03}	0.57				1.62	K=0.8	1.28
Q_2, ϕ_{STOP}	2.10×10^{-03}	0.52				1.61	K=0.7	1.29
Q_2, S_L	1.46×10^{-01}	0.58	-0.94				K=0.7	1.29
Q_2, V_L	5.14×10^{-03}	0.59	-0.16				K=0.7	1.29
Q_2, V_{LD}	2.13×10^{-03}	0.59	0.02				K=0.7	1.29
Q_5	1.57×10^{-03}	0.40					K=0.3	1.36
Q_2, Q_5, V_{RD}	1.26×10^{-04}	0.59	0.39	-0.02			K=0.9	1.28

Table A.9: RMXP2 Accident Prediction Equations

Predictor	Parameters					Multiplier	Error	BIC
Variables	b_0	b_1	b_2	b_3	b_4	Φ	Structure	
Q_2, Q_{11}, ϕ_{STOP}	1.79×10^{-04}	0.28	0.39			3.52	K=3.1	1.22
Q_2, Q_{11}	2.05×10^{-04}	0.40	0.44				K=2.0	1.23
Q_2, ϕ_{STOP}	3.08×10^{-03}	0.24				4.23	K=2.0	1.23
$Q_2, \phi_{CONSPICUOUS}$	3.23×10^{-03}	0.35				2.73	K=3.1	1.24
Q_2, V_R	1.34×10^{-01}	0.46	-1.65				K=1.7	1.25
Q_2	5.20×10^{-03}	0.39					K=1.3	1.26
Q_2, S_L	1.15×10^{-08}	0.42	2.89				K=1.4	1.27
Q_2, V_R	2.70×10^{-02}	0.41	-0.33				K=1.3	1.28
Q_{11}	1.12×10^{-03}	0.43					K=0.8	1.28
Q_2, V_{RD}	4.64×10^{-03}	0.40	0.04				K=1.3	1.28

Table A.10: RMXP3 Accident Prediction Equations

Predictor	Parameters					Multiplier	Error	BIC
Variables	B_0	b_1	b_2	b_3	b_4	Φ	Structure	
Q_5, Q_{11}, ϕ_{RTB}	1.30×10^{-06}	-1.34	2.57			0.33	K=3.5	0.83
$Q_5, Q_{11}, Q_4, \phi_{RTB}$	3.63×10^{-07}	-1.08	2.32	0.30		0.20	K=5.5	0.83
Q_5, ϕ_{RTB}	5.50×10^{-06}	1.06				0.39	K=2.1	0.84
Q_4, Q_5, f_{RTB}	1.08×10^{-06}	0.36	1.08			0.22	K=2.6	0.85
Q_5, V_L	6.08×10^{-05}	0.86	-0.49				K=1.4	0.85
Q_5, S_L	1.23×10^{-06}	0.93	0.53				K=1.4	0.85

Table A.11: RMXP4 Accident Prediction Equations

Predictor	Parameters					Multiplier	Error	BIC
Variables	B_0	b_1	b_2	b_3	b_4	Φ	Structure	
$(Q_4+Q_5+Q_6)$	1.14×10^{-04}	0.76					K=1.1	1.52
$(Q_4+Q_5+Q_6), \phi_{RTB}$	1.88×10^{-04}	0.68				1.52	K=1.1	1.53
$(Q_4+Q_5+Q_6), S_2$	1.23×10^{-02}	0.77	-1.06				K=1.1	1.54
$(Q_4+Q_5+Q_6), V_L$	3.34×10^{-05}	0.82	0.36				K=1.1	1.54

Table A.12: RMXP5 Accident Prediction Equations

Predictor Variables	Parameters b_0	b_1	b_2	b_3	b_4	Multiplier Φ	Error Structure	BIC
$(Q_1+Q_2+Q_3)$	3.44×10^{-03}	0.27					K=0.2	0.88
$(Q_1+Q_2+Q_3)$, ϕ_{STOP}	4.41×10^{-03}	0.12				2.21	K=0.2	0.89
$(Q_1+Q_2+Q_3)$, (V_R+V_L)	1.97×10^{-04}	0.24	0.50				K=0.2	0.90
$(Q_1+Q_2+Q_3)$, $(V_{RD}+V_{LD})$	3.30×10^{-03}	0.28	0.01				K=0.2	0.90

