Predicting Accident Rates for Cyclists and Pedestrians

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An important note for the reader

Land Transport New Zealand is a Crown entity established under the Land Transport New Zealand Amendment Act 2004. The objective of Land Transport New Zealand is to allocate resources in a way that contributes to an integrated, safe, responsive and sustainable land transport system. Each year, Land Transport New Zealand invests a portion of its funds on research that contributes to this objective.

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CONTENTS

Executive summary

Recent government legislation and policy is promoting an increase in walking and cycling within our cities and towns as an alternative to the increasing demand for motor vehicle travel. It is known that 46% of motor vehicle driver tours (round trips that begin and end at home) are under 10 km in total length and 19% under 4 km in length. This highlights the opportunities to increase the mode share of sustainable modes of walking and cycling.

Concern exists, however, that an increase in these modes, cycling in particular, could lead to a substantial increase in pedestrian and cyclist fatalities and injuries, particularly in larger centres where motorised traffic volumes are high and increasing. This research project investigates accident rates for cyclists and pedestrians in urban centres and the risk to these road users if traffic volumes or cycle and pedestrian volumes increase. The research was undertaken between 2002 and 2004 with data being collected in Christchurch, Palmerston North and Hamilton.

An international review of literature on accident prediction models (APMs) was carried out. This indicated that few studies focus on pedestrian and cycle accident rates. Hence a limited number of studies exists on which to base the research, but where possible this research builds on studies undertaken by others overseas. The researchers are not aware of research studies of this type undertaken previously in New Zealand.

The preferred modelling technique in the literature is generalised linear modelling with either a negative binomial or Poisson error structure (i.e. distribution of prediction variable accidents). A multiplicative model form including the product of at least two variables, which can include traffic volume variables, pedestrian volumes, cycle volumes or non-flow variables, was preferred as the model predicts zero accidents when one of the variables is zero.

The available research on pedestrian APMs and, to a lesser extent, cycle accident trends indicates a 'safety in numbers' effect, which implies that the risk to each pedestrian and cyclist drops as the number of users increases. A key issue investigated in this research is whether a similar trend occurs in New Zealand.

Reporting of accidents involving pedestrians and cyclists is an issue. A high proportion of cycle accidents do not involve motor vehicles and at least half of the cycle accidents occur off-road. Other than fatal cycle accidents, anecdotal evidence suggests that the reporting rate for serious and minor cycle accidents is low, and lower than for motor-vehicle-only accidents. Cycle accidents are not recorded in the Ministry of Transport's CAS database unless the accident occurs with a motor vehicle on the road or adjacent footpath.

Pedestrian accidents are also only recorded when they involve motor vehicles. The hospital and ACC interviews conducted in this study indicate that 37% of on-road/footpath accidents do not involve a motor vehicle. There are also pedestrian-only and pedestrian-cyclist accidents occurring off-road. The research indicates that the elderly are particularly at risk.

Pedestrian and cyclist accident casualties were surveyed using a questionnaire that was designed to obtain statistics on the number of such accidents on-road that involved or did not involve a motor vehicle and to obtain details of the accidents that are not readily available in police reports or in the Ministry of Transport's accident database.

Five survey techniques were used to interview pedestrian and cyclist casualties:

- a survey of staff on call at Christchurch Hospital,
- questionnaires left at three Christchurch after hours medical centres
- questionnaires mailed to accident casualties on the ACC database.
- a survey of staff in-house at Christchurch Hospital emergency department for two 1-month periods,
- telephone interviews of accident casualties on the ACC database.

The response rate to the first three techniques was low. The fourth and fifth techniques, and particularly the latter, had a good response rate.

A total of 311 survey questionnaires were completed, of which 264 involved accidents that occurred on a road or adjoining footpath and were at traffic signals, roundabouts or mid-block. The remaining accidents occurred off-road and were not analysed.

A comparison has been made between the age group of cyclist casualties and the proportion of cycle trips that each age group makes (as specified in the Land Transport Safety Authorities' travel survey). While the highest proportion of cycle accident casualties were in the 10—20 year age group, the number of cyclist accident casualties surveyed (25%) is much lower than the proportion of trips made by this age group (48%). In contrast, for the 30-40 year age group the proportion of cyclist accident casualties surveyed (20%) was much higher than the proportion of trips (7%). A similar, though less extreme trend is also observed for the 40—50 and 50—60 year age groups. These results compare well with data from the Ministry of Transport's Crash Analysis System (CAS).

The highest proportion of pedestrian accident casualties surveyed was in the 10—20 year age group (21%), which matched the number of trips made by the age group. The proportion of accident casualties surveyed in the 20—30 year age group (7%) was well below the proportion of trips made by this group (18%). In contrast, the proportion of accident casualties in the 80 plus category at 12% was well above the proportion of trips (1%).

Over one quarter (27%) of the on-road pedestrian accidents in the hospital surveys did not involve a motor vehicle. Previous research indicates that approximately 50% of cycle accidents are off-road. Hence, only approximately one third of all cycle accidents involve a motor vehicle, and are possibly entered into the Ministry of Transport's CAS database.

Major accident causes were also collected. Causes specified by cyclists include 'traffic failed to notice me' (48%), or 'traffic failed to give way to me' (28%). Major accident causes specified by pedestrians include 'traffic failed to notice me' (51%) and 'tripped and fell' (34%).

Traffic, pedestrian and cycle counts were collected from councils and in this research to enable APM development. The proportion of pedestrians crossing on the 'green man' was recorded for traffic signals within Christchurch City in these surveys. On average the proportion is around 81%. The average proportion before the am peak (60%) and after the pm peak (50%) appears to be the lowest. When traffic volumes are higher (during peak periods) the proportion crossing with the 'green man' tends to be higher.

APMs were developed using the generalised linear modelling technique for cyclist and pedestrian accidents at urban signalised crossroads, roundabouts and mid-block locations. Models for other intersection types (e.g. signalised T-junction) and accident types were also investigated, but because of the small sample size and low number of accidents it was not possible to develop good-fitting models.

For some intersection types it has been possible to develop a model to predict all pedestrian or cyclist accidents using the models developed for major accident types and a factor that takes into account the 'other' pedestrian or cyclist accidents.

The prediction models can be used to calculate the likely change in motor vehicle, pedestrian and cycle accidents and also accident rate per road user for a change in mode, particularly motor vehicle trips to pedestrian and cycle trips. Two mode change scenarios were evaluated. The first scenario is an increase in cycle and pedestrian volumes at all crossroad traffic signals (both two-way), mid-block sections and, for cyclists only, roundabouts. These were applied at all intersections in the dataset for Christchurch. The number of pedestrian and cycle trips was increased by up to 300% along with a corresponding decrease in traffic volumes. The second scenario considers a 20% shift of motor vehicle traffic from Fendalton Road and Memorial Avenue in Christchurch to cycle trips. In both scenarios there is a noticeable 'safety in numbers' effect. Generally, the overall increase in cycle and pedestrian accidents was not substantial and the crash rate per cyclist and pedestrian reduced.

This research raised areas to be researched further. Key areas are to:

- expand the sample sizes by including intersections in Auckland, Wellington and Nelson,
- collect data on more non-flow variables, particularly specific cyclist and pedestrian facilities,
- collect longer duration pedestrian and cyclist counts at sample sites,
- do further work on daily, weekly and seasonal trends in cyclist and pedestrian volumes, including effects of weather and school holidays on counts,
- consider non-commercial mid-block locations, priority controlled intersections and major driveways.

Abstract

Recent government legislation and policy promotes an increase in walking and cycling as an alternative to the increasing demand for motor vehicle travel. Concern exists, however, that an increase in these modes, particularly cycling, could lead to a substantial increase in pedestrian and cyclist fatalities and injuries. In this research, carried out between 2002 and 2004, accident rates for cyclists and pedestrians were investigated and interviews carried out with casualties. A high under-reporting rate was observed. Using traffic, cyclist and pedestrian counts and reported accidents between the 'active modes' and motor vehicles, accident prediction models (APMs) were developed. These include models for various accident types at signalised crossroads, roundabouts and mid-block locations. These models were used to calculate the likely change in motor vehicle, pedestrian and cycle accidents and also accident rate per road user for a change in mode, particularly motor vehicle trips to pedestrian and cycle trips. It was found that a noticeable 'safety in numbers' effect exists. Generally, the overall increase in cycle and pedestrian accidents was not substantial and the crash rate per cyclist and pedestrian reduced with increases in their numbers.

1. Introduction

1.1 Background

The New Zealand National Transport Strategy, issued in December 2002, placed a strong emphasis on walking and cycling as an alternative to motor-vehicle travel. One third of motor-vehicle trips made in New Zealand are less than 2 km in length and could probably be made on cycle or by foot. Two thirds are less than 6 km and could reasonably be made by cycle (Ministry of Transport 2003).

The Ministry of Transport is currently developing a strategy for promoting walking and cycling. An issue in increased walking and cycling is the potential for an increase in pedestrian and cycling fatalities and injuries. Cycle and pedestrian accidents are over-represented in the accident statistics for the amount of travel by these modes. In larger centres the perception is that cycling in particular, but also walking, is unsafe given increased traffic volumes on the road networks.

Only limited research has been undertaken in New Zealand on accident-causing mechanisms associated with pedestrian and cycle accidents. Research has been limited to analysis of accident trends in the Ministry of Transport's Crash Analysis System (CAS) database and the interviewing of small samples of cyclist accident casualties. More detailed research is required to allow a more focused emphasis on factors that will reduce the accident risks to cyclists and pedestrians.

This research project extends previous work undertaken by Turner (1995, 2000) on accident prediction models (APMs) for motorised modes of travel, to cycling and pedestrian accidents. It is acknowledged that reporting rates for such accidents, particularly where no motor vehicles are involved, are poor and that given the relative scarcity of such accidents compared with motor-vehicle accidents, there are problems with developing well-fitting models.

1.2 Study objectives

This study had a number of objectives, including:

- To assess the accident reporting rate for cyclists and pedestrians in Christchurch, Palmerston North and Hamilton, based on those reported to hospitals and from other sources (St John and Accident Compensation Corporation (ACC)). A secondary objective was to determine the proportion of accidents on-road that do not involve a motor vehicle.
- To develop APMs for pedestrian and cycle accidents at signalised intersections, roundabouts and mid-blocks on arterial routes.
- To develop guidelines to allow traffic engineers and transport planners to predict accident rates for pedestrians and cyclists and therefore enable the impact of transport planning improvements on those modes to be assessed, including shifts in travel mode.

The study consisted of two stages. Stage 1 was the Pilot Study and partly addressed the first two objectives. The major purpose of Stage 1 was to identify problem areas in terms of achieving the study objectives.

1.3 Stage 1 report

The Stage 1 report (Turner & Durdin unpublished) discussed findings from the Pilot Study of the hospital interviews and also the preliminary work on developing APMs. The purpose of the Pilot Study (Stage 1) was to establish whether sufficient data were available or could be collected to develop adequate APMs for cycle and pedestrian accidents at traffic signals, roundabouts and on major arterials. The poor reporting rates of such accidents were also considered.

During Stage 1 a review of data availability in three centres (Christchurch, Palmerston North and Hamilton) was undertaken, but more focused investigation was limited to Christchurch for logistical reasons. Model development was limited to cycle accidents at traffic signals and roundabouts. However, the viability of looking at pedestrian accidents and of considering accidents at mid-block locations on arterials was considered.

1.4 Final report

This report discusses:

- the pedestrian and cycle accident casualty interview surveys (carried out at the hospital and over the telephone),
- the development of APMs for cyclists and pedestrians,
- trends in accident occurrence and reporting rates.

The evolution of the interview survey technique used for pedestrian and cycle accident casualties are discussed, as are the merits of the various techniques in terms of achieving a good response rate. The results of the over 300 interview surveys are discussed, along with a summary of the key factors which appear to impact on pedestrian and cycle accidents.

APMs for cyclists and pedestrians have been developed using existing and surveyed count data of motor vehicle, cyclists and pedestrians, as well as reported injury accidents. Models have been developed for the key pedestrian and cycle accident types at each junction type. Various combinations of flow variables, and where available non-flow variables, have been used in the models.

2. Literature review

2.1 Introduction

APMs have been developed for road accidents in a number of countries over recent years. The majority of the studies have concentrated on motor-vehicle accidents occurring at intersections or on links between intersections. Some studies consider total accidents at each site, while others have considered specific motor-vehicle accident types and even accidents by time of day.

New Zealand researchers, like those in most other developed countries, have developed APMs for motor-vehicle accidents and total accidents at intersection and on links. Work has also been undertaken on developing prediction models at sites such as bridges and isolated curves. Some New Zealand studies are discussed in Section 2.3.

Fewer studies have considered other modes of travel (walking, cycling and rail) or different motor-vehicle classes (buses and trucks). It is known that the active modes (walking and cycling) have a higher accident risk than motorised modes of transport, and this shows up in the accident statistics. The accident-causing mechanisms in active mode accidents are quite different from those of motor-vehicle accidents and it is likely that different model variables will feature in such models. Studies involving non-motorised modes are discussed in Section 2.4.

Uncertainty exists in the accident data available for all modes of transport including reporting rates for pedestrian and cycle accidents (Section 2.2). It is known that the reporting rate of motor-vehicle accidents is low, particularly for lower severity accidents and that the reporting rate varies from region to region within New Zealand and even within regions. The reporting rate for pedestrian and cycle accidents is even lower and because of the smaller number of such accidents at each accident site (intersection or link) it is a more critical issue in the development of pedestrian and cycle APMs.

2.2 Accident reporting rate

2.2.1 New Zealand

The reporting rate for traffic accidents is low, especially for accidents involving only minor injuries. To assess this factor, the ratio of reported serious injury accidents to hospital admissions has been compared. The LTSA (2003b) suggested that the New Zealand reporting rate for serious injuries to hospital admissions had increased from 60% in 1997/1999 to 64% in 2001/2002. In Canterbury it had changed from 68% to 69% over the same period.

Since 1998 there has been a legal requirement in New Zealand for cycle accidents to be reported to the police. However, they have not always been then recorded in the CAS database when a motor vehicle is not involved. The proportion of accidents not involving motor vehicles needs to be established from other accident databases and through surveys of accident casualties.

Munster et al. (2001) studied the role of road features in cycle accidents not involving a motor vehicle on public roads, cycleways and footpaths. They concluded that cycle-only accidents, based on hospital and ACC data, appeared to be twice as frequent as accidents with motor vehicles.

Munster et al. (2001) reported that CAS is not required to contain information on accidents that do not involve a motor vehicle. Thus accidents which occur off-road, away from motor vehicles, are not included in the Ministry of Transport database. Similarly, accidents where a pedestrian is hit by a cyclist or where two cyclists collide are not included.

In a mailed-out survey with 335 responses, they found that 51% of the responses involved accidents that had occurred off-road.

The New Zealand Health Information Service shows that while admissions to hospitals for motor-vehicle accidents have declined (between 1994 – 1998), the number being admitted for cycle-only accidents has held constant (Munster et al. 2001).

Alsop & Langley (2001) compared accident data from hospitals and police in New Zealand. In 1995, fewer than two thirds of all accidents in which vehicle occupants were hospitalised were reported to the police.

The reporting rates varied significantly by age, injury severity, length of stay in hospital, month of accident, number of vehicles involved, whether or not a collision occurred, and geographic region (see Table 2.1). They did not vary by gender, ethnicity or day of the week of the accident.

The reporting rate was defined as the number of linked hospital records (i.e. they occurred in both the police and hospital database) as a proportion of the total hospital motor-vehicle accident records.

Table 2.1 Reporting rates.

Variable	Reporting rates
Age	49-66% depending on age group
Injury severity	51-81%, depending on severity
Length of stay in hospital	56-68%
Month of accident	56-69%
Number of vehicles involved	41-79%
Whether or not a collision occurred	54% for loss of control, varies for other types
Geographic region	40% in Whakatane to 75% in Wellington

The reporting rate for car occupants was 55% and for motorcyclists, 60%. The study did not investigate the specific reporting rate for cycle or pedestrian accidents.

2.3 New Zealand APMs

Previous APM research in New Zealand was undertaken in separate studies as described below. These studies considered only motor-vehicle accidents or total accidents. These studies are relevant for the modelling techniques and the model forms used, and how these have evolved over time. As far as the researchers are aware no APMs have previously been developed in New Zealand for cycle and pedestrian accidents.

2.3.1 Jackett (1992, 1993)

Jackett (1992) used accident, traffic volume, environmental and geometric data on 523 urban routes in Auckland, Wellington and Christchurch to calculate average accident rates, so that remedial work could be undertaken. He found a multiplicative model using Poisson regression was the most appropriate for mid-block accidents, intersection accidents and total accidents. The mid-block model took the form:

$$A = \exp(3.16 - 0.18X_1 - 0.27X_2 + 0.29X_3 + 0.27X_4) \quad \text{(Equation 2.1)}$$

where:

A = number of mid-block accidents (per 10^8 veh-km)
X_1 = 1 for residential development, 0 otherwise
X_2 = 1 for raised medians, 0 otherwise
X_3 = 1 for 50 km/h areas, 0 otherwise
X_4 = number of intersections per km

Even when intersections are removed, those sections with intersections still have a higher accident rate than those without, as it appears accidents some distance from an intersection but related to it, are included.

In a later study, Jackett (1993) refined the model and found that for mid-block accidents:

$$A = \exp(3.02 - 0.10X_1 - 0.16X_2 - 0.26X_3 – 0.32X_4 - 0.028X_5) \quad \text{(Equation 2.2)}$$

where:

A = number of mid-block accidents (per 10^8 veh-km)
X_1 = 1 for residential development, 0 otherwise
X_2 = 1 for flush medians, 0 otherwise
X_3 = 1 for raised medians, 0 otherwise
X_4 = 1 for 50 km/h areas, 0 otherwise
X_5 = number of intersections per km

It appears that roads with flush medians have reduced the accident increasing effects of residential land use. A similar effect comes from a low number of intersections per kilometre.

2.3.2 Gabites Porter (1993)

Gabites Porter (1993) analysed traffic counts and accident data for 107 signalised crossroads in several urban centres in New Zealand. Based on the work by Hauer et al. (1989), APMs were developed for the three most common accident types and four different time periods. The time periods were all day, business hours (7a.m. - 6p.m.), morning peak (7a.m. - 9a.m.) and evening peak (4p.m. – 6p.m.). The models were developed for both injury and property damage only (non-injury) accidents and took the form of the Hauer models:

$$A = kQ_a^{\alpha}Q_b^{\beta} \quad \text{(Equation 2.3)}$$

where:

A = accidents

Q_a, Q_b = flows

k_1, α and β = parameters.

2.3.3 Turner (1995)

Turner (1995) developed a series of APMs for accidents at intersections using generalised linear models. At traffic signals for example, he developed four models, to describe the four major accident types. These were developed for each of the three main centres in New Zealand, Auckland, Wellington and Christchurch over six time periods.

Turner (1995) produced models that allow accidents to be predicted from traffic volumes. The modelling was produced using macros that were developed for the statistical package, Minitab.

Models were developed using accident data from throughout New Zealand for a five-year period, where motor vehicles were involved.
The typical Turner model took the form:

$$A = b_0Q_a^{b1}Q_b^{b2} \quad \text{(Equation 2.4)}$$

where:

A = accidents in five years

Q_a and Q_b = approach flows

b_0, b_1 and b_2 = parameters

2.3.4 Turner (2000)

Turner (2000) expanded on the 1995 work undertaken during his PhD. This study expanded the work on prediction models at urban intersection site types to urban links and rural intersections and links.

Two main types of model were developed at intersections: Type 2 and Type 3 models. Type 2 models are those relating total accidents at an intersection to the product of two-way traffic volumes on the two roads intersecting. Type 3 models relate specific accident types to the turning movements of vehicles involved in such collisions.

Link models were developed for both total accidents and specific accident types using total link flow as the independent variable.

This study uses modelling techniques developed by Turner that are based on the work of Hauer et al. (1989). The models are generalised linear models with a negative binomial error structure.

2.4 Overseas APMs for non-motor-vehicle accidents

The UK Transport Research Laboratory (TRL) has undertaken a number of APM studies.

2.4.1 Hall (1986)

Hall (1986) studied four-arm single carriageway urban intersections with traffic signals, the most common form of traffic signals in the UK for which 177 intersections were studied, 24% with separate pedestrian phases.

There were 1772 accidents at the intersections over the four years studied. Pedestrian accidents made up 28.8% of the accidents.

Hall developed models using generalised regression techniques. The number of accidents was assumed to follow a Poisson error distribution. The models took the form:

$$A = 0.023\, QT^{1.28} (1 + PT^{0.30}) \qquad \text{(Equation 2.5)}$$

where:

QT = *Q1 +…+Q12* (the total vehicles inflow over 12 hours),

PT = *P1+…+P8* (the total pedestrian flows across the four legs).

Hall used 9 functions of vehicle flows and 7 of both vehicle and pedestrian flows. All were highly significant when related to total junction accident frequency (at a level better than 1%). The best variables (and the simplest) were the sum of all 12 incoming (turning) traffic movements (or the sum of the 4 incoming vehicle flows) and the total pedestrian flows across all 4 legs.

Hall identified a number of geometric variables that were correlated with the numbers of accidents. The models were developed for approach widths, number of lanes, sight distance on the approach to the traffic signals, gradient, displacement or offset of opposing roadways, presence of central island, and angle of approach of the roadways. Different accident types had different geometric variables, with only traffic flows being constant in all models.

2.4.2 Summersgill & Layfield (1996)

Summersgill & Layfield (1996) looked at 300 road links between major junctions in the UK. Over a five-year period 1590 injury accidents had occurred on these links.

Models were developed for single vehicle, rear-end shunt, head-on, hit parked car, private drive and ‘other’ vehicles accidents. In addition, pedestrian models were developed for ‘nearside’ pedestrian, ‘offside’ pedestrian and ‘other’ pedestrian accidents. It is the last three models that are of interest in this study.

The sample was stratified by annual average daily total vehicle flow (AADT) and by pedestrian flow crossing the road. A twelve-hour classified count of vehicle and pedestrian flow was taken at one point along the complete road link. The road link was then split into its component link and junction sections and 970 link sections were used in this study. For these link sections, four counts of vehicle and pedestrian flow were made during four separate periods of the day (a.m. peak, a.m. off-peak, p.m. off-peak and p.m. peak). Detailed measurements were made including: the lengths of the sections; the width of the roads; the occurrence, location and dimensions of all features, visibilities, and gradients.

Of the 1590 injury accidents that occurred on these link sections over the period April 1983 to March 1988, 693 were pedestrian accidents. Detailed tabulations are given showing accident densities, severities and rates by region. The accidents are also tabulated by accident group, road-user involvement and number of casualties per accident.

Various pedestrian crossing flows and densities were considered as variable in the models. Pedestrian flows included:

- *PT* being the total number crossing pedestrians,
- *PTON* being pedestrians using (or on) a pedestrian crossing, and
- *PTOFF* being pedestrians not using (or off) a pedestrian crossing.

Density variables included PTSL, PTONSL and PTOFFSL, which are similar to previous variables but are divided by the section length (SL) to produce a density. The first model considered included the flow (QT and PT) as a predictor variable. The model form was:

$$A = k\ QT^{\alpha} \times PT^{\beta} \qquad \text{(Equation 2.6)}$$

A more thorough analysis showed that an identical fit to the data can be obtained by introducing the variables in an alternative form that produces models that can be much more readily understood. In this form, the pedestrian variable was represented by PTSL, the pedestrian density across the link section (thousands of pedestrians per kilometre per 12 hour period) which is simply *PT/SL*. The model form was:

$$A = k \times SL \times QT^{\alpha} \cdot\times PTSL^{\beta} \qquad \text{(Equation 2.7)}$$

where the term *SL* is assigned as an 'offset variable' with its coefficient constrained to the value 1 in the fitting process.

For pedestrians, the best overall model was:

$$A = 0.141\ SL\ QT^{\ 0.745}\ PTSL^{\ 0.510} \qquad \text{(Equation 2.8)}$$

For pedestrian crossings, the best model was:

$$A = 0.0247\ QT^{\ 0.855}\ PTON^{\ 0.403} \qquad \text{(Equation 2.9)}$$

where *PTON* is the two-way pedestrian flow across the crossing.

For off-crossing accidents, the best model was:

$$A = 0.157\ SL\ QT^{\ 0.726}\ PTOFFSL^{\ 0.468} \qquad \text{(Equation 2.10)}$$

where *PTOFFSL* is the off-crossing pedestrian density for the link section.

The accident frequency in this study is directly proportional to the length of the link section and is proportional to vehicle flow and pedestrian density.

This model (and indeed all similar models) has the property that it predicts zero accidents for zero pedestrian flow. This is appropriate for pedestrian accidents and off-crossing accidents. The parameters for *PTSL*, *PTON* and *PTOFFSL* are also much less than one indicating a 'safety in numbers' effect. The effect is more pronounced than for vehicle flows.

2.4.2.1 *Nearside and offside pedestrian accidents*

Summersgill & Layfield also separated accidents by the direction that pedestrians approached the motor vehicle. Using *PTSL*, the pedestrian density across the link section (thousands of pedestrians per kilometre per 12-hour period) the model form was:

$$A = k \times SL \times QT^{\alpha} \times PTSL^{\beta} \qquad \text{(Equation 2.11)}$$

The models developed include:

For nearside pedestrian accidents:

$$A = 0.0413 \times SL \times QA^{0.533} \times PTSL^{0.348} \qquad \text{(Equation 2.12)}$$

where *QA* is the vehicle flow on the 'nearside' (thousands of vehicles per day). The 'nearside' vehicle flow is the single direction traffic flow next to the kerb from which the pedestrian starts their journey across the road.

For 'offside' pedestrian accidents:

$$A = 0.0413 \times SL \times QT^{0.443} \times PTSL^{0.414} \qquad \text{(Equation 2.13)}$$

Pedestrian APMs were also developed using non-flow variables.

Some of the more important findings of the study were as follows:

- The models predict on average more accidents on link sections with a pedestrian crossing than on those without, for any given vehicle and pedestrian density. However, those link sections in the sample without crossings had substantially lower pedestrian densities than those with crossings, and the error structure of the models must reflect that. So caution should be exercised in interpretation.
- Rear shunt and lane-changing accidents increased on link sections with a zebra (pedestrian) crossing.
- Some of the physical variables in the models appear to be correlated with speed. For example, increased visibility in the opposite direction of travel resulted in increased total, vehicle-only, and pedestrian accidents. It is likely that this and some of the other variables found to affect accidents do so by modifying speeds. However speed data were not available for this study.
- There was no difference in the predictions for a one-way link section and for one direction of a two-way link section for the models for total, vehicle only and pedestrian versus motor-vehicle accidents. There were more parking and parked vehicle accidents but fewer private-drive accidents on one-way link sections.

2.4.3 Davis (1998)

Davis (1998) developed a deterministic model for collisions between pedestrian and vehicles. He noted that accidents had a random factor, so his model led to a table of probabilities of a collision, for various mean traffic speeds and mean traffic flows. Davis focused on the 'mid-block dart-out' type of pedestrian accident, with pedestrians being hit by vehicles travelling in the nearest traffic lane. He ignored the risk of being hit by a vehicle travelling in the second or subsequent lane.

The Davis model was developed to allow comparison of the likely accident-reduction effects of various 'traffic calming' techniques. It focused on traffic volumes and traffic speed, adopting assumed values for the other variables:

- distance of pedestrian from the traffic lane before 'darting out',
- speed of pedestrian moving towards the street,
- perception and reaction time of motorist,
- braking deceleration.

The assumed values were:

- Distance of pedestrian from the traffic lane before 'darting out':
  6.5 m – assumes a driver notices a pedestrian 5 m from the street and that the collision occurs 1.5 m into the street.
- Speed of pedestrian moving towards the street:
  4.6 m/sec – taken from research by Eubanks (1994) on the median speed for 9-year old boys running 50 feet (15.2 m).
- Perception and reaction time of motorist:
  1.0 second - from Koppa (1997).
- Braking deceleration
  0.6g = 5.88 m/sec^2 - also from Koppa (1997).

Davis used the exponential spacing model to show that the probability that the pedestrian collides with the car is:

$$\Pr ob\left[v_1 \frac{x_2}{v_2} < x_1 < \frac{v_1^2}{2a} + v_v 1\rho / x_2, v_2, a, 1_\rho \right] = \int_b^\infty \left[e^{-\rho \frac{v_2 x_2}{v_2}} - e^{-\rho\left(\frac{v_1^2}{2a} + v_1 \rho\right)} \right] f_1(v_1) dv_1$$

(Equation 2.14)

where:

a is the deceleration of the car, under braking and is assumed to be 0.6g (5.88 m/sec^2),

b equals the larger of 0 and 2a(x^2 / v^2 - tp)

t_p is the perception reaction time interval, assumed to be 1.0 seconds

v_1 is the initial travel speed of the car

v_2 is the speed of the pedestrian, assumed to be 4.6 m/sec, the speed of a nine-year-old boy running

x_1 is the distance of the car from the collision point when the driver first notices the pedestrian running towards the street

x_2 is the distance the pedestrian is from the collision point, when first noticed by the driver (assumed to be 6.5 m)

ρ . is the space density of vehicles on the road, given by $\rho = q / \mu$ where q is the mean vehicle flow and μ mean vehicle speed.

This leads to a contour plot of collision probability as a function of mean vehicle speed and mean vehicle traffic flow (Figure 2.1):

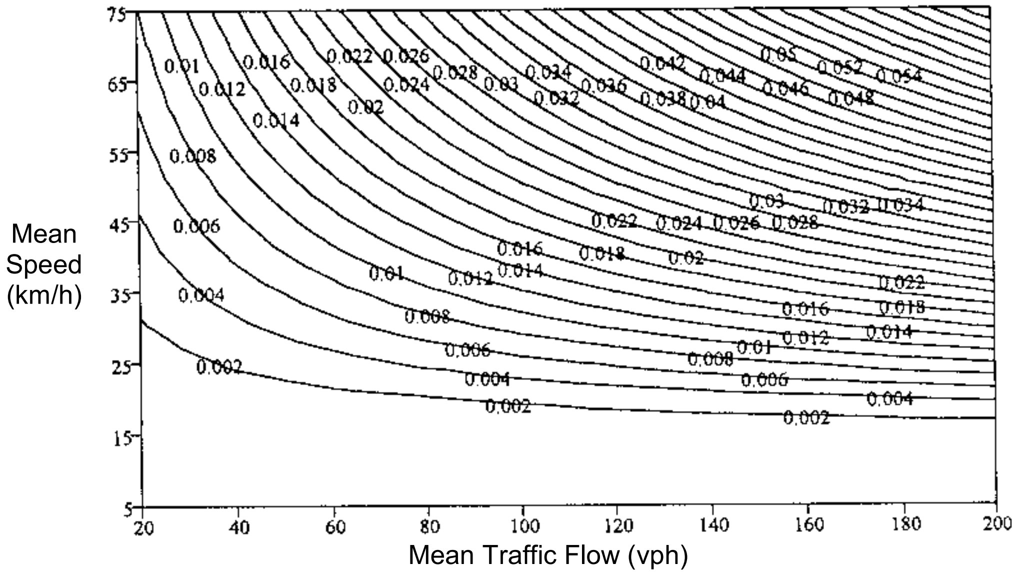

Figure 2.1 Contour plot of collision probability.

2.4.4 Risk & Shaoul (1982)

Risk & Shaoul (1982) suggested that it is important to separate exposure to risk and the degree of risk associated with each type of exposure.

Measuring risk by distance travelled provides only a broad estimate of the associated accident risk. Drivers have different risks as they travel through different sections of a road. It is convenient to estimate risk per 100,000 kilometres travelled, but the risk along each of those kilometres varies. Risk & Shaoul (1982) looked at classifying sections of roads into different risk levels, based on the number of side roads in the section, manoeuvres expected in the section and numbers of potential conflict points.

They suggested that a greater level of assessment of risk could be achieved, if allowance is made for the number of manoeuvres of pedestrians and traffic in the road section being considered.

2.4.5 Brude & Larsson (1993)

Brude & Larsson (1993) gathered data at junctions from 30 towns in Sweden, including only those with more than 100 or more pedestrian or cycle movements per annual average day. The predictive models were based on 165 pedestrian accidents at 285 junctions and 432 cycle accidents at 377 junctions. The least squares method was used to fit the model to the data.

Brude & Larsson's models were power functions. For pedestrians, they took the form:

$$PACCRATE = 0.0201 \times TOTRINC^{0.50} \times TOTPED^{-0.28} \quad \text{(Equation 2.15)}$$

where:

PACCRATE	is the number of accidents involving pedestrians per million passing pedestrians
TOTRINC	is the number of incoming motor vehicles
TOTPED	is the number of passing pedestrians per average annual day

For cyclists, the model is:

$$CACCRATE = 0.0494 \times TOTRINC^{0.52} \times TOTCYC^{-0.35} \quad \text{(Equation 2.16)}$$

where:

CACCRATE	is the number of accidents involving cyclists per million passing cyclists
TOTRINC	is the number of incoming motor vehicles
TOTCYC	is the number of passing cyclists per average annual day

The models show that the risk to pedestrians and cyclists increases with traffic flow, but decreases with increases in pedestrian or cyclists numbers. This is the 'safety in numbers' effect. They suggest that it would be desirable to concentrate pedestrians and cyclists at junctions with high quality facilities for them and little motor-vehicle traffic.

2.4.6 Leden (2002)

Leden (2002) used data from 300 signalised intersections in Hamilton, Ontario to investigate the accident rate between both left and right-turning vehicles and pedestrians. The model developed took the form:

$$A = kQ_a^{\alpha}Q_b^{\beta} + e \quad \text{(Equation 2.17)}$$

where:

A	is the accident frequency
Q_a and Q_b	are flow variables for pedestrian and motor-vehicle flows
k, α and β	are the parameters to be estimated
e	is the error term

Semi-protected situations, where left-turn traffic (same as right-turn traffic in New Zealand) faces no opposing traffic, were compared to similar right-turn situations, each with pedestrians crossing the running flow. At low volumes, the two types of movements have similar accident risks, but at higher vehicle flows, the right turns are safer than the semi-protected left turns. Laden found that the risk per pedestrian decreases with increased pedestrian flows, the 'safety in numbers' effect.

2.4.7 Shankar et al. (2003)

Shankar et al. (2003) addressed the problem of excessive numbers of zero pedestrian accidents in the data. They addressed it by using a zero-inflated Poisson (ZIP) model, where the probability statement Y_i for accident frequency becomes:

$$P(Y_i) = (1 - p_i)\, e^{-\lambda i}\, \lambda_i^k / k! + Z_i p_i \quad \text{(Equation 2.18)}$$

where:

Z_i =	1 when Y_i is observed to be zero,
Z_i =	0 for all other values.

They suggested that too many pedestrian accident zones with no reported accidents arise when the underlying or true accident rate is not obtained because the accident sampling period is too short.

2.5 Accident studies for cyclists and pedestrians

Atkinson & Hurst (1984) reported that cycle accidents in the US in the 1970s that did not involve motor vehicle were believed to be between 70% and 90% of all cycle accidents, depending on sample and definition of injury.

Their study used the questionnaire and methodology by Kaplan (1975) as a model. They sought information on cycle type, cycling distances travelled and accidents in New Zealand.

From a sample of 164 cycle-only accidents, Munster et al. (2001) found that 28% of accidents were attributed by the cyclist to road features. Of the accidents that related to road features (n=46), the most common feature causing accidents was gravel (34%). Other causes were collision with road work signs, potholes, cycle wheel becoming caught in railway track, cobblestones, joints at the edge of driveways, drains and other gaps, uneven surfaces, slippery surfaces, or other road features like barriers and judder bars. Surface irregularities (potholes, anything trapping the bicycle wheel, uneven surfaces and judder bars) accounted for 39% of road features that caused the accidents.

Older cyclists more often regarded road features as being a source of their accidents than younger cyclists. Younger cyclists tended to blame themselves more than older cyclists did. Most of the cyclists in this study believed that the responsibility for the accident rested with themselves. They particularly felt they could have travelled more slowly or been more attentive.

Accidents relating to road features were no more severe than other causes of accidents, i.e. they did not relate to a higher level of hospital admissions.

Jacobsen (2003) found that the likelihood of a pedestrian or cyclist being hit by a motorist varies inversely with the amount of walking and cycling. As walking and cycling increase, the risk per person declines. One of the examples is shown in Figure 2.2 where, as walking and cycling as a percentage of trips to work increase, the relative risk index for pedestrians and cyclists goes down.

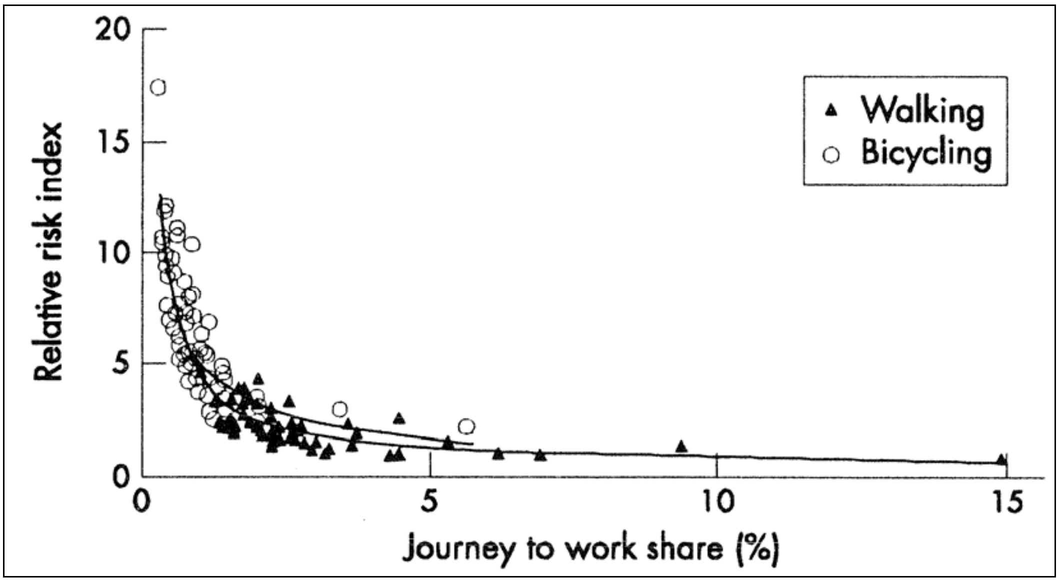

Figure 2.2 Walking and bicycling in 68 California cities in 2000 (Jacobsen 2003).

In Figure 2.3 he showed that as average cycling trip length increased the accident rate also fell.

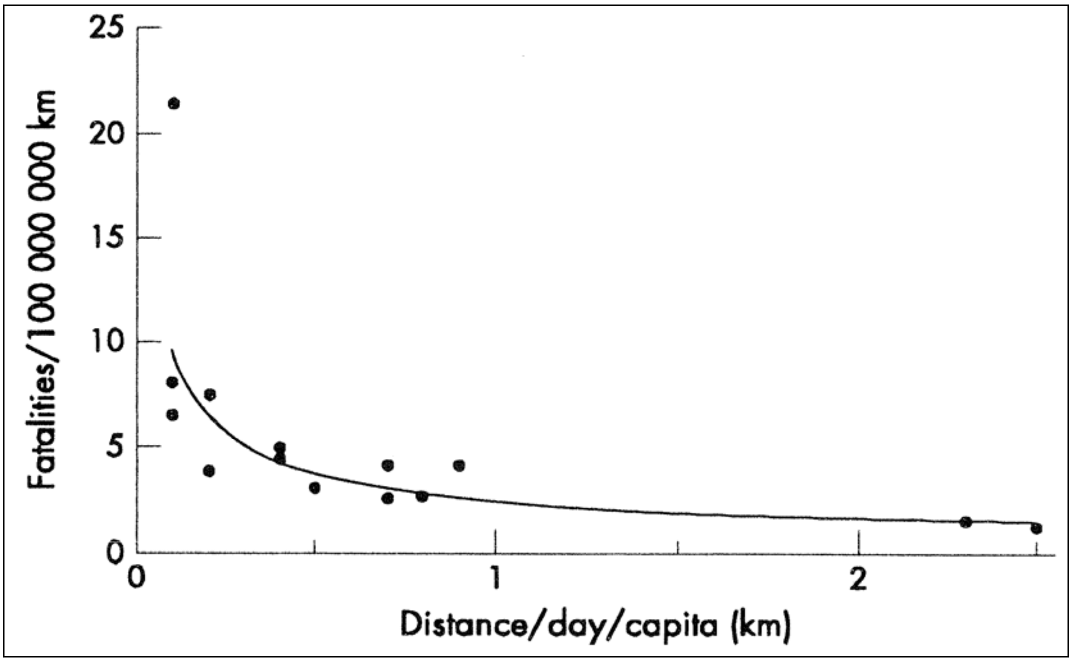

Figure 2.3 Bicycling in 14 European countries in 1998 (Jacobsen 2003).

Using data from California, Denmark, UK and other European countries, Jacobsen concluded that policies which increase the number of cyclists and walking seem to improve the safety of each individual cyclist or walker.

Ekman (1996) looked at the safety of pedestrians using pedestrian crossings (zebra crossings) and signalised crossings and compared them with crossing the road with no facilities. When looking at the accident rate per pedestrian crossing for different ages of pedestrians, as shown in Figure 2.4, the pedestrian (zebra) crossing had the highest accident rate for younger and older age groups and was only slightly lower than the signalised crossing for all other pedestrian ages. Ekman concluded that pedestrians had a false sense of 'protection' at the zebra and the signalised crossings.

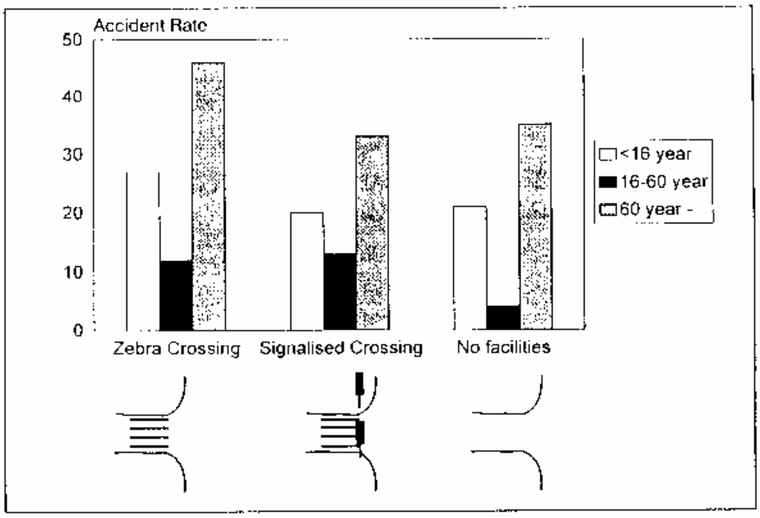

Figure 2.4 Accident rates for three crossing types by age group (Ekman 1996).

3. Pedestrian and cycle accident trends

3.1 Reporting of accidents

In New Zealand, traffic accidents involving injury where a vehicle is involved are required to be reported to the police, under Section 22 of the Land Transport Act 1998. Since 1998 this includes accidents on bicycles, skateboards and similar contrivances, even if a motor vehicle is not involved. It also includes injury accidents between cycles and pedestrians.

The police generally complete a Traffic Crash Report and send it to Land Transport New Zealand who enter the data into the Ministry of Transport’s Crash Analysis System (CAS) only if there has been injury and a motor vehicle is involved. Thus while a legal requirement exists for accidents involving only cycles to be reported, those that are reported do not always get into the CAS database.

For accidents on a public road that do not involve a vehicle, such as a pedestrian-only injury, no legal requirement exists.

The majority of fatal pedestrian and cyclist accidents and many serious ones where a motor vehicle is involved will be reported to the police. The literature indicates that there are many cycle and pedestrian accidents that do not involve a motor vehicle, so the CAS data is not a true reflection of cycle and pedestrian accidents on the road network.

3.2 National pedestrian accident statistics

For the whole of New Zealand, for the ten years from 1993 to 2002 there were 9788 pedestrians reported as injured (serious and minor injuries) in New Zealand and 582 killed (LTSA 2003a). The Injury Prevention Research Unit, Otago University (IPRU 2004) reports that during that 10-year period, 5672 people were discharged from hospitals in New Zealand after treatment for a pedestrian accident.

For non-motor-vehicle pedestrian accidents, from 1993 to 2002 there were 1742 people discharged from NZ hospitals (IPRU 2004). The hospital discharge rates, from the National Injury Query System, highlight some of the variation in available data definitions and sources. The hospital discharges are a subset of all injured pedestrians, and exclude all people seen in hospital emergency departments, but not admitted. They are typically the more severe injury accidents and would be classified as severe in the CAS database. The hospital discharges also exclude all people seen by doctors (i.e. general practitioners), and the biggest group of people who attend to their own injuries, or go to a pharmacy.

In 2001 the number of pedestrians injured per 100,000 population increased to 25.6 from 23.5 in 1999 (LTSA 2002). However, the rate has generally been dropping since 1970, as shown in Table 3.1.

Table 3.1 New Zealand pedestrian casualties and population statistics – historical, year ending 31 December 2001 (LTSA 2002).

Year	Population	Injured	Killed	Per 100,000 population	
				Injured	Killed
1970	2,852,100	1786	99	62.6	3.5
1971	2,898,500	1861	113	64.2	3.9
1972	2,959,700	1993	125	67.3	4.2
1973	3,024,900	2198	157	72.7	5.2
1974	3,091,900	2034	125	65.8	4.0
1975	3,143,700	1760	112	56.0	3.6
1976	3,163,400	1473	102	46.6	3.2
1977	3,166,400	1447	124	45.7	3.9
1978	3,165,200	1224	116	38.7	3.7
1979	3,163,900	1157	106	36.6	3.4
1980	3,164,100	1246	98	39.4	3.1
1981	3,195,800	1121	104	35.1	3.3
1982	3,229,800	1128	89	34.9	2.8
1983	3,269,500	1144	103	35.0	3.2
1984	3,299,500	1343	119	40.7	3.6
1985	3,311,200	1225	125	37.0	3.8
1986	3,316,700	1265	112	38.1	3.4
1987	3,349,100	1256	110	37.5	3.3
1988	3,356,200	1119	83	33.3	2.5
1989	3,384,510	1039	81	30.7	2.4
1990	3,429,100	1161	104	33.9	3.0
1991	3,449,700	1015	88	29.4	2.6
1992	3,485,400	1007	76	28.9	2.2
1993	3,524,800	949	74	26.9	2.1
1994	3,577,200	1063	54	29.7	1.5
1995	3,643,200	1053	71	28.9	1.9
1996	3,717,400	969	63	26.1	1.7
1997	3,761,100	925	54	24.6	1.4
1998	3,790,900	930	71	24.5	1.9
1999	3,810,700	895	63	23.5	1.7
2000	3,830,800	953	35	24.9	0.9
2001	3,850,100	986	52	25.6	1.4

NOTE: Population from 1997 is from Statistics NZ INFOS series DPEA.SDBC.

3.2.1 Accident locations

To determine where reported accidents involving pedestrians commonly occur in urban areas Figure 3.1 was produced for selected accident locations.

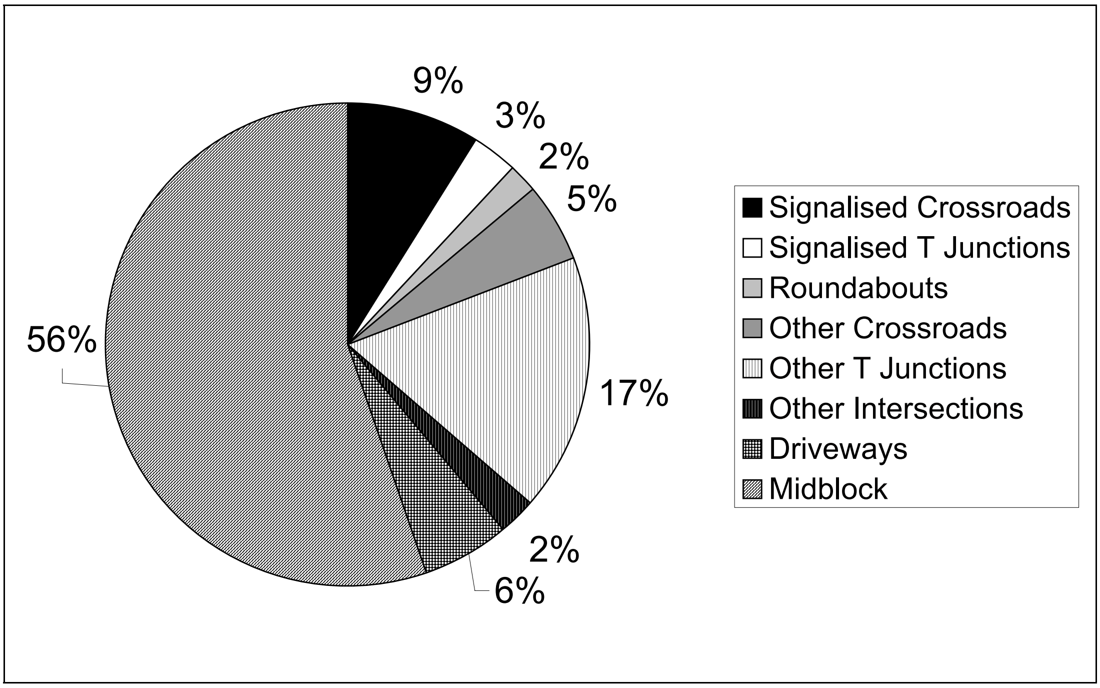

Figure 3.1 Reported pedestrian accident locations in NZ (1999-2003).