Table A.13: RMXP0 Accident Prediction Equations

Predictor Variables	Parameters b_0	b_1	b_2	b_3	b_4	Multiplier Φ	Error Structure	BIC
Q_{Major}, Q_{Minor}, S_{85}	5.54×10^{-12}	0.36	0.60	3.89			K=3.3	2.80
Q_{Major}, Q_{Minor}	4.21×10^{-04}	0.39	0.50				K=2.6	2.80
Q_{Major}, Q_{Minor}, $(V_{RD}+V_{LD})$, S_{85}	4.69×10^{-11}	0.37	0.63	0.09	3.31		K=3.5	2.82

High Speed Signalised Crossroads

Table A.14: RAXT1 Prediction Model Parameters

No.	b_0	b_1	b_2	b_3	f	Error Structure	BIC	AIC	p
Q_2, Q_{11}, ϕ_{VIC}	6.82×10-5	0.31	0.35		3.95	Poisson	1.60	1.51	0.55
Q_2, Q_{11}	8.60×10-5	0.36	0.41			Poisson	1.58	1.51	NC**
Q_{11}, ϕ_{VIC}	1.97×10-3		0.23		5.90	Poisson	1.61	1.54	NC**
Q_{11}	7.15×10-3		0.27			Poisson	1.62	1.57	NC**
Q_2	1.11×10-2	0.22				Poisson	1.63	1.58	NC**

**** NC (Not Calculated)**

Table A.15: RAXT2 Prediction Model Parameters

No.	b_0	b_1	b_2	b_3	f	Error Structure	BIC	AIC	P
Q_2, ϕ_{VIC}	2.17×10^{-2}	0.20			1.43	NB (K=0.9)*	2.59	2.52	0.55
Q_2	2.78×10^{-2}	0.20				NB (K=0.9)*	2.56	2.51	NC**
Q_7	1.71×10^{-1}		-0.01			NB (K=0.8)*	2.59	2.54	NC**
Q_2, Q_7	3.88×10^{-2}	0.22	-0.07			NB (K=0.9)*	2.60	2.52	NC**

***K is the Gamma shape parameter for the negative binomial (NB) distribution.**

**** NC (Not Calculated)**

Table A.16: RAXT3 Prediction Model Parameters

No.	b_0	b_1			f	Error Structure	BIC	AIC	P
Q_e, ϕ_{VIC}	4.16×10^{-7}	1.18			9.91	NB (K=1.7)*	2.99	2.92	0.08
Q_e	1.36×10^{-6}	1.28				NB (K=1.3)*	3.08	3.04	NC**

***K is the Gamma shape parameter for the negative binomial (NB) distribution.**

**** NC (Not Calculated)**

Table A.17: RAXT4 Prediction Model Parameters

No.	b_0	b_1			f	Error Structure	BIC	AIC	P
Q_e, ϕ_{VIC}	5.75×10^{-5}	0.70			1.15	NB (K=5.7)*	1.32	1.25	0.20
Q_e	5.91×10^{-5}	0.71				NB (K=6.2)*	1.28	1.23	NC**

***K is the Gamma shape parameter for the negative binomial (NB) distribution.**

**** NC (Not Calculated)**

Table A.18: RAXT5 Prediction Model Parameters

No.	b_0	b_1			f	Error Structure	BIC	AIC	P
Q_e, ϕ_{VIC}	1.04×10^{-2}	0.14			4.44	NB (K=1.7)*	2.47	2.40	0.35
Q_e	2.90×10^{-2}	0.18				NB (K=1.4)*	2.50	2.45	NC**

***K is the Gamma shape parameter for the negative binomial (NB) distribution.**

**** NC (Not Calculated)**

Table A.19: RAXT Prediction Model Parameters

No.	b_0	b_1	b_2		f	Error Structure	BIC	AIC	P
Q_{Major}, ϕ_{VIC}	3.55×10^{-4}	0.71			1.36	NB (K=4.3)*	5.06	4.92	0.17
Q_{Major}	2.27×10^{-4}	0.78				NB (K=4.2)*	4.96	4.87	NC**
Q_{minor}	3.58×10^{-2}		0.32			NB (K=3.9)*	4.99	4.89	NC**
Q_{Major}, Q_{minor}	2.48×10^{-4}	0.58	0.20			NB (K=4.6)*	5.05	4.90	NC**
Q_{Major}, Q_{minor}, ϕ_{VIC}	3.79×10^{-4}	0.52	0.19		1.33	NB (K=4.7)*	5.15	4.96	NC**