Figure 3.1 shows that most urban pedestrian accidents occur at mid-block locations and at driveways, although 38% of accidents occur at intersections.

Turner (1995) calculated the proportion and number of accidents involving pedestrians at various intersection types. At traffic signals 11-14% of accidents involved pedestrians. At roundabouts the proportion was 4-5%. This compares with 3-4% at priority crossroads and 11-13% at priority and uncontrolled T-junctions. At priority and uncontrolled junctions the total number of reported accidents per site is generally a lot lower than at traffic signals and roundabouts. Hence, the number of pedestrian accidents per site (3-13%) is low. Based on the number of pedestrian accidents per intersection it was decided to focus on traffic signals in this research project rather than priority junctions. As most pedestrian accidents occur away from intersections, mid-block sites were also studied, as too were roundabouts which have a high number of cycle accidents per intersection.

3.2.2 Accident types at mid-block locations

Pedestrian accidents occur frequently at mid-block locations in urban areas. Figure 3.2 shows the pedestrian accident types reported at all urban mid-block locations. The major accident types for all mid-block sections are NA and NB (pedestrians crossing the roadway). Refer to Appendix F for explanation of crash codes.

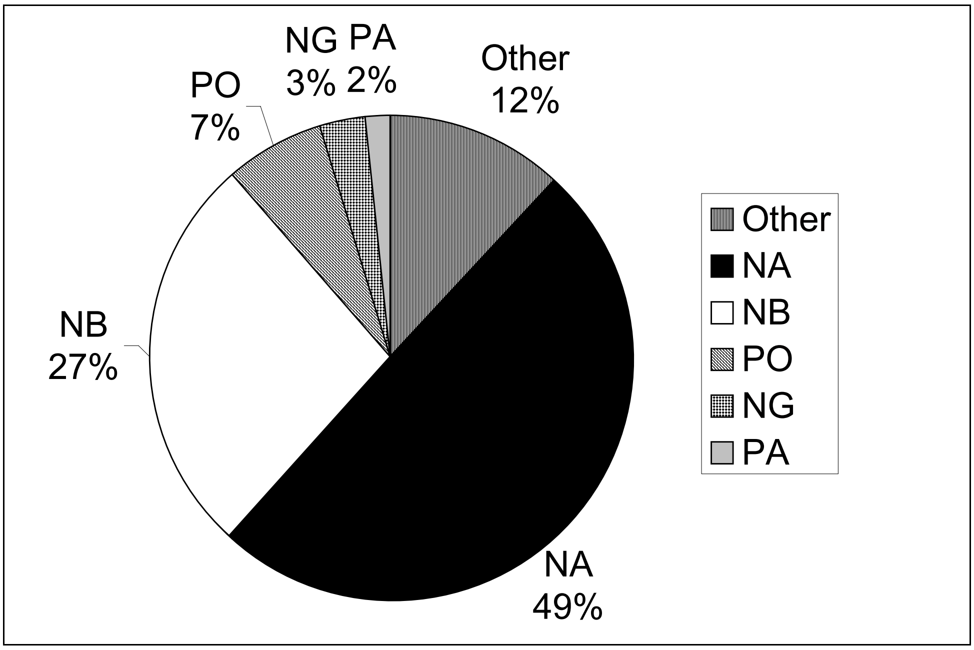

Figure 3.2 Reported pedestrian accidents at urban mid-block locations in New Zealand (1999-2003)*.

3.2.3 Accident types at signalised crossroads

Figure 3.3 shows the major accident types for all crossroad traffic signals. The major pedestrian accident types are NA, NB, ND and NF.

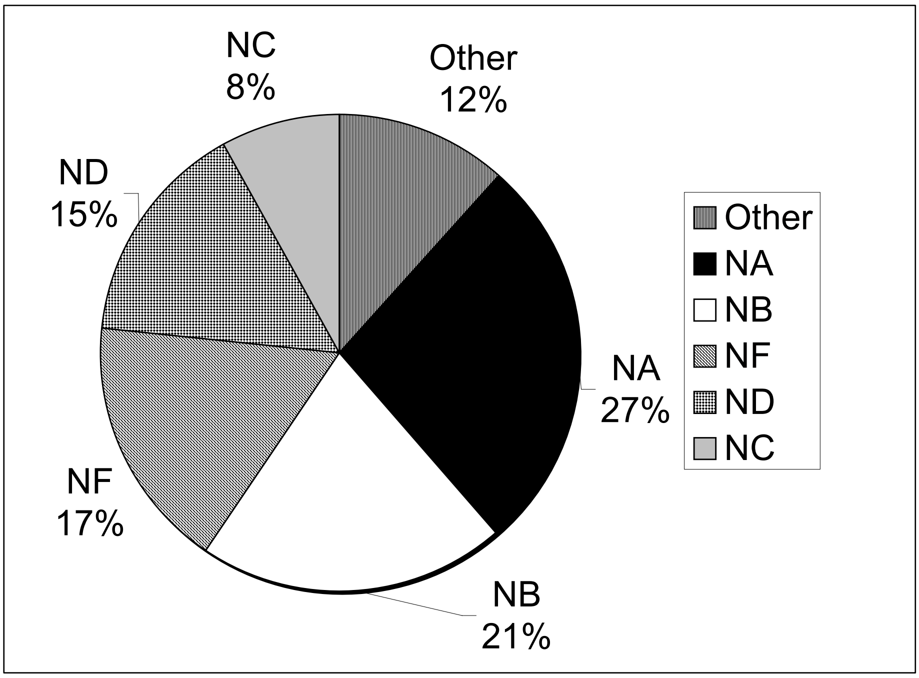

Figure 3.3 Reported pedestrian accidents at signalised crossroads in New Zealand (1999-2003)*.

* Refer to Appendix F for crash codes.

3.2.4 Accident types at signalised T-junctions

Figure 3.4 shows the pedestrian accident types at signalised T-junctions. The major pedestrian accident types are NA, NB and NF. Interestingly type NA (pedestrian hit from right side) is very much more common than type NB (pedestrian hit from left side).

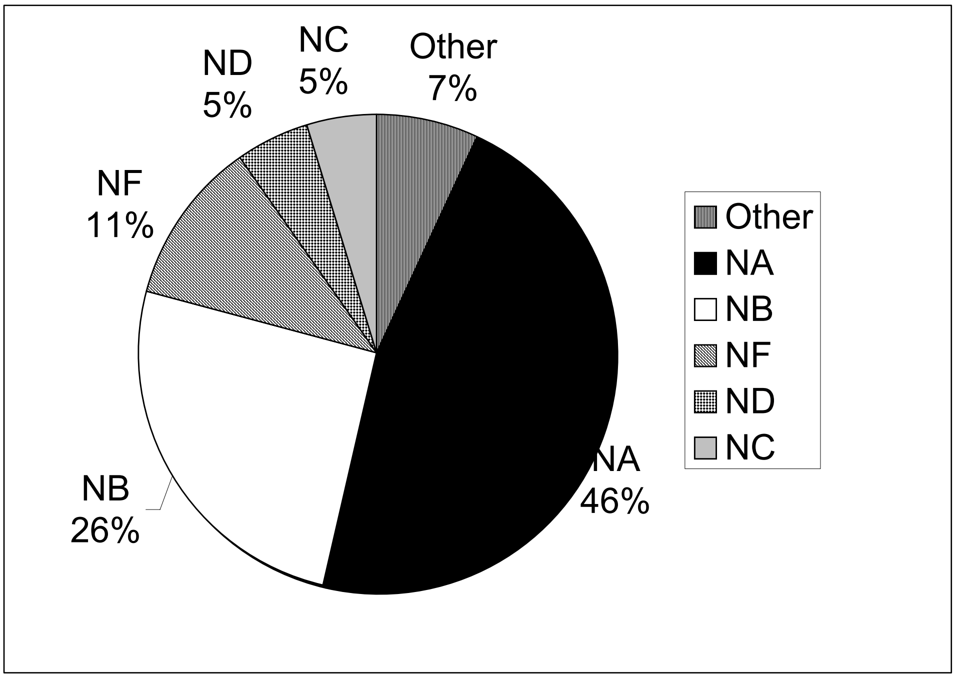

Figure 3.4 Reported pedestrian accidents at signalised T-junctions in New Zealand (1999-2003).

3.2.5 Accident types at roundabouts

Roundabouts generally come in two types, those with single approach and circulating lanes and those with two approach lanes and circulating lanes.

Figure 3.5 shows the type of pedestrian accidents reported as occurring at roundabouts the CAS database between 1999 and 2003 (see Appendix F). It indicates that the major pedestrian accident types at roundabouts are NA and NB.

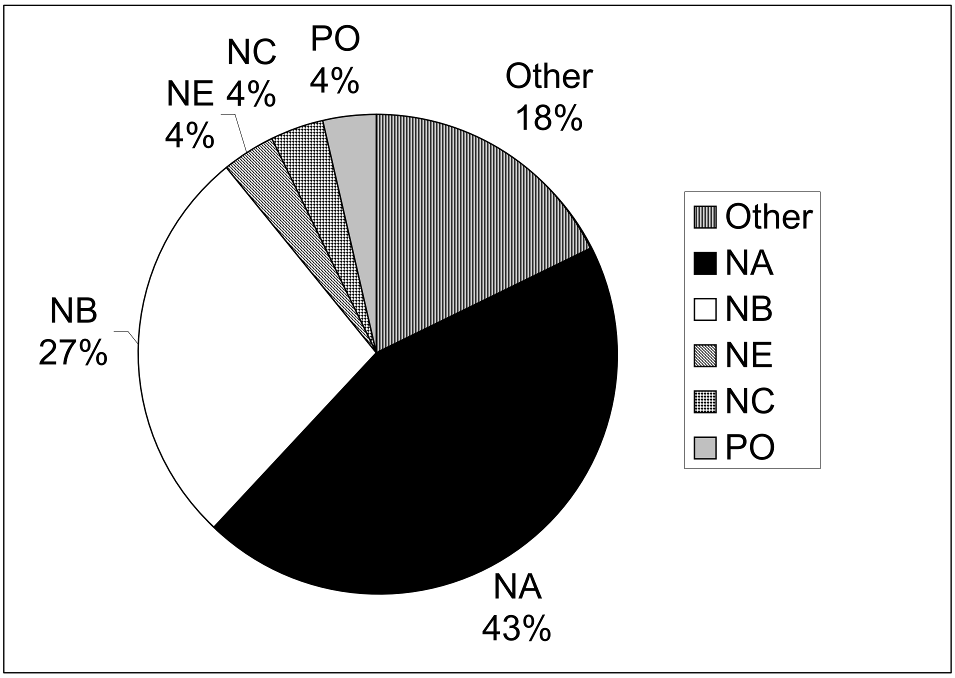

Figure 3.5 Reported pedestrian accidents at roundabouts in New Zealand (1999-2003).

3.3 Christchurch, Palmerston North and Hamilton pedestrian accident statistics

In the development of the APMs (refer to Chapter 6), sites were selected in Christchurch, Palmerston North and Hamilton. The number of accidents involving a pedestrian and a motor vehicle in these centres at traffic signals, roundabouts and mid-block locations in the period 1993 to 2002 inclusive is shown in Table 3.2.

Table 3.2 Location of pedestrian / motor-vehicle accidents, 1993-2002.

City	Traffic signals	Roundabouts	Mid-block	Others
Christchurch	241	18	475	260
Hamilton	35	12	227	77
Palmerston North	31	7	116	49
Total	307	37	818	386

The largest proportion of pedestrian accidents occur at mid-block locations, as it does nationally (Figure 3.1). A high proportion of pedestrian accidents also occur at traffic-signal-controlled intersections. This differs from the national statistics because these are major centres with a large number of high volume intersections. The number of accidents at roundabouts is low, which is probably because the majority of roundabouts are not in high pedestrian flow areas, such as commercial areas. Refer to Appendix A for a more detailed breakdown of junction and control types.

Of those intersections with traffic signals, three types were studied. All were three- or four-legged intersections, generally meeting at right angles. Other intersection layouts, including those with five or more legs, were excluded, being too few in number to make up a large enough sample size to be analysed.

The three types of traffic signal controlled intersections are:

- crossroads with all approaches having two-way traffic,
- crossroads with one-way traffic on one road and two-way traffic on the other,
- T-junctions with all approaches having two-way traffic.

For roundabout-controlled intersections all were four-legged and some incorporated dual circulating lanes, although there were far more single lane roundabouts.

The types of accidents recorded at the sites used for developing the APMs are detailed in Chapter 6.

3.4 National cycle statistics

In the ten-year period from 1993 to 2002 there were 7354 cyclists reported as injured and 139 killed (LTSA 2003a).

As shown in Table 3.3, since 1970, cyclist injuries have climbed to a peak in 1988, then declined, with some increases recently. In 2001 the number of cyclists injured per 100,000 population increased to 18.1 from 14.6 in 2000 (LTSA 2002). It increased further to 19.6 in 2002.

Table 3.3 New Zealand pedal cyclist casualties and population statistics – historical, year ending 31 December (LTSA 2002).

Year	Population	Injured	Killed	Per 100,000 Population	
				Injured	Killed
1970	2,852,100	1041	28	36.5	1.0
1971	2,898,500	1083	29	37.4	1.0
1972	2,959,700	1029	22	34.8	0.7
1973	3,024,900	1018	30	33.7	1.0
1974	3,091,900	969	26	31.3	0.8
1975	3,143,700	745	18	23.7	0.6
1976	3,163,400	736	14	23.3	0.4
1977	3,166,400	631	21	19.9	0.7
1978	3,165,200	588	30	18.6	0.9
1979	3,163,900	623	15	19.7	0.5
1980	3,164,100	745	22	23.5	0.7
1981	3,195,800	748	21	23.4	0.7
1982	3,229,800	881	30	27.3	0.9

Year	Population	Injured	Killed	Per 100,000 Population	
				Injured	Killed
1983	3,269,500	900	19	27.5	0.6
1984	3,299,500	958	31	29.0	0.9
1985	3,311,200	1106	21	33.4	0.6
1986	3,316,700	1012	22	30.5	0.7
1987	3,349,100	1051	18	31.4	0.5
1988	3,356,200	1081	20	32.2	0.6
1989	3,384,510	1051	20	31.1	0.6
1990	3,429,100	1054	27	30.7	0.8
1991	3,449,700	1000	22	29.0	0.6
1992	3,485,400	941	17	27.0	0.5
1993	3,524,800	910	17	25.8	0.5
1994	3,577,200	882	15	24.7	0.4
1995	3,643,200	813	15	22.3	0.4
1996	3,717,400	754	13	20.3	0.3
1997	3,761,100	724	12	19.2	0.3
1998	3,790,900	626	16	16.5	0.4
1999	3,810,700	619	8	16.2	0.2
2000	3,830,800	559	19	14.6	0.5
2001	3,850,100	696	10	18.1	0.3
2002	3,939,100	771	14	19.6	0.4

NOTE: Population from 1997 is from Statistics NZ INFOS series DPEA.SDBC.

Cyclist deaths have generally been declining (as shown in Figure 3.6). The death and injury rate per 100,000 population has been dropping since 1970 (as shown in Table 3.3), although there have been increases in 2000 and 2002. However, the decreasing injury rate may be related to decreasing cycling distances which would reduce the exposure per head of population.

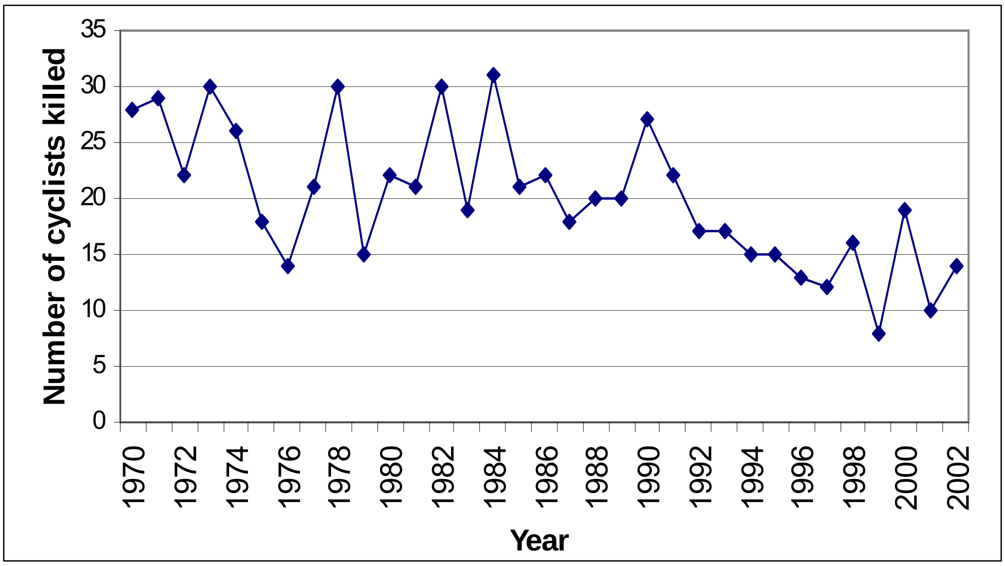

Figure 3.6 Number of cyclists killed in NZ per year, 1970 – 2002 (LTSA 2003a).

3.4.1 Accident locations

To determine where reported accidents involving cyclists commonly occur in urban areas Figure 3.7 was produced for selected accident locations.

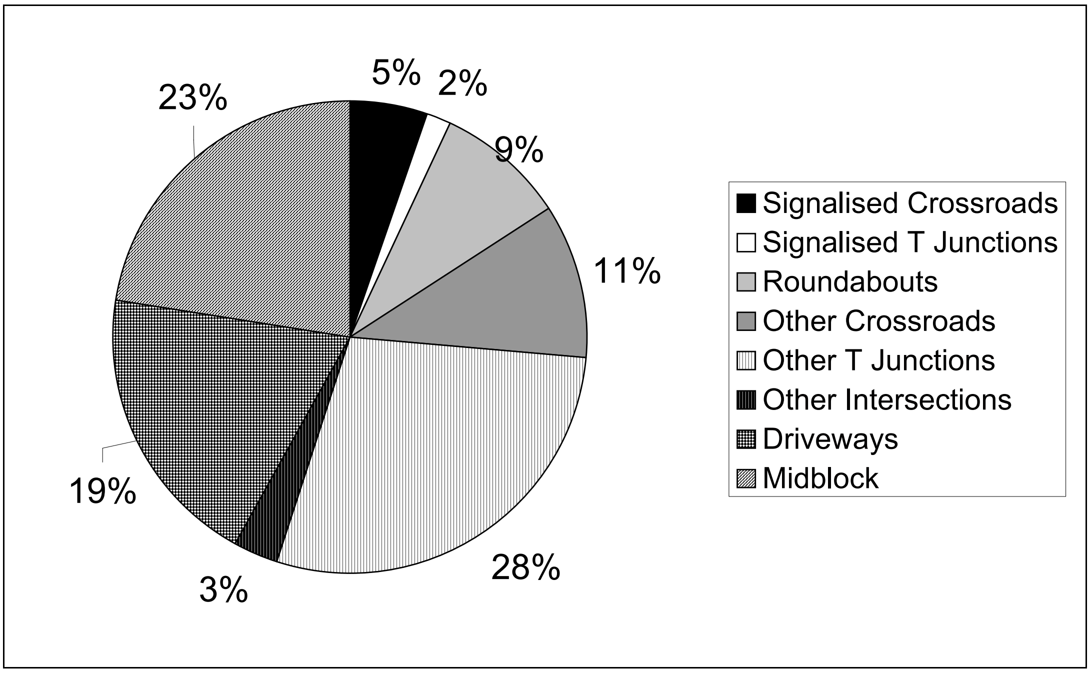

Figure 3.7 Reported cyclist accident locations in NZ (1999-2003).

Most of reported urban cyclist accidents occur at intersections, although 42% of accidents occur at mid-block locations and at driveways.

Turner (1995) calculated the proportion and number of accidents that involved cyclists at various intersection types. At traffic signals between 8% and 11% of accidents involved cyclists. At roundabouts the proportion was between 15% and 19%. This compares with

9% to 11% at priority crossroads and 12% to 13% at priority and uncontrolled T-junctions. At priority and uncontrolled junctions the total number of reported accidents per site is generally a lot lower than at traffic signals and roundabouts. Hence, the number of cyclist accidents per site (9% to 13%) is low. Based on the number of cyclist accidents per intersection it was decided to focus on roundabouts and traffic signals in this research project rather than priority junctions. As a large proportion of cycle accident occur away from intersections, mid-block sites were also studied.

3.4.2 Accident types at mid-block locations

Figure 3.8 shows major reported accident types for mid-block locations. The major accident types are EE, EA, AA, FA, and MC (see Appendix F).

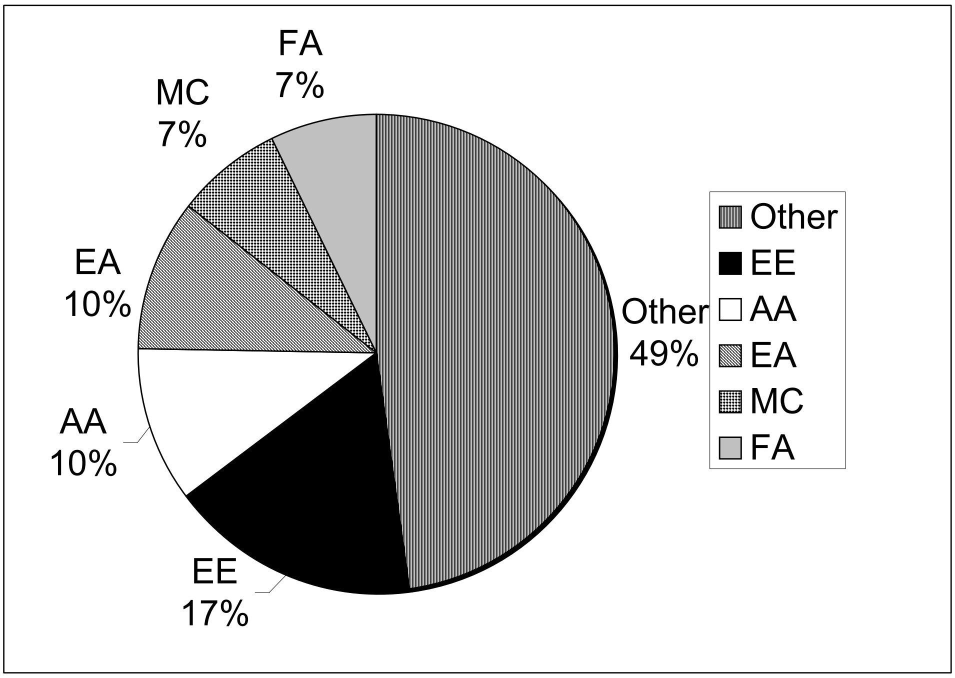

Figure 3.8 Reported cycle accidents at mid-block locations in New Zealand (1999-2003).

3.4.3 Accident types at roundabouts

Of all reported urban cycle accidents in New Zealand, 9% occur at roundabouts. Figure 3.9 shows the major cycle accident types, the majority of which are type HA. This accident type is also often coded as types KA, KB, JA and LB, all of which can be thought of as 'entering versus circulating' accidents.

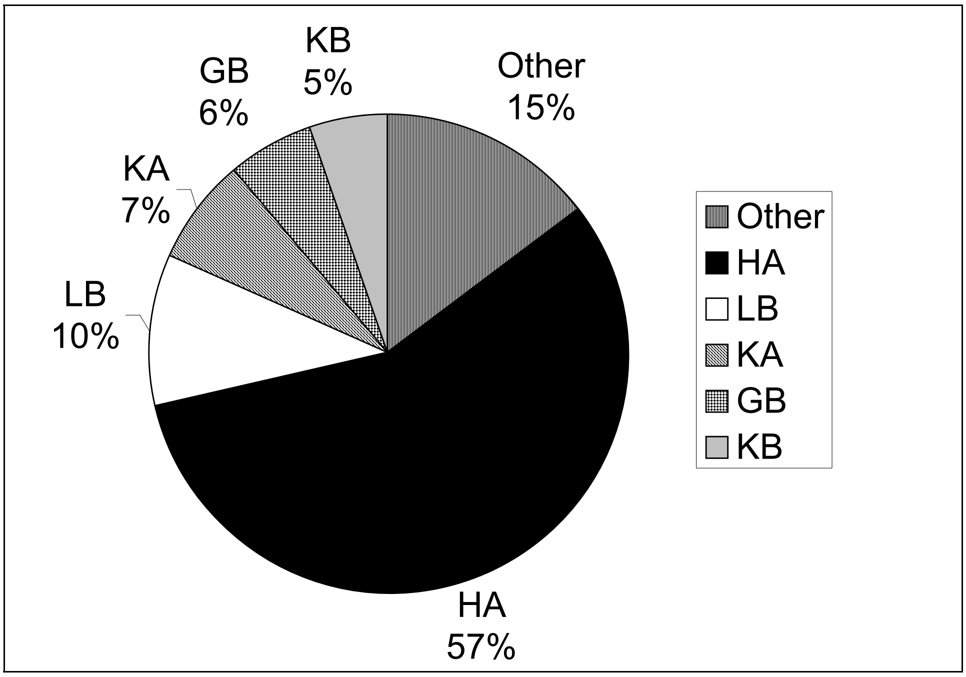

Figure 3.9 Reported cycle accidents at roundabouts in NZ (1999-2003).

3.4.4 Accident types at signalised crossroads

Figure 3.10 shows the major reported cycle accident type at signalised crossroads. The major accident types are HA and LB (see Appendix F).

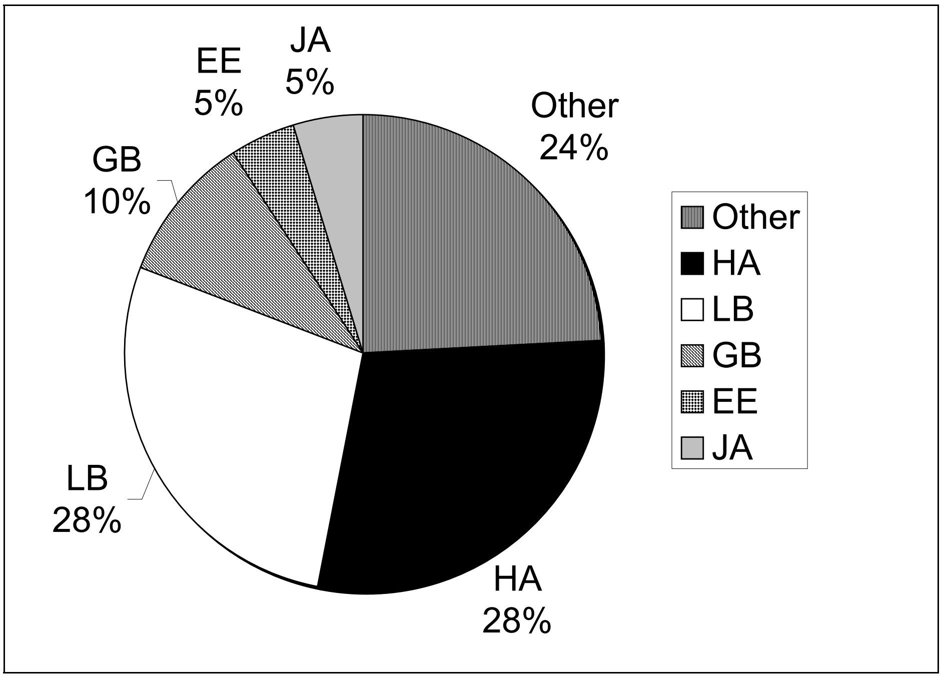

Figure 3.10 Reported cycle accidents at signalised crossroads in NZ (1999-2003).

3.4.5 Accident types at signalised T-junctions

Figure 3.11 shows the types of reported cycle accidents at T-junction traffic signals. The major accident type is LB.

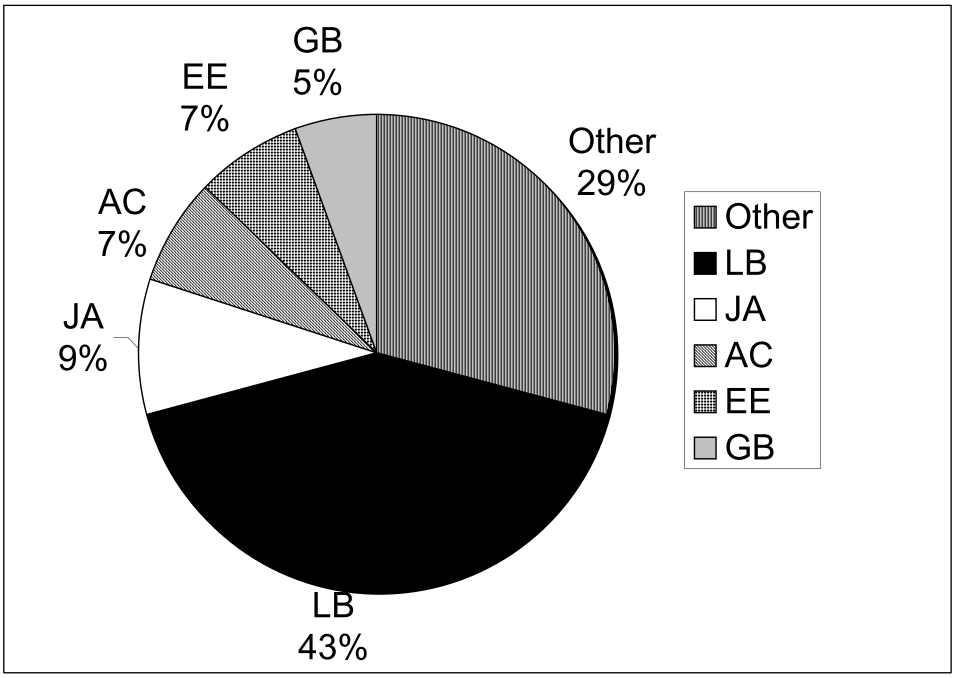

Figure 3.11 Reported cycle accidents at signalised T-junctions in NZ (1999-2003).

3.5 Christchurch, Palmerston North and Hamilton cycle accident statistics

In the development of the APMs (refer to Chapter 6), sites were selected in Christchurch, Palmerston North and Hamilton. The number of reported accidents involving a cyclist at traffic signals, roundabouts and mid-block locations in the period 1993 to 2002 inclusive is shown in Table 3.4.

Table 3.4 Cyclist / motor-vehicle accidents, 1993-2002.

City	Traffic signals	Roundabouts	Mid-block	Others
Christchurch	259	157	360	898
Hamilton	42	48	75	222
Palmerston North	30	38	74	207
Total	331	243	509	1327

The largest proportion of specified cycle accidents (excluding other) occur at mid-block locations. However, a significant number of cycle accidents also occur at traffic signals and roundabouts. Refer to Appendix A for a more detailed breakdown on junction and control types.

3.6 Cycle and pedestrian journeys & trip lengths

The National Travel Survey was conducted in 1989/90 and 1997/98. It provides data on travel by all modes and provides estimates of the amount of cycling and walking undertaken nationally.

The survey estimated that in 1997/98 there were 1151 million walking trips and 111 million cycling trips made annually in New Zealand. Walking trips are therefore about ten times more common than cycling trips.

The National Travel Survey (LTSA 2000a) shows that between 1989/90 and 1997/98, the estimated total cycle distance travelled in New Zealand declined by 19%. There were no similar figures for walking distances, but the number of trips solely by walking reduced by 400,000 trips during this period.

Cyclists were estimated to have travelled 290 million kilometres annually in 1997/98. It is estimated that cycling has been declining at an average of 2.7% per annum over this period (LTSA 2000a).

3.7 Reporting rates

Accident data were collected from the following three sources, so that the level of accident reporting from each source could be compared:

- Ministry of Transport CAS database,
- ACC database,
- St John database.

3.7.1 CAS accident data

The Ministry of Transport's accident database is the primary database providing accident statistical information to those working in the land transport area. Accidents recorded in this database are those where the police attend and complete a Traffic Crash Report (TCR), which is then supplied to Land Transport New Zealand who enter the data.

The accident data include location and time of accident, a description of the accident (which is later coded using 'movement codes') and accident causes.

3.7.2 ACC accident data

ACC supplied a database containing information on people injured while cycling or walking in Christchurch, Hamilton and Palmerston North in 2002. These data contained details of the person injured, the data of accident, type of injury, and general scene of accident. Only data where the location was coded as 'Road or Street' was used in the calculation of reporting rates. It was not possible to ascertain whether accidents with a location code of 'Place of Recreation' actually occurred on a road.

3.7.3 St John accident data

St John provided a database of all callouts logged involving motor vehicle, cyclist and pedestrian accidents in the Canterbury, West Coast and Nelson/Marlborough regions between 2000 and 2002. These data contained a description of the location of the accident and the date and time of accident.

3.8 Reporting rates for cyclists

Analysis of CAS and St John data in Christchurch for the three-year period between 2000 and 2002 indicated that for every cyclist injury accident reported in the CAS database, there was an additional 0.84 reported in the St John database (Table 3.5).

Table 3.5 Reported number of cycling accidents (2000 – 2002).

CAS	St John	Matching	Under-reporting factor
339	402	117	1.84

A further analysis was undertaken using 2001 data from CAS, St John and ACC. Figure 3.12 illustrates the matching of these data.

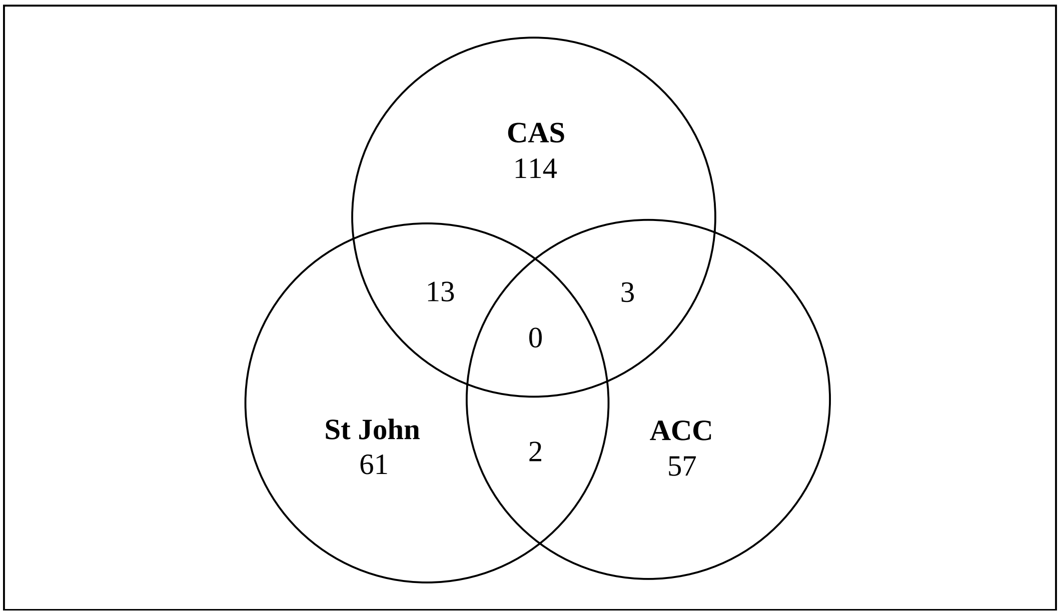

Figure 3.12 Cycle accidents in Christchurch 2001.

These data indicate that for every accident recorded in the CAS database, an additional 0.92 was reported in either the St John or ACC database.

Notably, there was a particularly small proportion of accidents in the ACC database (8%) that match with accidents in either the CAS or St John database. Comparatively CAS (12%) and St John (20%) had a higher proportion of accidents matching with the other two databases. The variation in the proportion of accidents being in both the CAS and St John databases from the analysis in Table 3.5 and Figure 3.12 is also noticeable and is possibly because the initial analysis used a longer analysis period.

It is unclear whether accidents coded as minor would be picked up in the ACC database. It is likely that the majority of St John accidents were serious accidents involving hospital admission. Hence, it is expected that a number of the CAS accidents would not be picked up in the St John database. The comparison indicates that either a significant proportion of accidents is not reported in each of the databases or that the data on location and time/date of accident from each source are incorrectly given or coded. Further research is required to determine the level of under-reporting in each database.

3.9 Reporting rates for pedestrians

Analysis of CAS and St John data in Christchurch for the three-year period between 2000 and 2002 indicated that for every pedestrian injury accident reported in the CAS database, an additional 0.47 was reported in the St John database.

Table 3.6 Reported number of pedestrian accidents (2000 – 2002)

CAS	St John	Matching	Under-reporting factor
260	227	104	1.47

Pedestrian accidents were difficult to identify in the ACC database hence no analysis was undertaken with their data.

3.10 International comparisons

3.10.1 Pedestrians

In 1998, New Zealand had the 10th lowest rate of pedestrian road deaths in countries that contribute to the International Road Traffic and Accident Database (IRTAD) with 14.1% of all road deaths being pedestrians (Table 3.7) (LTSA 2000b). This however, does not take into account the amount of walking in each country.

When the data for the year 2001 is given, as shown in Table 3.8, the position of New Zealand has improved from 10th position to 5th. This may reflect a fluctuation in the number of accidents rather than an improvement in the safety of pedestrians.

Table 3.7 1998: International comparison of percentage of deaths for pedestrians (LTSA 2000b).

Country	Year	Pedestrians killed (% of total)	Total killed on roads
Luxembourg	1998	5.3	57
Netherlands	1998	10.3	1066
Belgium	1998	10.8	1500
France	1998	11.7	8918
USA	1998	12.6	41471
Sweden	1998	13.0	531
Italy	1998	13.4	6326
Canada	1998	13.7	2934
Germany	1998	13.9	7792
New Zealand	1998	14.1	502
Norway	1998	14.2	352
Denmark	1998	14.6	499
Iceland	1998	14.8	27
Finland	1998	15.5	400
Spain	1998	16.7	5957
Austria	1998	17.1	963
Portugal	1998	19.1	2126
Switzerland	1998	20.4	597
Czech Republic	1998	24.3	1360
Ireland	1998	24.9	458
United Kingdom	1998	26.4	3581
Japan	1998	28.3	10805
Hungary	1998	29.8	1371
South Korea	1998	37.2	10416
Poland	1998	37.7	7080

Table 3.8 2001: International comparison of percentage of deaths for pedestrians (LTSA 2003a).

Country	Year	Pedestrians killed (% of total)	Total killed on roads
Iceland	2000	3.1	32
Belgium	2000	9.7	1470
France	2001	10.1	8160
Netherlands	2001	10.7	993
New Zealand	2001	11.4	455
Denmark	2001	11.6	431
USA	2001	11.6	42116
Austria	2001	12.2	958
Canada	2000	12.7	2927
Germany	2001	12.9	6977
Italy	2000	13.2	6410
Finland	2001	14.3	433
Luxembourg	2000	14.5	76
Slovenia	2001	15.1	278
Spain	2001	15.3	5517
Norway	2001	15.6	275
Sweden	2001	15.7	554
Greece	2000	18.4	2037
Switzerland	2001	19.1	544
Portugal	2001	20.2	1671
Ireland	2001	21.7	411
United Kingdom	2001	23.8	3598
Turkey	2001	23.9	3840
Czech Republic	2001	24.1	1334
Japan	2001	28.2	10060

3.10.2 Cyclists

In 1999, New Zealand had the seventh lowest rate of cyclist road deaths of countries that contribute to the IRTAD, with 3.2% of road fatalities involving cyclists (Table 3.9). In 2001 New Zealand was eight equal with Norway (Table 3.10). The overall percentage of cyclist fatalities has declined from 3.2% of all road fatalities to 2.2%. It also should be noted that the ranking does not take into account the amount of cycling in each country and a low ranking may be indicative of few trips being undertaken by cycle.

Table 3.9 1999 International comparison of percentage of cyclists deaths (LTSA 2000b).

Country	Year	Cyclists killed (% of total)	Total killed on roads
Iceland	1998	0.0	27
Luxembourg	1998	1.8	57
USA	1998	1.8	41471
Spain	1998	1.9	5957
Canada	1998	2.6	2934
South Korea	1998	2.8	10416
New Zealand	1998	3.2	502
Portugal	1998	3.5	2126
France	1998	3.6	8918
Ireland	1998	4.6	458
United Kingdom	1998	4.6	3581
Italy	1998	5.8	6326
Austria	1998	5.9	963
Norway	1998	7.1	352
Switzerland	1998	7.9	597
Germany	1998	8.2	7792
Belgium	1998	9.0	1500
Czech Republic	1998	9.6	1360
Poland	1998	9.8	7080
Sweden	1998	10.9	531
Denmark	1998	11.6	499
Japan	1998	12.6	10805
Finland	1998	13.5	400
Hungary	1998	16.0	1371
Netherlands	1998	18.2	1066

Table 3.10 2001 International comparison of percentage of cyclists deaths (LTSA 2003a).

Country	Year	Cyclists killed (% of total)	Total killed on roads
Iceland	2000	0.0	32
Greece	2000	1.1	2037
Luxembourg	2000	1.3	76
Canada	2000	1.4	2927
USA	2001	1.7	42116
Spain	2001	1.8	5517
Turkey	2001	2.1	3840
New Zealand	2001	2.2	455
Norway	2001	2.2	275
Ireland	2001	2.9	411
Portugal	2001	3.0	1671
France	2001	3.1	8160
South Korea	2001	3.6	8097
United Kingdom	2001	3.9	3598
Austria	2001	5.7	958
Italy	2000	5.8	6410
Slovenia	2001	6.1	278
Switzerland	2001	7.0	544
Sweden	2001	7.6	554
Belgium	2000	9.1	1470
Germany	2001	9.1	6977
Czech Republic	2001	10.6	1334
Poland	2001	11.0	5534
Japan	2001	12.8	10060
Denmark	2001	13.0	431

4. Christchurch Hospital and ACC interviews

4.1 Objective of cycle and pedestrian ACC casualty interviews

The objectives of the interview section of this study were:

- to obtain information on cycle and pedestrian accidents not readily available from police reports and CAS data,
- to obtain statistics on the number of cycle and pedestrian road accidents at traffic signals, roundabout and mid-block locations where no motor vehicle was involved.

4.2 Canterbury Health Board ethical approval

Before commencing the interviews, the study team was required to obtain ethical approval of the survey questionnaire and the method by which the people in the health sector would be approached and interviewed, as well as how the data were to be recorded and published.

The 'Ethical Approval' process is a requirement for all research in the health sector in New Zealand. Each region of New Zealand has an 'Ethics Committee' which typically has twelve members. Half represent the medical profession and the rest are described as 'lay members'.

One requirement of the 'Ethical Approval' process is to ensure that the Treaty of Waitangi requirements are met. In our case, negotiations were undertaken with the local Iwi, Ngai Tahu and the Urban Maori Authority, Nga Maata Waka.

The questionnaire, the patient consent form and patient information form all had to be approved by the Ethics Committee.

The 'Ethical Approval' process took five months. This was much longer than anticipated. The main concern of the 'Ethics Committee' was that people might give information to the interviewer that could be obtained by the courts and used against the interviewee. Attempts were made, in vain, to indicate that this was very unlikely. In the end, it was agreed to interview people and not to take their names or contact details. This made it very difficult to match accidents with those from the other databases.

4.3 Interview techniques

Pedestrian and cycle accident casualties were interviewed using several methods as outlined below.

Four sets of data were collected:

- **Pilot Study:** This required the hospital staff to call an answer service, to get an interviewer to attend. This began on 1 December 2002 and continued until the end of February 2003. In parallel with this, questionnaires were left at a number of medical centres around Christchurch. A third approach involved mailing out questionnaires to accident casualties on the ACC database. The response to these techniques was very low.

- **Main Study 1:** The first four-week period of in-house interviews in the Emergency Department at Christchurch Hospital was from 2 June to 29 June 2003. People were interviewed by research staff as they came into the Emergency Department, or as they progressed through the treatment (particularly if severely injured).
- **Main Study 2:** The second four-week period of in-house interviews in the Emergency Department at Christchurch Hospital was from 3 – 30 November 2003 from 7a.m. to 9.30p.m. each day.
- **Main Study 3:** ACC telephone interviews were conducted from 23 February 2004 and covered accidents that happened in the 2002 calendar year. People from Christchurch, Palmerston North and Hamilton were interviewed. This method proved the most effective and efficient at collecting a large amount of data.

4.3.1 Cyclist and pedestrian accident selection criteria

4.3.1.1 Christchurch Hospital interviews

Pedestrians and cyclists involved in accidents occurring on a public road or footpath in Christchurch City were interviewed at Christchurch Hospital. The key determinant was that the accident occurred on the road reserve. Accidents both involving and not involving motor vehicles were included in the survey.

4.3.1.2 ACC interviews

People who were involved in pedestrian and cycle accidents on public roads were interviewed in Christchurch, Palmerston North and Hamilton. In the main study, ACC data were supplied for the year 2002. Each accident casualty was called and interviewed by telephone using the same questionnaire used at the hospital.

4.3.2 Interview questionnaire structure

The same questionnaire was used for all studies. A copy of the survey questionnaire is provided in Appendix C. The questionnaire included the following factors:

- **demographics** (age and gender)
- **travel mode** (pedestrian/ cyclist/ other e.g. skateboarding)
- **cycle type** (mountain bike/ 10-speed/ other) and set up (e.g. lights)
- **date and time of accident**
- **location of accident** (road/ footpath/ other)
- **light conditions** (dark/ twilight/ daylight)
- **weather** (during accident or other conditions)
- **accident type** (e.g. pedestrian v. car, pedestrian only)
- **road, footpaths or cycleway conditions** (e.g. loose gravel)
- **cause of accident** (often several factors for each accident)
- **accident description** (a description of the sequence of events and a diagram)
- **estimate of speed of vehicles and cyclists**

- **trip purpose** (e.g. school/ recreation/ work)
- **injury sustained during accident** (e.g. grazes, bruises and head injury)
- **emergency services that attended accident** (if any)
- **information on previous pedestrian and/or cycle accidents** (in the past 2 years)

4.4 Survey results

4.4.1 Sample size

In total 311 completed survey questionnaires were obtained, of which 264 met the criteria in Section 4.3.1. The remaining 47 accidents occurred off-road and were not included in the analysis.

The following sections show each of the key data fields collected during the interviews and a number of important cross tabulations. For some of the fields (e.g. month of the year) only part of the data have been used in the analysis for the reason given.

4.4.2 Age by proportion

The age demographics of casualties and those who walk or cycle are compared in the following two figures. For each age group the proportion of total trips undertaken by that age group was compared with the proportion of those surveyed in this study. The proportion of those who walk or cycle in each age group was obtained from the LTSA Travel Survey (LTSA 2000a).

Figure 4.1 shows the comparison between those surveyed as casualties and those who cycle. This shows that generally the proportion of cyclists matches the proportion of casualties surveyed in each age group. However, the age group 10-20 makes up a high proportion of cycle trips. It is interesting that this age group does not have an equal number of casualties in the survey. This is perhaps counter-intuitive in that it is expected that this age group would have a higher accident rate caused by a limited knowledge of road rules. Children are more likely to take a risk and children generally lack the experience to deal with high volumes of traffic. The result could be caused by the sampling methodology. Figure 4.1 indicates that cyclists 30-60 years old, particularly 30-40, feature more in the number of accident casualties surveyed than in the proportion of cycle trips. This may be a result of cyclists in this age group being more likely to travel down higher-volume roads and having a higher exposure by travelling longer distances.

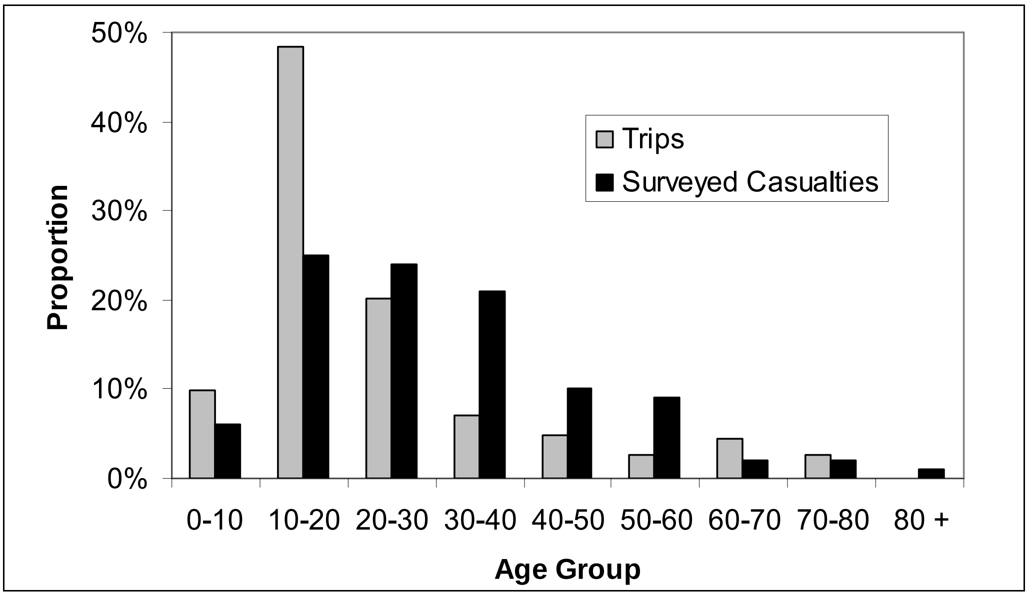

Figure 4.1 Relationship between proportion of total cycle trips undertaken by each age group and proportion of total cycle accidents in each age group.

Figure 4.2 shows the comparison between the ages of casualties surveyed in this study and the proportion of pedestrians of different ages from the LTSA (2000a) travel survey. The number of trips undertaken by a particular age group was generally proportional to those surveyed casualties. One particularly noticeable exception occurs when comparing the number of trips and number of surveyed casualties in the 80+ age group. This is clearly a vulnerable group of pedestrians because of decreased physical ability and mental response time. Accident victims in this age group are possibly more likely to suffer serious or fatal injuries because of frailty. This is confirmed by New Zealand accident statistics (LTSA 2002) which shows that per head of population the fatality rate for those pedestrians over 80 killed is 5.1 per 100,000 compared with the average over the entire population of 1.1 per 100,000.

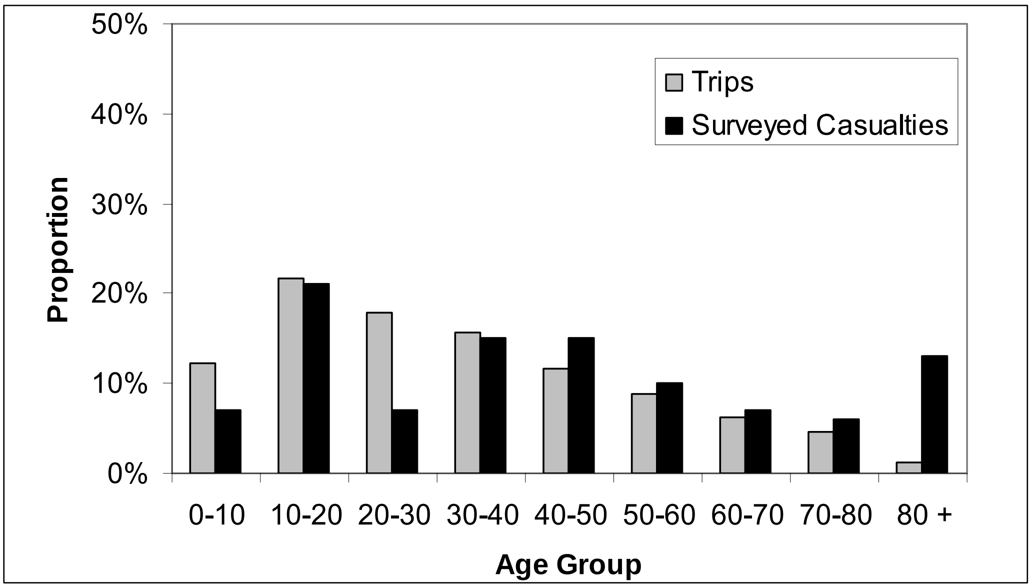

Figure 4.2 Relationship between proportion of total pedestrian trips undertaken by each age group and proportion of total pedestrian accidents in each age group.

To make a comparison between casualties surveyed and those reported to police, the proportion of casualties in each age group from the survey was compared with statistics from the LTSA (2002).

Figure 4.3 shows the comparison between cyclist casualties by age group between this study and the CAS accident database. This graph shows some interesting relationships, mainly that the proportion of injury accidents involving cyclists in the 10–20 age group reported to police is higher than the proportion of cyclist casualties surveyed in this study. This relationship also seems to be reversed in 20–30 and 30–40 age groups. A possible reason for this could be attitudes in society, perhaps towards those cyclists 10–15 years of age. They may be encouraged by others to report accidents involving motor vehicles, while males in the 20–40 age group may see the reporting of accidents as unnecessary.

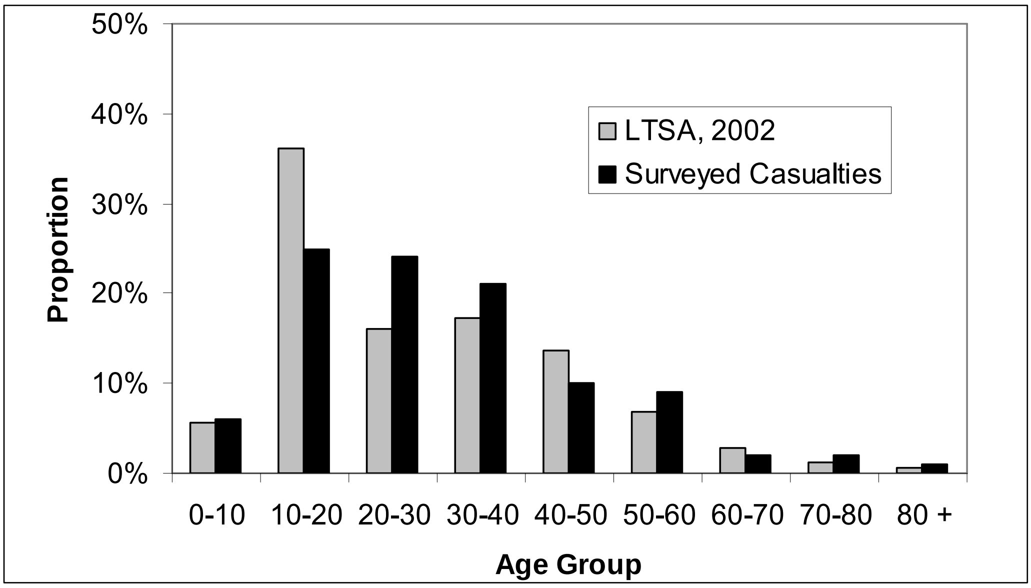

Figure 4.3 Relationship between proportions of total cycle accidents in each age group in this study compared with national LTSA data (2002).

Figure 4.4 shows the comparison between the proportion of pedestrian injury accidents reported to police by age group and the proportion of pedestrian casualties in each age group that were surveyed as part of this study. This shows some variation in the proportion in each age group between those surveyed and accidents reported in the CAS database. A noticeable trend is the lower reporting rate in the CAS data of 80+ pedestrian crashes. The reverse is true in the 0–10 age group.

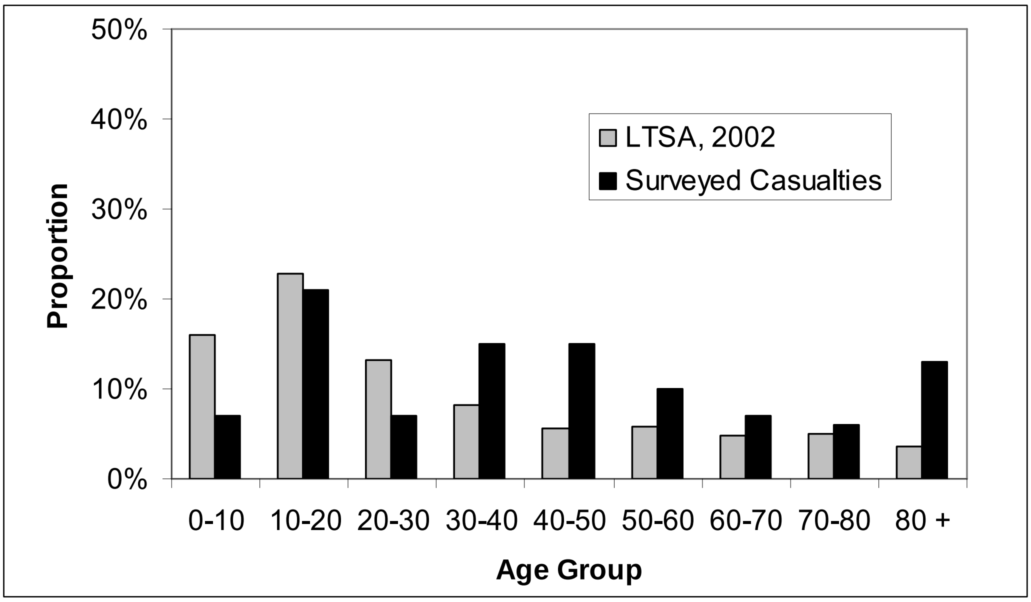

Figure 4.4 Relationship between proportions of total pedestrian accidents in each age group in this study compared with that in LTSA (2002).

4.4.3 Accident type

Figure 4.5 shows the proportion of pedestrian casualties surveyed that involve motor vehicles, cyclists and pedestrians only. Note that these proportions represent all accidents that occur on the road. Pedestrian accidents off-road were excluded from the analysed data. Of these accidents, the only accidents likely to be reported to the police are those involving motor vehicles. There was a relatively high number of pedestrian-only accidents (30%) in the survey. Such accidents may occur when a pedestrian falls over on slippery paving.

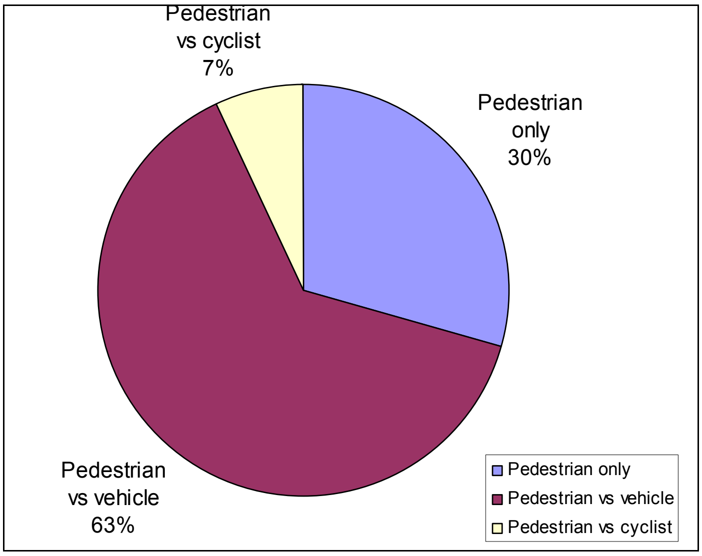

Figure 4.5 Type of accidents involving pedestrians.

Figure 4.6 shows the proportion of cyclist casualties surveyed that involve the cyclist only, a motor vehicle or a pedestrian. It is unsurprising that accidents with motor vehicles comprised most of the accidents. However, a large proportion (nearly a quarter) of accidents involved only the cyclist. In the survey cyclists were quite honest in their responses saying that they weren't paying attention or were distracted, causing them to have an accident.

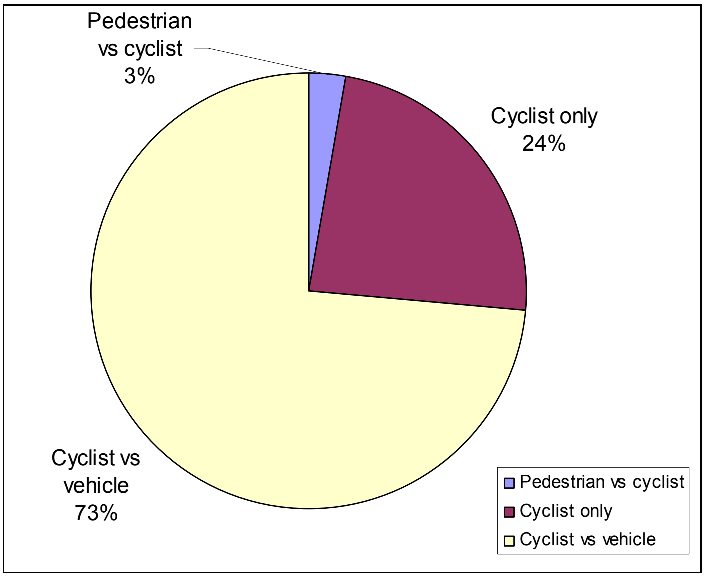

Figure 4.6 Type of accidents involving cyclists.

4.4.4 Cycle and pedestrian injury type

The survey data for this study was disaggregated into the most severe type of injury the cyclist or pedestrian suffered. Figure 4.7 shows the most severe injury suffered by cycle accident casualties.

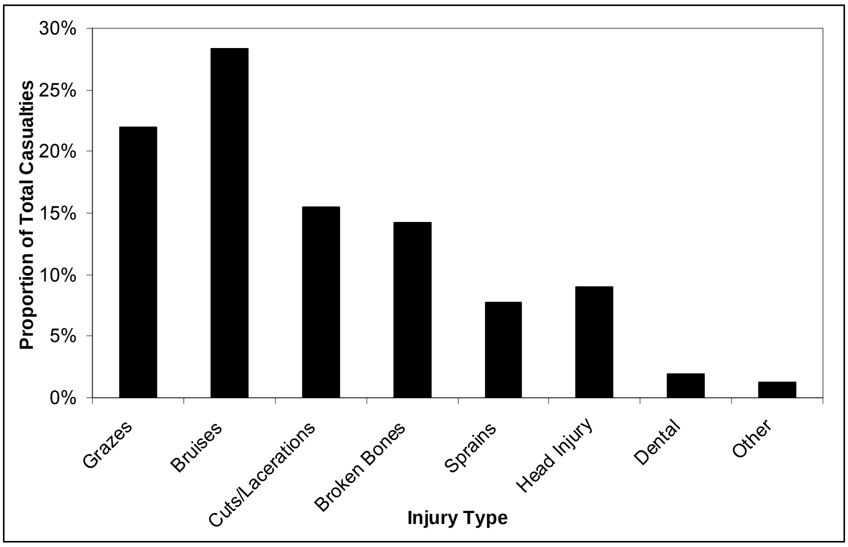

Figure 4.7 Cycle injuries by type.

Figure 4.8 shows the pedestrian injuries by type for those pedestrians who were surveyed as part of this study. Grazes and bruises were a large proportion of the injuries sustained by both pedestrians and cyclists.

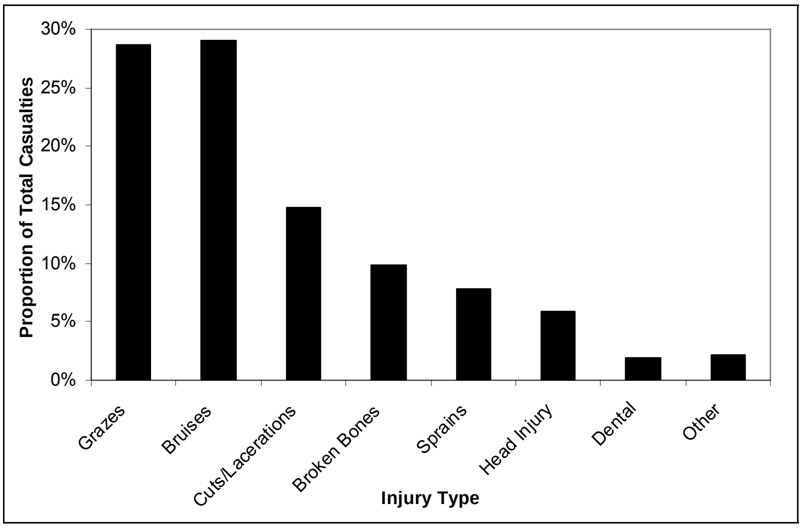

Figure 4.8 Pedestrian injuries by type.

4.4.5 Accident cause

Figures 4.9 and 4.10 show the causes stated by accident casualties for cycle and pedestrian accidents respectively. The percentage of cyclists reporting they lost balance or attributing their injury to loose or slippery surface is 28%. A high percentage (76%) of cyclists stated that other traffic failed to notice them or failed to give way to them. Surprisingly, the number of cyclists who reported drivers opening doors on them or who were 'squeezed by traffic' was under 5%.

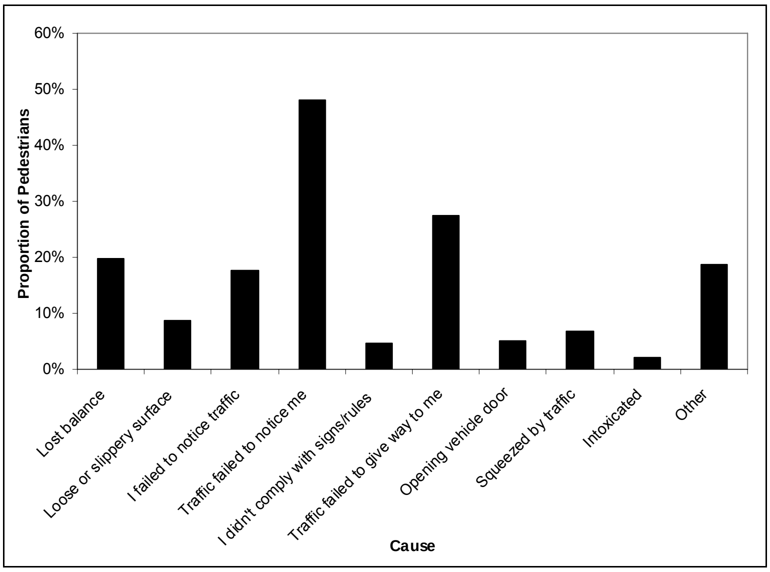

Figure 4.9 Cycle accident causes.

The percentage of pedestrians reporting that they tripped and fell or attributing their injury to loose or slippery surface is 44%. A high percentage (72%) report that other traffic failed to notice them or failed to give way to them. 24% of the injured pedestrians admitted that they did not comply with the traffic rules. This compares with the average proportion of pedestrians that cross with the 'green man' at traffic signals of 70%, at sites in Christchurch, as determined in a later part of this study. Hence, an average 30% of pedestrians crossed on the 'red' man, 'no signal' or within 20 m of the controlled crossing.

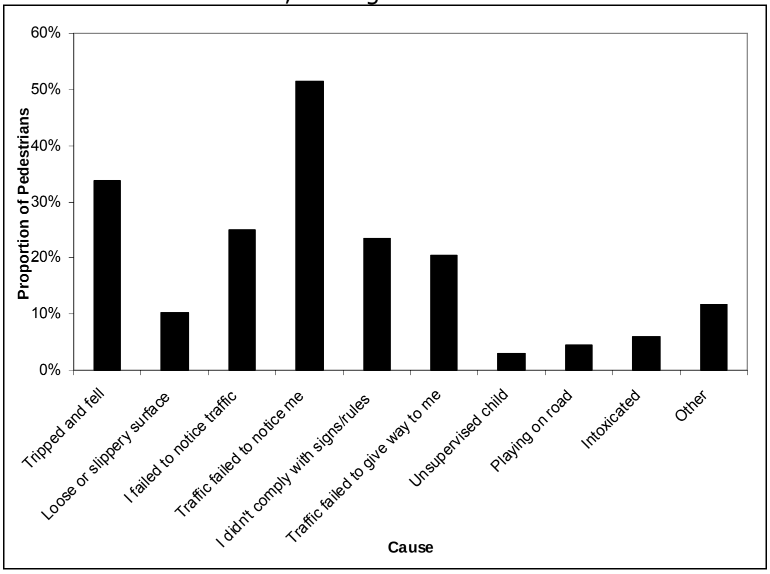

Figure 4.10 Pedestrian accident causes.

4.4.6 Time of year

Month of year data is only available from the ACC interviews where accident data for a whole year was surveyed. Figure 4.11 shows the breakdown by month of year for cycle accidents based on a total of 193 cycle accidents. Figure 4.12 shows the breakdown by month of year for cycle accidents entered in the CAS database between 1999 and 2003. These figures show some considerable differences.

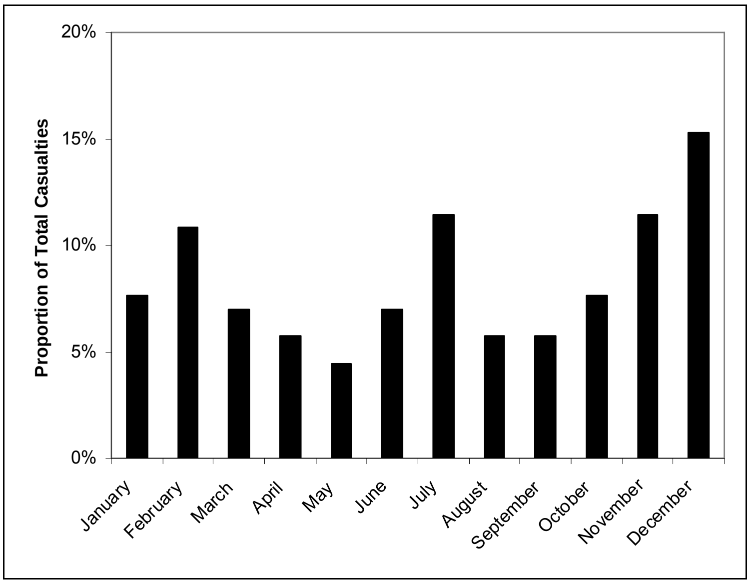

Figure 4.11 Month of year of cycle accidents in survey.

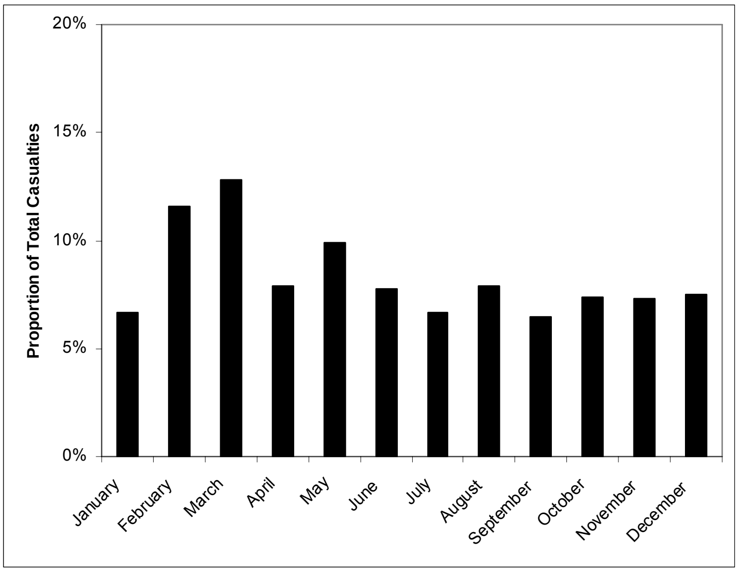

Figure 4.12 Month of year of cycle accidents in CAS (1999-2003).

There are insufficient pedestrian accidents in the ACC sample to consider monthly variations in such accidents.

4.4.7 Day of the week

Figure 4.13 follows approximately the variation in cycle flows that can be observed during the week, with higher flows on weekdays and lower flows on weekends, when there are no school and fewer journey to work cyclists. Figure 4.14 shows similar results from accidents reported in CAS.

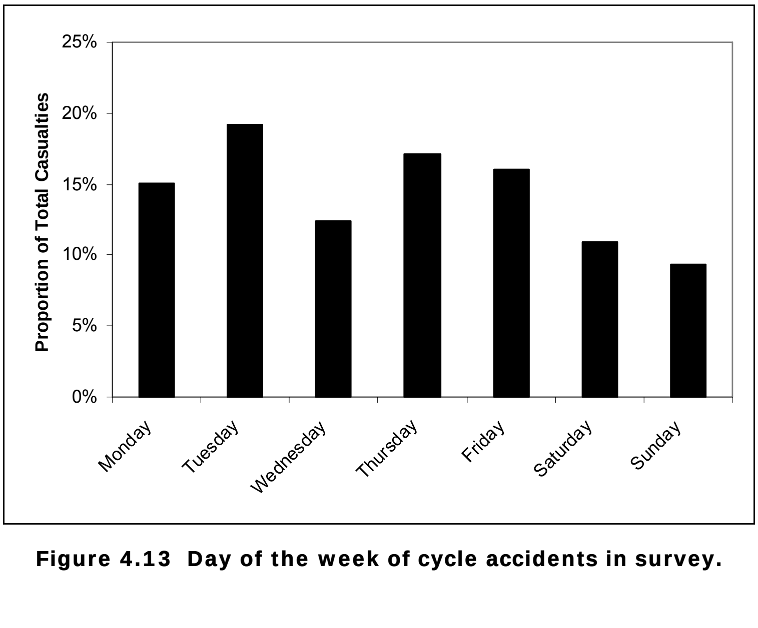

Figure 4.13 Day of the week of cycle accidents in survey.

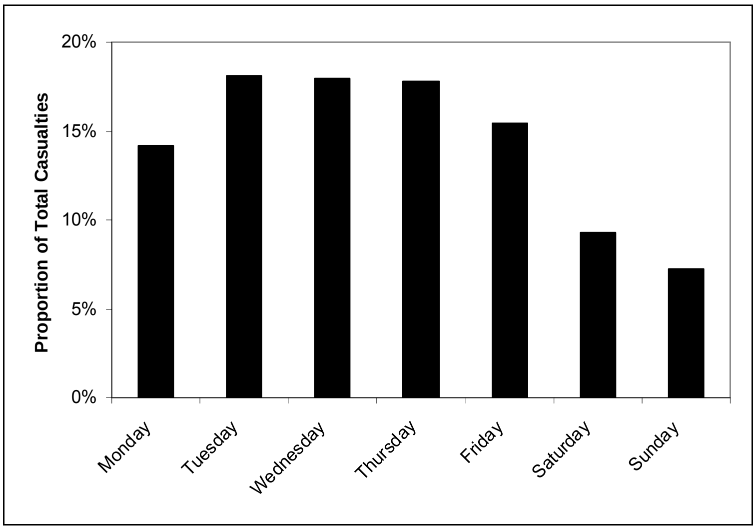

Figure 4.14 Day of the week of cycle accidents in CAS (1999-2003).

Figure 4.15 shows much more variation in pedestrian accidents by day of the week. The variability is likely to be caused by the smaller sample size rather than a conclusive trend. It is difficult to explain why the casualty rate would be lower on Tuesdays and so high on Sundays, compared to Saturdays. This does not compare well with Figure 4.16 which shows the day of the week of pedestrian accidents that are reported in CAS.

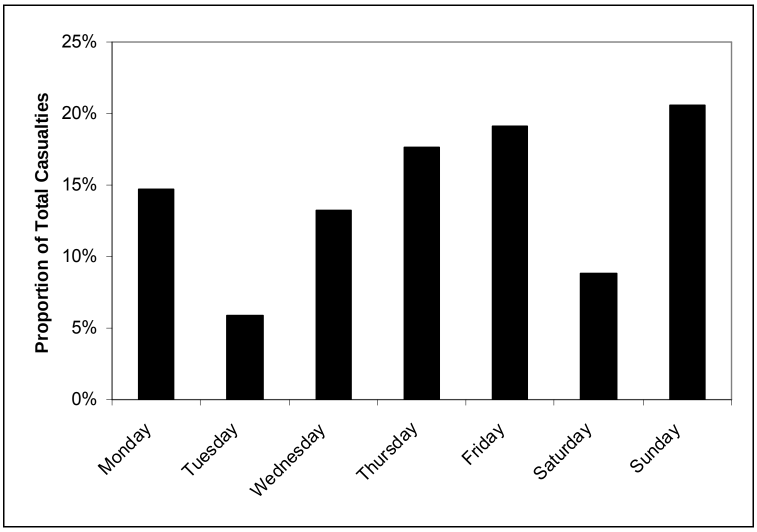

Figure 4.15 Day of the week of pedestrian accidents in survey.

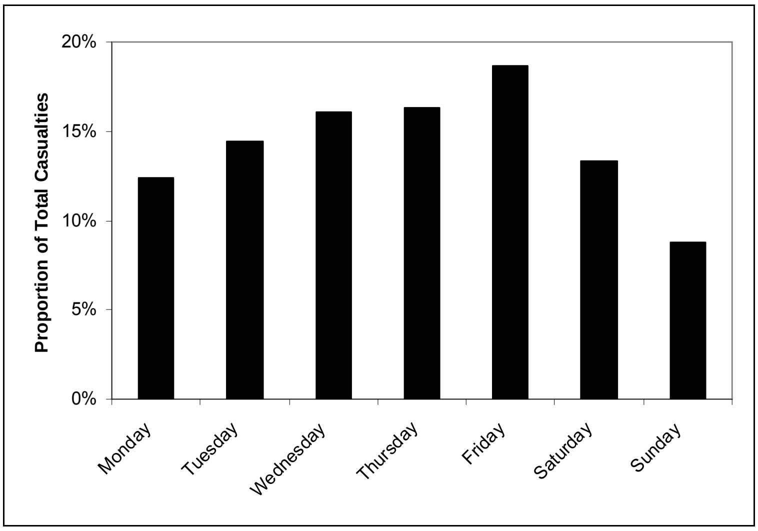

Figure 4.16 Day of the week of pedestrian accidents in CAS (1999-2003).

4.4.8 Time of the day

Figure 4.17 shows the time of day that cycle accident casualties reported the accident occurred. This can be compared with the cycle flow profile derived from continuous count sites in Christchurch (Section 5.5.2). This accident profile corresponds approximately to the flow profile with a large number of accidents occurring in the morning and evening peaks, particularly the latter.

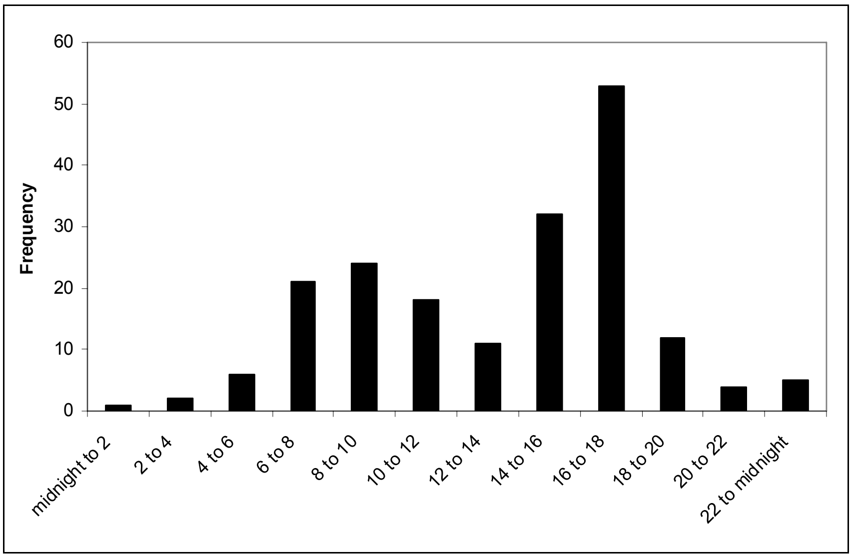

Figure 4.17 Time of day of cycle accidents.

Pedestrian accidents are more evenly distributed over the day (Figure 4.18), although there are peaks observed around lunchtime and after school and work finishes, i.e. evening peak period.

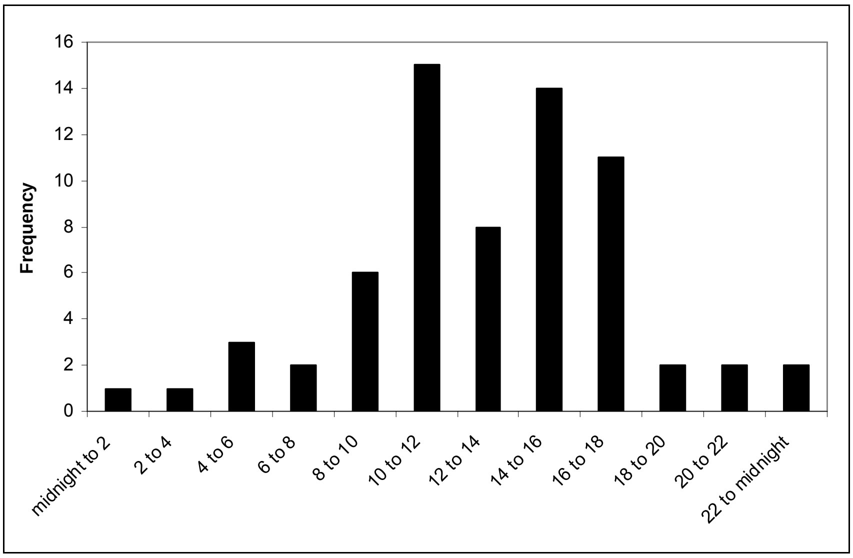

Figure 4.18 Time of day of pedestrian accidents.

4.4.9 Pedestrian and cycle trip purpose

Figure 4.19 shows the trip purpose of pedestrian and cyclist accident casualties surveyed.

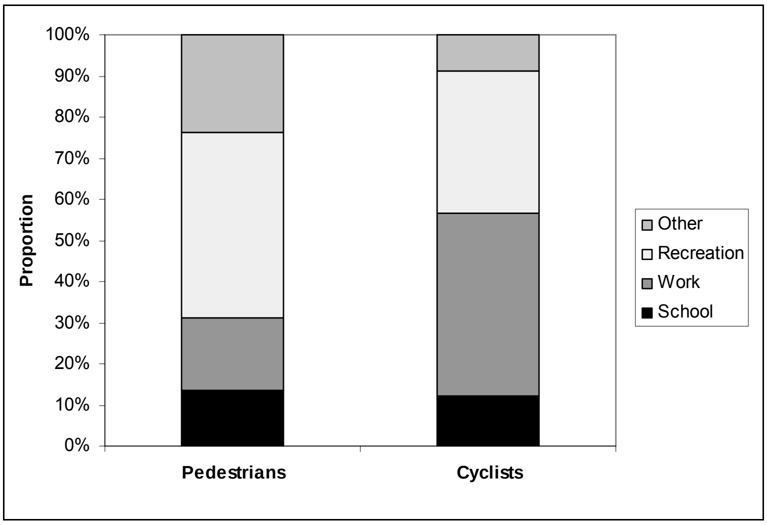

Figure 4.19 Trip purposes of pedestrian and cycle accident casualties surveyed.

Figure 4.19 shows that a large percentage of trips by cyclists are either commuter or recreational trips. Pedestrian trips were predominantly for recreational or 'other' purposes (such as shopping). Surprisingly few of the pedestrian accident casualties were on the journey to or from work.

5. Collection of count data

5.1 Existing data sources

Cycle, pedestrian and vehicle count data were collected from Christchurch, Palmerston North and Hamilton. These cities were chosen because they have significant numbers of cyclists using their urban roading network.

All three councils have in place some form of cycle count programme. The Palmerston North City Council also collects pedestrian counts at intersections. In Christchurch, City Council annual pedestrian counts are collected outside retail stores in the central city (for valuation purposes). However, generally there were few pedestrian counts and mid-block cycle counts.

Where data on cycle and pedestrian counts are available in most centres, generally it was not in a suitable format for developing APMs. To develop APMs, detailed counts specifying the number of cyclists and pedestrians performing each turning and crossing manoeuvre need to be available. Such data enable various accident type models to be developed using particular flow combinations.

For traffic signals, information was also available on non-flow factors such as number of opposing lanes, intersection depth, and lane widths. These data were collected as part of a previous Beca study (Turner 2004).

5.2 Christchurch City count data

5.2.1 Motor-vehicle counts

Motor-vehicle counts were obtained from the Christchurch City Council (CCC). The CCC has a regular programme of collecting manual turning volumes at intersections. It is preferable that the movement data is collected manually rather than automatically through SCATS. SCATS data are generally less accurate than manual counts, especially for shared lanes.

Most intersection counts were one hour in duration and collected over two time periods, typically the morning and evening peak periods. However, for a number of intersections additional counts were collected, normally in the weekday interpeak. These counts were used to calculate daily turning count volumes. All intersection counts were disaggregated by approach and by movement, i.e. left, through, and right for each approach.

For mid-block locations, the daily average number of two-way through-vehicle movements was used in the APMs. The CCC has a regular count programme that collects link volumes using tube counters on a large number of links. Where link count data were not available for a study section a volume was estimated from turning movement counts at intersections at each end of the mid-block section.

5.2.2 Cycle counts

Cycle counts are collected by the CCC as part of its intersection count programme (these data are available in an electronic form), and in a separate cycle count programme. The separate cycle counts are generally more accurate than those collected with motor-vehicle counts. In the latter case surveyors can be distracted by the volume of motor vehicles and miss cyclists. However, the separate cycle count data are not available in an electronic format.

Given that pedestrian counts needed to be collected for the study, it was decided to also collect additional cycle counts in Christchurch. The counts were collected between 21 July and 24 October 2003, and included over 1,640 quarter-hour counts at traffic signals, roundabouts and mid-block locations. These counts were collected on weekdays and during the school term.

For each intersection, the total duration of counts collected was one hour, with two-quarter hour counts collected in the morning and evening peaks. There were also longer duration counts collected at some sites to enable identification of daily and weekly trends. These longer counts were compared with those produced from the continuous count sites (Section 5.5.2).

The cycle counts recorded were disaggregated into movement and approach. Thus for a regular four leg intersection, 12 cycle movements are possible.

5.2.3 Pedestrian counts

Given the limited number of pedestrian counts available, pedestrian counts were collected for the study. At traffic-signal-controlled intersections, pedestrians were counted crossing each intersection approach in three categories:

- those who begin crossing with the 'green man' pedestrian signal on the crosswalk,
- those who begin to cross while the steady and flashing 'red-man' is displayed on the pedestrian signal, or crossing without the pedestrian signal being activated,
- those who do not cross at the crosswalk but do so within 50 m of the crosswalk.

The numbers of pedestrians in each of these three groups were recorded for each quarter hour survey period for each approach of the intersection. At roundabouts, pedestrians were counted crossing at the crossing point in the splitter island. At mid-block locations, pedestrians were counted crossing the road within the 100 m study section.

5.3 Hamilton City count data

5.3.1 Motor-vehicle counts

Traffic volume data for Hamilton were limited to mid-block tube counts. Hence tube counts were used for Hamilton mid-block sections in the research. Where a count was not available within a section, it was estimated from link volumes on adjoining road sections.

5.3.2 Cycle counts

Mid-block cycle counts at 13 sites were carried out using the same methodology as for mid-block counts in Christchurch. Two half-hour long counts in the morning and evening peaks were undertaken at each site on 9 and 11 December 2003.

5.3.3 Pedestrian counts

Counts of pedestrians crossing the 100 m mid-block survey section were collected in unison with cycle counts.

5.4 Palmerston North City count data

5.4.1 Motor-vehicle counts

The Palmerston North City Council undertakes manual counts of pedestrian, cycle and motor-vehicle movements at key intersections, disaggregated by movement and approach. Counts were available for each of the intersections included in the study. The data were collected between 2000 and 2003. The turning volume counts were generally of a longer duration than the counts collected in Christchurch and were typically for the periods 7:30-9:00a.m. and 3:30-5:30p.m. Some counts included other time periods as well. When additional count data were available they were used to improve the daily estimate of the numbers of motor vehicles making each manoeuvre.

5.4.2 Cycle counts

As specified above, cycle turning volume counts were collected at the same time as motor vehicle and pedestrian counts. Most of the available counts were collected during university and school holidays. We expect that the cycle counts collected underestimate the average cycle flows at each site. To take into account the lower holiday flows, correction factors were applied (Section 5.5.2).

5.4.3 Pedestrian counts

Pedestrian counts were also collected in unison with cycle and vehicle counts. The counts were disaggregated by each approach. However, unlike the Christchurch counts they were not further disaggregated into whether pedestrians were crossing on green man, red man or within 50 m of the crossing.

5.5 Count correction factors

5.5.1 Motor-vehicle correction factors

Hourly factors derived by Turner (1995) were applied to the raw traffic counts to determine the AADT for each turning movement. The procedure used to factor up short duration counts was similar to that of Turner (1995) and involved dividing each hourly count by the typical percentage of flow occurring in that hour and multiplying it by the relevant daily and monthly flow factors.

Two different hourly profiles were used. The first profile was for the central business and suburban shopping areas, where flows were consistently high during the day between the morning and evening peaks. The second profile is for suburban areas, where flows are significantly lower in the inter-peak compared with the peak period flows. Local knowledge was used to select the appropriate profile to apply to each intersection. The AADTs were also factored using annual factors to the mid-point of the 10-year accident analysis period.

5.5.2 Cycle correction factors

Because the counts that were undertaken were of fairly short duration and did not cover long periods of each day, correction factors were required to determine the daily average flow. Also, cycle flows are highly variable depending on such things as the weather, school holidays, day of the week, types of cyclists using a route and other factors. Control counts using automatic detectors were established at six sites around Christchurch to build cycle profiles that could be used to factor the manual counts at the sites in the study. The daily cycle flow profile is shown in Figure 5.1.

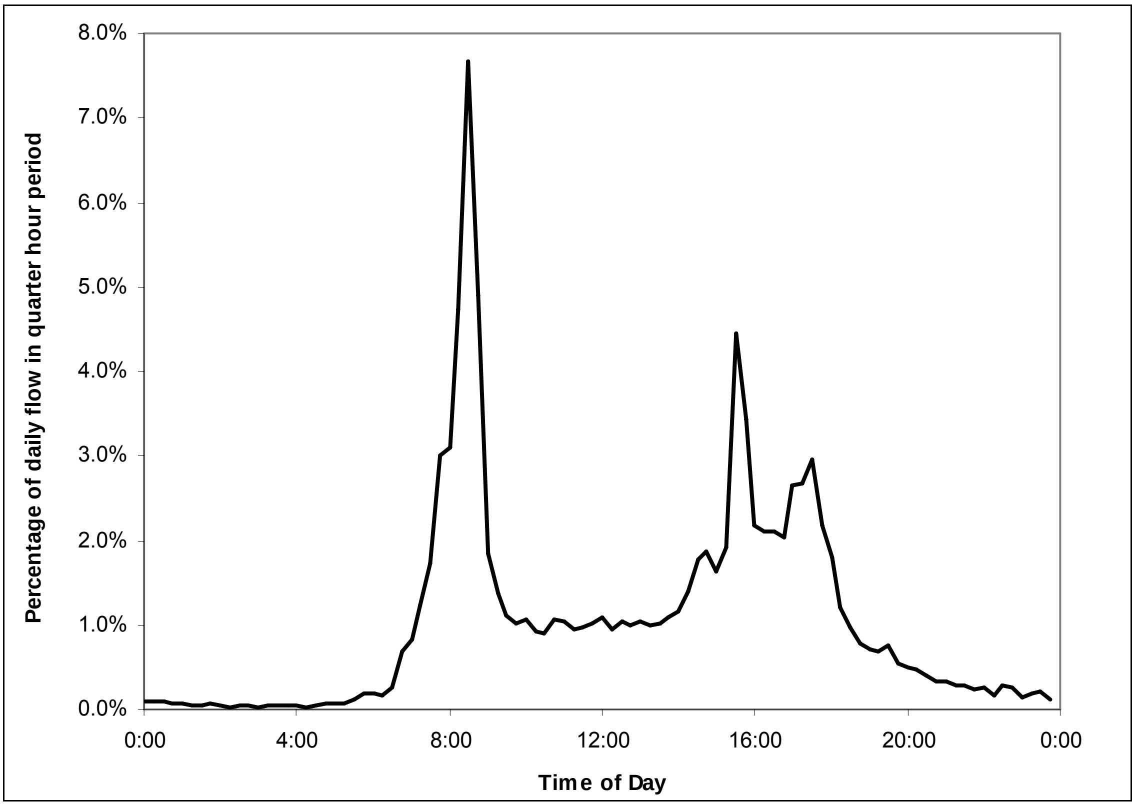

Figure 5.1 Quarter-hourly cycle flow (cpd) profile.

Data at the control sites had been collected for a period of a year, but unfortunately for technical reasons data from late September to the start of December 2003 was not available. Fortunately, few counts were undertaken within this time period and those that were collected could be factored using the 'rough order' day of the week and seasonal factors. The variation in cycle flows by week at the control sites is shown in Figure 5.2.

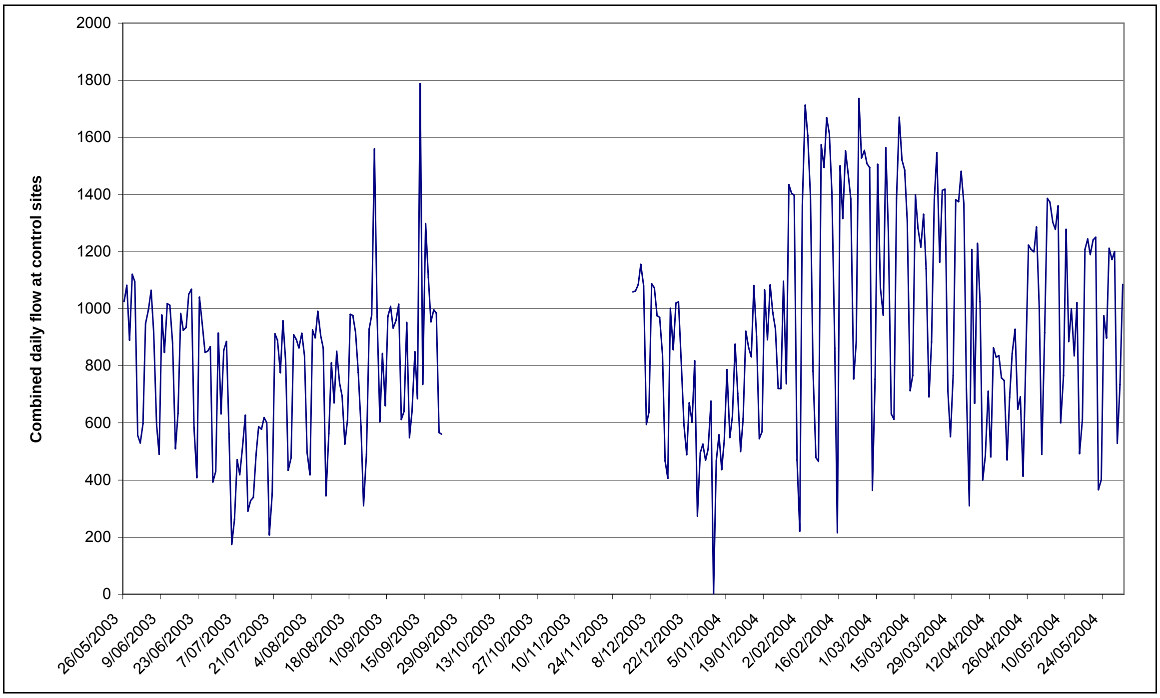

Figure 5.2 Total daily cycle flow (cpd) at control sites (June 2003–May 2004).

There were no continuous count data available from either Palmerston North or Hamilton, so the factors produced for Christchurch were used to explain the seasonal trend. The assumption was that school and university holidays would coincide in all three centres. However, difference in weather between the cities could not be taken into account. Future studies should establish profiles for other cities.

5.5.3 Pedestrian correction factors

Control sites were also established for pedestrian counts. Three count sites were monitored, again all based in Christchurch. The pedestrian sites had pressure detectors that counted pedestrians who stood on them. This was found to be a more accurate way of counting pedestrians than using pedestrian call button actuations. The pressure sensitive mats produce actuations that were calibrated to reflect the number of pedestrians crossing in a particular signal cycle. The longer duration manual counts were used in the calibration.

The continuous pedestrian flow count data, as with cycle counts, were collected over a period of a year excluding the period between the end of September 2003 and the start of December 2003. Seasonal pedestrian profiles were then developed using the same method as for cycle profiles, based on the total flow at the control sites on the count day. Quarter-hourly daily flow profiles (Figure 5.3) were also developed. It was observed that differences in the pedestrian profiles for the control site in the central city were significant compared with control sites in suburban areas. Hence two separate daily profiles were developed. Pedestrian counts collected in the central city were factored by the 'CBD' profile and those outside the central city by the 'suburban' profile.