***K is the Gamma shape parameter for the negative binomial (NB) distribution.**

**** NC (Not Calculated)**

High-speed Signalised T-junctions

Table A.20: RATT1 Prediction Model Parameters

No.	b_0	b_1	b_2	b_3	f	Error Structure	BIC	AIC	p
Q_3, Q_5, ϕ_{VIC}	3.76×10^{-2}	0.41	-1.20		2.85	NB (K=2.3)*	3.61	3.42	0.07
Q_3, Q_5	6.48×10^{-1}	0.66	-1.15			NB (K=1.6)*	3.55	3.41	NC**
Q_3	1.87×10^{-3}	0.65				NB (K=1.1)*	3.54	3.44	NC**
Q_3, ϕ_{VIC}	5.87×10^{-3}	0.43			2.66	NB (K=1.4)*	3.62	3.48	NC**
Q_5	7.96×10^{-3}		-1.11		2.85	NB (K=1.8)*	3.68	3.58	NC**

***K is the Gamma shape parameter for the negative binomial (NB) distribution.**

**** NC (Not Calculated)**

TableA.21: RATT2 Prediction Model Parameters

No.	b_0	b_1			f	Error Structure	BIC	AIC	P
Q_{Major}, ϕ_{VIC}	2.28×10^{-2}	0.29			0.89	Poisson	3.96	3.82	0.20
Q_{Major}	2.83×10^{-2}	0.27				Poisson	3.79	3.70	NC**

**** NC (Not Calculated)**

TableA.22: RATT3 Prediction Model Parameters

No.	b_0	b_1	b_2	b_3	f	Error Structure	BIC	AIC	P
Q_1, ϕ_{VIC}	3.18×10^{-2}	0.12			1.67	Poisson	2.31	2.17	0.10
Q_1	1.87×10^{-2}	0.23				Poisson	2.16	2.06	NC**
Q_5	5.38×10^{-1}		-0.18			Poisson	2.19	2.09	NC**

No.	b_0	b_1	b_2	b_3	f	Error Structure	BIC	AIC	P
Q_1, Q_5	**8.05×10^{-1}**	**0.30**	**-0.47**			**Poisson**	**2.31**	**2.17**	**NC****

**** NC (Not Calculated)**

TableA.23: RATT4 Prediction Model Parameters

No.	b_0	b_1			f	Error Structure	BIC	AIC	P
Q_{Major}, ϕ_{VIC}	**5.77×10^{-3}**	**0.32**			**1.06**	**Poisson**	**2.85**	**2.71**	**0.22**
Q_{Major}	**5.17×10^{-3}**	**0.34**				**Poisson**	**2.67**	**2.57**	**NC****

**** NC (Not Calculated)**

TableA.24: RATT5 Prediction Model Parameters

No.	b_0	b_1			f	Error Structure	BIC	AIC	P
Q_{Major}, ϕ_{VIC}	**1.82×10^{-3}**	**0.37**			**2.81**	**Poisson**	**2.61**	**2.47**	**0.01**
Q_{Major}	**3.74×10^{-5}**	**0.58**				**Poisson**	**2.60**	**2.51**	**NC****

**** NC (Not Calculated)**

TableA.25: RATT6 Prediction Model Parameters

No.	b_0	b_1			f	Error Structure	BIC	AIC	P
Q_{Major}, ϕ_{VIC}	**1.40×10^{-3}**	**0.41**			**5.04**	**NB (K=8.0)***	**2.81**	**2.67**	**0.17**
Q_{Major}	**7.80×10^{-5}**	**0.84**				**NB (K=0.9)***	**2.88**	**2.79**	**NC****

***K is the Gamma shape parameter for the negative binomial (NB) distribution.**

**** NC (Not Calculated)**

TableA.26: RATT Prediction Model Parameters

No.	b_0	b_1	b_2		f	Error Structure	BIC	AIC	P
Q_{Minor}, ϕ_{VIC}	**2.87×10^{-1}**		**0.14**		**1.77**	**NB (K=3.7)***	**5.84**	**5.70**	**0.51**
Q_{Minor}	**7.18×10^{-2}**		**0.32**			**NB (K=3.7)***	**5.78**	**5.69**	**NC****
Q_{Major}, Q_{minor}	**7.79×10^{-1}**	**-0.31**	**0.41**			**NB (K=3.7)***	**5.93**	**5.79**	**NC****
Q_{Major}	**4.07×10^{-1}**	**0.12**				**NB (K=3.5)***	**5.97**	**5.88**	**NC****
Q_{Major}, Q_{minor}, ϕ_{VIC}	**1.24**	**-0.20**	**0.21**		**1.70**	**NB (K=3.7)***	**6.00**	**5.81**	**NC****