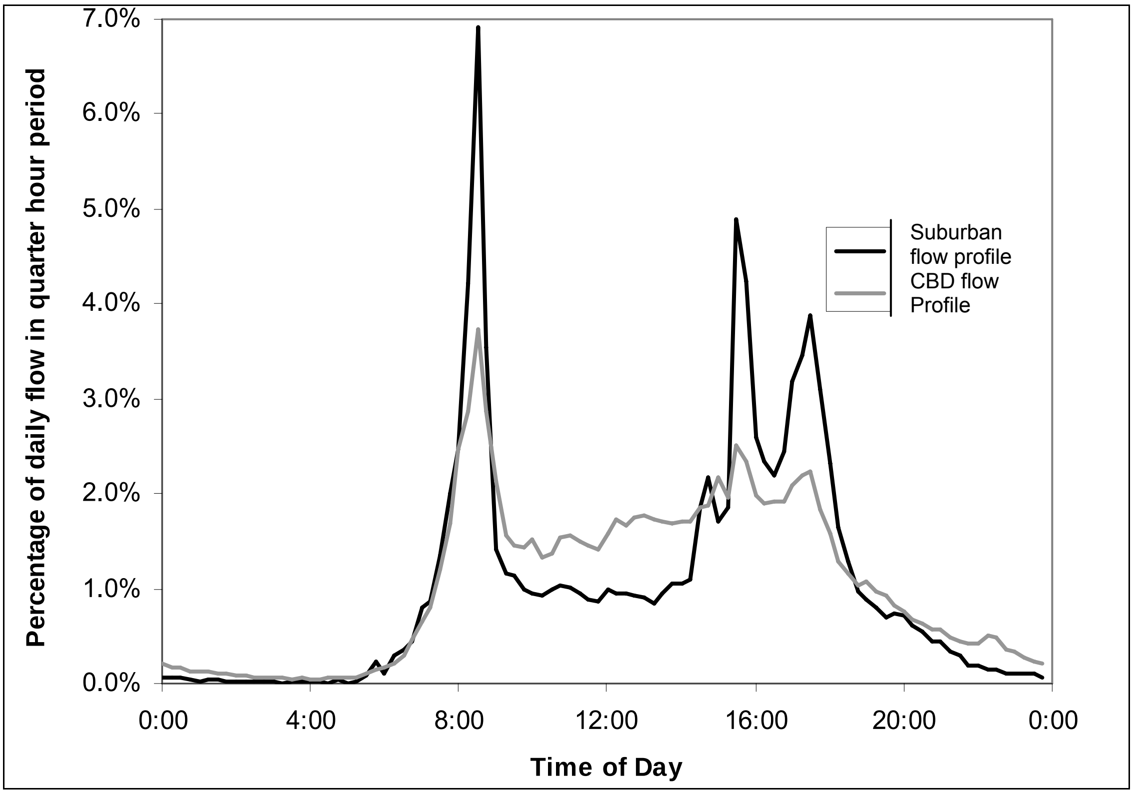

Figure 5.3 Quarter hourly pedestrian flow (ppd) profiles.

5.6 Pedestrian compliance at traffic signals

Pedestrian crossing data were divided into:

- those who crossed with the green pedestrian signal ('the green man'),
- those who began to cross on the red pedestrian signal ('red man' or flashing red man),
- those who crossed up to 50 m away from the intersection or crossed at the intersection without activating the pedestrian phase.

Using these data, the proportion of pedestrians who cross on the 'green man' or 'red man' when the pedestrian phase is activated was determined. These proportions do not include those pedestrians who crossed at the intersection without activating the pedestrian phase, as these could not be differentiated from those who crossed away from the intersection. Legally pedestrians may not cross when there is a steady or flashing 'red man', but may cross if no signal is displayed.

Figures 5.4 to 5.7 show the proportion of pedestrians who crossed on the 'red man' when the pedestrian phase had been activated by intersection type and time of day, alongside crossing minutes surveyed in each hourly period.

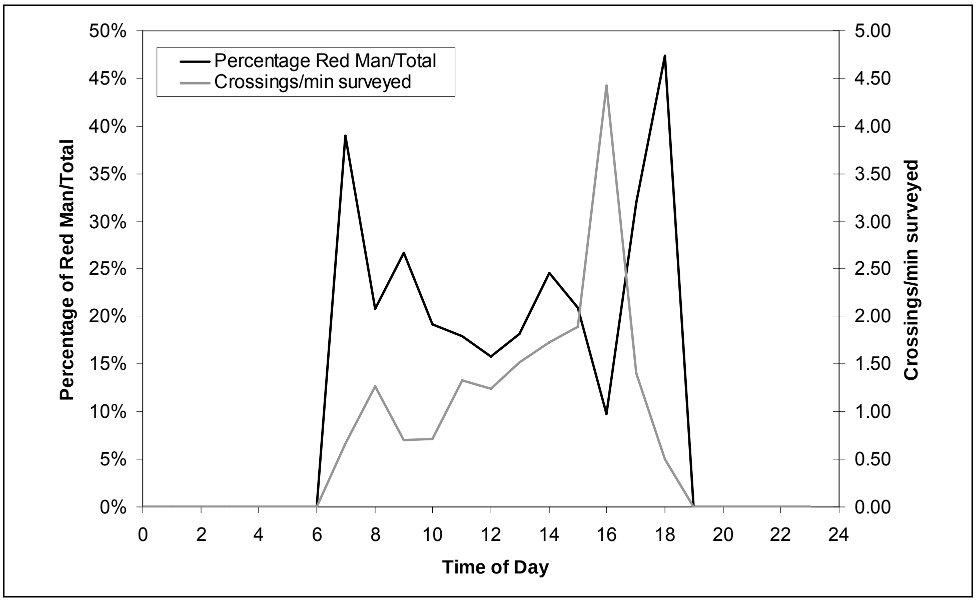

Figure 5.4 Crossings per minute and percentage that cross on the 'red man' in all of Christchurch.

When flows are at their highest (in the evening peak), a larger percentage of pedestrians appear to cross on the 'green man' (see dip in profile to around 10% at 16:00 hours). This is likely to be the result of vehicle flows being high at this time of the day. Pedestrians may only be able to cross when the pedestrian phase is in operation. It is interesting that the proportion who cross with the 'red man' peaks just after this time, possibly because pedestrians are in more of a hurry to get home after work.

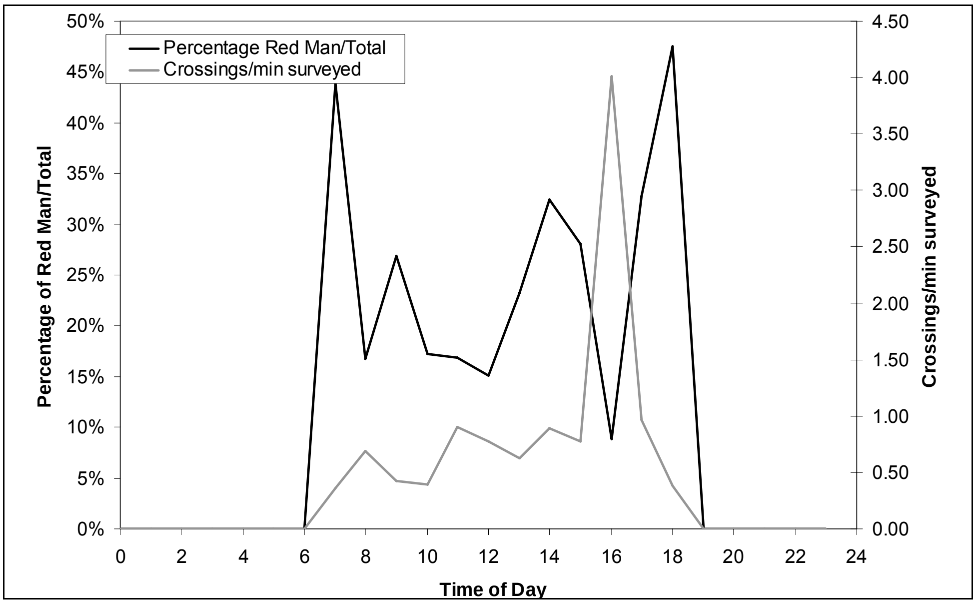

Figure 5.5 Crossings per minute and percentage that cross on the 'red man' within four avenues of Christchurch.

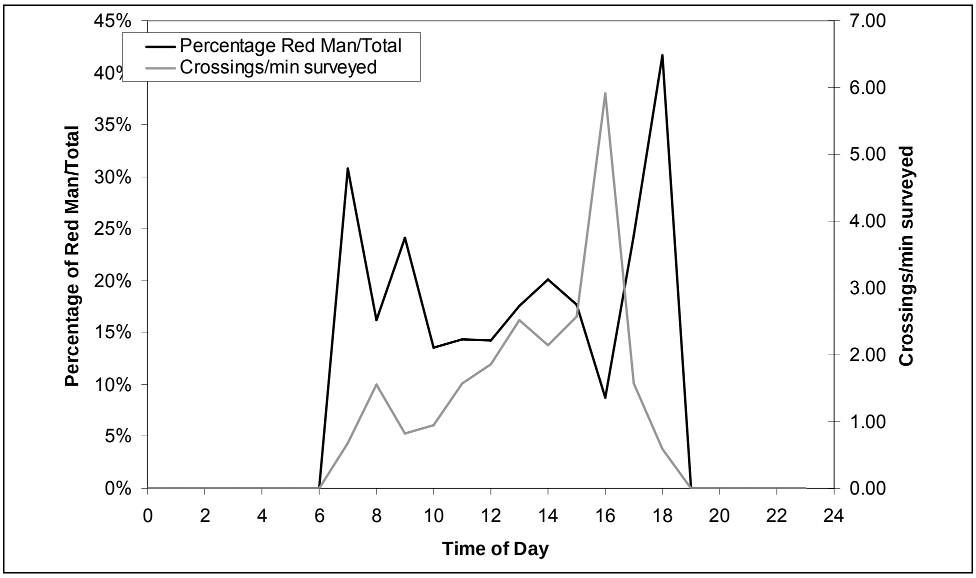

Figure 5.6 Crossings per minute and percentage who cross on the 'red man' at signalised crossroads in Christchurch.

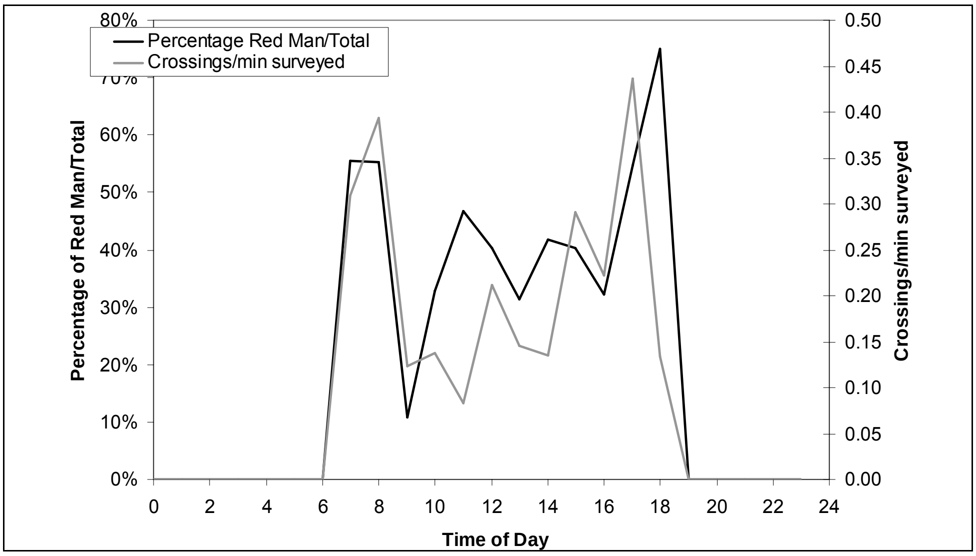

Figure 5.7 Crossings per minute and percentage who cross on the 'red man' at signalised T-junctions in Christchurch.

The pattern in the above figures is that pedestrians cross on the 'green man' less often outside the peak hours. The percentage of people who cross on the 'red man' for all intersection types is around 40% before the a.m. peak and around 60% following the p.m. peak.

The proportion crossing on the 'green man' is highest for signalised 4-leg intersections (approx. 84%), and lowest for one-way crossroads or T-junctions, where only 56% cross on the 'green man'.

6. Accident prediction models (APMs)

6.1 Database composition

In previous studies of this type (e.g. Turner 2000), data had been collected and manipulated in Excel spreadsheets. It was thought that there would be merit in combining the number of spreadsheets used in previous studies and new data into an Access database. Hence, a relational Microsoft Access database was developed for the study. The database enabled effective processing and manipulation of vehicle, cycle and pedestrian count data. Within the main database, separate tables were developed for each type of intersection and also for the mid-block sections used in the analysis. These databases contain the raw pedestrian and cycle count data collected during the study surveys, along with vehicle count data obtained from each council.

In addition, coded accident data from the Ministry of Transport's Crash Analysis System (CAS) were also extracted and inserted into the database. This enabled cross-table queries to be performed. Having these raw data in one electronic source enabled easier manipulation than in the traditional spreadsheet format and allowed the flow factors and accident data to be easily updated.

6.2 Model form

Based on a review of international literature, it was determined that the model for this study should be developed using maximum-likelihood techniques. The models are called generalised linear models and typically have a negative binomial or Poisson error structure. Generalised linear models were first introduced to road accident studies by Maycock & Hall (1984), and extensively developed in Hauer et al. (1989). These models were further developed and fitted using accident data and traffic counts in the New Zealand context for motor-vehicle-only accidents by Turner (1995).

The aim of the modelling exercise is to develop relationships between the mean number of accidents (as the dependent variable flows), and traffic, cycle and pedestrian flows, and non-flow predictor variables. Typically the models are of the following form:

$$A = b_0 x_1^{b_1} x_2^{b_2} \quad \text{(Equation 6.1)}$$

where:

A is the annual mean number of accidents

x_n is the average daily flow of vehicles, pedestrians or cyclists

b_n are the model coefficients

Additional flows or non-flow variables can be added to the model in a multiplicative form by adding various $x_i^{b_i}$ variables on to the end of the equation. In the modelling process, these models are first transformed to a linear form by taking logarithms. This is the reason the models are called linear models even though the final model form is multiplicative.

$$\eta = \log A = \log b_0 x_1^{b_1} x_2^{b_2} = \log b_0 + b_1 \log x_1 + b_2 \log x_2 \qquad \text{(Equation 6.2)}$$

The selected model error structure is either Poisson or negative binomial. The Poisson model is used where the variance in accident numbers is roughly equal to or less than the mean over the majority of the traffic flow range. However, generally the variability is higher than the mean and hence the "negative binomial" model is used. The negative binomial model is a mixture of the Poisson and gamma distributions. The model is described using two parameters k and μ, where k along with the coefficients b_0, b_1, b_2 must be estimated from the data. A more detailed explanation of the models is given in Turner (1995) and Hauer et al. (1989).

6.3 Model variables

The flow variables used in the models are based on those defined in Turner (1995) where each movement is numbered in a clockwise direction at intersections, starting at:

- the northern approach for crossroads,
- the side road approach for T-junctions,
- the approach of the one-way street at crossroads that have a one-way street.

Individual movements are denoted as a lower case character for the user type (e.g. *q* for motor vehicles, *c* for cyclists and *p* for pedestrians). Totals of various movements (e.g. approach flows) are denoted with an upper case character. For each model developed these are shown diagrammatically for clarity. Generally models are developed for each approach and are defined using the variables for the first approach only.

6.4 Model identification

APMs have been developed for the major cyclist and pedestrian accident types for each type of intersection control (traffic signals and roundabouts) and road layout (3- or 4-arm one-way streets). Models were also developed for mid-block locations.

The model forms selected and then analysed were influenced by four main factors:

- the number (or sample size) of sites available for each intersection type of the same control and layout, e.g. signalised T-intersections and signalised X-intersections,
- the number of accidents reported for each of the major pedestrian and cyclist accident types,
- the interaction of vehicles and cyclists/pedestrians in different types of accidents: models were developed on an approach-by-approach, two-way movements or intersection basis depending on available data,
- the availability of non-flow data such as intersection layout variables.

The first step was to identify the major accident types involving cyclists and pedestrians for each intersection type. This was achieved by producing pie graphs showing national accident types reported at each intersection type, and from bar charts of accident types at sampled intersections. The major accident types were then identified and model forms were developed for each accident type using the key movements of the various modes (motor-vehicles, pedestrians and cyclists).

Pedestrian accidents have separate accident codes (N and P) and were easy to isolate in CAS. Cycle accidents however are coded in CAS using the same coding as for motor vehicles. Cycle accidents can however be identified using vehicle coding and using the CAS tabulations function.

For the major accident types, the conflicting flow combinations that were involved in the accident were identified and included in the 'flow–only' model. Additional non-conflicting flows were added to some models if it was thought that these non-conflicting flows contributed to accident occurrence. Some models were then developed further depending on the availability of non-flow variables. Non-flow variables were available only for signalised crossroads, where information on the geometry was readily available. Each model is identified by a unique code as set out in Appendix G.

6.5 Model interpretation

6.5.1 Parameter interpretation

This section specifies how to interpret the outcomes from the modelling exercise. The general form of the APMs is as shown in Equation 6.1.

In this model the parameter b_0 acts as a constant multiplicative value. When the number of reported injury accidents is not dependent on the values of the two variables (x_1 and x_2), then the model parameters would be zero and the value of b_0 would be equal to the mean number of accidents.

The value of the parameter indicates the relationship that a particular variable has (over its flow range) with accident occurrence. There are five types of relationship, as presented in Figure 6.1 and discussed in Table 6.1.

Generally APMs 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. However there are cases where parameters have a value outside this range, e.g. rear-end motor-vehicle accidents, where the values of b_i are consistently above 1.0. It can be expected that as traffic densities increase the interaction between vehicles will increase, causing an increase in the rear-end accident rate. In a number of situations it is unclear why the parameters are outside the typical range, indicating that further research is required to confirm the exponent values.

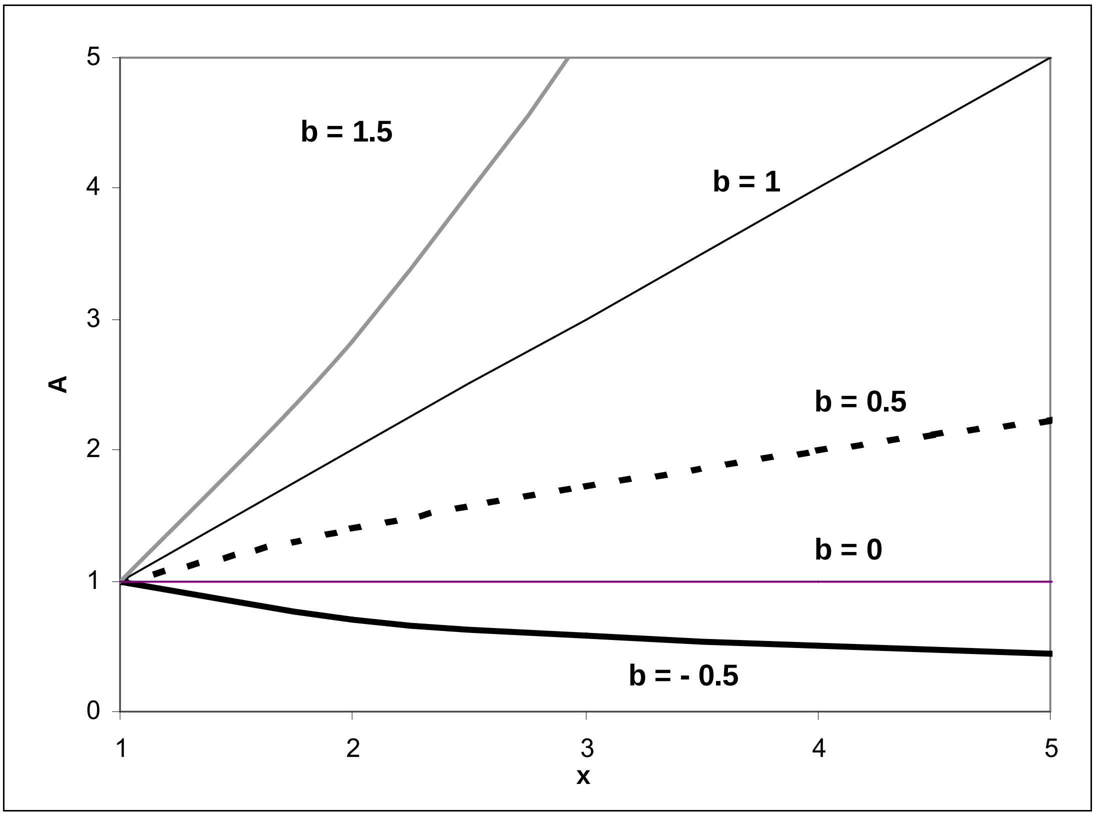

Figure 6.1 Relationship between accidents and predictor variable x for different values of model exponents (b_1).

Table 6.1 Relationship between predictor variable and accident rate.

Value of exponent	Relationship with accident rate
$b_i > 1$	For increasing values of the variable, the number of accidents will increase, and at an increasing accident rate
$b_i = 1$	For increasing values of the variable, the number of accidents will increase at a constant accident rate
$0 < b_i < 1$	For increasing values of the variable, the number of accidents will increase at a decreasing accident rate
$b_i = 0$	There will be no change in the number of accidents with increases in the value of the variable
$b_i < 0$	For increasing values of the variable, the number of accidents will decrease

6.5.2 Adding variables - log-likelihood

The benefit of adding additional variables to a model can be tested by determining whether a significant reduction in the log-likelihood has occurred. The log-likelihood is a negative value and the smaller the value the better the model fit. In determining the preferred model it is a matter of trading off a parsimonious set of predictor variables (or smallest number of variables that explains a significant amount of the variability) and getting a further reduction in the likelihood function.

6.5.3 Confidence intervals

95% confidence intervals were produced for a number of the APMs. The 95% confidence intervals and expected value are presented in graphical form. The plots show the upper and lower confidence limits and the fitted model (expected number of accidents) for each variable. The equations used to develop the confidence intervals are presented in Appendix E.

The confidence intervals plotted are for the mean value of all intersections with the same independent (or predictor) variable (or traffic volume) values. Thus, it is not appropriate to compare the observed number of accidents at a single site with the confidence interval. The confidence interval for accident occurrence at a particular site would in fact be much larger than the confidence interval for the mean value. Given the differences in confidence interval bands, it is more appropriate to compare the total observed number of accidents at a series of intersections with the total predicted number of accidents over the series of intersections. It is easier to predict accidents at a number of sites or within a network rather than at individual sites.

6.6 Cycle APMs for signalised crossroads

6.6.1 Injury accidents involving cyclists

Figure 6.2 shows the number of accidents of each type that involve cyclists at signalised cross-intersections in the sample set. The trend in accident types is similar to New Zealand national data presented in Chapter 3. Because of the scarcity of accidents involving cyclists, a 10-year accident period (1994-2003) was used in the models.

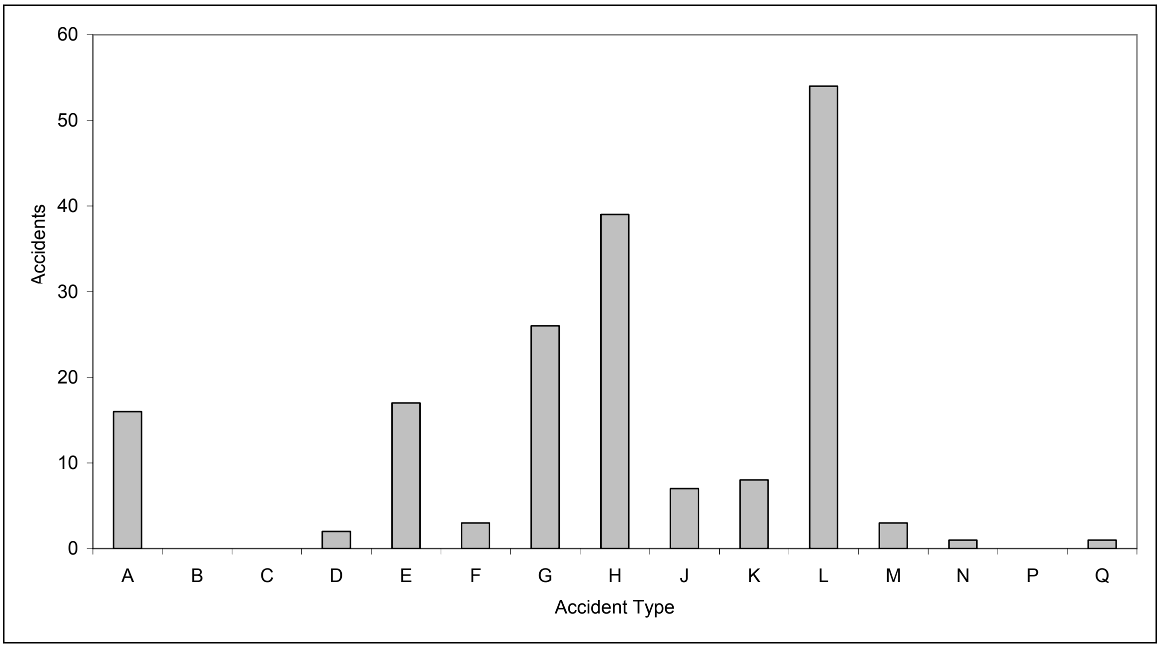

Figure 6.2 Accidents at signalised crossroads involving cyclists.

The various accident types in Figure 6.2 can be further subdivided into more specific accident types. Figure 6.3 shows the percentage of total accidents involving cyclists for each accident sub-type (see Appendix F). This plot compares well with that of Figure 3.10 for all cycle accidents at signalised crossroads.

Clearly both HA and LB accidents are major accident types at signalised crossroads. Type HA accidents occur when a straight-through vehicle collides with another straight-through vehicle at right angles (also called 'running the red' accidents). In 66% of cycle accidents the cyclist was hit from the left by a motor vehicle.

LB accidents involve a collision between a vehicle travelling straight-through and a vehicle coming from the opposing direction and turning right. In 69% of accidents the cyclist was travelling straight through.

There was sufficient data to develop APMs for type LB and HA accidents (Sections 6.6.2 to 6.6.8). A third model called 'same direction' was developed by combining accident types A, E, F and G.

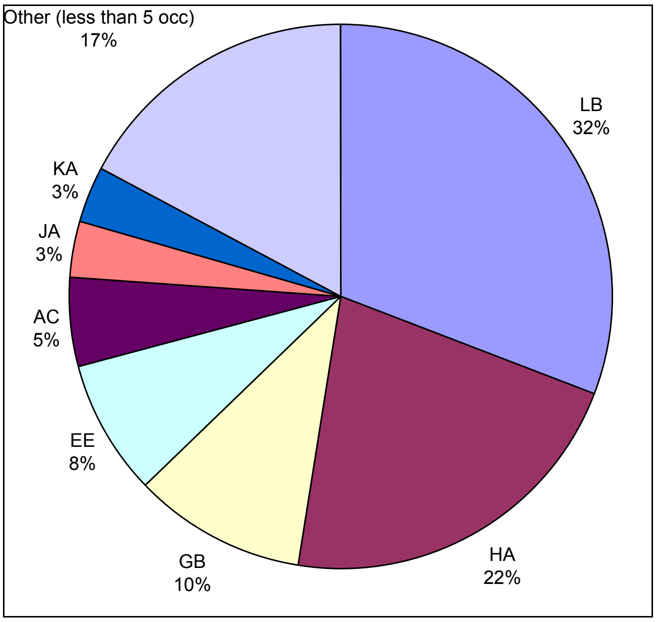

Figure 6.3 Major accident types at signalised crossroads.

6.6.2 APM type: UCXT1 (same direction)

A significant proportion of the cycle accidents occur where the cyclist collides with a stationary vehicle or collides with a motor vehicle travelling in the same direction. Accident types A, E, F and G have been combined to create a 'same direction' model. The majority of such accidents occur when motorists and cyclists are approaching an intersection. The flow-only form of this model is presented in Equation 6.3 and the variables shown graphically in Figure 6.4:

$$A = b_o \times Q_e^{b_1} \times C_e^{b_2} \quad \text{(Equation 6.3)}$$

where:

Q_e = the daily flow of entering vehicles for the approach (i.e. $q_1 + q_2 + q_3$ for the northern approach),

C_e = the daily flow of entering cyclists for the approach (i.e. $c_1 + c_2 + c_3$ for the northern approach).

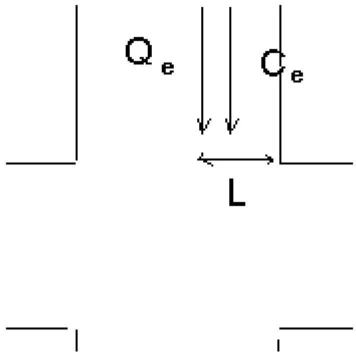

Figure 6.4 UCXT1 model variables.

Table 6.2 presents some statistics of the sample set, while Table 6.3 presents the model parameters.

Table 6.2 Statistics for UCXT1 accidents (10-year data).

Size of sample set	446 approaches
Number of accidents in sample set	61 accidents
Maximum number of accidents for an approach	2 accidents
Sample mean of accidents	0.137 accidents
Sample variance of accidents	0.136 accidents^2

Table 6.3 Annual flow-only APM for UCXT1 accidents.

b_0	b_1	b_2	Error structure	log-likelihood
7.491×10^{-4}	0.2865	0.0909	Poisson	−183.917

The small exponent of the entering flow (b_2) in Table 6.3 indicates that this type of accident is not largely affected by variations in the entering cycle flow. The rate of increasing accidents with increasing vehicle flow also drops off quickly.

To gain further insight into the daily flows of vehicles and cyclists entering each approach, Table 6.4 presents some statistics of the data used in developing this model. Figure 6.5 is a three dimensional plot of the predicted annual mean number of accidents over these flow ranges.

Table 6.4 Further statistics for UCXT1 accidents (10-year data).

Measure	Q_e	C_e
Median	6783	63
Minimum	39	8
Lower quartile	4285	42
Upper quartile	9600	96
Maximum	21996	1159

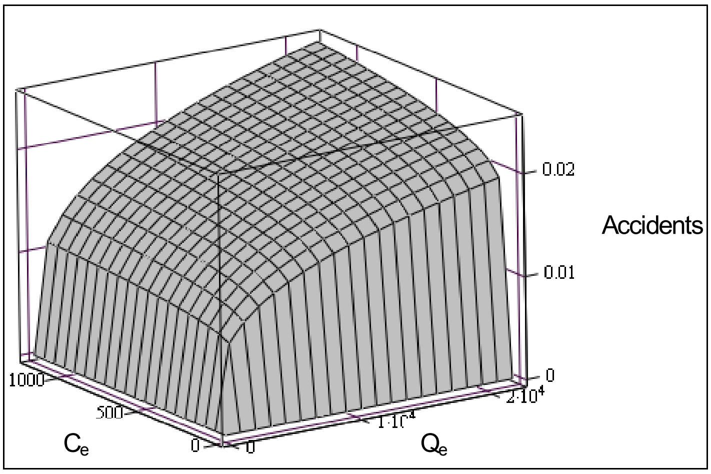

Figure 6.5 Predicted mean number of UCXT1 accidents.

The sample set was sorted by both entering vehicle and cycle flows. Two bar charts were then produced (Figures 6.6 and 6.7) comparing the reported and predicted numbers of accidents. For each bar chart four flow bands were used: between the minimum and lower quartile flow, lower quartile and median flow, median and upper-quartile, and upper-quartile and maximum flow.

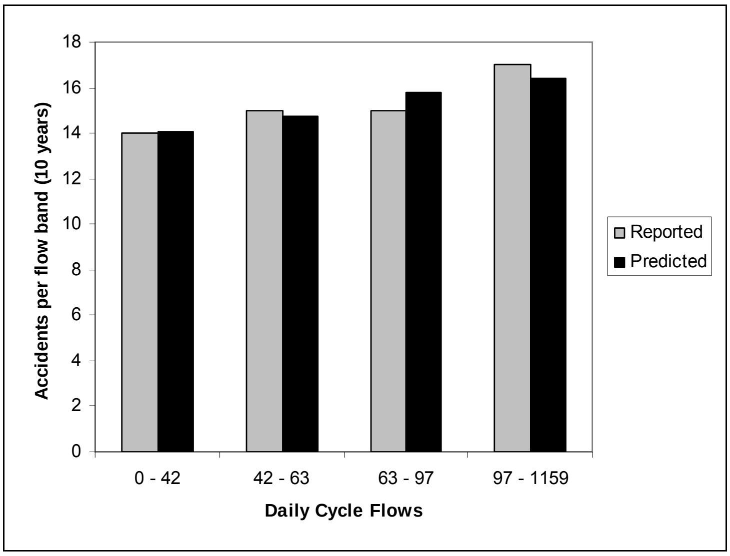

Figure 6.6 Reported and predicted UCXT1 accidents by cycle volume.

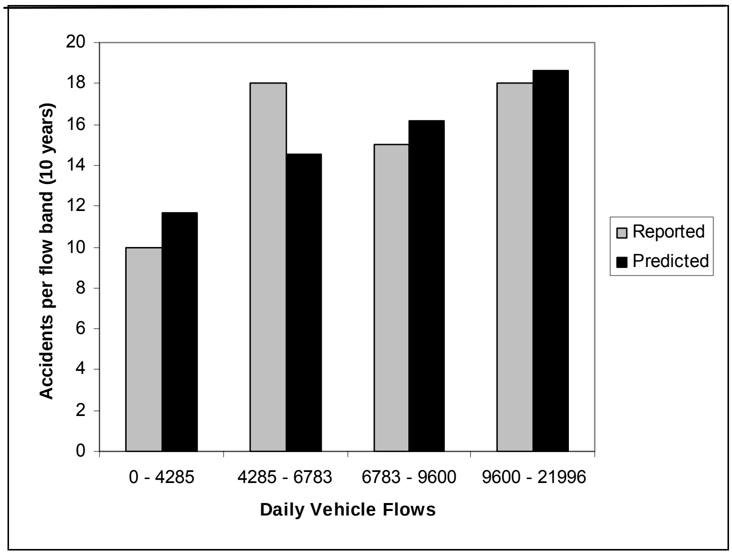

Figure 6.7 Reported and predicted UCXT1 accidents by vehicle volume.

Figures 6.6 and 6.7 show a good fit between the reported number of accidents and the predicted number of accidents where sites were aggregated by flows.

Confidence intervals for the mean number of accidents of this type were also produced. In three dimensions these would take the form of two additional surfaces above and below that in Figure 6.5. Two figures are produced here showing the predicted mean number of accidents and the corresponding 95% confidence intervals. Figure 6.8 shows the confidence interval for this model where entering vehicle flows are held constant at the median value in the sample set and entering cycle flows vary. Figure 6.9 shows the confidence interval where entering cycle flows are held constant at the median value in the sample set and entering vehicle flows vary.

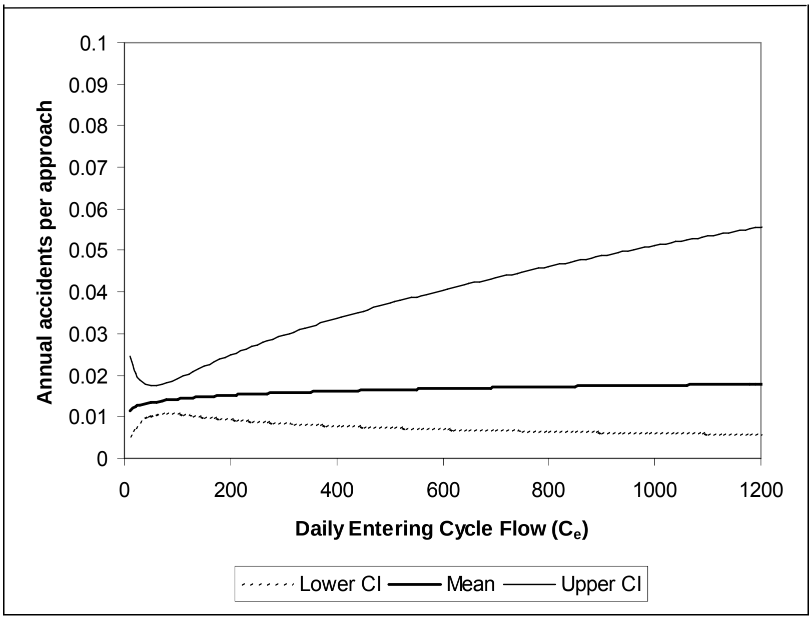

Figure 6.8 95% Confidence interval for median vehicle entering flows (UCXT1).

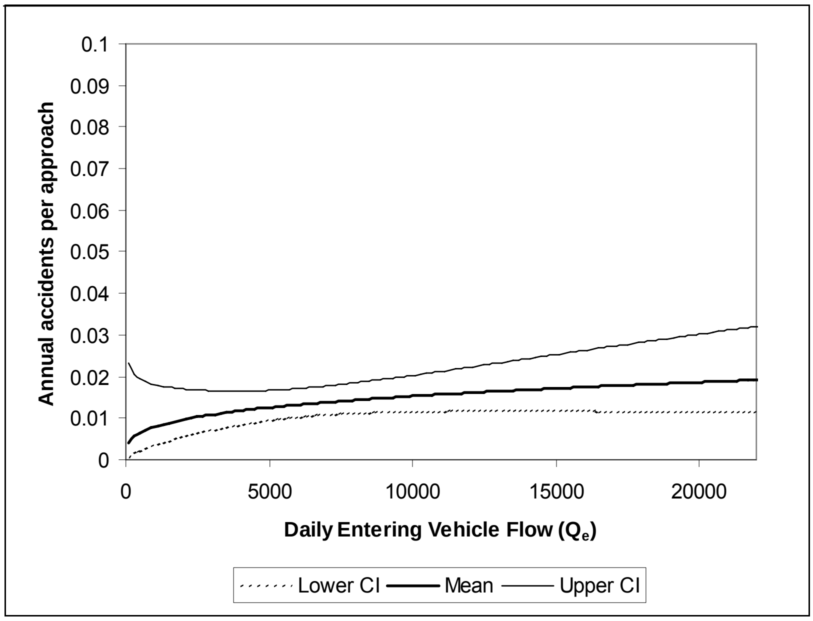

Figure 6.9 95% Confidence interval for median cycle entering flows (UCXT1).

Figures 6.8 and 6.9 do not have a particularly wide confidence interval. This is because the variance of the parameter estimates (b_0, b_1, *and* b_2) is not large, again indicating a reasonably well-fitting model. The reason for the large increase in the range between the upper and lower bounds of the confidence interval in the upper ranges of flow is that there are few junctions with these higher flow rates and therefore fewer observations to establish a relationship. Correspondingly, around the median value of the data, where there are a considerable number of intersections, and hence observations, the confidence limits are much narrower.

6.6.3 APM type: UCXT1L (same direction, including lane width)

This model (Equation 6.4) includes the width of the kerbside lane (L). If a cycle lane is present, the width of kerbside lane includes both the width of the cycle lane and the kerbside lane combined. Table 6.5 compares the resulting APM with that of the flow-only model.

$$A = b_o \times Q_e^{b_1} \times C_e^{b_2} \times L^{b_3} \qquad \text{(Equation 6.4)}$$

where:

L = the lane width in metres, including the cycle lane if present (refer to Figure 6.4)

Table 6.5 Annual APMs for UCXT1 accidents.

Model	b_0	b_1	b_2	b_3	Error structure	log-likelihood
UCXT1 (flow-only model)	7.491×10^{-4}	0.2865	0.0909	–	Poisson	−183.917
UCXT1L (including lane width)	1.008×10^{-3}	0.2846	0.0845	−0.2024	Poisson	−183.822

The negative value of the exponent b_3 for the model including lane width indicates that with increasing total lane widths the accident rate reduces. However, comparing the log-likelihoods of the two models, the addition of lane width as a variable does not significantly improve the fit of the model (i.e. no significant change occurs in the log-likelihood).

To determine more accurately the effect of cycle lanes on accident rates a more thorough analysis would have to be carried out, taking into account when the cycle lane was installed and using a larger sample set.

6.6.4 APM type: UCXT2 (intersecting)

This model includes all accidents of the type HA, where cyclists have been hit from the left or right side by vehicles travelling at a direction 70 to 110 degrees from the direction of travel of the cyclist. Equation 6.5 shows the form of the flow-only model, and the variables are shown in Figure 6.10. Tables 6.6 and 6.7 present some statistics for the sample set and the fitted model, respectively.

$$A = b_o \times q_5^{b_1} \times q_{11}^{b_2} \times c_2^{\ b_3} \qquad \text{(Equation 6.5)}$$

where:

q_5 = the daily flow of through vehicles approaching from the cyclists left,

q_{11} = the daily flow of through vehicles approaching from the cyclists right,

c_2 = the daily flow of through cyclists for an approach.

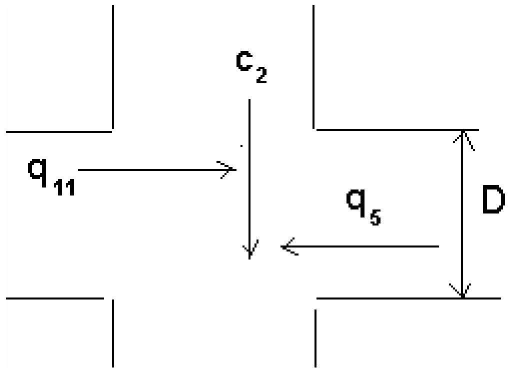

Figure 6.10 UCXT2 model variables.

Table 6.6 Statistics for UCXT2 accidents (10-year data).

Size of sample set	424 approaches
Number of accidents in sample set	29 accidents
Maximum number of accidents for an approach	2 accidents
Sample mean of accidents	0.068 accidents
Sample variance of accidents	0.069 accidents^2

Table 6.7 Annual flow-only APM for UCXT2 accidents.

b_0	b_1	b_2	b_3	Error structure	log-likelihood
5.285×10^{-6}	−0.4303	1.2139	0.1226	Poisson	−102.469

Of these accidents, 66% involved the cyclist being hit from the left, therefore it is surprising that the exponent for q_5 is negative while the exponent for q_{11} is positive and quite large. To investigate this further, a separate model for cyclists being hit from the left was developed in the following section. One model was also developed for the cyclist being hit from the right, but as there were only 10 accident occurrences out of 424 approaches the resulting model fitted poorly, and it is not presented in the report.

6.6.5 APM type: UCXT2 (intersecting, cyclist hit from left)

This model (Equation 6.6) predicts the number of HA type accidents where a cyclist is hit from the left by a motor vehicle. Table 6.8 presents some statistics for this sample set and Table 6.9 presents the fitted model.

$$A = b_o \times q_5^{b_1} \times c_2^{\,b_2} \qquad \text{(Equation 6.6)}$$

Table 6.8 Statistics for UCXT2 (cyclist hit from left) accidents (10-year data).

Size of sample set	424 approaches
Number of accidents in sample set	19 accidents
Maximum number of accidents for an approach	1 accident
Sample mean of accidents	0.045 accidents
Sample variance of accidents	0.043 accidents^2

Table 6.9 Annual flow-only APM for UCXT2 (cyclist hit from left) accidents.

b_0	b_1	b_2	Error structure	log-likelihood
1.019×10^{-5}	0.7018	0.0249	Poisson	−75.5622

This model has a very small exponent for the cycle flow, indicating that a 'safety in numbers' effect occurs for cyclists performing this manoeuvre (refer to the literature review for other studies where this has been observed). Given the low mean number of accidents of this type no further analysis was considered worthwhile.

6.6.6 APM type: UCXT3 (right-turn against)

The model is used to predict accident type LB where the 'primary' vehicle travelling straight through is a cyclist (Equation 6.7, Figure 6.11). Some statistics for this sample set are presented in Table 6.10 and the fitted model in Table 6.11.

$$A = b_o \times q_7^{b_1} \times c_2^{b_2} \qquad \text{(Equation 6.7)}$$

q_7 = the daily flow of right-turning vehicles approaching from the opposing direction to the cyclist

c_2 = the daily flow of through cyclists for an approach

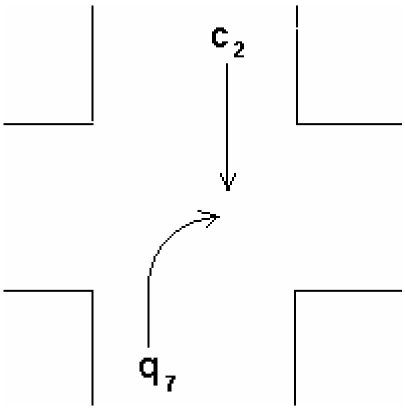

Figure 6.11 UCXT3 model variables.

Table 6.10 Statistics for UCXT3 accidents (10-year data).

Size of sample set	351 approaches
Number of accidents in sample set	35 accidents
Maximum number of accidents for an approach	2 accidents
Sample mean of accidents	0.094 accidents
Sample variance of accidents	0.102 accidents^2

Table 6.11: Annual APM for UCXT3 accidents.

b_0	b_1	b_2	Error structure	log-likelihood
4.405×10^{-4}	0.3430	0.1978	NB, k=1.3	-117.548

The small exponent of cycle flows (b_2) indicates a 'safety in numbers' effect where the accident rate per cyclist decreases substantially as the number of cyclists increases.

The model will be examined further as it explains a large proportion of accidents at signalised crossroads. Further statistics on the sample set are presented in Table 6.12, along with a 3D plot of the predicted number of accidents in Figure 6.12.

Table 6.12 Further statistics for UCXT3 accidents.

Measure	q_7	c_2
Median	894	36
Minimum	29	3
Lower quartile	504	18
Upper quartile	1462	65
Maximum	9989	1149

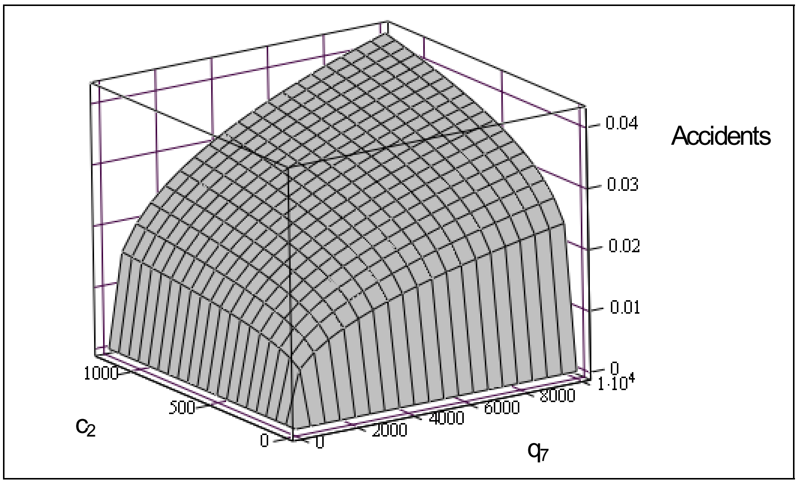

Figure 6.12 Predicted number of UCXT3 accidents.

The sample set was then sorted by both right-turning vehicle flows and straight-through cycle flows. Two bar charts were produced (Figures 6.13 and 6.14) comparing the predicted number of accidents and the reported number of accidents. These figures show a reasonably good fit between the observed and predicted number of accidents.

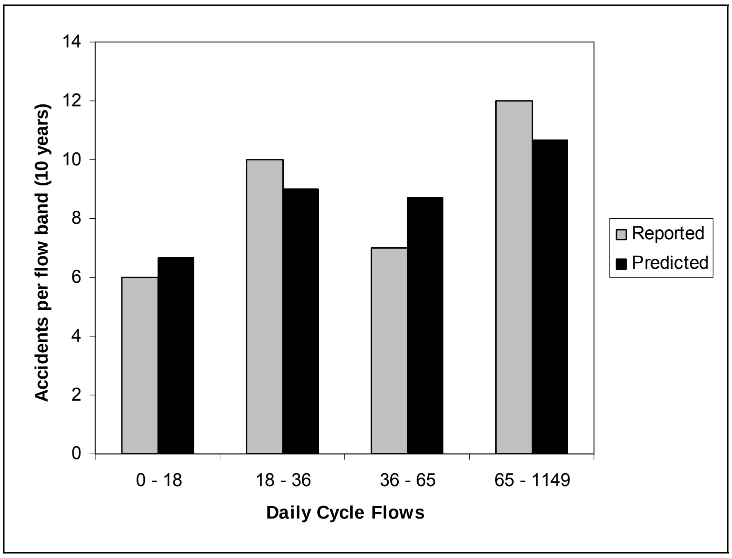

Figure 6.13 Reported and predicted UCXT3 accidents by cycle volumes.

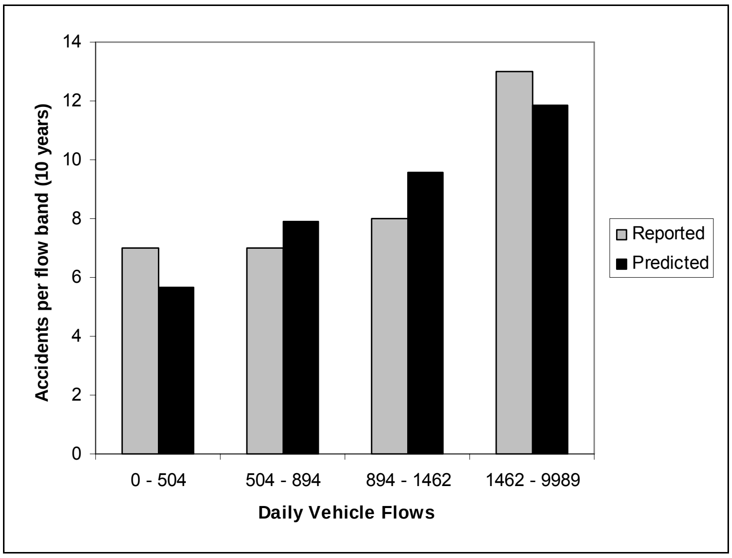

Figure 6.14 Reported and predicted UCXT3 accidents by vehicle volumes.

Figures 6.15 and 6.16 present 95% confidence intervals for the mean number of accidents for median vehicle and cycle flows respectively.

Both these figures show dramatically increasing ranges between the upper and lower bounds of the confidence intervals as the flows become high. This is because the distribution of flows is skewed towards lower flows.

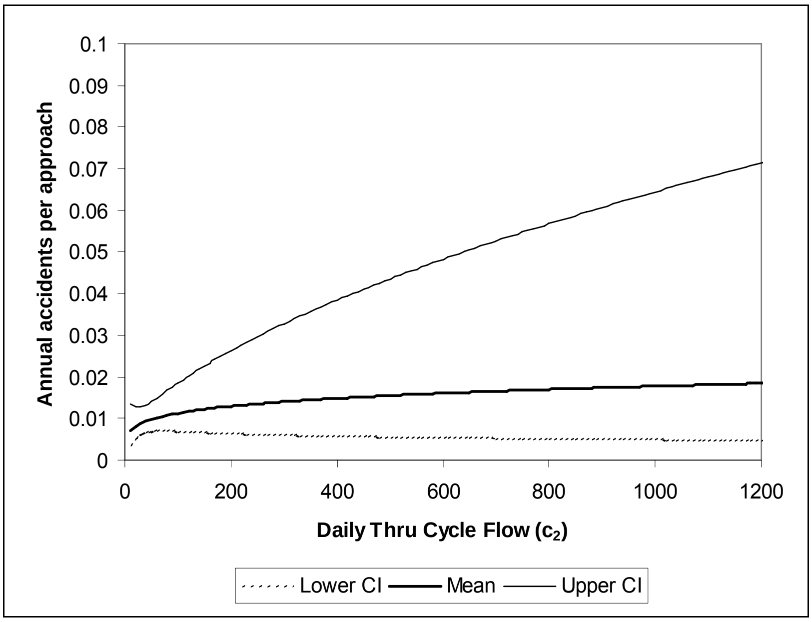

Figure 6.15 95% confidence interval for median vehicle flows.

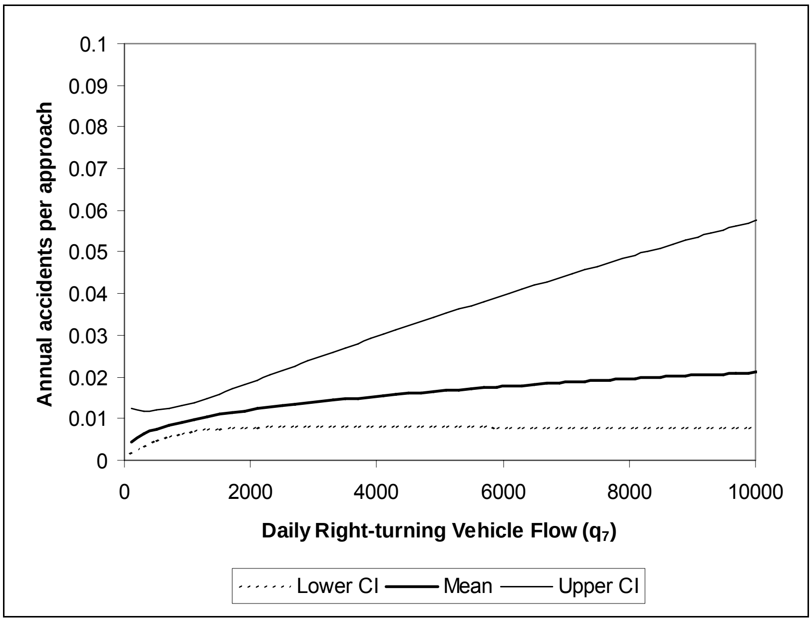

Figure 6.16 95% Confidence interval for median cycle flows (cpd).

6.6.7 APM type: UCXT3V,Q (right-turn against, including non-conflicting flow variables)

This section examines adding variables that are not conflicting flows to the UCXT3 model. These variables are visibility for the motor vehicles turning right to the right-most through lane and the flow variable q_2, the flow of vehicles travelling in the same direction as the cyclist but not included in collisions of this type.

The visibility was measured as the visibility from the limit line of the right-turn lane to the centre of the right-most opposing through lane (i.e. furthest from the kerb-line) minus the recommended visibility from Austroads (2002) (refer to Turner 2004 for details of this data). Therefore, where sight distance was less than the minimum recommended, the visibility value used would be negative. In terms of developing an APM the presence of negative values causes some problems, therefore 100 m was arbitrarily added to the actual minus minimum recommended visibility to ensure the variable was positive. Equation 6.8 presents this model form, while Equation 6.9 presents the form of the model including q_2.

$$A = b_o \times q_7^{b_1} \times c_2^{b_2} \times (100 + V)^{b_3} \qquad \text{(Equation 6.8)}$$

where:

V = actual visibility of right-turning vehicles to vehicles in the right-most opposing lane, minus the minimum recommended (in metres)

$$A = b_o \times q_7^{b_1} \times c_2^{b_2} \times q_2^{\ b_3} \qquad \text{(Equation 6.9)}$$

where:

q_2 = motor-vehicle flow opposing right-turning vehicles

Table 6.13 presents the fitted APM parameters and shows (note log-likelihood has not changed significantly) that neither of these additional variables produces a model that is significantly better than the conflicting flow-only model, implying that the non-conflicting flow variables have little effect on the occurrence of accidents.

Table 6.13 Annual APMs for UCXT3 accidents.

Model	b_0	b_1	b_2	b_3	Error structure	log-likelihood
UCXT3 (Flow- only model)	4.405×10^{-4}	0.3430	0.1978		NB, k=1.3	−117.548
UCXT3V (Including (100+V))	2.280×10^{-4}	0.3354	0.1970	0.1584	NB, k=1.3	−117.495
UCXT3Q (Including q_2)	1.009×10^{-3}	0.3588	0.2025	−0.1128	NB, k=1.4	−117.446

6.6.8 APM type UCXT4: (right-turn against, motor vehicle travelling through)

This model is similar to the UCXT3 model except that the roles of the cyclist and motor vehicle are reversed (Figure 6.17). This accident type is less prevalent at the study sites than UCXT3 accidents. The model form is presented in Equation 6.10 and some statistics on the sample set can be found in Table 6.14.

$$A = b_o \times q_2^{b_1} \times c_7^{b_2} \qquad \text{(Equation 6.10)}$$

where:

c_7 = the daily flow of right-turning cyclists approaching from the opposing direction to the motor vehicle,

q_2 = the daily flow of through motor vehicles for an approach.

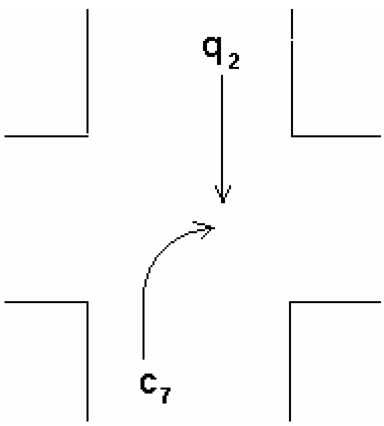

Figure 6.17 UCXT4 model variables.

Table 6.14 Statistics for UCXT4 accidents (10-year data).

Size of sample set	351 approaches
Number of accidents in sample set	15 accidents
Maximum number of accidents for an approach	2 accidents
Sample mean of accidents	0.043 accidents
Sample variance of accidents	0.058 accidents^2

Table 6.15 presents the fitted parameters of the APM. The value of the exponent of cycle flows (b_2) seems counterintuitive, indicating that the total number of accidents decreases with increasing numbers of cyclists. However, this is consistent with the trend observed in the sample set (Figure 6.18, flow bands are in quartiles of flow), as accidents are more frequent at approaches with lower cycle flows. Given that the mean number of accidents per approach of this type is small (0.044 accidents per 10 years) this model was not examined further. A larger sample set would be required to develop a better fitting model.

Table 6.15 Annual flow-only APM for UCXT4 accidents.

Model	b_0	b_1	b_2	Error structure	log-likelihood
Flow-only model	3.413×10^{-4}	0.3603	−0.2077	Poisson	−68.8796

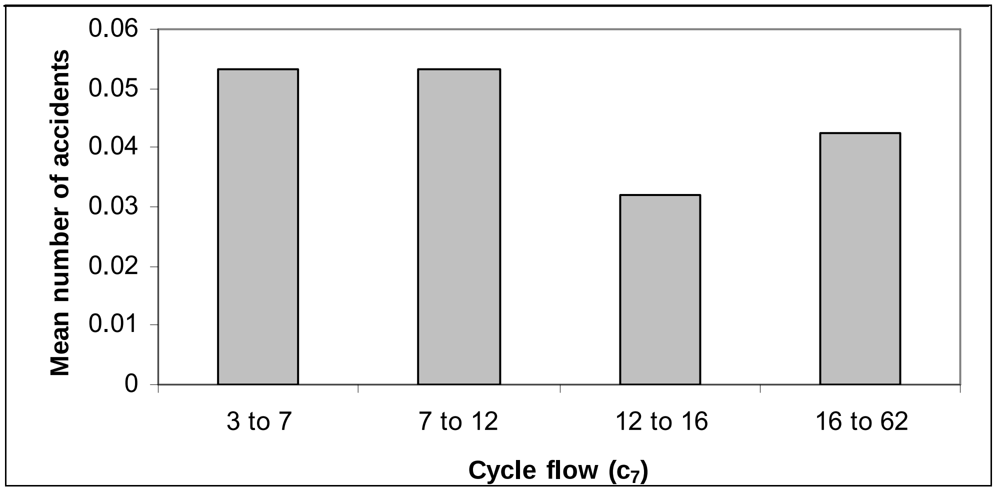

Figure 6.18 Cycle flow (cpd) c_7 versus the mean number of accidents.

6.7 Pedestrian APMs for signalised crossroads

6.7.1 Injury accidents involving pedestrians

Figure 6.19 shows the number and type of accidents involving pedestrians at the signalised crossroads in the dataset. Although pedestrian accidents can also be coded as type P (pedestrians not crossing the road) these were very infrequent.

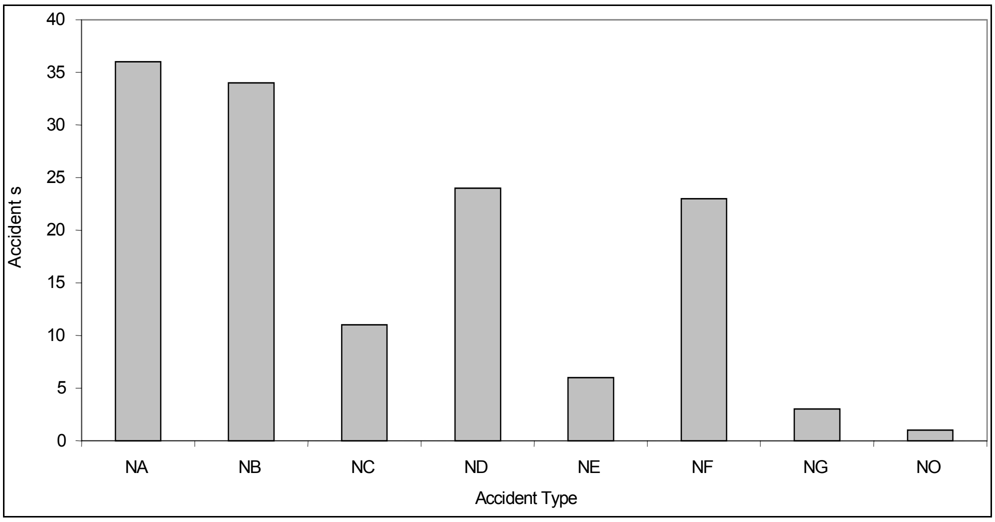

Figure 6.19 Accidents at signalised crossroads involving pedestrians.

Of the accidents involving pedestrians at signalised crossroads, 87% involved a light vehicle (including vans and SUVs), 12% a heavy vehicle, and 1% involved a cyclist. Because of the relatively small number of accidents involving heavy vehicles this will not be considered as an explanatory variable in any of the models.

6.7.2 APM type: UPXT1 (intersecting)

Accident types NA and NB where vehicles collide with pedestrians crossing at right angles are the main injury accident type involving pedestrians.

The direction of travel of the motor vehicle in type NA/NB accidents is recorded in CAS. However, this is insufficient to determine the approach on which accidents occurred. Therefore, rather than having four datasets per intersection (one per approach) this accident type had two (one for the minor road and one for the major road).

Figures 6.20 and 6.21 were produced to assess the likely relationship between the flow variables and the accidents.

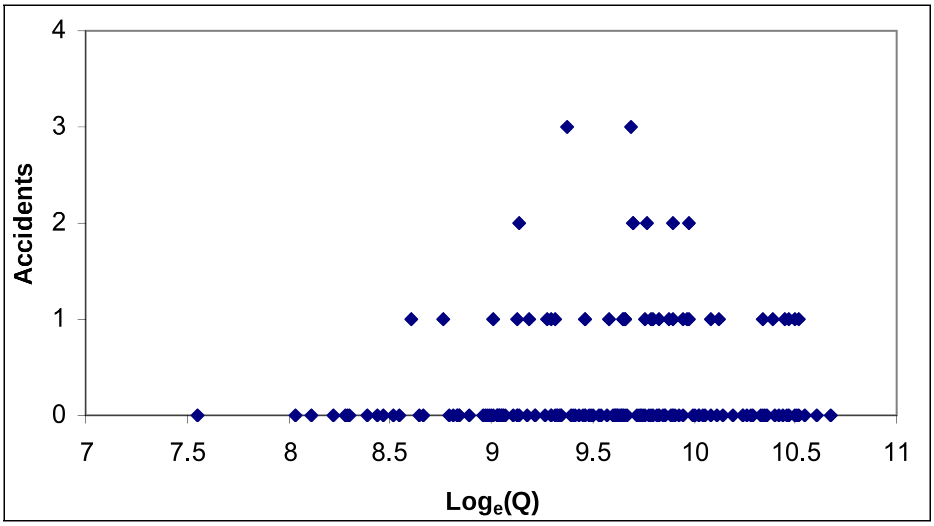

Figure 6.20 Natural log of two-way vehicle flow versus NA and NB accidents.

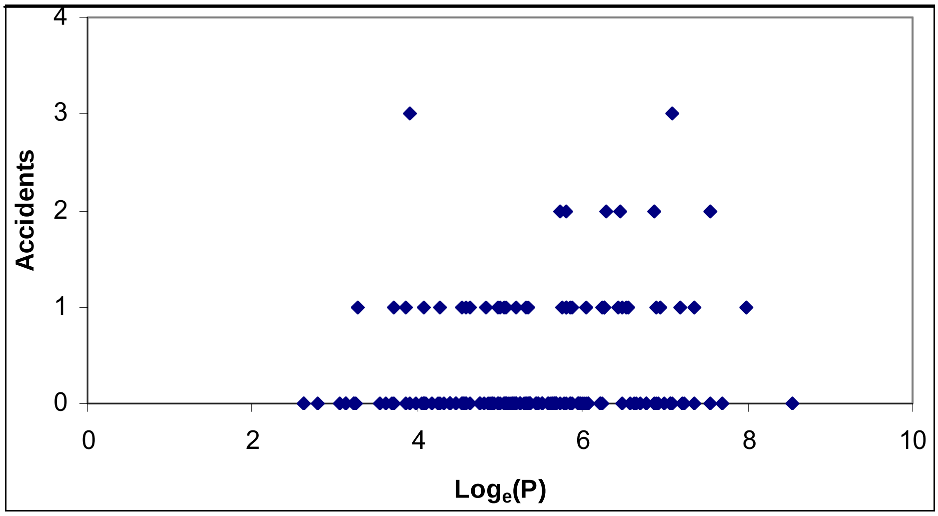

Figure 6.21 Natural log of pedestrian crossing volumes versus NA and NB accidents.

Figures 6.20 and 6.21 indicate that both P and Q are likely to have positive exponents in an APM. Equation 6.11 shows the form of this model, with Figure 6.22 defining graphically the variables.

$$A = b_o \times Q^{b_1} \times P^{b_2} \qquad \text{(Equation 6.11)}$$

where:

Q = the average two way vehicle flow on opposing links, e.g. for approach 1 and 3: $[[q_1+q_2+q_3+q_4+q_8+q_{12}] + [q_7+q_8+q_9+q_2+q_6+q_{10}]]/2$

P = pedestrians crossing those links within 50 m of the intersection

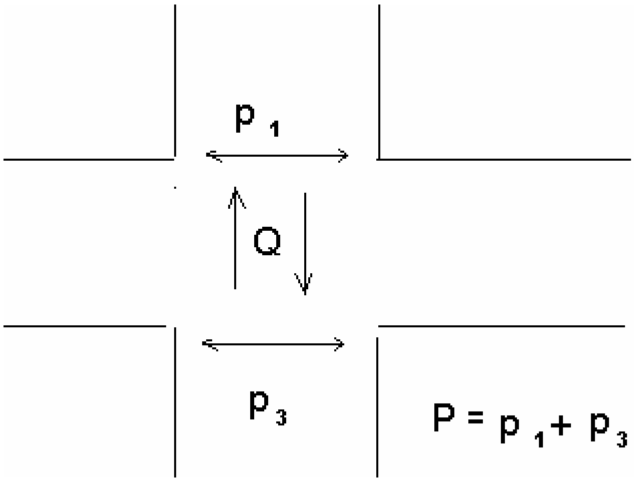

Figure 6.22 UPXT1 model variables.

Table 6.16 shows statistics for the accident sample set used to develop the APMs.

Table 6.16 Statistics for UPXT1 accidents (10-year data).

Size of sample set	176 flow combinations
Number of accidents in sample set	52 accidents
Maximum number of accidents for a flow combination	3 accidents
Sample mean of accidents	0.295 accidents
Sample variance of accidents	0.346 accidents^2

Table 6.17 shows the fitted parameters of the APM.

Table 6.17 Annual flow-only APM for UPXT1 accidents.

b_0	b_1	b_2	Error structure	log-likelihood
7.279×10^{-6}	0.6340	0.3959	NB, k=3.7	−116.332

As observed in the APMs produced for cycle accidents, a 'safety in numbers' phenomenon occurs. This indicates that in locations where there are higher than average pedestrian volumes, the accident rate per pedestrian is reduced.

Because this APM predicts a significant proportion of pedestrian accidents at traffic signals, the model has been developed further. Table 6.18 presents further statistics on the sample set, while Figure 6.23 shows a three dimensional surface of the model over the pedestrian and motor-vehicle flow range.

Table 6.18 Further Statistics on UPXT1 accidents.

Measure	*Q*	*P*
Median	15116	210
Minimum	1902	14
Lower quartile	9213	97
Upper quartile	20221	415
Maximum	43285	5079

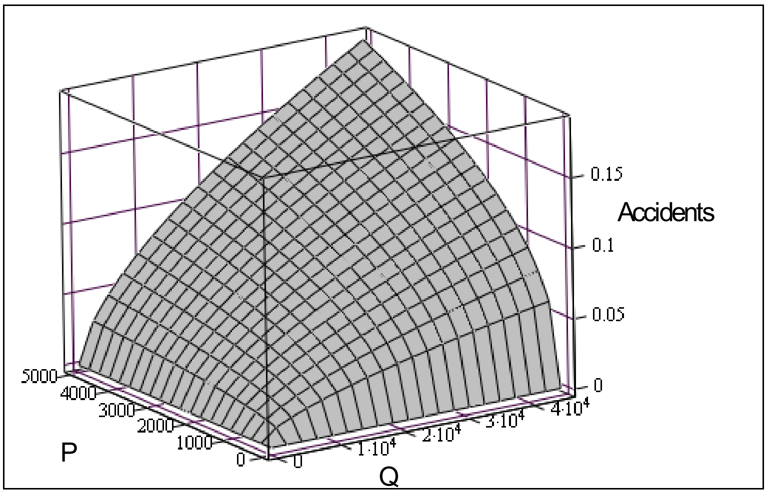

Figure 6.23 Predicted number of UPXT1 accidents.

The sample set was then sorted by both two-way vehicle flow and crossing pedestrian volumes and the number of predicted and reported accidents compared (Figures 6.24 and 6.25).

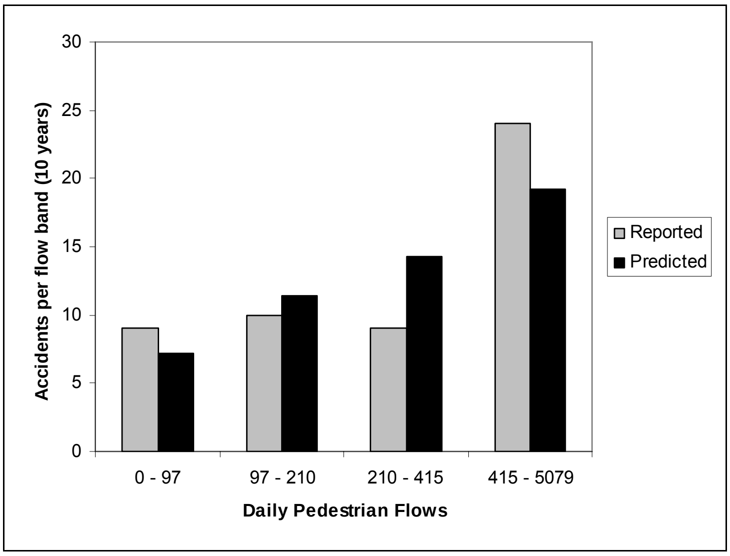

Figure 6.24 Reported and predicted UPXT1 accidents (by pedestrian volume).

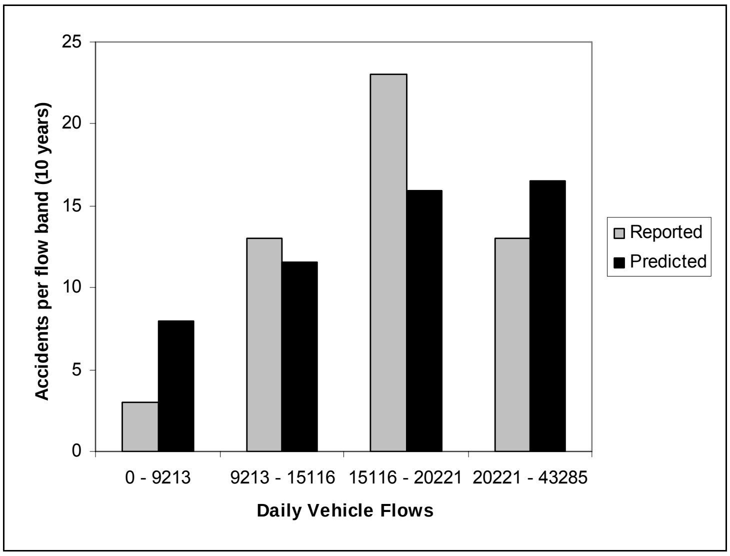

Figure 6.25 Reported and predicted UPXT1 accidents (by vehicle volume).

Figures 6.24 and 6.25 show some variation between the predicted number of accidents and the reported number of accidents.

This can be explained by observing the 95% confidence interval of the estimated mean number of accidents in Figures 6.26 and 6.27 for median vehicle flows and median pedestrian flows respectively. Figure 6.26 shows a particularly wide interval for pedestrian crossing volumes at all but low flows. This is a result of the pedestrian flows being skewed to sites with low pedestrian volumes.

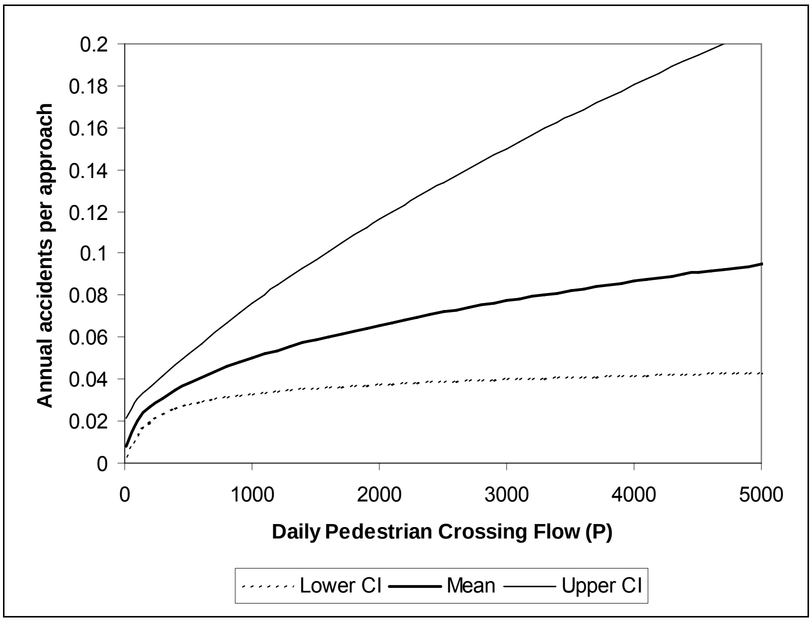

Figure 6.26 95% confidence interval for median vehicle flows.

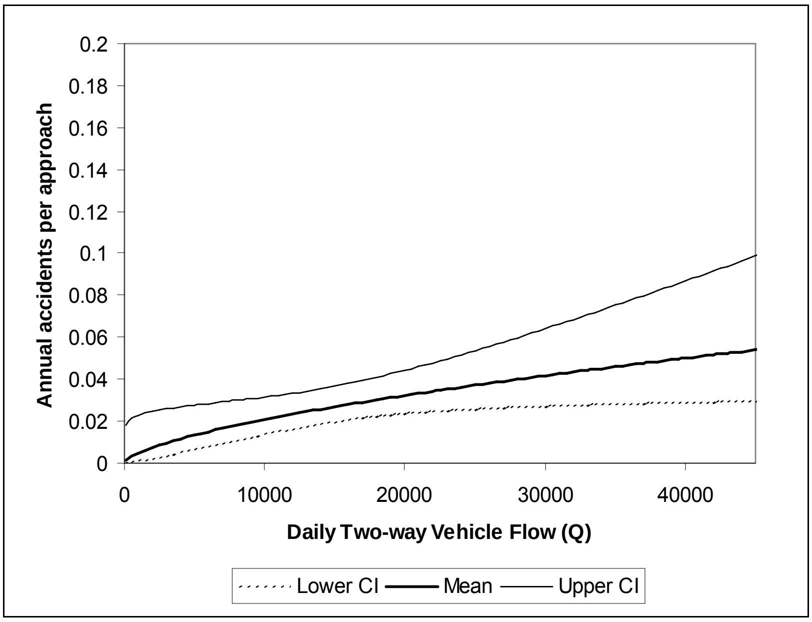

Figure 6.27 95% confidence interval for median pedestrian flows (ppd).

6.7.3 APM type UPXT1O,W (intersecting, including non-conflicting flow variables)

This section examines the introduction of two new variables. One variable is the proportion of pedestrians crossing with the 'green man' at traffic. This is determined by dividing the number of pedestrians crossing on the green pedestrian phase by the total number of pedestrians crossing during the survey period. The other variable is intersection depth (distance parallel to road from limit line to limit line). This was used as a proxy for the distance that pedestrian would cross.

Figures 6.28 and 6.29 were produced to assess the relationship between pedestrian accidents and both the proportion of pedestrians crossing with the 'green man' and intersection depth. These figures indicate that a direct relationship does not exist between the number of accidents and the proportion of pedestrians crossing on the 'green man' or intersection depth. However, other variables such as presence of medians for wider crossings may be obscuring the relationship.

The proportion crossing on the 'green man' variable, having a value between 0 and 1, causes problems with the modelling process. To overcome this problem the variable was transformed to be between 1 and 2. The variable has a value of 1 when 100% of pedestrians cross on the 'green man', and a value of 2 where 0% cross with the 'green man'. Equation 6.12 presents this model form.

$$A = b_o \times Q^{b_1} \times P^{b_2} \times (2 - O)^{b_3} \qquad \text{(Equation 6.12)}$$

where:

O = the proportion crossing with the 'green man'

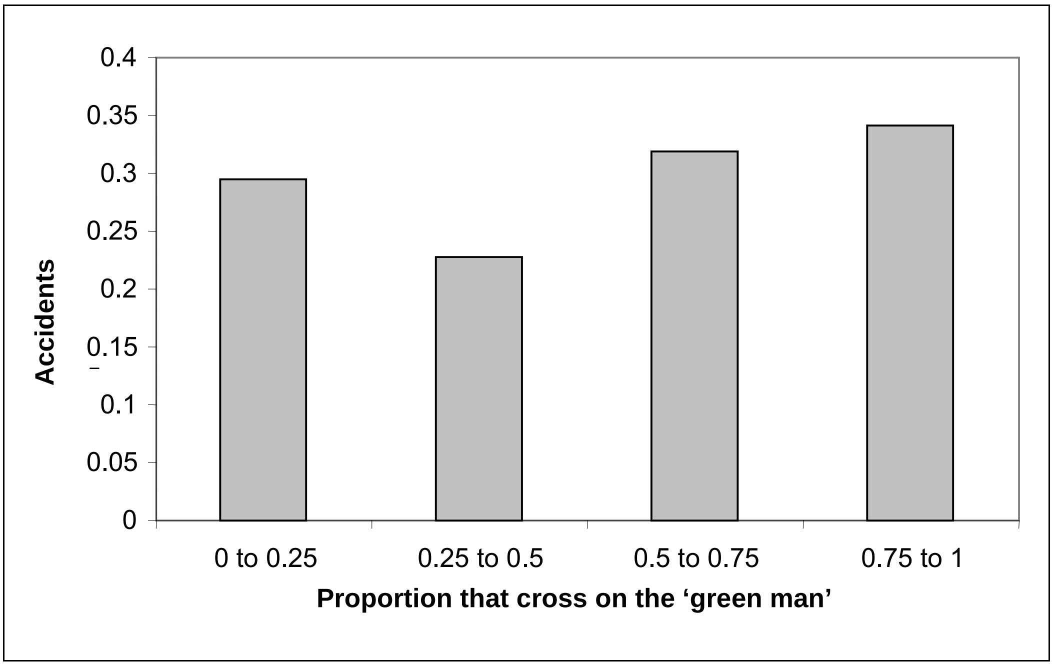

Figure 6.28 Proportion of pedestrians crossing on the 'green man'.

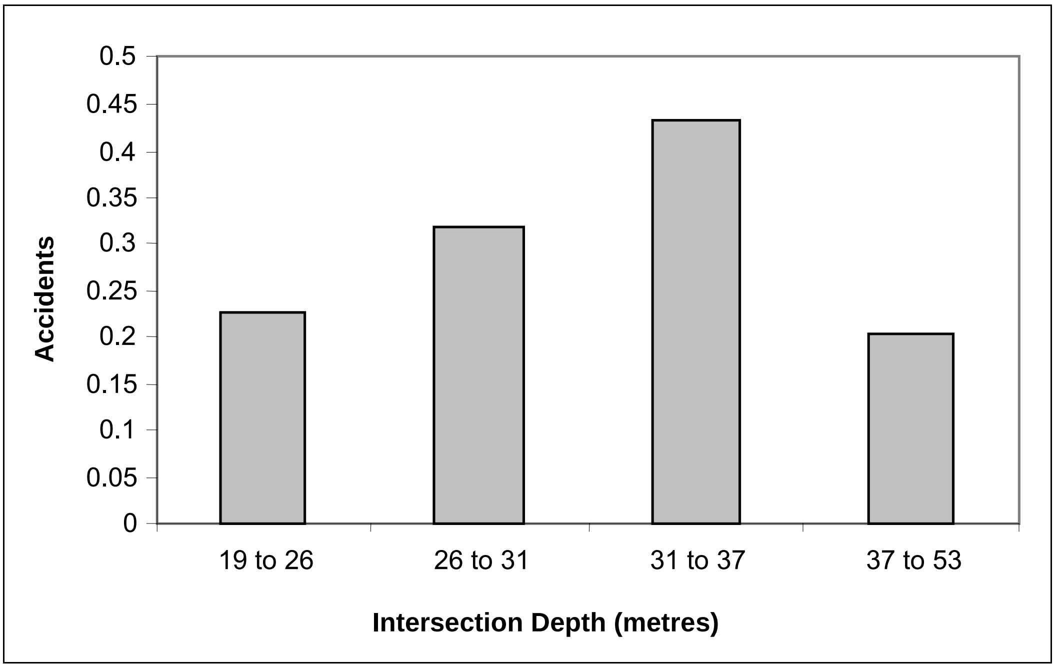

Figure 6.29 Crossing distance versus N and NB accidents.

The APM that included crossing distance has a similar form:

$$A = b_o \times Q^{b_1} \times P^{b_2} \times W^{b_3} \qquad \text{(Equation 6.13)}$$

where:

W = the average crossing distance (for both approaches)

Table 6.19 presents the fitted APM variables for Equations 6.12 and 6.13.

Table 6.19 Annual APMs for UPXT1 accidents.

Model	b_0	b_1	b_2	b_3	Error structure	log-likelihood
UPXT1 (flow-only model)	7.279×10^{-6}	0.6340	0.3959	–	NB, k=3.7	−116.33
UPXT1W (incl. intersection depth (w))	1.978×10^{-5}	0.7917	0.3680	−0.689 2	NB, k=3.7	−115.99
UPXT1O (incl. crossing compliance (o))	1.243×10^{-7}	0.8048	0.6295	2.6825	NB, k=6.6	−113.72

The addition of the 'green man' variable (*O*) improves the log-likelihood. The change in log-likelihood is greater than the model with intersection depth and is therefore the preferred model form. The positive value of parameter b_3 indicates that the number of accidents increases where the proportion of pedestrians crossing on the green man is lower.

6.7.4 APM type: UPXT2 (turning)

Although not as common as type NA and NB accidents, accident types NC, ND, NE and NF are a significant group of pedestrian accident types. Types NC and NE involve left-turning vehicles colliding with pedestrians while types ND and NF involve right-turning vehicles. The following flow-only model (Equation 6.14) is for a combination of these four accident types involving right and left turners.

$$A = b_o \times q_4^{b_1} \times q_{12}^{b_2} \times p_1^{b_3} \qquad \text{(Equation 6.14)}$$

where:

q_4 = the daily flow of right-turning vehicles turning into the street the pedestrian is crossing

q_{12} = the daily flow of left-turning vehicles turning into the street the pedestrian is crossing

p_1 = the daily flow of pedestrians crossing an approach

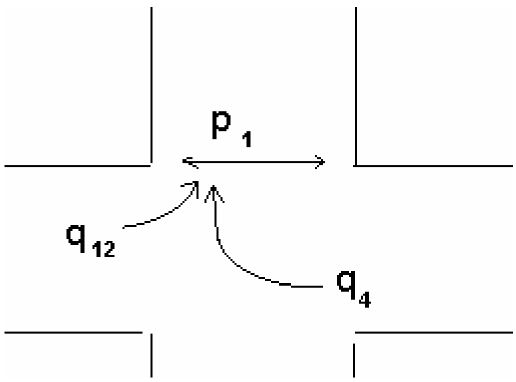

Figure 6.30 UPXT2 model variables.

Table 6.20 presents some statistics for the accident sample set used to develop the APM.

Table 6.20 Statistics for UPXT2 accidents (10-year data).

Size of sample set	351 approaches
Number of accidents in sample set	54 accidents
Maximum number of accidents for an approach	4 accidents
Sample mean of accidents	0.154 accidents
Sample variance of accidents	0.233 accidents^2

Table 6.21 presents the exponents of the APM (Equation 6.14). The small b_2 exponent for the left-turning flow (q_{12}) is close to zero, indicating that changes in this flow contribute little to the number of accidents observed. This is consistent with the data, which show a larger number of accidents involving right-turning vehicles and a small number of accidents involving left-turning vehicles.

Because of this outcome, two separate models were developed (Types 3 and 4) for accidents involving left- and right-turning vehicles.

Table 6.21 Annual flow-only APM for UPXT2 accidents.

b_0	b_1	b_2	b_3	Error structure	log-likelihood
5.066×10^{-5}	0.4982	−0.0510	0.5730	NB, k=0.4	−145.251

6.7.5 APM type: UPXT3 (right-turning)

This APM is used to predict the mean number of accidents for an approach with given flows for accident types ND and NF, which involve right-turning vehicles colliding with pedestrians crossing the road. The flow-only model is presented in Equation 6.15, and the variables are illustrated in Figure 6.31. Table 6.22 presents statistics for the sample set used to develop the model.

$$A = b_o \times q_4^{b_1} \times p_1^{b_2} \qquad \text{(Equation 6.15)}$$

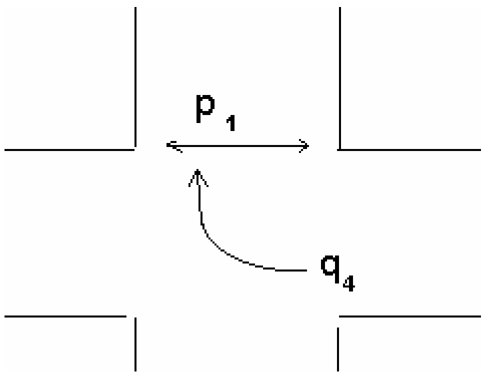

Figure 6.31 UPXT3 model variables.

Table 6.22 Statistics for UPXT3 accidents (10-year data).

Size of sample set	351 approaches
Number of accidents in sample set	39 accidents
Maximum number of accidents for an approach	2 accidents
Sample mean of accidents	0.111 accidents
Sample variance of accidents	0.113 accidents^2

The parameters for the UPXT3 model are presented in Table 6.23.

Table 6.23 Annual flow-only APM for UPXT3 accidents.

b_0	b_1	b_2	Error structure	log-likelihood
5.430×10^{-5}	0.4343	0.5127	NB, k=0.7	−118.428

This APM is interesting in that the exponent of pedestrian flows is larger than the exponent of vehicle flows. This differs from previous models where the 'safety in numbers' effect is much more pronounced given the lower exponent for pedestrians than for motor vehicles. Further statistics on the sample set are presented in Table 6.24. Figure 6.32 shows a 3D plot of the model.

Table 6.24 Further statistics on the sample set for UPXT3 accidents.

Measure	q_4	p_1
Median	838	71
Minimum	6	2
Lower quartile	478	25
Upper quartile	1409	165
Maximum	9989	2512

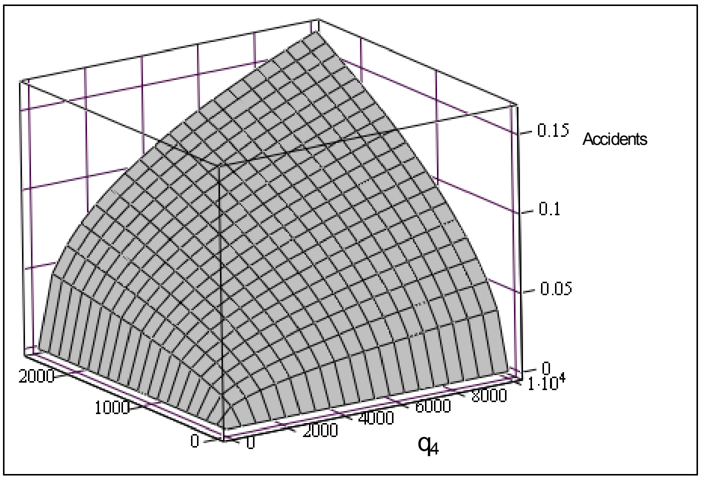

Figure 6.32 Predicted number of UPXT3 accidents.

Figures 6.33 and 6.34 have been produced to compare the APM fit against the observed accident data.

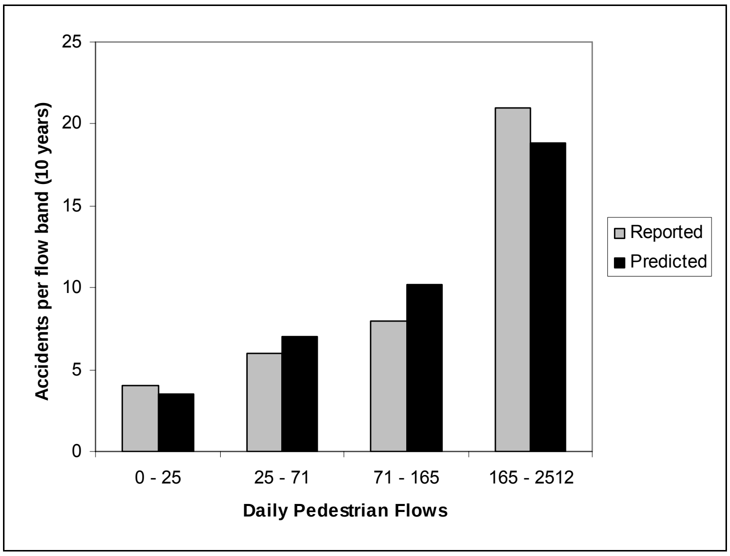

Figure 6.33 Reported and predicted number of UPXT3 accidents (by pedestrian volume).

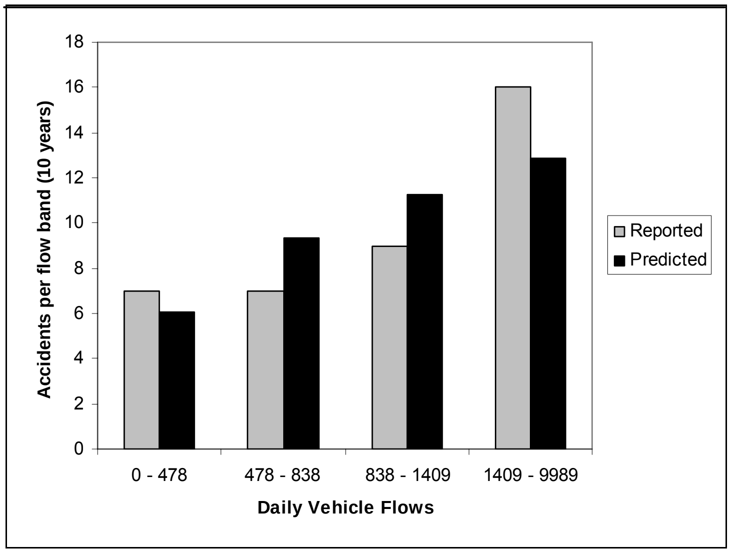

Figure 6.34 Reported and predicted number of UPXT3 accidents (by vehicle volume).

Figures 6.33 and 6.34 show that the model fits the observed data reasonably well when sorted by pedestrian volume, but less so when sorted by vehicle volume. To examine this relationship further, 95% confidence intervals were produced for median vehicle and pedestrian flows (Figures 6.35 and 6.36).

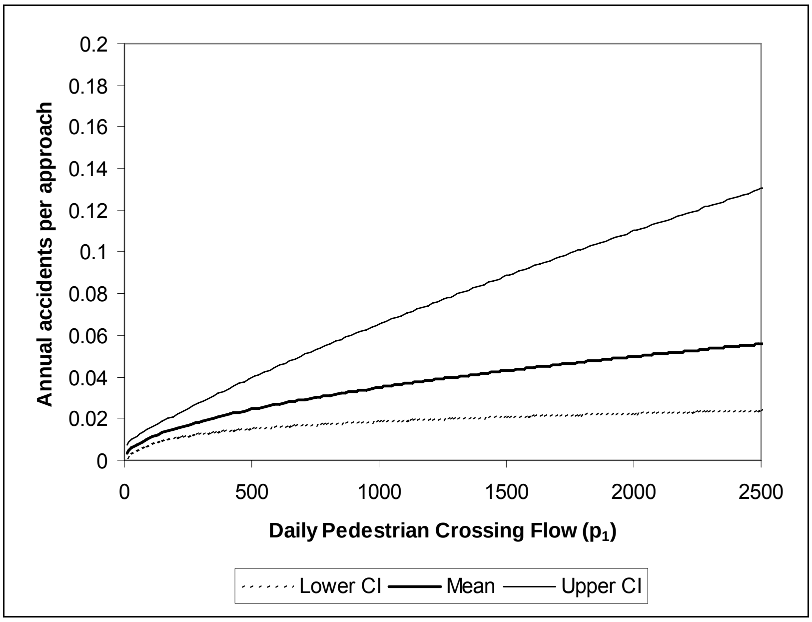

Figure 6.35 95% Confidence interval for median vehicle flows.

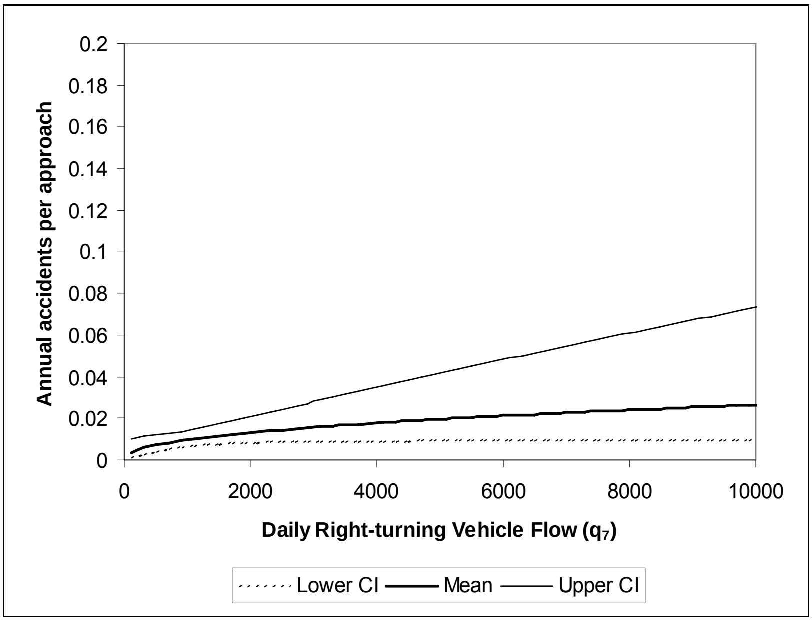

Figure 6.36 95% Confidence intervals for median pedestrian flows.

Figures 6.35 and 6.36 show the effect of having only a small number of sites at higher volumes, causing the width of the confidence intervals to become comparatively large when compared with the mean number of accidents.

6.7.6 APM type: UPXT3O,W,N,Q (right-turning, including non-conflicting flow variables)

Non-conflicting flow variables were added to the pedestrian UPXT3 model. The following variables were considered:

- the proportion crossing on the 'green man',
- crossing width,
- number of through lanes opposing right turners,
- straight-through vehicle flow opposing q_4 (q_{11}).

The APM forms used are presented in Equations 6.16 to 6.19.

Flow model including the proportion crossing with the 'green man' variable:

$$A = b_o \times q_4^{b_1} \times p_1^{b_2} \times (2 - O)^{b_3} \qquad \text{(Equation 6.16)}$$

where:

O = the proportion that cross with the 'green man'

Flow model including crossing distance:

$$A = b_o \times q_4^{b_1} \times p_1^{b_2} \times W^{b_3} \qquad \text{(Equation 6.17)}$$

where:

W = the average intersection depth

Flow model including number of opposing lanes to right-turning vehicles:

$$A = b_o \times q_4^{b_1} \times p_1^{b_2} \times N^{b_3} \qquad \text{(Equation 6.18)}$$

where:

N = number of opposing lanes to right turning vehicles

Flow model including straight-through vehicle flow opposing q_4

$$A = b_o \times q_4^{b_1} \times p_1^{b_2} \times q_{11}{}^{b_3} \qquad \text{(Equation 6.19)}$$

where:

q_{11} = straight-through vehicle flow opposing right-turning vehicles

Table 6.25 shows the fitted APM parameters. One of the model relationships could be unexpected to some, this being the relationship between accidents and the proportion of pedestrians crossing on the 'green man'. This model implies that fewer accidents occur when fewer pedestrians cross on the 'green man' and possibly indicates that there are safety issues where pedestrians are crossing legally and motorists filter turn right.

Table 6.25 Annual APMs for pedestrian UPXT3 accidents.

Model	b_0	b_1	b_2	b_3	Error structure	log-likelihood
UPXT3 (flow-only model)	5.430×10^{-5}	0.4343	0.5127	–	NB, k=0.7	−118.428
UPXT3 (incl. crossing compliance (O))	4.016×10^{-4}	0.3831	0.3346	−2.3999	NB, k=0.8	−116.195
UPXT3 (incl. intersection depth)	4.153×10^{-7}	0.3507	0.5741	1.4918	NB, k=0.9	−116.873
UPXT3 (incl. number opposing lanes)	4.937×10^{-5}	0.5527	0.4252	−2.3321	NB, k=1.1	−112.685
UPXT3 (incl. opposing traffic volume)	1.802E-02	0.5576	0.4605	−0.7805	NB, k=1.1	−111.785

The drop in the log-likelihood for the models that include N and q_{11} is greater than that calculated for the models that include O and W. This implies that N and q_{11} are more important prediction variables. For both these models the exponent b_3 is negative, meaning that for higher opposing flows or number of opposing lanes the mean number of accidents is lower. Possible reasons for this are:

- the higher through flows and lanes shield pedestrians from collisions with right-turning vehicles, as they travel with this flow,
- intersections of this type are more likely to have exclusive right-turn phases.