***K is the Gamma shape parameter for the negative binomial (NB) distribution.**

**** NC (Not Calculated)**

Roundabouts

TableA.27: AAXR Prediction Model Parameters

No.	b_0	b_1	b_2		f	Error Structure	BIC	AIC	P
Q_{Minor}	**1.21×10^{-2}**		**0.47**			**NB (K=9.6)***	**4.41**	**4.33**	**0.18**
Q_{Major}	**1.38×10^{-2}**	**0.43**				**NB (K=7.3)***	**4.48**	**4.41**	**NC****
Q_{minor}, ϕ_{HS}	**1.12×10^{-2}**		**0.47**		**1.09**	**NB (K=9.7)***	**4.48**	**4.37**	**NC****
Q_{Major}, Q_{Minor}	**1.25×10^{-2}**	**-0.01**	**0.48**			**NB (K=9.6)***	**4.49**	**4.37**	**NC****
Q_{Major}, Q_{minor}, ϕ_{HS}	**1.31×10^{-2}**	**-0.07**	**0.53**		**1.11**	**NB (K=9.7)***	**4.56**	**4.41**	**0.14**

***K is the Gamma shape parameter for the negative binomial (NB) distribution.**

**** NC (Not Calculated)**

Appendix C – Unique Identification Codes for APMs

Unique Identification Code for APMs

Each APM developed is identified by a unique code which gives information on the environment, user type, location, control and type of crashes it predicts:

1st Character – Environment

M	**Motorway/Expressway**
R	**Rural**
U	**Urban**

2nd Character – User

A	**All**
C	**Cyclists**
M	**Motor Vehicles**
P	**Pedestrians**
W	**Wheeled Vehicles (motor vehicles and cyclists)**

3rd Character – Location

M	**Mid-block**
R	**Ramp**
T	**T-junction**
X	**Crossroads**

4th Character – Control

G	**Give way**
N	**None (Mid-block)**
O	**Other**
P	**Priority (includes stop, GW and uncontrolled)**
R	**Roundabout**
S	**Stop**
T	**Traffic Signals**
U	**Uncontrolled**
Z	**Zebra**

5th Character – Model Number

0	**Product of links model**
1,2,3,4,...	**Individual crash type model (allocated in numerical order)**

Appendix D – Flow Ranges for APMs

T-Junction APMs

Model	Variable	80th percentile AADT (vpd)	
		Lower	Upper
RMTP0	Q_{Major}	800	14700
	Q_{Minor}	150	2600
RMTP1	q_1	0	600
	q_5	250	6600
RMTP2	q_3	50	950
	q_4	250	6900
RMTP3	q_5+q_6	350	7200
RMTP4	q_3+q_4	400	7750
RMTP5	q_1+q_2	100	1350

Crossroad APMs

Model	Variable	80th percentile AADT (vpd)	
		Lower	Upper
RMXP0	Q_{Major}	350	9700
	Q_{Minor}	100	1400
RMXP1	q_5	150	5000
	q_2	0	300
RMXP2	q_2	0	300
	q_{11}	150	5000
RMXP3	q_5	150	5000
	q_4	0	300
RMXP4	$q_4+q_5+q_6$	150	5300
RMXP5	$q_1+q_2+q_3$	50	650

High-speed Signalised T-Junctions APMs

Model	Variable	80th percentile AADT (vpd)	
		Lower	Upper
RATT0	Q_{Minor}	1650	19800
RATT1	q_3	300	6450
	q_5	5700	17200
RATT2	Q_{Major}	12700	46000
RATT3	q_1	300	5300
RATT4	Q_{Major}	12700	46000
RATT5	Q_{Major}	12700	46000
RATT6	Q_{Minor}	1700	19800

High-speed Signalised Crossroads APMs

Model	Variable	80th percentile AADT (vpd)	
		Lower	Upper
RAXT0	Q_{Major}	19200	54300
RAXT1	q_2	1450	16000
	q_{11}	100	16000
RAXT2	q_2	450	17800
RAXT3	Q_e	2300	24900
RAXT4	Q_e	2300	24900
RAXT5	Q_e	2300	24900

Roundabout APMs

Model	Variable	80th percentile AADT (vpd)	
		Lower	Upper
AAXR	Q_{Minor}	2250	12400