6.7.7 APM Type: UPXT4 (left-turning)

This APM is for accident types NC and NE, which involve left-turning vehicles colliding with pedestrians crossing the road. This type of accident is less likely than accidents involving right-turning vehicles and pedestrians. The flow-only model form is as shown in Equation 6.20. Figure 6.37 shows these movements and Table 6.26 presents statistics on the sample set.

$$A = b_o \times q_{12}^{b_1} \times p_1^{b_2} \quad \text{(Equation 6.20)}$$

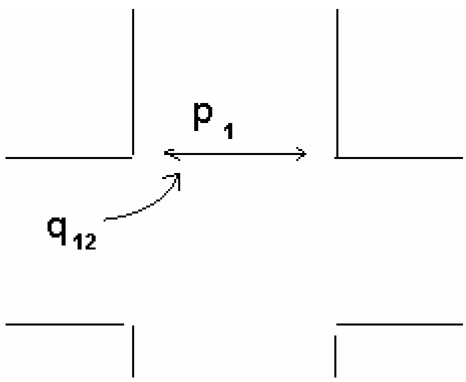

Figure 6.37 UPXT4 model variables.

Table 6.26 Statistics for UPXT4 accidents.

Size of sample set	351 approaches
Number of accidents in sample set	15 accidents
Maximum number of accidents for an approach	2 accidents
Sample mean of accidents	0.043 accidents
Sample variance of accidents	0.058 accidents$_2$

The exponents of the fitted APM are presented in Table 6.27. The exponent of the left-turning flow (a conflicting flow) is negative, implying that more accidents occur when the flow of left-turning vehicles is low. This is counter-intuitive and may be caused by the low number of accidents observed in the sample set.

Table 6.27 Annual flow-only APM for UPXT4 accidents.

b_0	b_1	b_2	Error structure	log-likelihood
7.760×10^{-4}	-0.1761	0.6083	NB, k=0.1	−57.112

6.8 Cycle APMs for roundabouts

6.8.1 Injury accidents involving cyclists

Using Land Transport New Zealand's system for coding accidents, accidents were grouped by accidents type in Figure 6.38 (see Appendix F for explanation of codes).

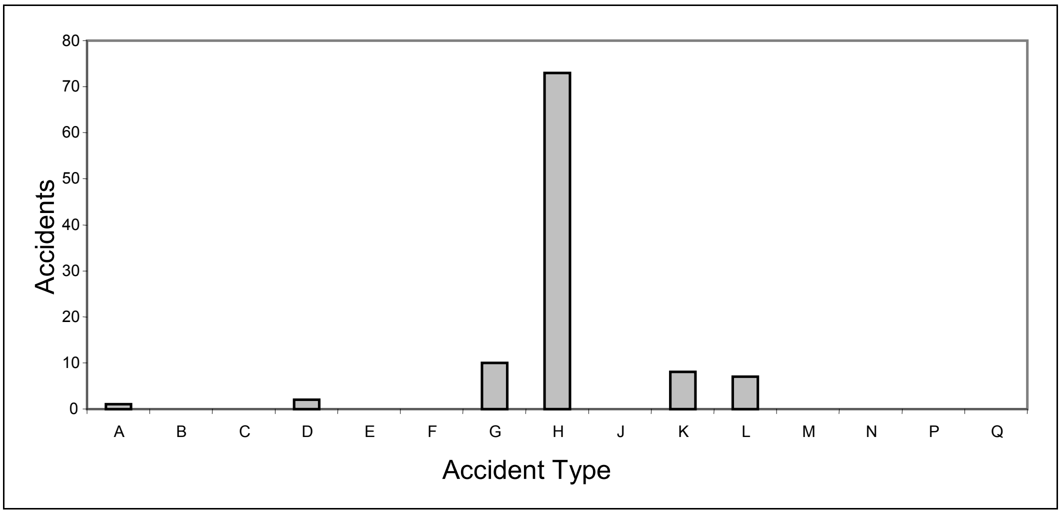

Figure 6.38 Accidents at roundabouts involving cyclists.

The proportions in Figure 6.39 are clearly comparable with national statistics for all cycle accidents at roundabouts (Figure 3.9). As observed in Figure 3.9, HA type accidents are the dominant accident type involving cyclists at roundabouts. The accident types can be further subdivided into sub-types (Figure 6.39).

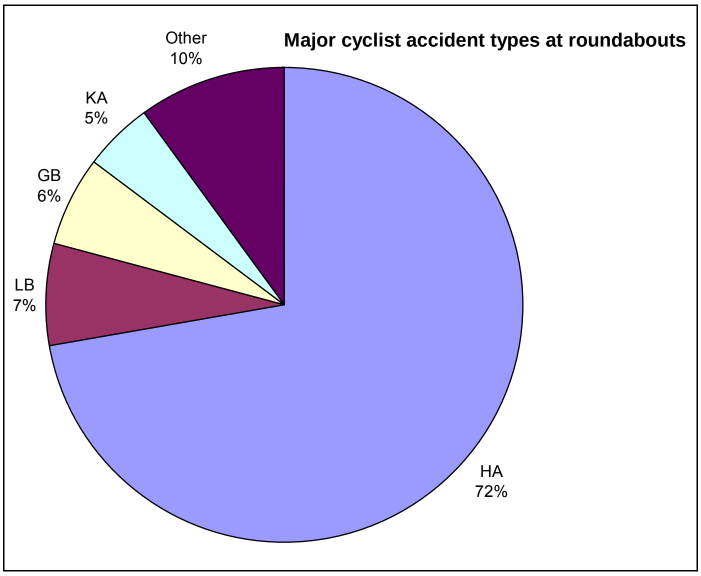

Figure 6.39 Major accident types at roundabouts.

Of the HA-type accidents, 95% occurred when the cyclist was circulating and the motor vehicle entering. All of the GB-type accidents involved the cyclist being cut off by a motor vehicle.

6.8.2 APM type: UCXR1 (Intersecting)

While most of accidents between an entering vehicle and a circulating vehicle are coded as HA, occasionally these are coded as LB, KB and KA (with the main and secondary vehicle roles reversed). Given this uncertainty in the coding, we have considered accident types, HA, LB, KB and KA as one accident type (UCXR1).

The flow-only model is presented in Equation 6.21 and the accident statistics in Table 6.28.

$$A = b_o \times Q_e^{b_1} \times C_c^{b_2}$$ (Equation 6.21)

where:

b_0, b_1 and b_2 are model parameters,

Q_e = motor-vehicle flow entering the intersection from an approach (e.g. for approach 1, $q_1+q_2+q_3$)

C_c = circulating cyclist flow passing the approach (e.g. for approach 1, $c_7+c_{10}+c_{11}$)

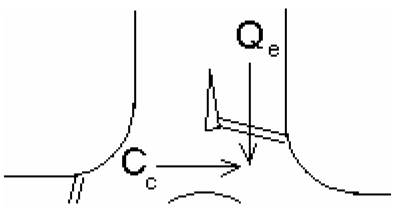

Figure 6.40 UCXR1 model variables.

Table 6.28 Statistics for UCXR1 accidents (10-year data).

Size of sample set	180 approaches
Number of accidents in sample set	82 accidents
Maximum number of accidents at an intersection	5 accidents
Sample mean of accidents	0.456 accidents
Sample variance of accidents	0.763 $accidents^2$

Table 6.29 presents the fitted exponents of this model. The exponents indicate that the number of accidents is more dependent on the entering flow of motor vehicles than on the circulating flow of cyclists.

Table 6.29 Annual APM for UCXR1 accidents flow-only.

b_0	b_1	b_2	Error structure	log-likelihood
2.399×10^{-5}	0.7851	0.3163	NB, k=0.8	−154.641

Further statistics for the sample set are presented in Table 6.30. The 3D plot of the model is presented in Figure 6.41.

Table 6.30 Further statistics for UCXR1 accidents.

Measure	Q_e	C_c
Median	3814	26
Minimum	37	0
Lower quartile	2447	15
Upper quartile	5269	43
Maximum	14395	218

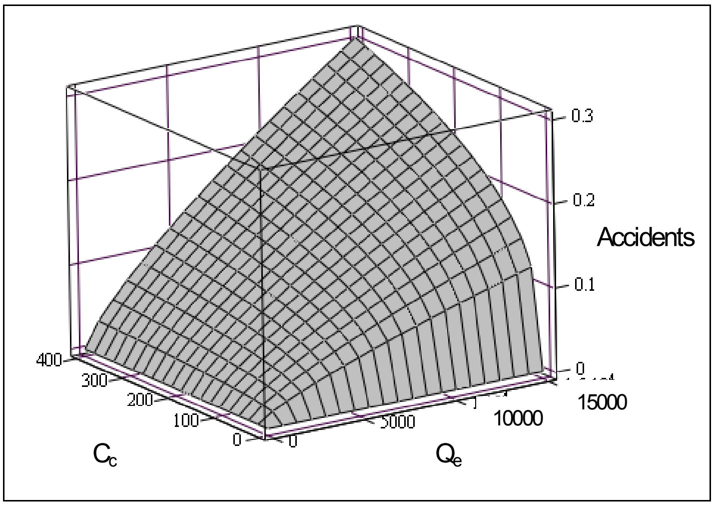

Figure 6.41 Predicted number of UCXR1 accidents at roundabouts.

Figures 6.42 and 6.43 compare the predicted and estimated number of accidents for sites in four flow bands sorted by cycle and vehicle flows. Figure 6.43 shows that this model overstates the number of accidents at higher vehicle volumes. Figure 6.44 shows that the average daily cycle volume increases with vehicle volume for the first three vehicle flow bands but decreases in the fourth vehicle flow band. This represents the fact that cyclists avoid roundabouts with higher vehicle volumes, something the model cannot take account of.

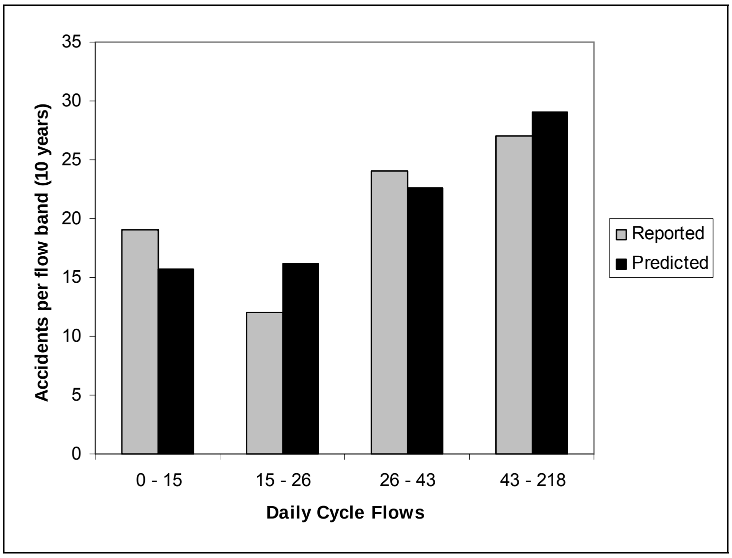

Figure 6.42 Reported and predicted UCXR1 accidents by cycle volume at roundabouts.

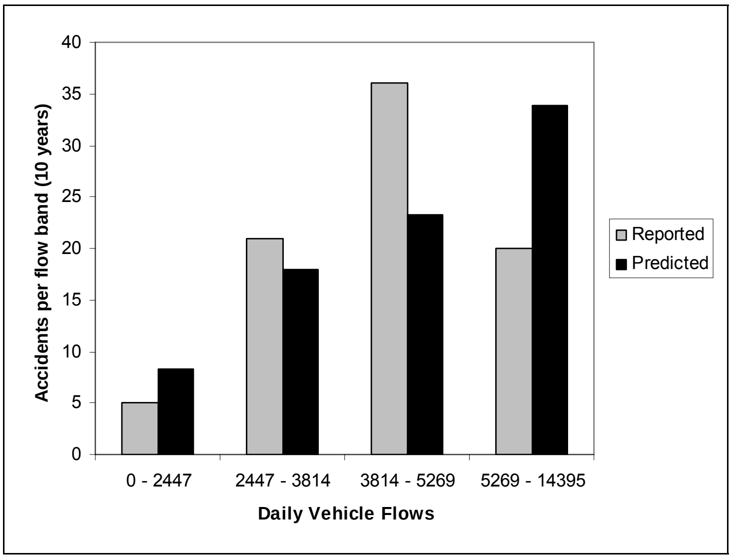

Figure 6.43 Reported and predicted UCXR1 accidents at roundabouts.

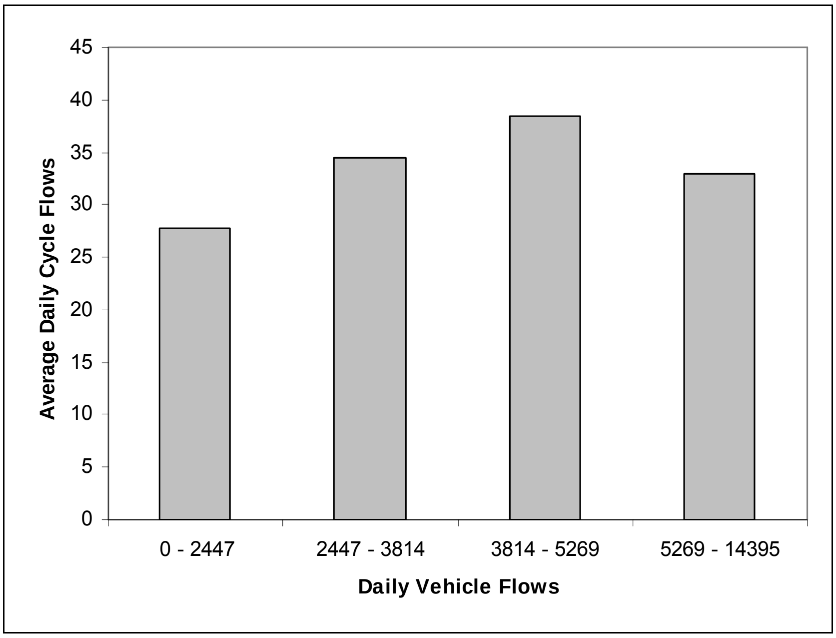

Figure 6.44 Average daily cycle volumes compared with by vehicle volumes at roundabouts.

95% confidence intervals for the mean number of accidents were produced for median vehicle flows (Figure 6.45) and median cycle flows (Figure 6.46).

Figure 6.46 shows that for the median circulating cycle flow the corresponding confidence interval is reasonably narrow and does not begin to widen until the flow of vehicles is above its upper quartile (5,269 vehicles/day).

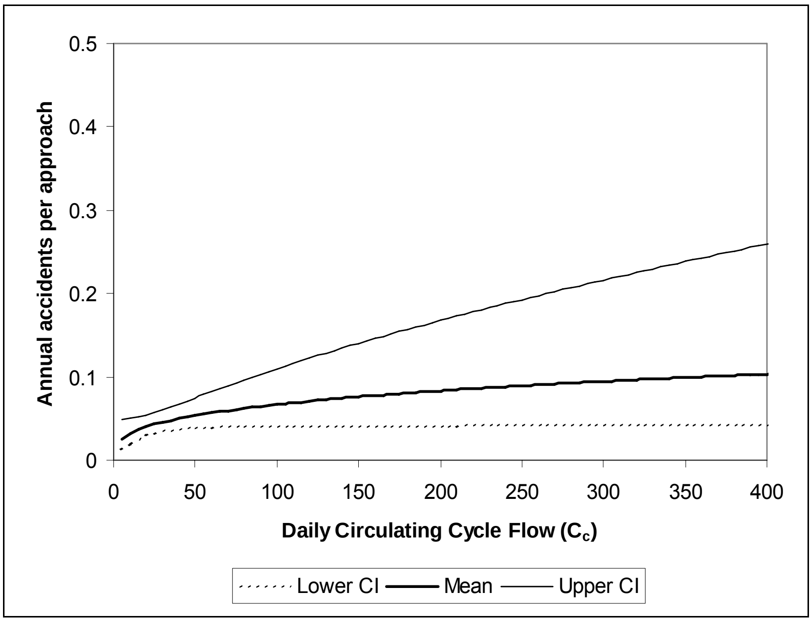

Figure 6.45 95% confidence interval for median vehicle flows.

Figure 6.45 shows that the confidence interval is reasonably wide at higher cycle flows, which is a result of few sites with particularly high cycle flows.

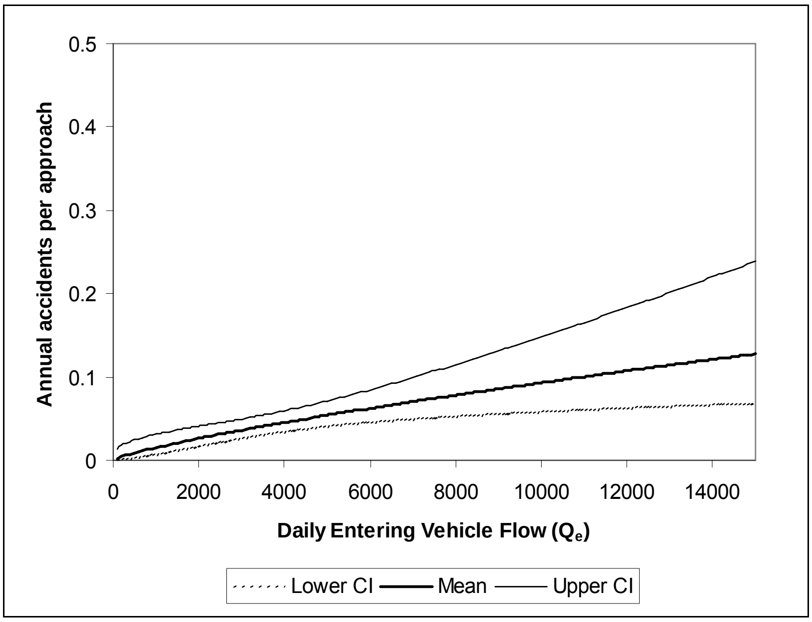

Figure 6.46 95% confidence interval for median cycle flows (cpd).

6.8.3 APM Type: UCXR2 (entering versus same direction)

This APM attempts to predict entering versus same direction accidents involving cyclists (Type G). In comparison with type HA accidents, these accidents are relatively scarce. The form of the flow-only APM is presented in Equation 6.22 and the accident statistics in Table 6.31.

$$A = b_o \times Q_e^{b_1} \times C_e^{b_2} \qquad \text{(Equation 6.22)}$$

where:

b_0, b_1 and b_2 are model parameters

Q_e = motor-vehicle flow entering the intersection from an approach (e.g. for approach 1, $q_1+q_2+q_3$)

C_e = the cycle flow entering the intersection from the same approach (e.g. for approach 1, $c_1+c_2+c_3$)

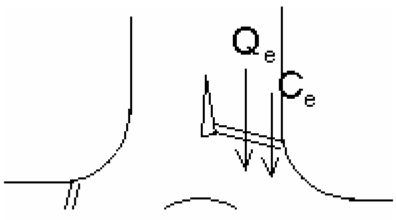

Figure 6.47 UCXR2 model variables.

Table 6.31 Statistics for UCXR2 accidents (10-year data).

Size of sample set	180 approaches
Number of accidents in sample set	10 accidents
Maximum number of accidents at an intersection	2 accidents
Sample mean of accidents	0.056 accidents
Sample variance of accidents	0.086 accidents^2

Table 6.32 presents the exponents of the APM. The exponent for vehicle flows (b_1) is quite large and the k value is small indicating a large amount of variability. Hence this is a poorly fitting model, as a result of a small number of accident observations.

Table 6.32: Annual flow-only APM for UCXR2 accidents.

b_0	b_1	b_2	Error structure	log-likelihood
3.062×10^{-10}	1.7581	0.5017	NB, k=0.1	−33.5947

6.9 Pedestrian APMs for roundabouts

6.9.1 Injury accidents involving pedestrians

Pedestrian accidents at roundabouts are infrequent events, as roundabouts are generally located away from areas of high pedestrian flow. Figure 6.48 shows the small number of reported accident (13 accidents) for the sample set. The main accident types are NA and NB.

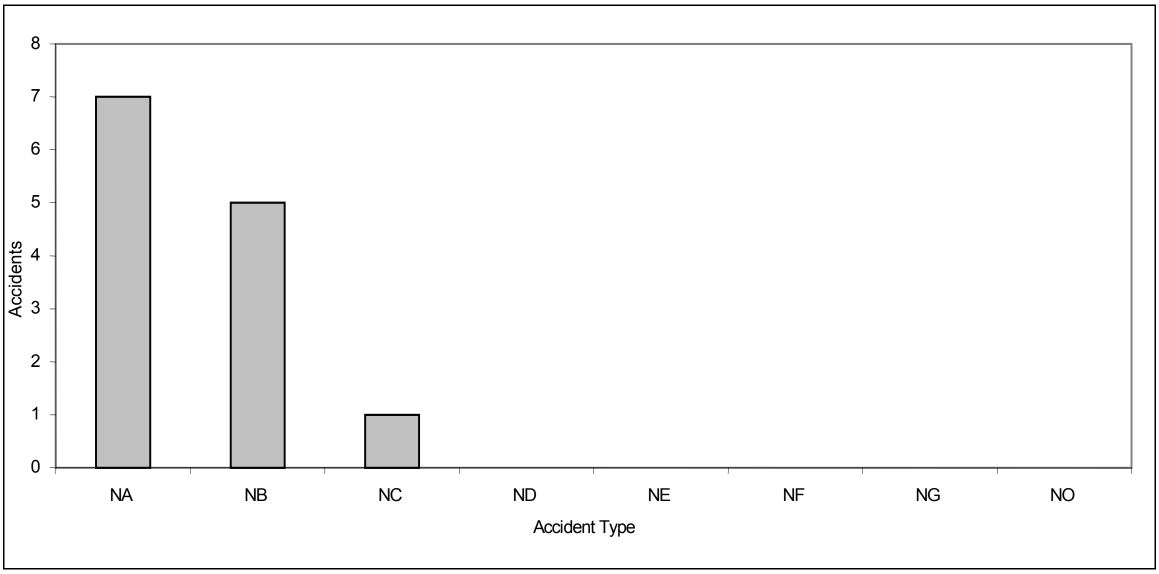

Figure 6.48 Accidents at roundabouts involving pedestrians (over 10 years).

6.9.2 APM Type: UPXR1 (intersecting)

This model predicts accident types NA and NB, where vehicles hit pedestrians crossing at right angles to them. Because of limitations in the coded accident data from CAS this model combines pedestrian flows and accidents from two approaches rather than assessing all four approaches separately. The flow-only model is presented in Equation 6.23, with the variables shown in Figure 6.49 and the accident statistics are in Table 6.33.

$$A = b_o \times Q^{b_1} P^{b_2} \qquad \text{(Equation 6.23)}$$

where:

b_0, b_1 and b_2 are model parameters

Q = the average two way vehicle flow on opposing links (e.g. for approach 1 and 3: $[[q_1+q_2+q_3+q_4+q_8+q_{12}] + [q_7+q_8+q_9+q_2+q_6+q_{10}]]/2$)

P = pedestrians crossing those links within 50 m of the intersection ($p_1 + p_3$)

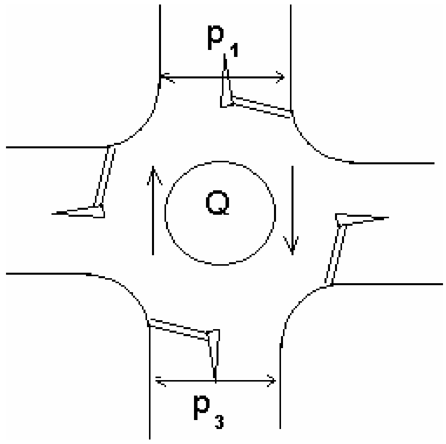

Figure 6.49 UPXR1 model variables.

Table 6.33 Statistics for UPXR1 accidents.

Size of sample set	90 flow combinations
Number of accidents in sample set	12 accidents
Maximum number of accidents for a flow combination	2 accidents
Sample mean of accidents	0.133 accidents
Sample variance of accidents	0.184 accidents^2

The exponents of the corresponding flow-only APM are presented in Table 6.34. Unlike most of the models produced in this study no strong relationship exists between vehicle flow and accidents as the exponent b_1 is close to zero. This may be a symptom of having only a small number of accidents in the dataset.

Table 6.34 Annual flow-only APM for UPXR1 accidents.

b_0	b_1	b_2	Error structure	log-likelihood
1.326×10^{-3}	−0.0853	0.6237	NB. k=0.4	−34.7893

6.10 Cycle APMs for mid-block locations

6.10.1 Injury accidents involving cyclists

Figure 6.50 shows the number and types of pedestrian accidents at the sampled mid-block sites. Of the 'E' type accidents (collision with obstruction), four were type EA (collision with a parked vehicle) and three were type EE (collision with an opening door). However, some type EA accidents may have been with car doors as this EE is a relatively new accident code.

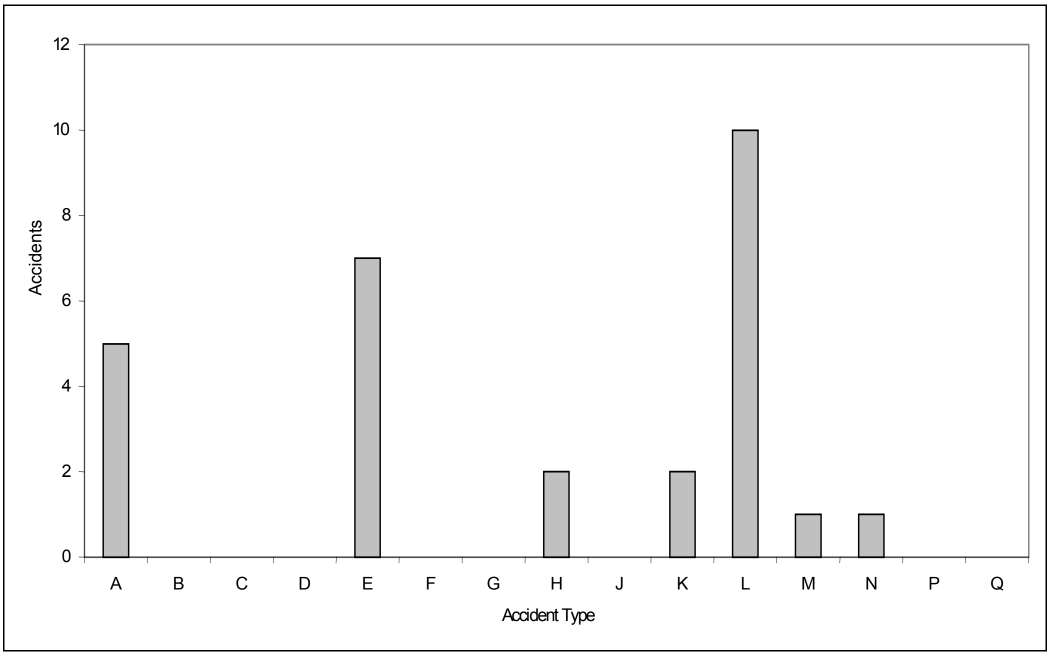

Figure 6.50 Accidents at mid-block sections involving cyclists (over 10 years).

6.10.2 APM Type: UCMN1 (same direction)

The accident types that were included in this model were A (overtaking and lane change), E (collision with obstruction), F (rear end), and G (turning versus same direction). The form of the flow-only model for this accident type is presented in Equation 6.24. Statistics for the sample set are presented in Table 6.35.

$$A = b_o \times Q^{b_1} \times C^{b_2} \quad \text{(Equation 6.24)}$$

where:

b_0, b_1 and b_2 are model parameters

Q = the two-way flow along the link

C = the two-way cycle flow along the link

Table 6.35 Statistics for UCMN1 accidents (10-year data).

Size of sample set	62 sections
Number of accidents in sample set	12 accidents
Maximum number of accidents in a section	2 accidents
Sample mean of accidents	0.194 accidents
Sample variance of accidents	0.191 accidents^2

The fitted exponents (Table 6.36) indicate that accidents are more dependent on the two-way motor-vehicle flow than the cycle flow. A safety in numbers relationship is observed with the comparatively small exponent for cycle flows (b_2).

To refine this model, a larger sample set is required. This would enable models to be created for each accident type (A, E, F and G).

Table 6.36 Annual flow-only APM for UCMN1 accidents.

b_0	b_1	b_2	Error structure	log-likelihood
9.518×10^{-8}	1.1557	0.2547	Poisson	−29.5151

6.10.3 APM Type: UCMN2 (all accidents)

This model is for all accidents involving a cyclist at mid-block locations. The model form is shown in Equation 6.25, while statistics for the sample set are presented in Table 6.37.

$$A = b_o \times Q^{b_1} \times C^{b_2} \qquad \text{(Equation 6.25)}$$

where:

b_0, b_1 and b_2 are model parameters

Q = the two-way flow along the link

C = the two-way cycle flow along the link

Table 6.37 Statistics for UCMN2 accidents (10-year data).

Size of sample set	62 sections
Number of accidents in sample set	16 accidents
Maximum number of accidents in a section	2 accidents
Sample mean of accidents	0.258 accidents
Sample variance of accidents	0.260 accidents^2

Table 6.38 presents the parameters for the fitted APM. As with UCMN1 accidents, the exponent for b_1 is large. Figure 6.51 shows a plot of the number of accidents at a mid-block section against the natural log of the two-way flow of vehicles. The figure shows that a strong relationship exists between increasing vehicle flow and the number of accidents involving cyclists, and supports the large value of the exponent for vehicle flows. Table 6.39 presents some flow statistics for the sample set, while Figure 6.52 shows the predicted mean number of accidents over the flow ranges.

Table 6.38 Annual flow-only APM for UCMN2 accidents.

b_0	b_1	b_2	Error structure	log-likelihood
1.728×10^{-8}	1.3768	0.2286	Poisson	−34.2503

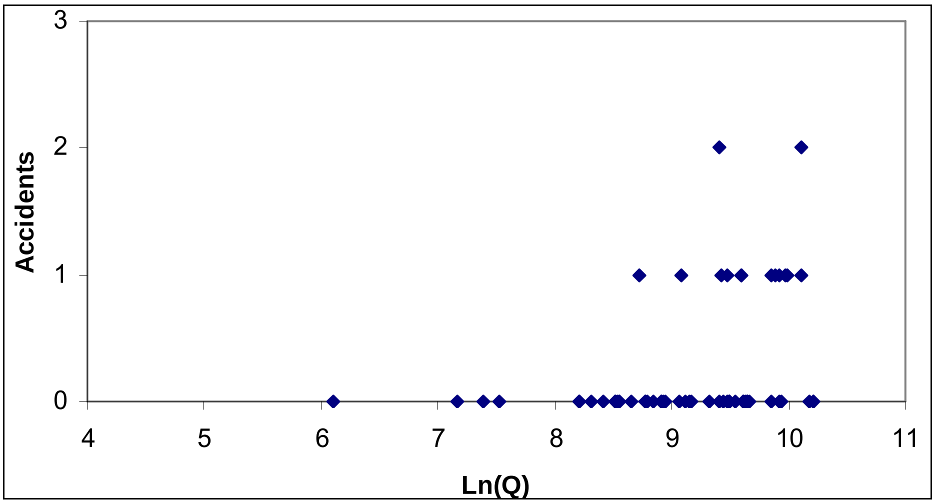

Figure 6.51 Natural log of two-way vehicle flow versus accidents involving cyclists at mid-block locations.

Table 6.39 Further statistics for UCMN2 accidents sample set.

Measure	*Q*	*C*
Median	12318	191
Minimum	446	32
Lower quartile	6422	111
Upper quartile	15425	259
Maximum	27295	389

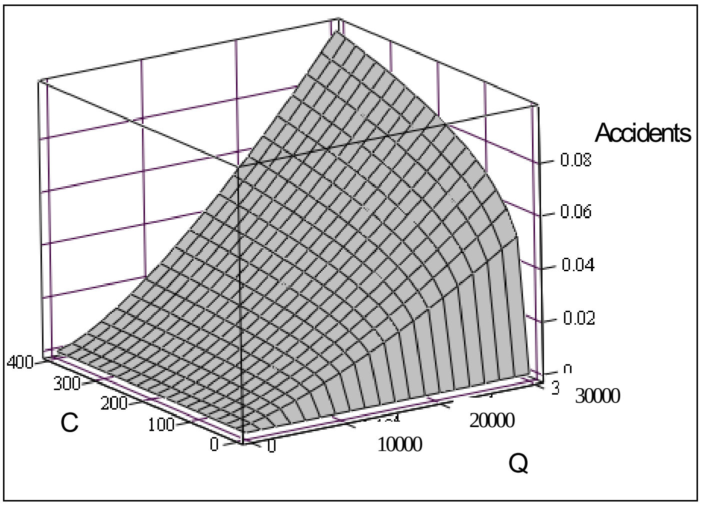

Figure 6.52 Predicted number of accidents involving cyclists.

Figures 6.53 and 6.54 compare the predicted and reported number of accidents involving cyclists across the traffic and cycle volume ranges.

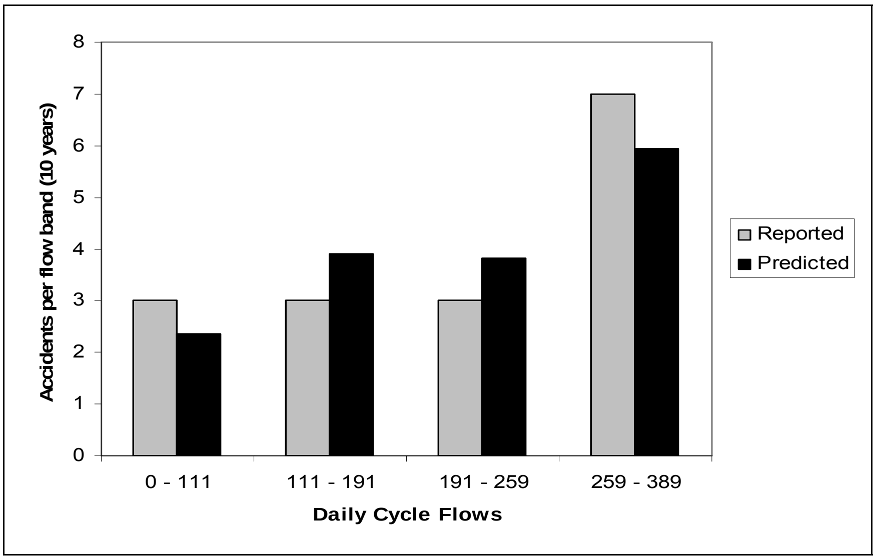

Figure 6.53 Predicted and reported number of UCMN2 (by cycle volume).

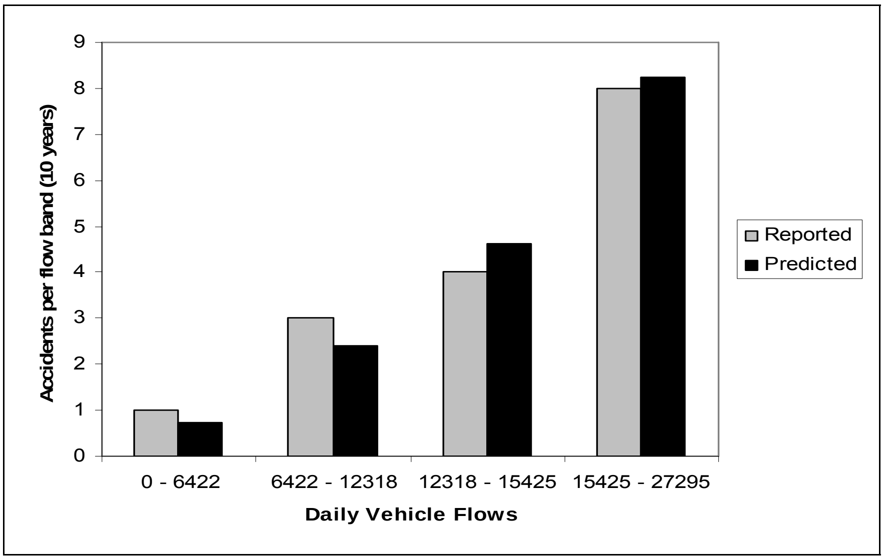

Figure 6.54 Predicted and reported number of UCMN2 accidents (by vehicle volume).

Figures 6.53 and 6.54 show that the model fits the observed data reasonably well. Figures 6.55 and 6.56 show the confidence interval for the median vehicle and cycle flows. The width of the confidence interval is relatively narrow over the majority of the flow range. We recommend caution when using the models for flow levels where the confidence intervals are wide. This occurs at low cycle volumes (< 50 per day) and high traffic volumes (> 22,000 per day).

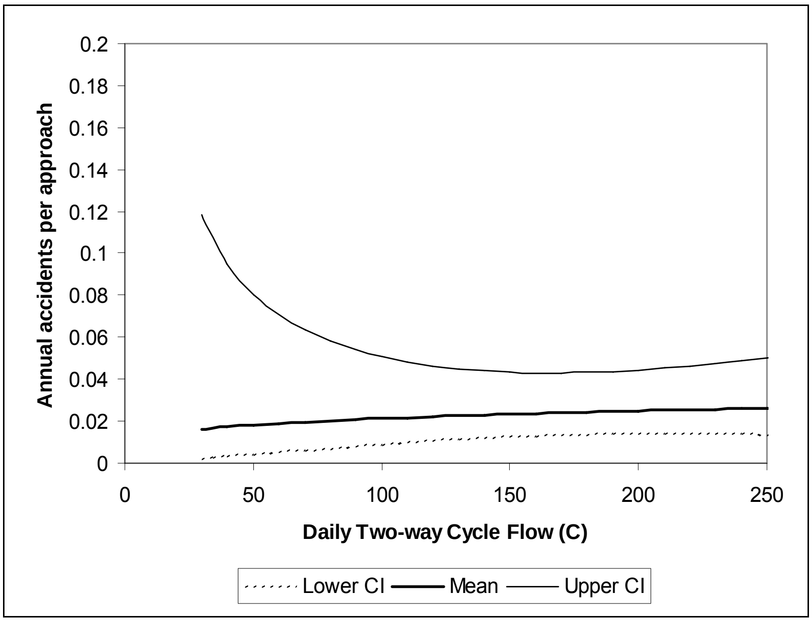

Figure 6.55 95% confidence interval for accidents for median two-way vehicle volume.

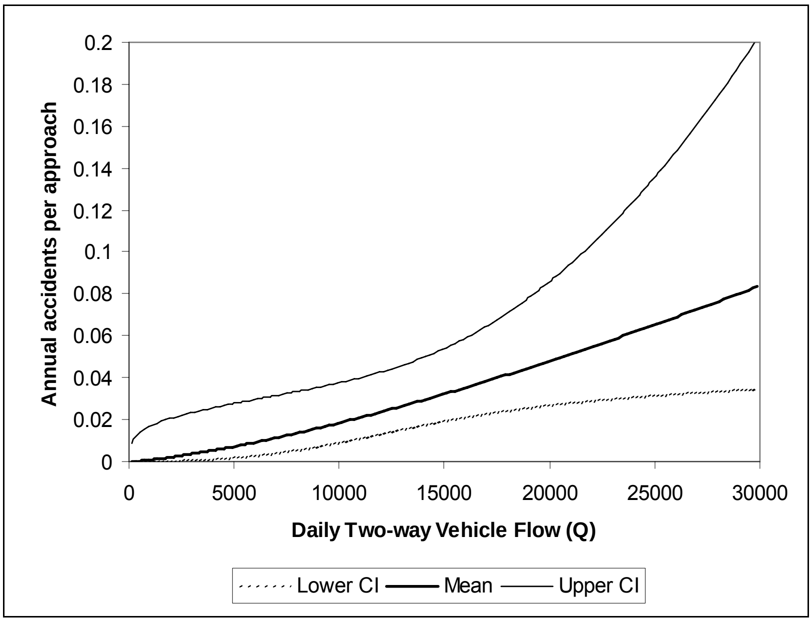

Figure 6.56 95% confidence interval for accidents for the median two-way cycle volume.

6.11 Pedestrian APMs for mid-block locations

6.11.1 Injury accidents involving pedestrians

Figure 6.57 shows the number and type of injury accidents involving pedestrians at the mid-block sections in the study. In addition to the Type N accidents shown, one type P accident occurred (that being type PF, entering or leaving vehicle).

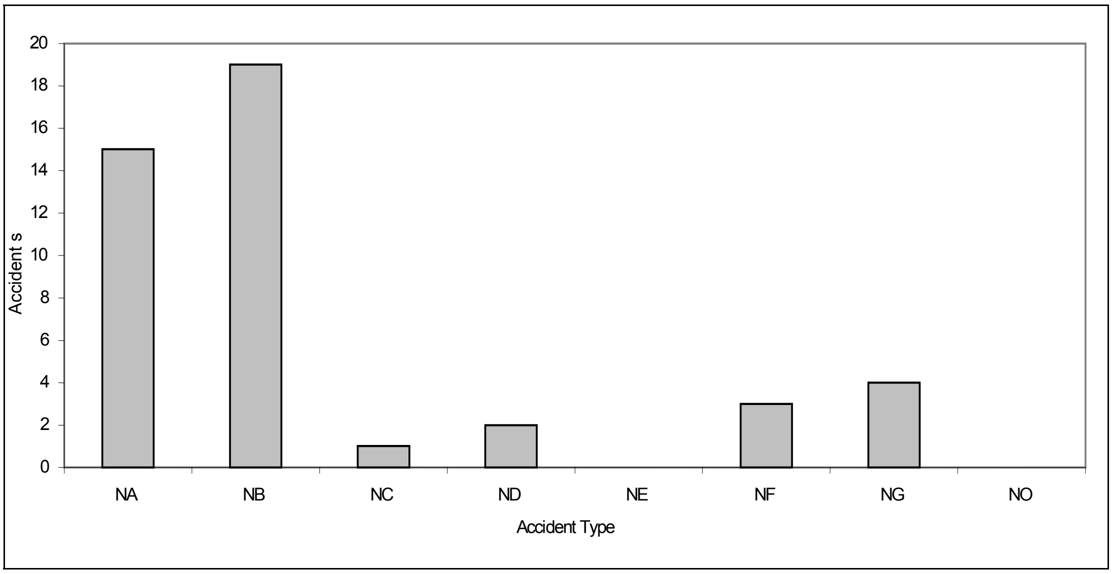

Figure 6.57 Accidents at mid-block locations involving pedestrians by accident type.

6.11.2 APM Type: UPMO1 (intersecting)

This APM (Equation 6.26) includes NA and NB mid-block accidents. Mid-block NA and NB accidents occur where vehicles collide with pedestrians crossing. Statistics on the sample set are included in Table 6.40.

$$A = b_o \times Q^{b_1} P^{b_2} \qquad \text{(Equation 6.26)}$$

where:

b_0, b_1 and b_2 are model parameters

Q = the two-way flow along the link

P = average daily pedestrian flow crossing the road in the 100 m section

Table 6.40 Statistics on sample set for UPMO1 accidents (10-year data).

Size of sample set	62 sections
Number of accidents in sample set	33 accidents
Maximum number of accidents in a section	2 accidents
Sample mean of accidents	0.532 accidents
Sample variance of accidents	0.483 accidents^2

The exponents for the flow predictor variables are presented in Table 6.41. The parameter values indicate that a 'safety in numbers' effect occurs. The exponent for pedestrian flows (b_2) is comparatively small compared with the exponent for vehicle flows (b_1).

Table 6.41 Annual flow-only APM for pedestrian type 1 accidents.

b_0	b_1	b_2	Error structure	log-likelihood
3.064×10^{-5}	0.6584	0.2041	Poisson	−55.6305

6.11.3 APM Type: UPMO2 (All accidents)

All pedestrian accident types were included in the UPMO2 model. The form of the model is shown in Equation 6.27 and accident statistics are presented in Table 6.42.

$$A = b_o \times Q^{b_1} P^{b_2} \qquad \text{(Equation 6.27)}$$

where:

b_0, b_1 and b_2 are model parameters

Q = the two-way flow along the link

P = average daily pedestrian flow crossing the road in the 100 m section

Table 6.42 Statistics for UPMO2 accidents (10-year data).

Size of sample set	62 sections
Number of accidents in sample set	39 accidents
Maximum number of accidents in a section	3 accidents
Sample mean of accidents	0.629 accidents
Sample variance of accidents	0.565 accidents^2

The parameter values for the APM are presented in Table 6.43. As expected, the parameter values are similar to the UPMO1 models as there are common accidents in the two sample sets.

Table 6.43 Annual flow-only APM for UPMO2 accidents.

b_0	b_1	b_2	Error structure	log-likelihood
1.863×10^{-5}	0.6924	0.2564	Poisson	−59.6055

Further statistics for the sample set are presented here in Table 6.44. The mean number of predicted accidents is shown in Figure 6.58.

Table 6.44 Further statistics for UPMO2 accidents.

Measure	*Q*	*P*
Median	12318	699
Minimum	446	33
Lower quartile	6422	291
Upper quartile	15425	1581
Maximum	27295	6808

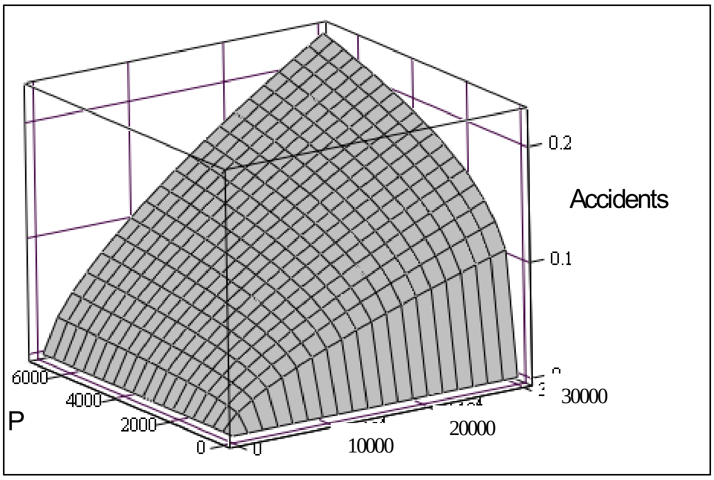

Figure 6.58 Predicted number of accidents involving pedestrians in a 100 m mid-block section.

Figures 6.59 and 6.60 compare the predicted and reported number of accidents by flow band. Although these show some variation, they seem to fit the data reasonably well.

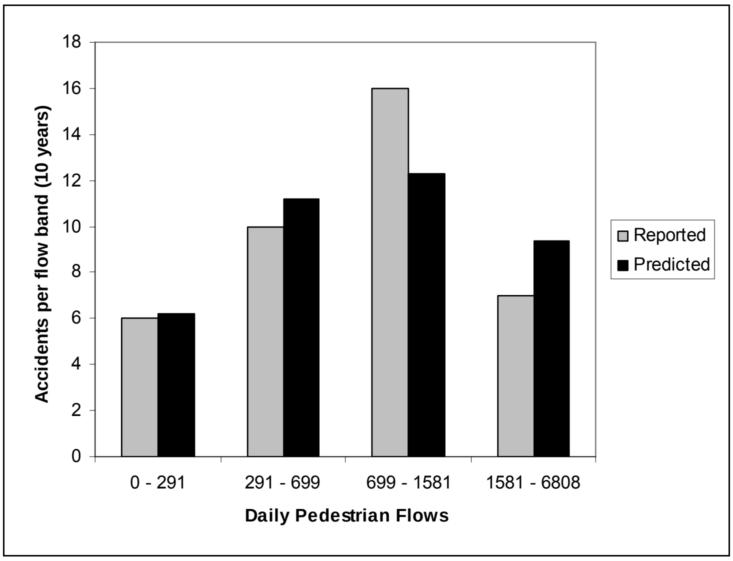

Figure 6.59 Predicted and reported number of UPMO2 accidents (by pedestrian volume).

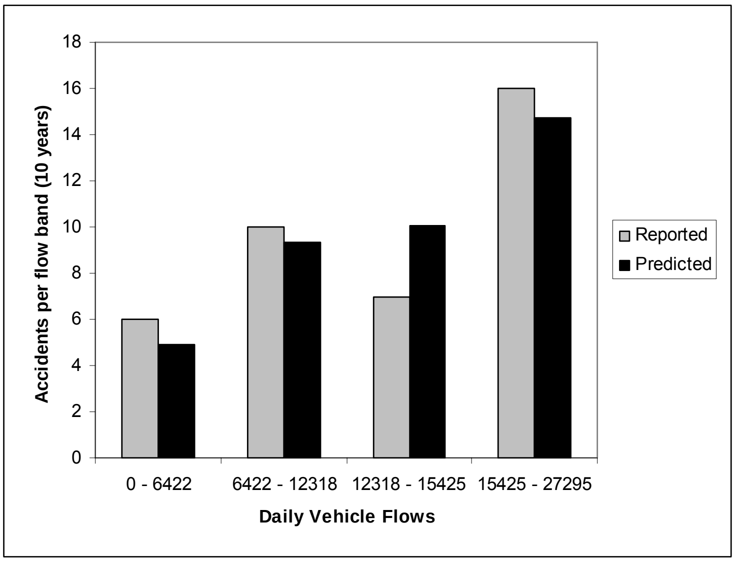

Figure 6.60 Predicted and reported number of UPMO2 accidents (by vehicle volume).

Figures 6.61 and 6.62 show 95% confidence intervals for the mean number of accidents at median pedestrian and vehicle flows. Figure 6.61 shows that at high pedestrian flows (the median is 699 pedestrians/day) a lot of uncertainty exists in the estimate of the mean. This could be improved by adding more sites with higher pedestrian volumes to the sample set.

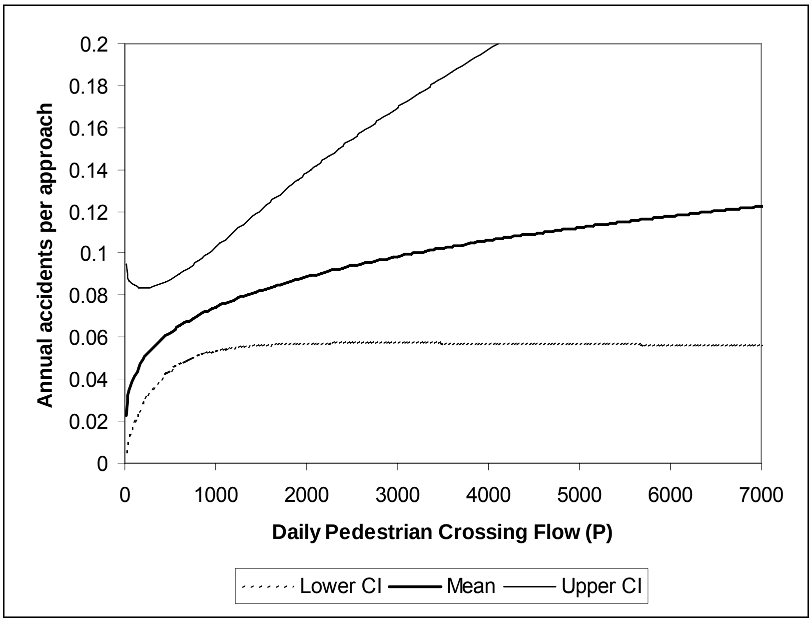

Figure 6.61 95% confidence interval for median two-way vehicle flow.

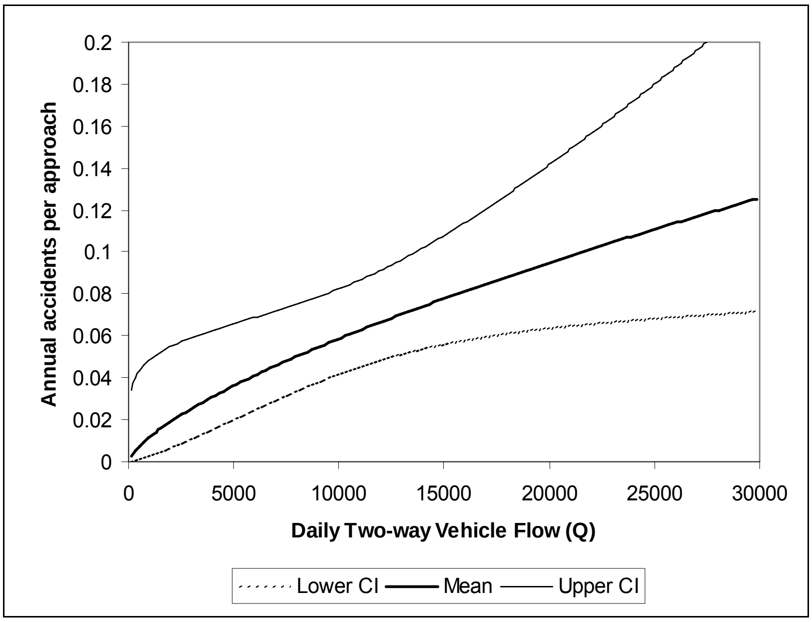

Figure 6.62 95% confidence interval for the median pedestrian crossing flow.

6.12 Cycle APMs for signalised T- junctions

6.12.1 Injury accidents involving cyclists

Figure 6.63 illustrates the types of accidents involving cyclists at signalised T-junctions (for a description of accident type coding see Appendix F). Type L accidents (right-turn against) were the predominant accident type at signalised T-junction. Of the eight type G accidents (turning versus same direction), four were of type GB (left-turn side swipe) and two were of type GF (two turning).

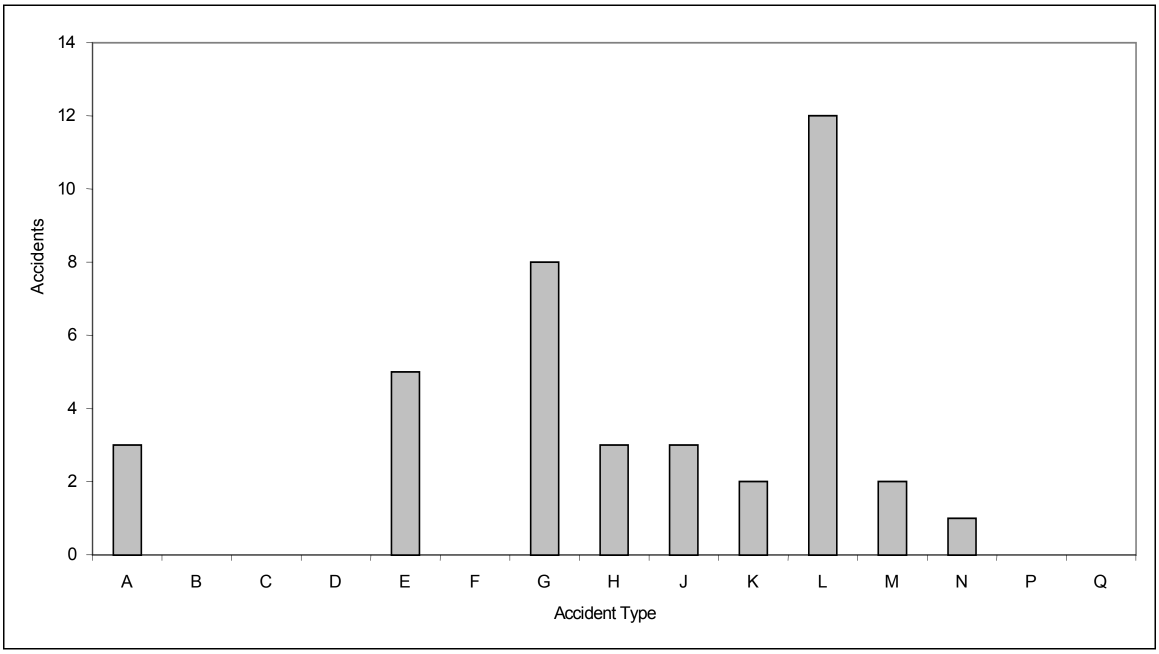

Figure 6.63 Cycle accidents at signalised T-junctions.

6.12.2 APM Type: UCTT1 (same direction)

The accident types indicated in this APM are types A (overtaking and lane change), E (collision with obstruction), F (rear end), and G (turning versus same direction). For this sample set, six accidents occurred on the stem of the 'T', seven to the top left of the 'T' and eight to the top right of the 'T' (see Figure 6.64 for orientation). Equation 6.28 presents the flow-only model and Table 6.45 presents the accident statistics in developing this model.

$$A = b_o \times Q_e^{b_1} \times C_e^{b_2} \qquad \text{(Equation 6.28)}$$

where:

b_0, b_1 and b_2 are model parameters

Q_e = the total motor-vehicle flow entering the intersection from a particular approach (e.g. for approach 1 (side road) q_1+q_2)

C_e = the total cycle flow entering the intersection from the same approach (e.g. for approach 1 (side road) c_1+c_2)

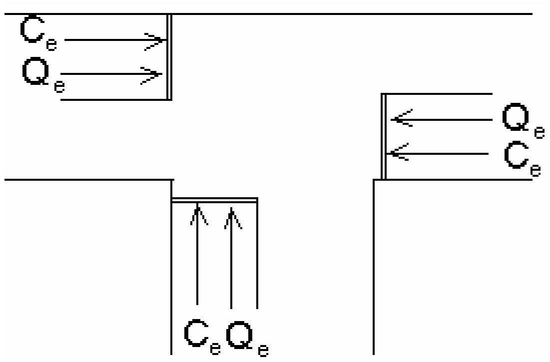

Figure 6.64 UCTT1 model variables.

Table 6.45 Statistics for UCTT1 accidents (10-year data).

Size of sample set	96 approaches
Number of accidents in sample set	21 accidents
Maximum number of accidents for an approach	3 accidents
Sample mean of accidents	0.219 accidents
Sample variance of accidents	0.383 accidents^2

The fitted parameters of this model are presented in Table 6.46. This model indicates that at higher cycle and vehicle flows, the number of accidents is lower. This is counter-intuitive. This is likely to be caused by the small number of observed accidents and different accident mechanisms for the approach at the stem of the 'T'. A larger sample set is required.

Table 6.46 Annual flow-only APM for UCTT1 accidents.

b_0	b_1	b_2	Error structure	log-likelihood
0.1425921	−0.1818	−0.0624	NB, k=0.2	−52.3462

6.12.3 APM Type: UCTT2 (right-turn-against)

Right-turn-against accidents (type LB and LA) can only occur at a T-junction when the straight-through vehicle enters the intersection from the top right approach (see Figure 6.65) of the 'T'. The form of the flow-only model is presented in Equation 6.29. Table 6.47 shows statistics for the sample set.

$$A = b_o \times q_3^{b_1} \times c_5^{b_2} \qquad \text{(Equation 6.29)}$$

where:

b_0, b_1 and b_2 are model parameters

q_3 = the motor-vehicle flow, turning right from the approach to the top left of the 'T' (see Figure 6.65)

c_5 = the cyclist flow, entering the intersection from the top right approach of the 'T' and travelling through

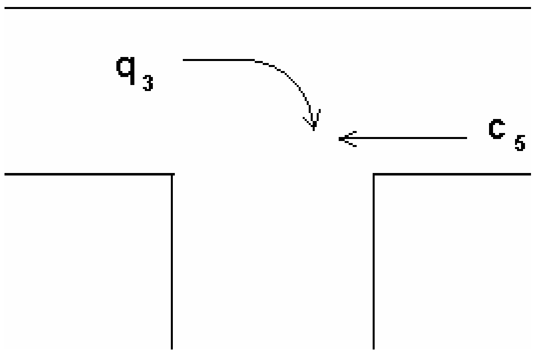

Figure 6.65 UCTT2 model variables.

Table 6.47 Statistics for APM for UCTT2 accidents (10-year data).

Size of sample set	32 approaches
Number of accidents in sample set	8 accidents
Maximum number of accidents for an approach	2 accidents
Sample mean of accidents	0.250 accidents
Sample variance of accidents	0.323 accidents^2

The parameters of this model (Table 6.48) have some unusual values, likely to be caused by the small number of accident observations. A larger sample set is required.

Table 6.48 Annual flow-only APM for UCTT2 accidents.

b_0	b_1	b_2	Error structure	log-likelihood
0.003122	−0.1294	0.7329	NB, k=1.1	−19.2876

6.13 Pedestrian APMs for signalised T-junctions

6.13.1 Injury accidents involving pedestrians

Figure 6.66 shows the number and type of accidents involving pedestrians at signalised T-junctions. Of the seven accidents of type NF (where the right-turning driver collides with a pedestrian coming from the left), five occurred when the vehicle came from the stem of the 'T'. It should be noted that providing crossings to be crossed by right-turning traffic from the stem of the 'T' is not recommended. The remainder of the accidents involved pedestrians crossing the main road (not the side road).

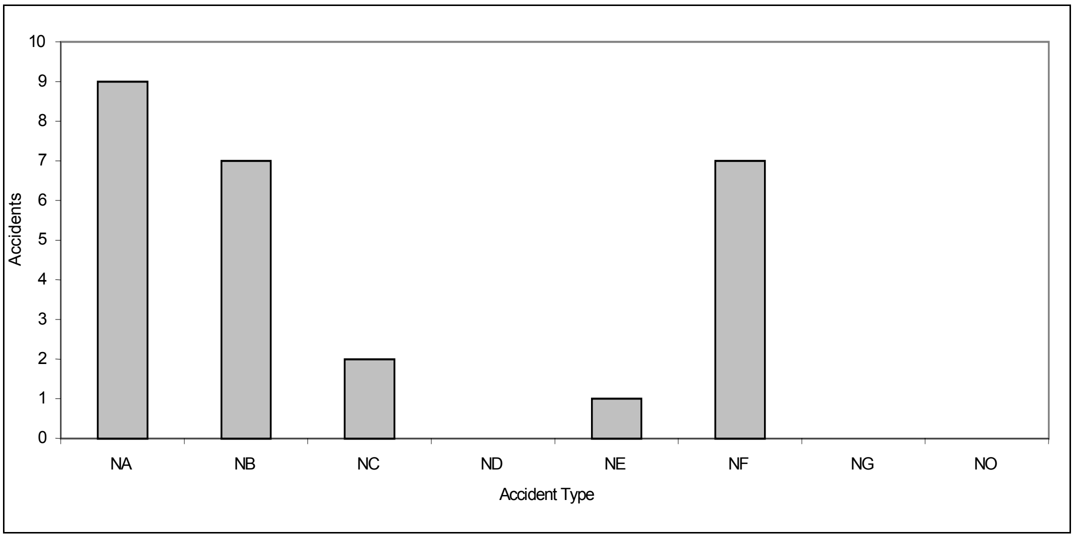

Figure 6.66 Pedestrian accidents at signalised T-junctions.

6.13.2 APM Type: UPTT1 (intersecting)

This APM includes Type NA and NB (pedestrians and vehicles intersecting) accidents on the major road. It is not possible to isolate whether the pedestrian crossed to the left or right of the side road on the major road (that is p_2 and p_3 in Figure 6.67). Hence, accidents on these approaches have had to be combined. The form of the flow-only APM is presented in Equation 6.30. Statistics for the sample set are shown in Table 6.49.

$$A = b_o \times Q^{b_1} P^{b_2}$$ (Equation 6.30)

where:

b_0, b_1 and b_2 are model parameters

Q = the two-way vehicle flow along the major road

P = the daily pedestrian flow crossing the major road (p_2 + p_3)

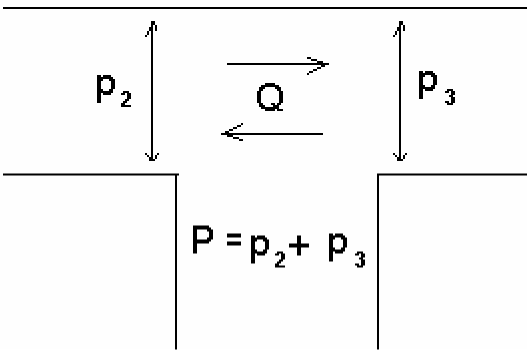

Figure 6.67 Predictor variables for UPTT1 APMs.

Table 6.49 Statistics for UPTT1 accidents (10-year data).

Size of sample set	32 intersections
Number of accidents in sample set	18 accidents
Maximum number of accidents	6 accidents
Sample mean of accidents	0.563 accidents
Sample variance of accidents	0.849 accidents^2

The exponent for vehicle flows in the fitted APM (Table 6.50) has a large value. This may be the result of a small sample set and limited number of accident observations. A larger sample set is required to confirm this relationship.

Table 6.50 Annual flow-only APM for UPTT1 accidents.

b_0	b_1	b_2	Error structure	log-likelihood
1.391×10^{-12}	2.0545	0.6670	NB, k=0.4	−33.9708

6.14 Cycle APMs for signalised crossroads where one road is one-way

6.14.1 Injury accidents involving cyclists

Figure 6.68 shows the accident types that occurred at signalised crossroads on one-way streets in the sample set. Of the 7 HA-type (crossing) accidents two involved cyclists travelling the wrong way down the one-way street. Of the remaining 5 HA-type accidents, four occurred when the cyclist was approaching from the right as a motor vehicle was travelling down the one-way street. There were also 7 'same direction' accidents (Type E, A, F and G). Overall, given the small number of observed cycle accidents and the diverse nature of the accidents, it was considered unlikely that a good fitting model could be produced. Hence no APM was developed for cycle accidents at this site type.

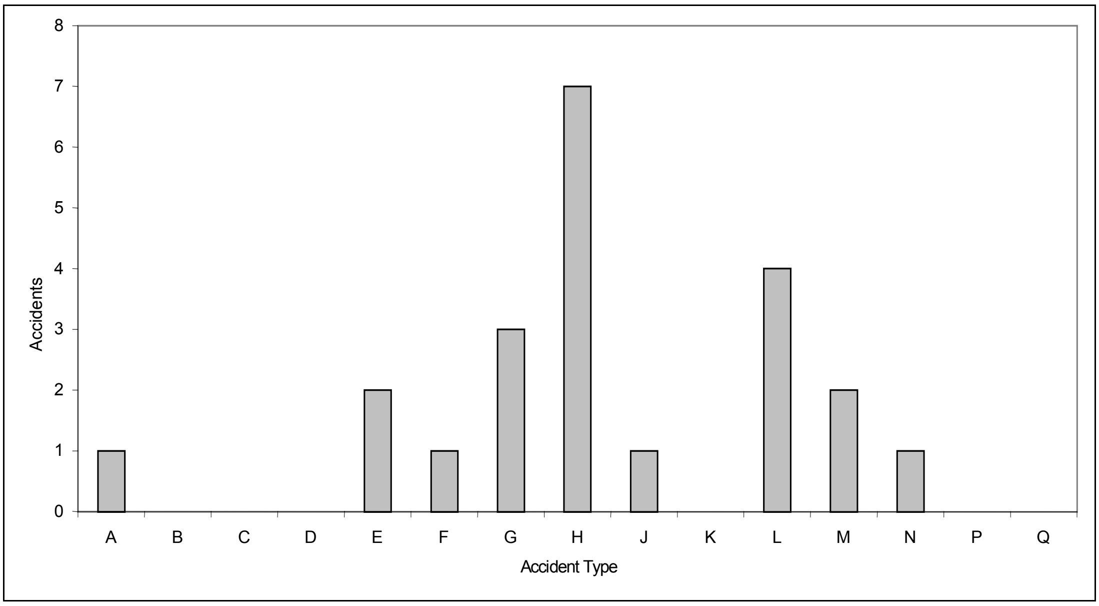

Figure 6.68 Cycle accidents at signalised crossroads where one road is one-way.

6.15 Pedestrian APMs for signalised crossroads where one road is one-way

6.15.1 Injury accidents involving pedestrians

Figure 6.69 shows the number and type of accidents involving pedestrians at signalised crossroads on the one-way system. Of the 16 NA and NB (pedestrian crossing, vehicle travelling through) accidents, 7 occurred where the pedestrians were crossing the one-way street and 9 occurred where the pedestrians were crossing the two-way street. Because of the different accident mechanisms contributing to the accidents, 2 separate models were considered, one for accidents on the two-way street and the other for accidents on the one-way street.

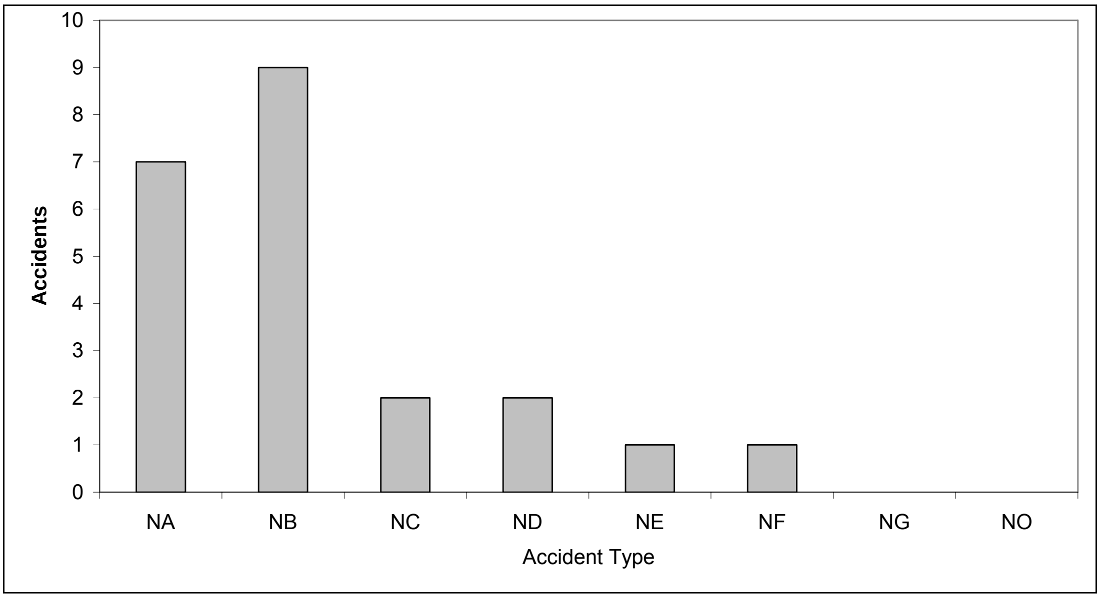

Figure 6.69 Pedestrian accidents at signalised crossroads where one road is one-way.

Both models have the same form of flow-only model which is shown in Equation 6.31. The accident statistics are shown in Table 6.51.

$$A = b_o \times Q^{b_1} P^{b_2} \qquad \text{(Equation 6.31)}$$

where:

b_0, b_1 and b_2 are model parameters

Q = either the average two-way flow on the two-way street or the flow on the one-way street

P = the average daily pedestrian flows crossing the road (either those crossing the two-way street or crossing the one-way street respectively)

Table 6.51 Statistics for pedestrian accidents (10-year data).

Statistic	Side streets	One-way street
Size of sample set	28	28
Number of accidents in sample set	9 accidents	7 accidents
Maximum number of accidents	2 accidents	3 accidents
Sample mean of accidents	0.321 accidents	0.250 accidents
Sample variance of accidents	0.300 accidents	0.417 accidents^2

The fitted exponents for these two models (Table 6.52) are quite different for the two-way street and the one-way street, indicating that separate models were warranted. Two of the exponents are outside these normal ranges (0–1.3). This is probably a result of a small sample set and few accident observations. A large sample size is required to develop better fitting models.

Table 6.52 Annual flow-only APM for pedestrian accidents.

Model	b_0	b_1	b_2	Error structure	log-likelihood
Side street	0.1341288	−0.4532	0.4449	Poisson	−18.8609
One-way	5.833×10^{-13}	1.2199	1.7791	Poisson	

7. Application of models

7.1 Introduction

This section discusses how the APMs can be applied by traffic engineers and transport planners to predict accident rates and to assess the safety implications of changes in travel mode from motor vehicle to cycle and walking trips.

7.2 Total APMs for intersections and links

7.2.1 Using total APMs

The APMs discussed in previous sections can be used in combination to calculate total pedestrian and cycle accidents at roundabouts, traffic signals and mid-block sections. Given the generally low number of cycle and pedestrian accidents observed at each intersection and along short mid-block sections, it is recommended that comparisons between observed and predicted accidents be undertaken along longer sections of mid-block, a number of intersections or both. Such a comparison will indicate if pedestrians or cyclists observed accident rates in an area, perhaps a commercial area, are higher than might be expected.

7.2.2 Cycle accidents at signalised crossroads

A combined APM has been developed for cycle accidents at signalised crossroads where all arms are two-way (and there are no turning restrictions). The total accident model uses the APMs developed for the two main accident types, these being same direction and right-turn-against (where the cyclist is travelling straight through). The total mean accident rate for a signalised intersection can be estimated by using the following equation:

$$A_{UCXT} = 1.74(A_{UCXT1} + A_{UCXT3}) \qquad \text{(Equation 7.1)}$$

where:

A_{UCXT1} = the total predicted same-direction accidents between cyclists and motor vehicles

A_{UCXT3} = the total predicted right-turn-against accidents (where the cyclist is travelling straight through the intersection)

1.74 is a multiplier to take account of other cycle accidents occurring at such intersections

The total number of accidents of each type can be determined using Equations 7.2 and 7.3. The cycle and motor-vehicle movements for this intersection type are defined in Figures 7.1 and 7.2

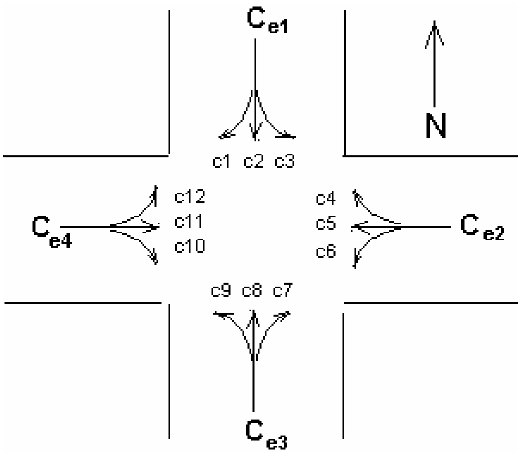

Figure 7.1 Cycle movements.

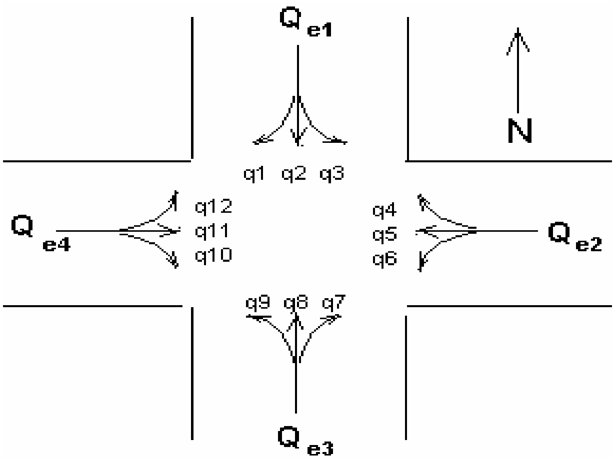

Figure 7.2 Vehicle movements.

Total cycle accidents for UCXT1 (same direction) can be calculated using the following equations:

$$A_{UCXT1} = 7.49 \times 10^{-4} \left[(Q_{e1}^{\ 0.287} C_{e1}^{\ 0.091}) + (Q_{e2}^{\ 0.287} C_{e2}^{\ 0.091}) + (Q_{e3}^{\ 0.287} C_{e3}^{\ 0.091}) + (Q_{e4}^{\ 0.287} C_{e4}^{\ 0.091}) \right]$$

(Equation 7.2)

where:

Q_e = the total vehicle flow entering the intersection from a particular approach. e.g. Q_{e1} is the entering flow for the northern approach and is the sum of q_1, q_2, and q_3

C_e = the total cycle flow entering the intersection from a particular approach. e.g. C_{e1} is the entering flow for the northern approach and is the sum of c_1, c_2, and c_3

Total cycle accidents for UCXT3 (right-turn-against accidents involving cyclists travelling straight through) can be calculated as follows:

$$A_{UCXT3} = 4.41 \times 10^{-4} \left[(q_7^{\ 0.340} c_2^{\ 0.198}) + (q_{10}^{\ 0.340} c_5^{\ 0.198}) + (q_1^{\ 0.340} c_8^{\ 0.198}) + (q_4^{\ 0.340} c_{11}^{\ 0.198}) \right]$$

(Equation 7.3)

7.2.3 Cycle accidents at roundabouts

A combined cycle APM has been developed for 4-arm roundabouts. The model is essentially the type HA model, where cyclists circulating at a roundabout collide with vehicles entering the roundabout. The difference is that the combined model incorporates an additional multiplicative factor to take into account other cycle accidents at roundabouts. Again it is recommended that the model be used to compare the mean predicted number of accidents with the actual mean number of accidents over a number of roundabouts or along a route rather than at individual sites.

The predicted mean number of cycle accidents for a roundabout can be estimated using Equation 7.4. The first co-efficient takes account of other accident types. The vehicle and cycle movements are defined in Figures 7.3 and 7.4.

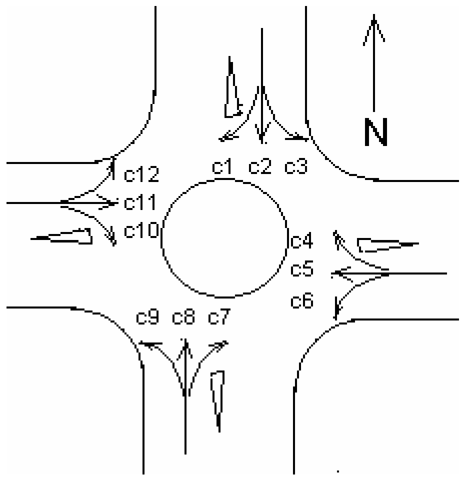

Figure 7.3 Cycle movements.

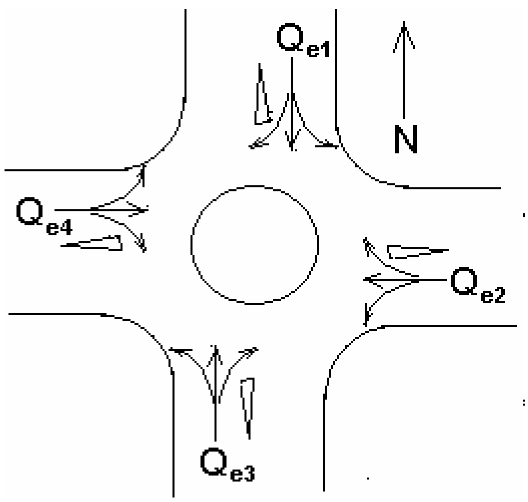

Figure 7.4 Vehicle movements.

$$A_{UCXR} = 2.96 \times 10^{-5} \left[(Q_{e1}^{0.785} C_{c1}^{0.316}) + (Q_{e2}^{0.785} C_{c2}^{0.316}) + (Q_{e3}^{0.785} C_{c3}^{0.316}) + (Q_{e4}^{0.785} C_{c4}^{0.316}) \right]$$

(Equation 7.4)

where:

Q_e = the total vehicle flow entering the intersection from a particular approach

C_c = the total cycle flow circulating at a point in front of an approach, i.e.

C_{c1} = $(c_7 + c_{10} + c_{11})$

C_{c2} = $(c_{10} + c_1 + c_2)$

C_{c3} = $(c_1 + c_4 + c_5)$

C_{c4} = $(c_4 + c_7 + c_8)$

7.2.4 Cycle accidents at mid-block locations

The total cyclist accident model for mid-block locations is based on the UCMN mid-block cycle model. The total mean number of accidents involving cyclists for a mid block section can be estimated using Equation 7.5:

$$A_{UCMN} = 1.73 \times 10^{-7} Q^{1.38} C^{0.229} L$$ (Equation 7.5)

where:

Q = the total two-way daily vehicle flow for the link

C = the total two-way daily cycle flow for the link

L = the length of the link in kilometres

7.2.5 Cycle accidents at other types of intersections

Total and major accident type prediction models could not be developed for other intersection types, such as signalised T-junctions and signalised crossroads where one road is one-way. It was not possible to produce good-fitting models for these intersections because there were too few observed cycle accidents and a relatively small number of sites.

7.2.6 Pedestrian accidents at signalised crossroads

A combined APM was developed for pedestrians at signalised crossroads. The model is based on two pedestrian accident models:

- pedestrian crossing the road and motor vehicle travelling straight through,
- pedestrian crossing an intersection hit by a right-turning motor vehicle.

The total mean number of accidents involving pedestrians at a signalised crossroad can be calculated using the following formula:

$$A_{UPXT} = 1.20(A_{UPXT1} + A_{UPXT3})$$ (Equation 7.6)

where:

A_{UPXT1} = the predicted number of accidents involving vehicles travelling along each link colliding with pedestrians who are crossing at right angles

A_{UPXT3} = the predicted number of accidents involving right-turning vehicles colliding with pedestrians crossing the road

1.20 is a multiplier to take into account other types of pedestrian accidents at traffic signals

The total number of pedestrian accidents can be calculated using the following equations. The pedestrian (*p*) and motor-vehicle (*q*) movements for each model are defined in Figures 7.5 and 7.6.

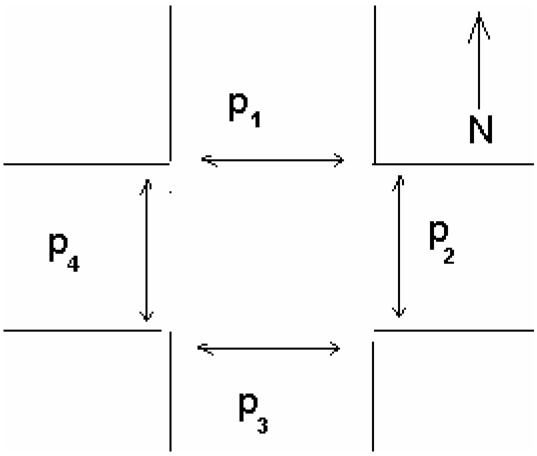

Figure 7.5 Pedestrian movements.

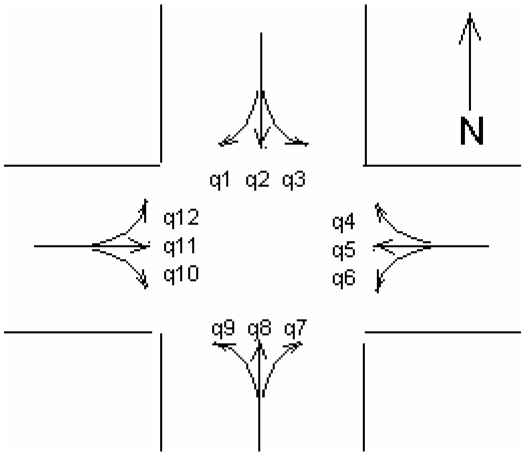

Figure 7.6 Vehicle movements.

The total number of pedestrian accidents of Type UPXT1 (where vehicles are travelling straight through and colliding with a pedestrian crossing the road at right angles) is calculated using Equation 7.7. This model assumes data on the proportion crossing with the 'green man' is not available.

$$A_{UPXT1} = 7.28\times10^{-6}\left[(Q_{1,3}^{0.634}(p_1+p_3)^{0.396})+(Q_{2,4}^{0.634}(p_2+p_4)^{0.396})\right] \quad \text{(Equation 7.7)}$$

where:

$Q_{1,3}$ = the total two-way daily vehicle flow for the link in the north-south direction

$Q_{2,4}$ = the total two-way daily vehicle flow for the link in the east-west direction.

The second model, Type UPXT3 (for accidents where right-turning vehicles collide with pedestrians crossing the road) has the following form:

$$A_{UPXT3} = 5.43\times10^{-5}\left[(q_1^{0.434}p_4^{0.513})+(q_4^{0.434}p_1^{0.513})+(q_7^{0.434}p_2^{0.513})+(q_{10}^{0.434}p_3^{0.513})\right]$$

(Equation 7.8)

7.2.7 Pedestrian accidents at mid-block locations

The mean number of total pedestrian accidents at mid-block locations can be calculated using the UPMO2 model. While pedestrian crossing volumes are used in the models, the total model predicts total pedestrian accidents, including those where the pedestrian is walking in the same direction as traffic.

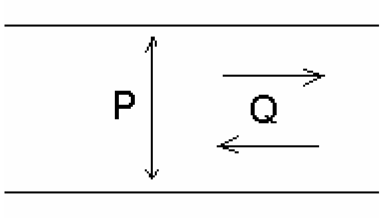

Figure 7.7 Pedestrian (*p*) and vehicle (*q*) movements.

The total mean number of accidents involving pedestrians for a mid-block section can be estimated using the following formula:

$$A_{UPMO2} = 1.86 \times 10^{-4} Q^{0.692} P^{0.256} L \qquad \text{(Equation 7.9)}$$

where:

Q = the total two-way daily vehicle flow for the link

P = the total daily number of pedestrians crossing this section

L = the length of the link in kilometres

7.2.8 Pedestrian accidents at other types of intersections

Good-fitting APMs could not be produced for pedestrian accidents at roundabouts because of their low occurrence rate and the low pedestrian flows at roundabouts considered in this study.

Similarly, APMs could not be developed for intersection types such as signalised T-junctions and signalised crossroads where one road is one-way. Larger sample sizes would be required to develop models for these other intersection types.

7.3 Changes in mode choice (to cycling and walking)

7.3.1 Introduction

With more emphasis on promoting walking and cycling, the hope is that the proportion of trips made by pedestrians and cyclists will increase over time. Concern exists, however, that an increase in volumes will result in an increase in pedestrian and cycle accidents, given that the accident risk for those groups is typically higher than for motor vehicles.

To investigate the likely accident effects resulting from a change in mode choice (to cycling and walking), a case study was undertaken for a group of intersections and mid-block sites in Christchurch. The expected numbers of accidents and accident rate per cyclist, pedestrian and motor vehicle were calculated using APMs for current traffic, cycle and pedestrian volumes. The first scenarios consider a major increase in both cycle and pedestrian numbers, of 300%. The number of motor-vehicle trips was reduced by the change in mode, so the number of total trips remained unchanged. The expected change in the accident rate for each model was then plotted.

A second scenario was then investigated for a number of arterial routes in Christchurch. In this case, traffic flows were reduced by 20%, with all trips changing to cycle trips. Again, the change in accident rate was plotted.

For both scenarios the number of cycle or pedestrian accidents was calculated using the APMs presented in Section 7.2. For motor-vehicle-only accidents the APMs in Transfund (1997) were used. It should be noted that large increases in pedestrian or cyclist volumes may be outside of the range of the models and may therefore be inaccurate.

7.3.2 Increases in the number of cyclists

This scenario investigates increases in the number of cyclists of 300% at signalised crossroads, roundabouts and mid-block locations in Christchurch. For each intersection type it is assumed that each additional cyclist will replace one motor-vehicle trip on the road. A vehicle occupancy rate of 1.0 has been assumed for the analysis.

7.3.2.1 Signalised crossroads

Figure 7.8 shows the change in the annual total number of accidents at signalised crossroads in Christchurch. This plot shows a slight increase in cycle accidents and a decrease in motor-vehicle accidents. This trend however is not very dramatic, especially considering the considerable increase in the percentage of cyclists. Overall however the number of cyclists and cycle accidents is very small when compared to the volume of motor vehicles and number of motor-vehicle-only accidents at each intersection. A 300% increase in the number of cyclists corresponds to a decrease in motor vehicles of only 2.9%.

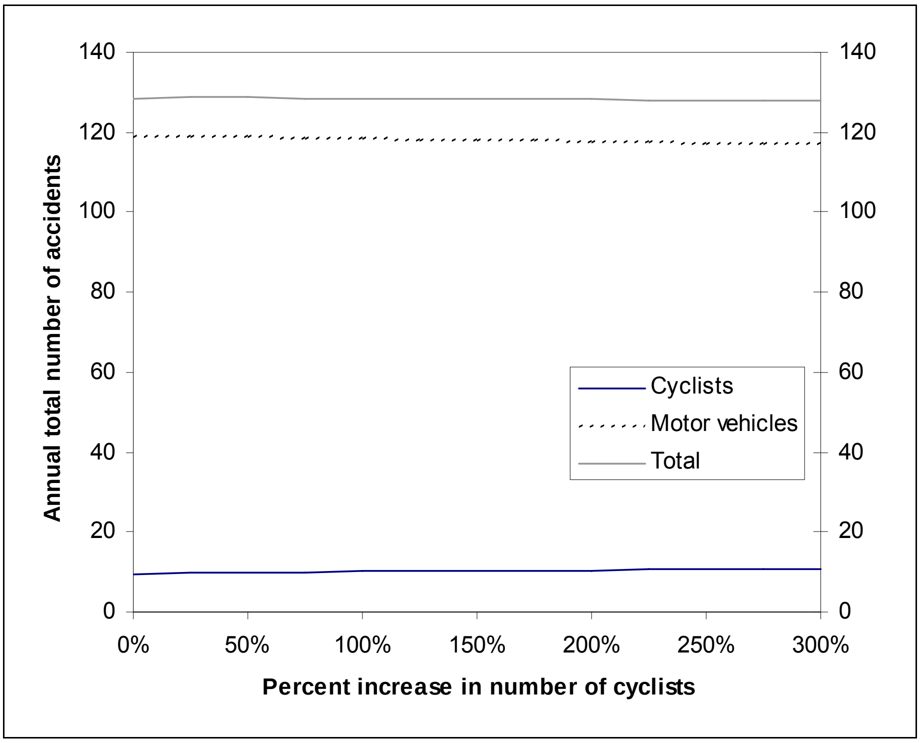

Figure 7.8 Cyclists and motor-vehicle accidents at signalised crossroads in Christchurch.

Figure 7.9 shows the accident rates for cyclists and motorists for each signalised intersection. It shows that at current cycle and traffic flows the predicted accident rate per cyclist is more than eight times higher than for a motor vehicle. However, for a 300% increase in the number of cyclists, the accident rate per cyclist drops to just over two times the accident rate for motor vehicles, which represents a decrease of nearly 70%. This demonstrates the ‘safety in numbers’ effect.

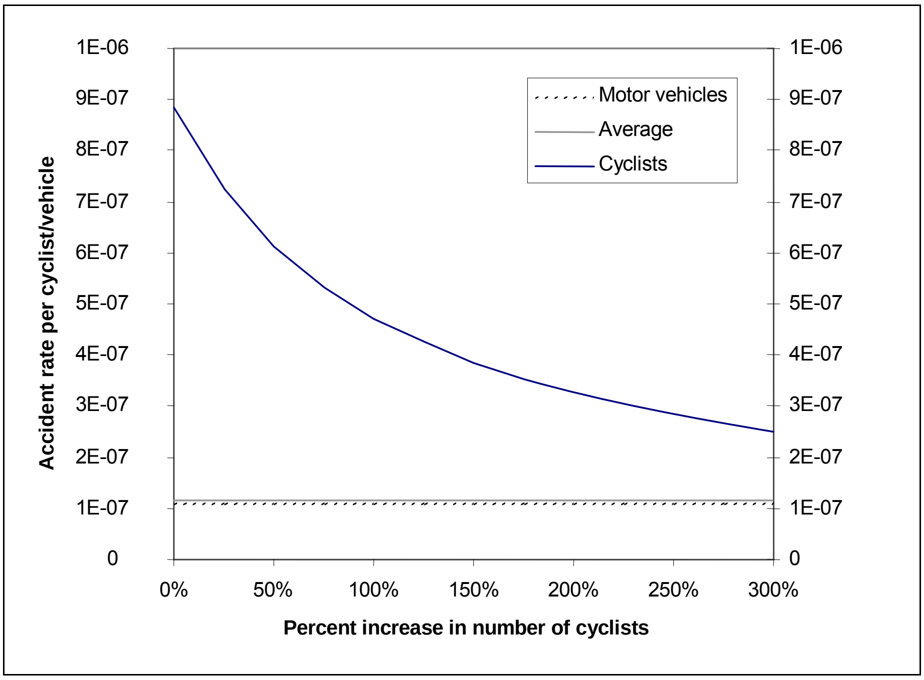

Figure 7.9 Cyclists and motor-vehicle accident rate at signalised crossroads.

7.3.2.2 Roundabouts

Cycle accidents make up a significant proportion of the total number of accidents at roundabouts. The proportion of cycle accidents is much higher than other intersection types.

Figure 7.10 shows the predicted total number of accidents, the number of cyclist accidents and the number of motor-vehicle-only accidents that would result from an increase in cycle numbers of 300%. The figure shows an increase of approximately 50% in the number of accidents involving cyclists from this mode change.

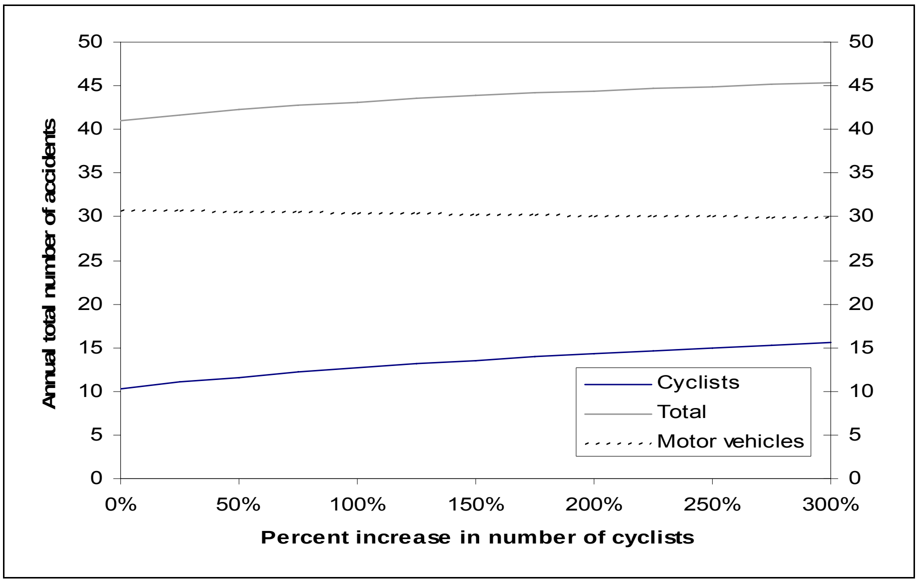

Figure 7.10 Cyclist and motor-vehicle accidents at roundabouts.

While the overall accident rate increases, Figure 7.11 shows that the accident rate per cyclist does drop significantly, although not as dramatically as at signalised crossroads.

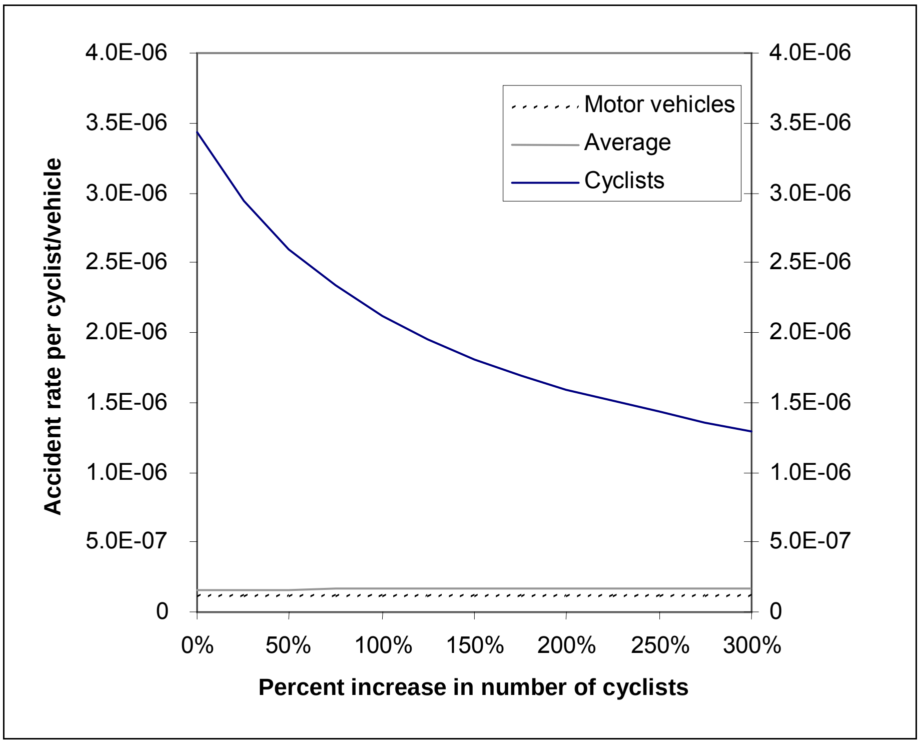

Figure 7.11 Cyclist and motor-vehicle accident rates at roundabouts.

7.3.2.3 Mid-block

Figure 7.12 shows the total predicted number of accidents for the 100-m mid-block sections selected in Christchurch (a total of 50 sections). Note the comparatively low number of accidents per section when compared with signalised crossroads and roundabouts. This is mainly because the sections are only 100 m long. The number of predicted cycle accidents does however make up a significant proportion of the total predicted number of accidents (29% of all accidents).

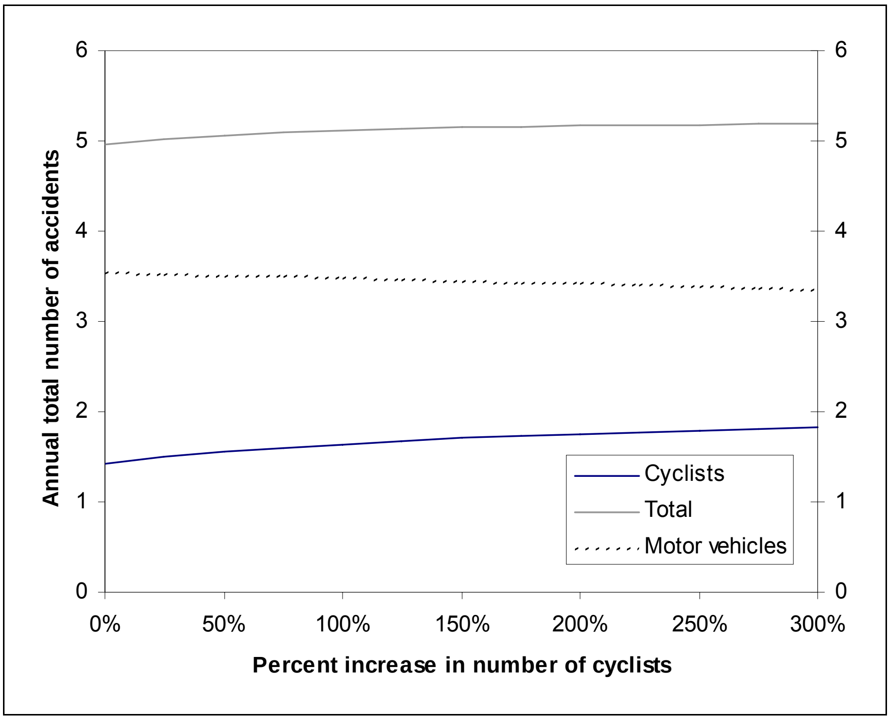

Figure 7.12 Cyclist and motor-vehicle accidents at mid-block sections.

Figure 7.13 shows the accident rate for cyclists passing through the 100-m mid-block sections. The cycle accident rate is nearly 25 times larger than that of motor vehicles at current traffic volumes. It is unlikely that the cycle accident rate is this high over the entire road. The commercial (strip shopping) mid-block sections in this study were in areas where there are high pedestrian crossing flows. Figure 7.13 shows that a large drop-off in the accident rate per cyclist occurs as the cycle volumes increase.

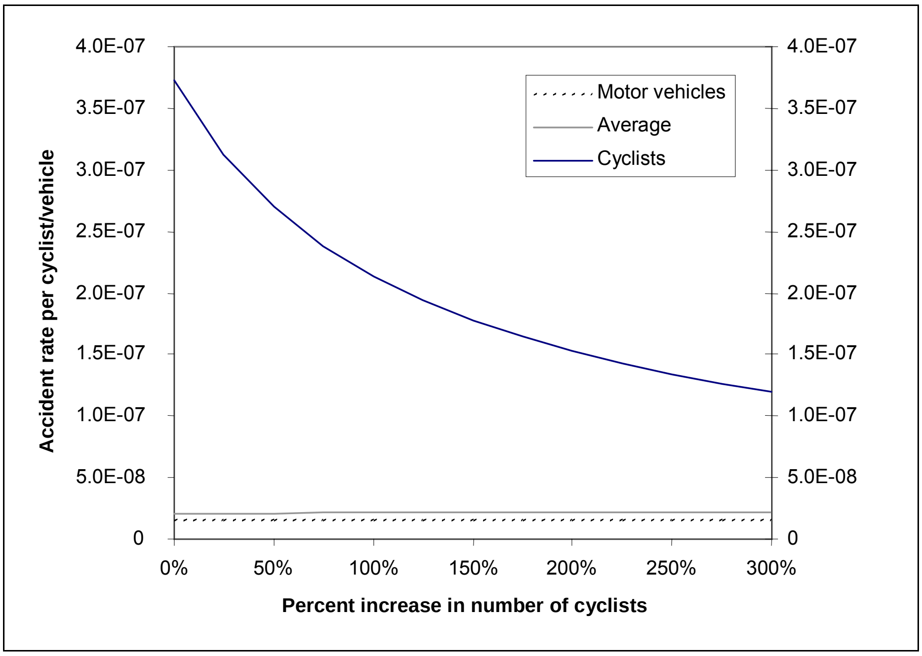

Figure 7.13 Cyclist and motor-vehicle accident rates along commercial mid-block sections in Christchurch.

7.3.3 Increases in the number of pedestrians

This scenario investigates increases in the number of pedestrians at signalised crossroads and mid-block locations in Christchurch, the increase being in the order of 300% compared with current volumes. The additional pedestrians are displaced motor-vehicle drivers.

7.3.3.1 Signalised crossroads

Figure 7.14 shows the change in the annual total number of accidents at signalised crossroads in Christchurch resulting from a 300% increase in walking trips. The plot shows a slightly decreasing number of accidents involving motor vehicles only, and only a very slight overall increase in the combined number of pedestrian and motor-vehicle accidents.

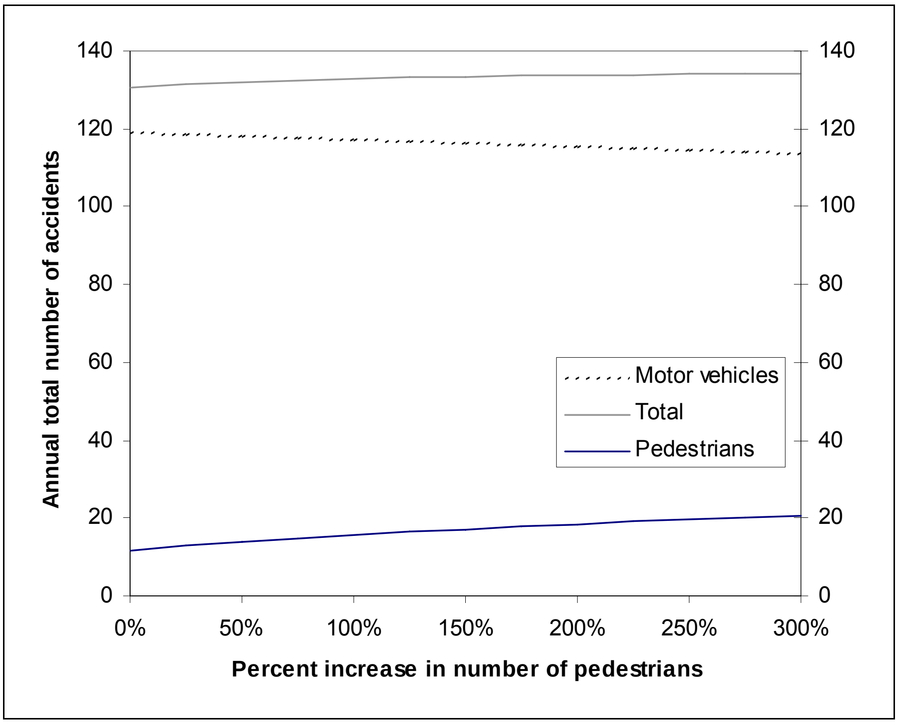

Figure 7.14 Pedestrian and motor-vehicle accidents at signalised crossroads in Christchurch.

Despite the overall increase in pedestrian accidents, the accident rate per pedestrian crossing the road at a signalised crossroad decreases dramatically (by 55%). This change in accident rate (or accident risk) is illustrated in Figure 7.15 and illustrates the 'safety in numbers' effects for pedestrians.

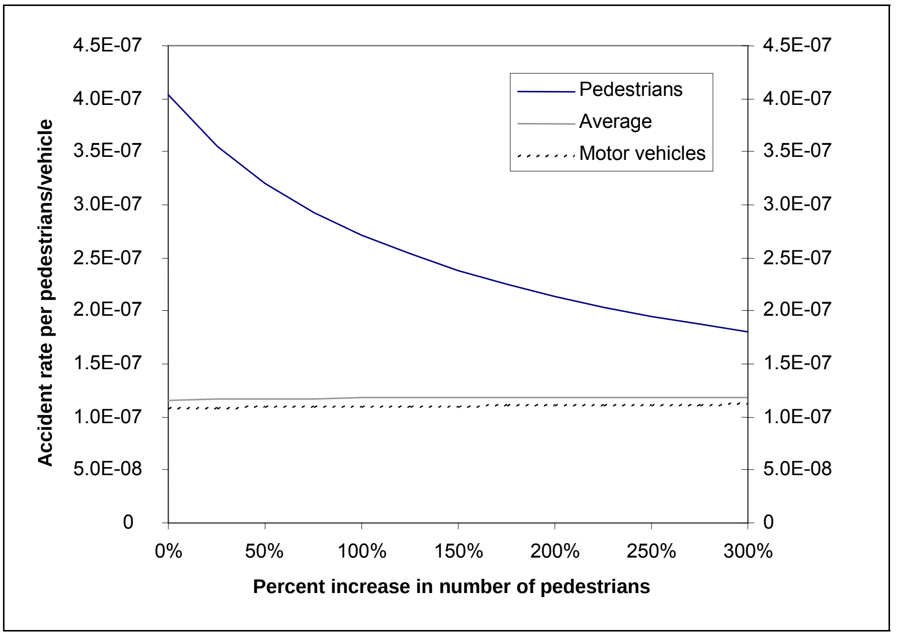

Figure 7.15 Pedestrian and motor-vehicle accident rate at signalised crossroads.

7.3.3.2 Mid-block

The number of expected pedestrians accidents at mid-block sections was calculated using APMs. For an increase of approximately 60% in the crossing walking trips (with corresponding decrease in motor-vehicle trips), the number of expected pedestrians versus motor-vehicle accidents actually becomes larger than the number of expected motor-vehicle-only accidents. This is illustrated in Figure 7.16.

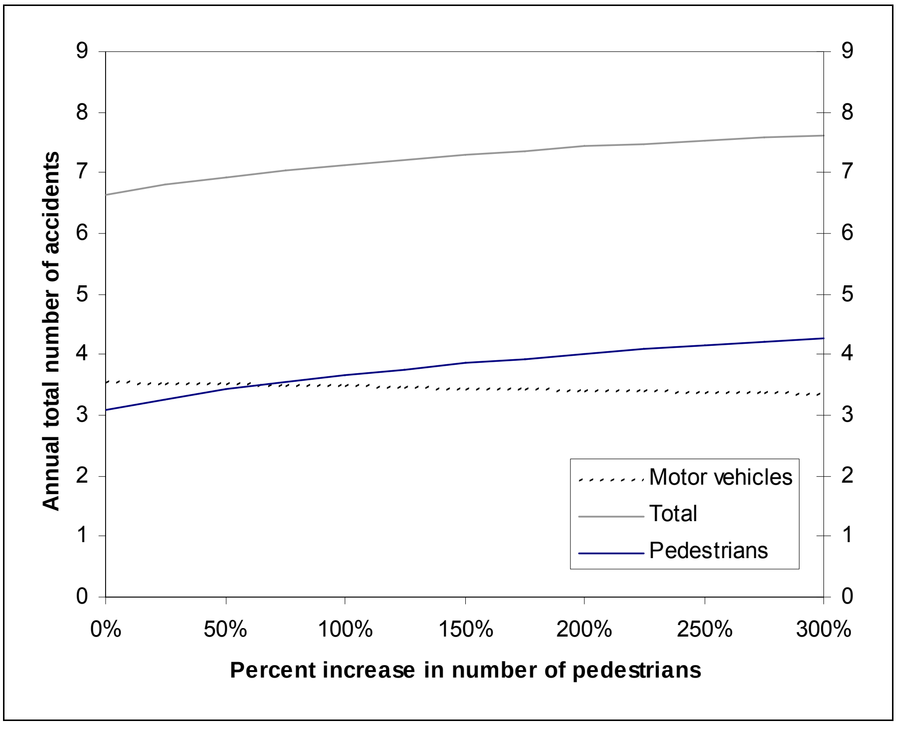

Figure 7.16 Pedestrian and motor-vehicle accidents along mid-block sections in Christchurch.

Figure 7.17 shows the expected accident rate per pedestrian crossing the mid-block section and expected accident rate for motor vehicles travelling along the section.

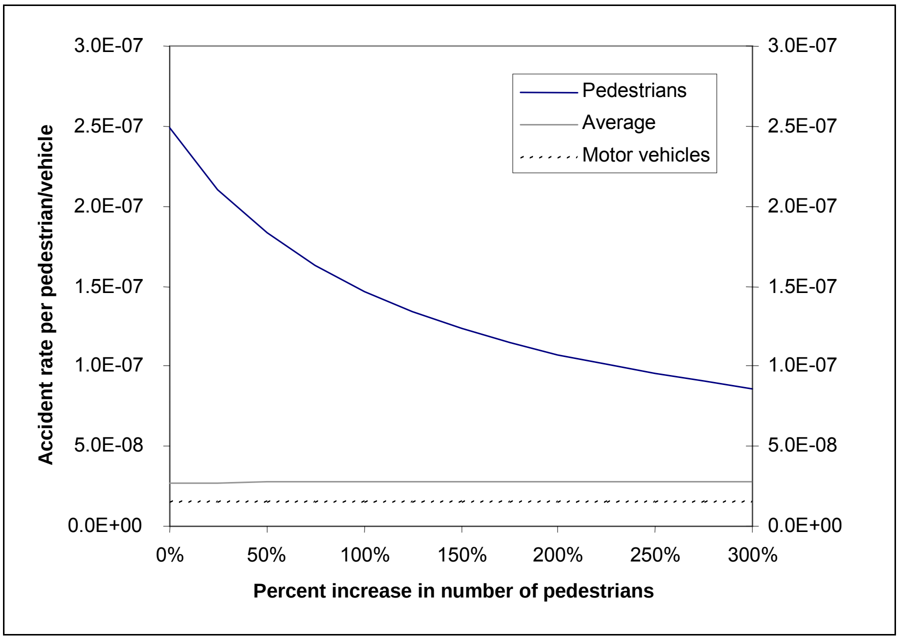

Figure 7.17 Pedestrian and motor-vehicle accident rates along mid-block sections.

7.3.4 Larger shifts in mode choice to cycling

In this scenario, a large mode shift to cycle was investigated at six signalised intersections along Memorial Avenue and Fendalton Road (in Christchurch). Although there are also two mid-block signalised crossings along this route these have not been included in this analysis. Nor have mid-block accidents. Another signalised T-junction is also along this route but counts were not collected in this study, and it too was excluded from this analysis.

The route currently has relatively high cycling volumes and is the main route for cyclists and motor vehicles travelling from the centre of Christchurch to the University and Christchurch International Airport. This route is also close to a large secondary school (Burnside High School). Figure 7.18 shows a map of the route and the locations of the signalised crossroads.

The route currently carries a higher proportion of cyclists (1.3%) than the Christchurch average of sites in the dataset (1.0%).

For this analysis, the total number of trips along the route was kept constant. A reduction of up to 20% in the number of motor vehicles was assumed. A 20% reduction in motor-vehicle trips corresponds to a 1,480% increase in the number of cyclists. This is an average increase in the total daily estimated number of cyclists travelling through these six intersections from 430 cyclists per day to 6,700 cyclists per day. This is a ratio of 1 cyclist for every 3.7 motor vehicles. It is stressed that this is only a theoretical example and achieving such a change would require a cultural shift.

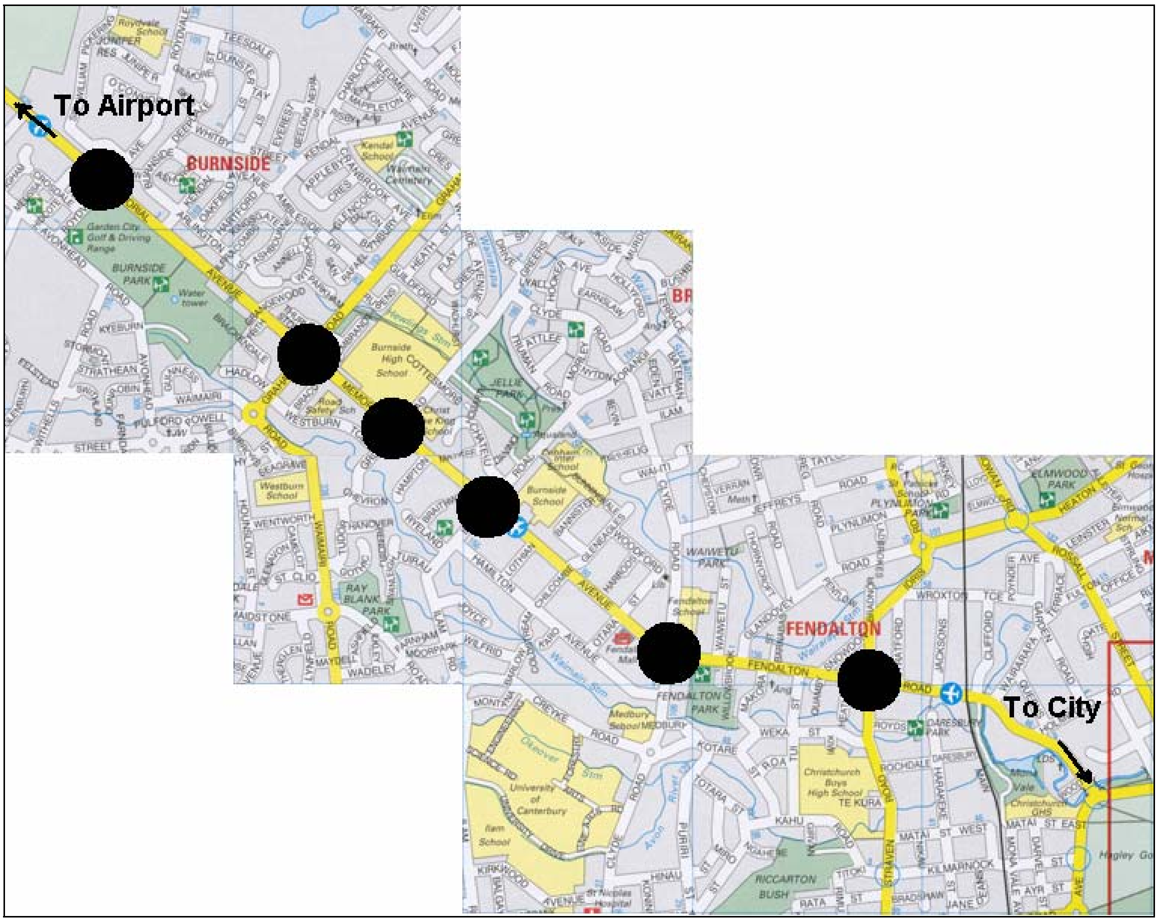

Figure 7.18 Traffic signal sites used in analysis along Memorial Ave/Fendalton Road, Christchurch.

The number of accidents involving 1. cyclists and motor vehicles and 2. motor vehicles only at the six intersections was calculated. Figure 7.19 shows how the predicted number of accidents changes when motor-vehicle drivers switch to cycling. It shows that although the number of accidents involving cyclists is increasing, this is only by a small amount and is at a reducing rate. Overall the total number of accidents decreases because of the decrease in the number of motor-vehicle accidents.

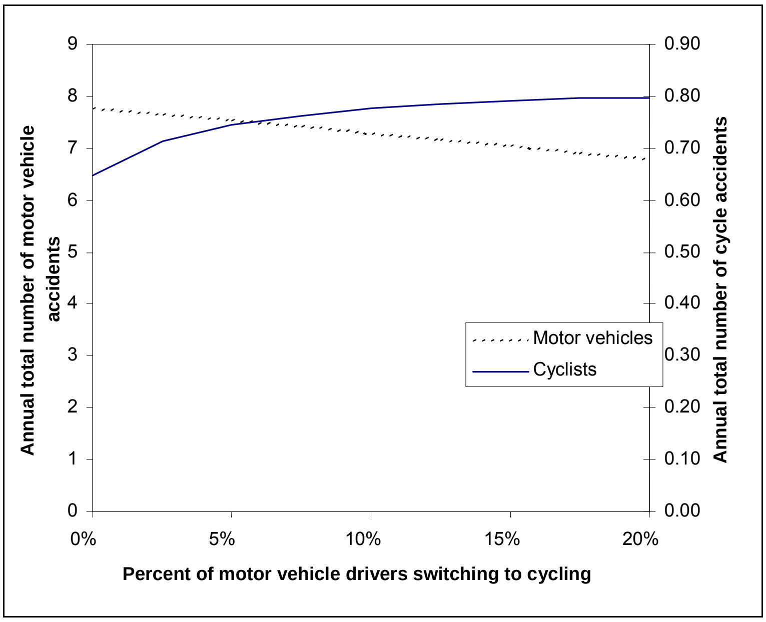

Figure 7.19 Expected number of accidents at intersections along Memorial Ave / Fendalton Road, Christchurch.

Figure 7.20 shows the expected accident rates for cyclists and motor vehicles at the six intersections. It can be seen that a modal shift of approximately 8% of drivers to cycling (an increase of 590% in the numbers of cyclists) would reduce the accident rates for cyclists to a similar value as for motor vehicles. It is important to note that the APMs used for this scenario were developed using significantly lower volumes of cyclists than considered in this scenario. Evidence is found in overseas literature that the 'safety in numbers' effect only applies up to a certain volume of cyclists. Further research in this area is required.

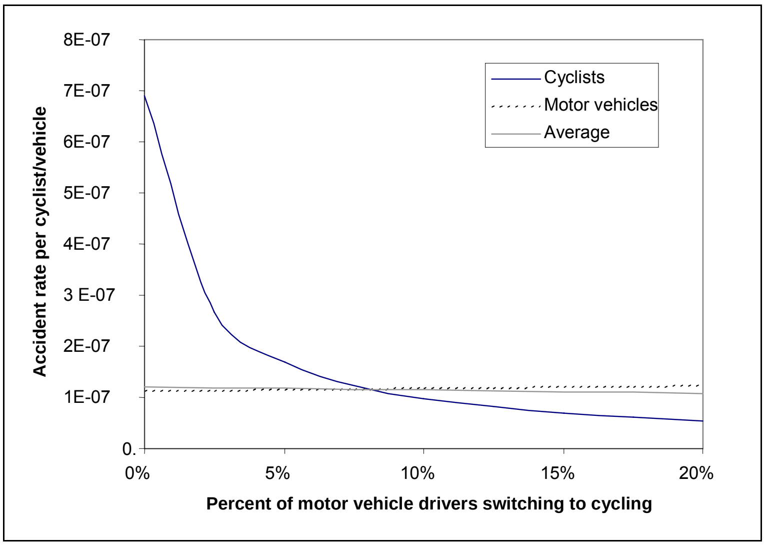

Figure 7.20 Expected accident rate at intersections along Memorial Ave / Fendalton Road, Christchurch.

8. Conclusion

8.1 Summary

The main conclusions of this research project are:

- A significant proportion of cycle and pedestrian accidents occur off the roadway (50% for cyclists) or are on-road but do not involve a motor vehicle. The number of on-road accidents involving motor vehicles is between 60 and 75%.
- A comparison between CAS, ACC and St John databases indicates that the reporting rate of pedestrian and cyclist accidents in the CAS database is low, as many accidents in those other databases did not match the CAS database. This needs further research to confirm the extent of the under-reporting.
- Of the pedestrians interviewed in the Christchurch Hospital/ACC survey involved in road accidents, the largest number of injuries was the 10–20 age group. This percentage of accidents, however, matched the percentage of trips by this age group. The 80+ age group, in contrast, had a percentage of pedestrian accidents far higher than the percentage of all walking trips by this group.
- Of those injured cyclists interviewed, the most commonly injured age group was again those in the 10–20 age group, although this percentage was far less than the percentage of trips by this group. The age group that has far more injuries than the percentage of trips undertaken was the 30–40 age group (which might be influenced by those cyclists travelling on higher volume roads or over longer distances).
- Traffic failing to notice or give way to pedestrians and cyclists was a major factor in the accidents that were discussed in the interviews. Factors such as loose or slippery surface, opening car door, squeezed by traffic, did not feature significantly in the accidents. The most commonly reported injury for both cyclists and pedestrians was bruises (28%) with the number of injuries reported decreasing with severity of the injury.
- An analysis of the pedestrian count data at signalised intersections indicated that that the proportion of pedestrians crossing on the 'green man' at traffic signals was lowest before the morning peak period and following the evening peak periods.
- A 'safety in numbers' effect is observed for cycle accidents at traffic signals, roundabouts and mid-block sites. An increase in cycle numbers will not therefore necessarily increase the number of accidents substantially.
- A 'safety in numbers' effect is also observed for pedestrian accidents at traffic signals and mid-block sites. Insufficient data exists to conclude whether a 'safety in numbers' effect occurs at roundabouts.
- An insufficient number of sites exists in the database to develop models for crossroad traffic signals where one road is one-way and for signalised T-junctions.

The sample size of this type of intersection, and also roundabouts, needs to be increased to produce better models.

- APMs were developed to predict total pedestrian and cycle accidents at traffic signals and mid-block locations and for total cycle accidents at roundabouts. These models were used to show the effect of shifts in mode choice from motor vehicles to cycling and walking and the resulting safety in numbers effects.

8.2 Areas for future research

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

- Expansion of the sample sizes, particularly for roundabouts, crossroad signals with one road one-way and T-junction signals by including sites in Auckland, Wellington and Nelson to improve the models.
- Development of separate models for single and multi-lane roundabouts, as overseas literature suggests that those junctions have greatly different accident rates for cyclists.
- Collection of data on non-flow variables and in particular on on-street carparking, vehicle speed, sight distance, cycle facilities and pedestrian facilities (such as crossings and pedestrian refuges) and inclusion of these factors in APMs.
- Collection of longer duration pedestrian and cycle counts at existing survey sites and all new sites.
- Development of the daily, weekly and seasonal cycle and pedestrian profiles further using continuous count data available from Christchurch City Council and other councils. Investigate effects of weather and school holidays on counts.
- Addition to sample set of non-commercial mid-block locations (to see if higher risk exists at lower pedestrian crossing volumes) and other priority-controlled intersections to sample set. Investigate impact of (wide) commercial driveways on pedestrian accidents.
- Examination of the change to the base cyclist and pedestrian accident rate with the provision of features such as cycle lanes and pedestrian refuges.
- Updating the existing models for motor-vehicle accidents so they no longer include accidents involving pedestrians and cyclists.

8.3 Recommendations

The following recommendations should be considered:

- Land Transport New Zealand should enter all reported accidents in the CAS database.
- Road Controlling Authorities (RCAs) should regularly count cyclists and pedestrians on their roads and intersections.
- RCAs and other agencies should not avoid encouraging cycling and walking in the belief that it will increase the overall number of accidents.

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Appendix A Pedestrian and cycle statistics

Table A1 Reported pedestrian accidents - Christchurch, Palmerston North and Hamilton 1993 – 2002 inclusive by junction type.

		Worst Injury FSMN				
Local Body	**Junction Type**	**1 Fatal**	**2 Serious**	**3 Minor**	**4 Non-injury**	**Grand Total**
Christchurch City	Driveway	6	14	39	5	64
	Multi Rd Join	0	3	5	3	11
	Roundabout	1	4	10	3	18
	T-Type Junction	5	57	111	12	185
	Unknown	23	154	271	27	475
	X-Type Junction	8	43	150	32	233
	Y-Type Junction	0	3	5	0	8
Christchurch City Total		**43**	**278**	**591**	**82**	**994**
Hamilton City	Driveway	1	5	9	1	16
	Multi Rd Join	0	0	5	0	5
	Roundabout	0	3	8	1	12
	T-Type Junction	0	17	34	7	58
	Unknown	5	72	133	17	227
	X-Type Junction	0	5	23	5	33
Hamilton City Total		**6**	**102**	**212**	**31**	**351**
Palmerston North City	Driveway	0	3	3	1	7
	Roundabout	0	2	5	0	7
	T-Type Junction	0	11	26	1	38
	Unknown	5	26	84	1	116
	X-Type Junction	1	3	30	1	35
Palmerston North City Total		**6**	**45**	**148**	**4**	**203**
Grand Total		**55**	**425**	**951**	**117**	**1548**

Note: 'Unknown' are typically mid-block locations

Table A2 Reported pedestrian accidents - Christchurch, Palmerston North and Hamilton 1993 – 2002 inclusive by traffic control device.

		Worst Injury FSMN				
Local Body	**Traffic Control**	**1 Fatal**	**2 Serious**	**3 Minor**	**4 Non-injury**	**Grand Total**
Christchurch City	Give Way Sign	3	25	43	7	78
	Nil	8	49	97	8	162
	School Patrol	0	1	2	1	4
	Stop Sign	1	6	25	3	35
	Traffic Signal	8	46	151	36	241
	Unknown	23	151	273	27	474
Christchurch City Total		**43**	**278**	**591**	**82**	**994**
Hamilton City	Give Way Sign	0	7	12	1	20
	Nil	6	87	166	23	282
	School Patrol	0	0	1	1	2
	Stop Sign	0	0	8	0	8
	Traffic Signal	0	6	23	6	35
	Unknown	0	2	2	0	4
Hamilton City Total		**6**	**102**	**212**	**31**	**351**
Palmerston North City	Give Way Sign	0	6	17	0	23
	Nil	4	35	97	2	138
	Stop Sign	0	0	2	0	2
	Traffic Signal	1	3	25	2	31
	Unknown	1	1	7	0	9
Palmerston North City Total		**6**	**45**	**148**	**4**	**203**
Grand Total		**55**	**425**	**951**	**117**	**1548**

Note: ‘Unknown’ are typically mid-block locations

Table A3 Reported cyclist accidents - Christchurch, Palmerston North and Hamilton 1993 – 2002 inclusive by junction type.

		Worst Injury FSMN				
Local Body	**Junction Type**	**1 Fatal**	**2 Serious**	**3 Minor**	**4 Non-injury**	**Grand Total**
Christchurch City	Driveway	3	42	127	62	234
	Multi Rd Join	0	2	5	6	13
	Roundabout	0	28	96	33	157
	T-Type Junction	2	84	356	112	554
	X-Type Junction	5	57	212	72	346
	Y-Type Junction	1	3	4	2	10
	Unknown	5	68	226	61	360
Christchurch City Total		**16**	**284**	**1026**	**348**	**1674**
Hamilton City	Driveway	1	10	53	13	77
	Multi Rd Join	1	2	3	2	8
	Roundabout	0	6	30	12	48
	T-Type Junction	0	13	79	17	109
	X-Type Junction	0	6	44	18	68
	Y-Type Junction	0	1	1	0	2
	Unknown	4	16	43	12	75
Hamilton City Total		**6**	**54**	**253**	**74**	**387**
Palmerston North City	Driveway	0	7	25	16	48
	Multi Rd Join	0	1	0	0	1
	Roundabout	0	3	25	10	38
	T-Type Junction	1	13	77	25	116
	X-Type Junction	1	12	48	8	69
	Y-Type Junction	0	2	1	0	3
	Unknown	3	11	48	12	74
Palmerston North City Total		**5**	**49**	**224**	**71**	**349**
Grand Total		**27**	**387**	**1503**	**493**	**2410**

Table A4 Reported cyclist accidents - Christchurch, Palmerston North and Hamilton 1993 – 2002 inclusive by traffic control device.

		Worst Injury FSMN				
Local Body	**Traffic Control**	**1 Fatal**	**2 Serious**	**3 Minor**	**4 Non-injury**	**Grand Total**
Christchurch City	Give Way Sign	2	59	237	80	378
	Nil	4	88	297	111	500
	Stop Sign	2	17	87	25	131
	Traffic Signal	3	43	154	59	259
	Unknown	5	77	251	73	406
Christchurch City Total		**16**	**284**	**1026**	**348**	**1674**
Hamilton City	Give Way Sign	0	17	92	26	135
	Nil	5	29	120	30	184
	Stop Sign	0	2	12	8	22
	Traffic Signal	1	4	27	10	42
	Unknown	0	2	2	0	4
Hamilton City Total		**6**	**54**	**253**	**74**	**387**
Palmerston North City	Give Way Sign	0	12	75	30	117
	Nil	3	23	98	29	153
	Stop Sign	0	8	22	6	36
	Traffic Signal	1	4	23	2	30
	Unknown	1	2	6	4	13
Palmerston North City Total		**5**	**49**	**224**	**71**	**349**
Grand Total		**27**	**387**	**1503**	**493**	**2410**

Appendix B Ethical approval letter

Canterbury Ethics Committee
4th Floor, 250 Oxford Terrace
P.O. Box 3877
Christchurch
Phone (03) 372 3018
Fax (03) 372 1015
Email: sally_cook@moh.govt.nz

2 December 2002

RECEIVED
04 DEC 2002
SAT

Dr S Turner
Beca Carter Hollings & Ferner Ltd
P O Box 13960
Christchurch

Attention: Tony Francis

Dear Dr Turner

Predicting accident rates for cyclists and pedestrians
Investigators: Dr S Turner, T Francis, P Durdin, Prof G Wood, Prof J Cross, Dr A Williamson
Ethics reference: CTY/02/08/128
Information sheet/consent form version 7 dated 27 November 2002

Thank you for the revised information sheet, consent form and questionnaire version 9 dated 27 November 2002.

I am pleased to advise that, using the delegated authority granted her by the Committee, the Chairperson of the Canterbury Ethics Committee has given final ethical approval for this study to proceed in Canterbury.

Approval is until 31 December 2004. The Committee will review the study annually and notify you if it withdraws approval. It is your responsibility to forward a progress report in November 2003. Failure to do so may result in withdrawal of ethical approval. A final report is also required at the conclusion of the study. Report forms are available from the administrator.

It is also a condition of approval that the Committee is advised of any adverse events, if the study does not commence, or the study is altered in any way, including all documentation eg advertisements, letters to prospective participants. Please quote the above ethics committee reference number in all correspondence.

The Committee wishes you well with your research.

Yours sincerely

Sally Cook
Ethics Committee Administrator

Accredited by Health Research Council

Appendix C Hospital interview questionnaire

Pedestrian and Cyclist Study Survey

Interviews at the Emergency Department, Christchurch Hospital

28 May 2003

DATE of Interview: ……………………………………………

Interviewer: ……………………………………………

If the accident occurred:

- On a public road or footpath,
- In Christchurch City and
- At traffic signals, a roundabout or on a road

please complete this questionnaire.

Interviewer:

1. **Please read the information sheet to the patient or allow them to read it**
2. **Take the patient through the Consent Form. They need to tick the three boxes on the right side, and complete the sections with their personal details.**
3. **You need to sign etc the consent form.**
4. **Staple the completed questionnaire and the consent form and place them in the envelope for your shift. Leave them in the Emergency Department for me to collect**

NOTE: We keep the questionnaire separate from the consent form, so the two cannot be linked

Tony Francis, Telephone 3322 722 or 021 332 885

Questionnaire

1. **Personal Details**

☐$_1$ Male ☐$_2$ Female

Age: ……………………… years old

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2

2. How were you travelling?

☐1 Pedestrian
☐2 Cyclist
☐3 Other e.g. skateboarding

If "Other" please describe: ....

2A: Cycle Type

☐ Mountain bike; ☐ 10 speed; ☐ Other (describe please ....)

2B: Lights on bike? Yes ☐ No ☐

3. Time and Date of Accident etc

Time ....
Day ....
Month ....
Year ....

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3A: Light conditions: Did the accident happen in the

- ☐ dark,
- ☐ at twilight, or in the
- ☐ daylight?

3B: Weather: Was the weather:

- ☐ Wet (i.e. raining)
- ☐ Windy (i.e. more than a light breeze)
- ☐ Other poor weather (Please describe: ....

4. Accident Type

- ☐1 Pedestrian only e.g. tripped and fell
- ☐2 Pedestrian vs. Vehicle
- ☐3 Pedestrian vs. Cyclist
- ☐4 Cyclist only
- ☐5 Cyclist vs. Vehicle
- ☐6 Other

If "Other" please describe: ....

Christchurch Hospital Pedestrian and Cyclist Study Survey Form 28 May 2003

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5. Location of Accident

☐1 Road ☐2 Footpath

If "Other" please describe: ....

6. Location Description

Name of Road:..

Name of other Road (if at intersection): ....

☐1 Intersection e.g. at the Smith Street and John Street intersection

☐2 Distance from intersection e.g. 100m south of Smith Street

☐3 Other e.g. Outside 43 Smith Street

Please Describe: ....

6A: Road, footpaths or cycleway conditions:

Was there any loose gravel on the road etc? Yes ☐ No ☐

Did the condition of the road etc contribute to the accident? Yes ☐ No ☐

Any comments on the surface condition of the road, footpath or cycleway?

....

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7. Cause of Accident

Please tick one or more boxes for the cause of your accident.

Pedestrians

- ☐1 Tripped and fell
- ☐2 Loose or slippery surface
- ☐3 I failed to notice traffic
- ☐4 Traffic failed to notice me
- ☐5 I didn't comply with traffic signs/signals/rules
- ☐6 Traffic failed to give way to me
- ☐7 Unsupervised child
- ☐8 Playing on road
- ☐9 Intoxicated
- ☐10 Other (specify) ....

Cyclists

- ☐11 Lost balance
- ☐12 Loose or slippery surface
- ☐13 I failed to notice traffic
- ☐14 Traffic failed to notice me
- ☐15 I didn't comply with traffic signs/signals/rules
- ☐16 Traffic failed to give way to me
- ☐17 Opening vehicle door
- ☐18 Squeezed by traffic
- ☐19 Intoxicated
- ☐20 Other (specify)

8. Accident Description (sequence of events)

Please describe the sequence of events that led up to the accident. For example:

1) I was walking south towards the city on the footpath on the eastern side of Hills Road and came to the Shirley Road intersection.
2) I waited at the traffic signals for the pedestrian crossing signal to turn green.
3) As the signal changed I began to cross but was hit by a car turning right from Hills Road into Shirley Road.
4) The driver tried to brake, but can't have seen me until it was too late.

1. ....

2. ....

Christchurch Hospital Pedestrian and Cyclist Study Survey Form 28 May 2003

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6

3. ....

4. ....

5. ....

6. ....

8A: Estimate of speed

How fast do you think **you** were travelling prior to the accident? ☐ km/h

How fast do you think **the other vehicle** was travelling prior to the accident? ☐ km/h

9. Accident Diagram

Please draw a diagram of your accident. *Indicate road names and directions if possible*

10. Trip Purpose

The main purpose of my trip was:

☐1 School	☐3 Recreation
☐2 Work	☐4 Other (specify) ....

11. Injury Type (you may mark more than one)

☐1 Grazes	☐5 Sprains
☐2 Bruises	☐6 Head Injury
☐3 Cuts / Lacerations	☐7 Dental
☐4 Broken Bones	☐8 Other (specify)

Main Injury ....

12. Emergency Services

Did any of the following attend the collision? (You may mark more than one)

☐1 Police
☐2 Ambulance
☐3 Fire

13. Previous Pedestrian and/or Cycle Accidents (in the Past 2 Years)

Please describe any other pedestrian or cycle accidents you have been involved in, in the past two years.

Please classify the injuries you sustained in each of these accidents in the "Injury" column.

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S denotes serious injuries, such as broken bones, concussion and generally any injury requiring hospital treatment.

M denotes minor injuries, such as bruises, grazes and minor cuts and basically any injury that can be treated with first aid.

N denotes no injury was sustained.

Pedestrian or Cyclist (P/C)	**Date & Time**	**Location**	**Description**	**Injury (S/M/N)**

14. Other Comments

Please feel free to add any other comments, which you feel the other questions have not adequately addressed.

....

....

....

Thank you

If you have any questions, please call Tony Francis on 3322 722.

Appendix D List of sites used in study

Signalised Cross Roads

Site ID	Location	Centre
7	Aldwins/Buckleys/Linwood	Christchurch
8	Aldwins/Ensors/Ferry	Christchurch
12	Amyes/Goulding/Shands	Christchurch
15	Antigua/Brougham/Strickland	Christchurch
17	Antigua/Moorhouse	Christchurch
18	Antigua/Oxford	Christchurch
31	Armagh/Fitzgerald	Christchurch
33	Armagh/Manchester	Christchurch
36	Halswell/Halswell Junction/Sparks	Christchurch
49	Avonside/Fitzgerald/Kilmore	Christchurch
50	Avonside/Gayhurst/Gloucester	Christchurch
53	Avonside/Stanmore	Christchurch
60	Barbadoes/Edgeware	Christchurch
80	Barington/Frankleigh/Milton	Christchurch
83	Barrington/Lincoln/Whiteleigh	Christchurch
93	Bealey/Carlton/Harper/Park	Christchurch
94	Bealey/Colombo	Christchurch
96	Bealey/Fitzgerald/London/Whitmore	Christchurch
98	Bealey/Manchester	Christchurch
100	Bealey/Papanui/Victoria	Christchurch
114	Blenheim/Clarence	Christchurch
115	Blenheim/Curletts	Christchurch
119	Blenheim/Matipo	Christchurch
129	Breezes/Pages	Christchurch
130	Breezes/Wainoni	Christchurch
138	Brougham/Burlington/Gasson	Christchurch
139	Brougham/Collins/Jerrold/Simeon	Christchurch
140	Brougham/Colombo	Christchurch
142	Brougham/Ensors	Christchurch
144	Brougham/Opawa	Christchurch
145	Brougham/Selwyn	Christchurch
146	Brougham/Waltham	Christchurch
165	Byron/Colombo/Sandyford	Christchurch
180	Carmen/Shands/Main South	Christchurch
181	Carmen/Waterloo	Christchurch
184	Cashel/Fitzgerald	Christchurch

Site ID	Location	Centre
188	Cashel/Manchester	Christchurch
201	Chalmers/Goulding/Main South	Christchurch
209	Clarence/Riccarton/Straven	Christchurch
212	Clyde/Fendalton/Memorial	Christchurch
221	Colombo/Huxley/Milton	Christchurch
232	Colombo/Tuam	Christchurch
234	Colombo/Wordsworth	Christchurch
242	Cranford/Edgeware/Sherborne	Christchurch
244	Cranford/Innes	Christchurch
247	Cranford/Westminster	Christchurch
254	Curletts/Hoon Hay/Lincoln/Halswell	Christchurch
255	Curletts/Main South	Christchurch
258	Curletts/Peer/Yaldhurst	Christchurch
287	Edgeware/Madras	Christchurch
300	Falsgrave/Fitzgerald/Moorhouse	Christchurch
304	Fendalton/Idris/Straven	Christchurch
306	Ferry/Fitzgerald	Christchurch
307	Ferry/Hargood/Radley	Christchurch
310	Ferry/Moorhouse/Wilsons	Christchurch
311	Ferry/Palinurus/Rutherford	Christchurch
315	Fitzgerald/Gloucester	Christchurch
316	Fitzgerald/Hereford	Christchurch
319	Fitzgerald/Tuam	Christchurch
320	Fitzgerald/Worcester	Christchurch
329	Gasson/Madras/Moorhouse	Christchurch
330	Gasson/Wordsworth	Christchurch
333	Glandovey/Heaton/Rossall/Strowan	Christchurch
336	Gloucester/Linwood	Christchurch
338	Gloucester/Manchester	Christchurch
341	Gloucester/Oxford	Christchurch
342	Gloucester/Rolleston	Christchurch
343	Gloucester/Stanmore	Christchurch
344	Gloucester/Woodham	Christchurch
346	Grahams/Memorial	Christchurch
348	Grahams/Wairakei	Christchurch
351	Greers/Harewood	Christchurch
352	Greers/Memorial	Christchurch
353	Greers/Wairakei	Christchurch
373	Hargood/Keighleys/Linwood	Christchurch
387	Heaton/Innes/Papanui	Christchurch

Site ID	Location	Centre
395	Hereford/Manchester	Christchurch
408	Hills/Shirley/Warrington	Christchurch
416	Idris/Wairakei	Christchurch
418	Ilam/Memorial	Christchurch
431	Kahu/Kilmarnock/Straven	Christchurch
450	Langdons/Main North/Mary	Christchurch
456	Lincoln/Lyttelton/Wrights	Christchurch
475	Main North/QEII/Northcote	Christchurch
480	Main South/Parker/Seymour	Christchurch
490	Manchester/Tuam	Christchurch
491	Manchester/Worcester	Christchurch
496	Marshland/New Brighton/North Parade/Shirley	Christchurch
504	Memorial/Roydvale	Christchurch
510	Milton/Selwyn	Christchurch
511	Milton/Strickland	Christchurch
519	Moorhouse/Selwyn	Christchurch
534	Oxford/Worcester	Christchurch
562	Shakespeare/Waltham/Wordsworth	Christchurch
566	Stanmore/Worcester	Christchurch
999	Carlton Mill Road	Christchurch
9070	Botanical / College	Palmerston North
9100	Bourke/Pitt/Cuba	Palmerston North
9130	Fitzherbert / College	Palmerston North
9145	Fitzherbert / Ferguson	Palmerston North
9160	Fitzherbert / Park	Palmerston North
9175	Fitzherbert / Te Awe Awe / Manawaroa	Palmerston North
9190	Main St East / Victoria	Palmerston North
9205	Milson / Ruahine / Tremaine	Palmerston North
9220	Pitt / Church	Palmerston North
9235	Pitt / Main West	Palmerston North
9250	Princess / Broadway	Palmerston North
9265	Princess / Church	Palmerston North
9280	PRINCESS / Main St East	Palmerston North
9300	Rangitikei / Featherston	Palmerston North
9310	RANGATIKEI / GREY / WALDING	Palmerston North
9325	Rangitikei / Tremaine	Palmerston North
9340	Ruahine / Featherston	Palmerston North
9370	Ruahine / Ferguson	Palmerston North
9625	Albert / Ferguson	Palmerston North
9805	BOTANICAL / PIONEER	Palmerston North

Signalised Crossroads on the One-way System

Site ID	Location	Centre
21	Antigua/Tuam	Christchurch
27	Armagh/Barbadoes	Christchurch
30	Armagh/Durham	Christchurch
32	Armagh/Madras	Christchurch
58	Barbadoes/Cashel	Christchurch
61	Barbadoes/Ferry	Christchurch
62	Barbadoes/Gloucester	Christchurch
63	Barbadoes/Hereford	Christchurch
64	Barbadoes/Kilmore	Christchurch
70	Barbadoes/Tuam	Christchurch
72	Barbadoes/Worcester	Christchurch
81	Barrington/Jerrold North	Christchurch
82	Barrington/Jerrold Sth	Christchurch
170	Cambridge/Durham/Gloucester	Christchurch
172	Cambridge/Hereford	Christchurch
187	Cashel/Madras	Christchurch
189	Cashel/Montreal	Christchurch
222	Colombo/Kilmore	Christchurch
227	Colombo/Salisbury	Christchurch
228	Colombo/St Asaph	Christchurch
273	Durham/Peterborough	Christchurch
277	Durham/Tuam	Christchurch
339	Gloucester/Montreal	Christchurch
396	Hereford/Montreal	Christchurch
414	Riccarton/Oxford/Tuam/Hagley	Christchurch
441	Kilmore/Manchester	Christchurch
451	Latimer East/Worcester	Christchurch
472	Madras/Tuam	Christchurch
488	Manchester/Salisbury	Christchurch
489	Manchester/St Asaph	Christchurch
517	Montreal/Tuam	Christchurch

Signalised T-Junctions

Site ID	Location	Centre
3	Aikmans/Papanui	Christchurch
9	Aldwins/Harrow	Christchurch
14	Annex/Blenheim	Christchurch
40	Athelstan/Barrington	Christchurch
46	Avonhead/Yaldhurst	Christchurch
101	Bealey/Sherborne	Christchurch

Site ID	Location	Centre
107	Berwick/Cranford	Christchurch
117	Blenheim/Hansons	Christchurch
123	Blighs/Papanui	Christchurch
141	Brougham/Durham	Christchurch
155	Buckleys/Russell	Christchurch
229	Colombo/Strickland	Christchurch
230	Colombo/Tennyson	Christchurch
245	Cranford/Main North	Christchurch
259	Daniels/Main North	Christchurch
261	Deans/Kilmarnock	Christchurch
265	Division/Riccarton	Christchurch
342	Gloucester/Rolleston	Christchurch
367	Hansons/Riccarton	Christchurch
394	Hereford/Linwood	Christchurch
414	Hospital/Riccarton	Christchurch
476	Main North/Prestons	Christchurch
478	Main North/Sawyers Arms	Christchurch
482	Main South/Springs	Christchurch
500	Matipo/Riccarton	Christchurch
523	North Avon/North Parade	Christchurch
525	North Avon/Stanmore	Christchurch
538	Papanui/St Albans	Christchurch
579	Riccarton/Waimairi	Christchurch
580	Middlepark/Yaldhurst	Christchurch
999	Carlton Mill	Christchurch
9805	Botanical / Featherston	Palmerston North
9807	Broadway/Square	Palmerston North
9810	Church/Square	Palmerston North

Roundabouts

Site ID	Location	Centre
5	Albert/Centaurus/Wilsons	Christchurch
24	Apsley/Cutts/Woodbury	Christchurch
42	Avondale/Bassett/New Brighton	Christchurch
44	Avonhead/Grahams/Merrin	Christchurch
45	Avonhead/Maidstone	Christchurch
78	Barrington/Cashmere/Purau	Christchurch
90	Beach/Bower	Christchurch
108	Berwick/Forfar/Warrington	Christchurch
110	Bexley/Breezes/Bridge/Dyers	Christchurch
113	Birmingham/Vanadium/Wrights	Christchurch

Site ID	Location	Centre
131	Bridge/Estuary	Christchurch
135	Bristol/Holly	Christchurch
150	Buchanans/Carmen	Christchurch
152	Buchanans/Pound	Christchurch
162	Burwood/Mairehau	Christchurch
164	Burwood/QEII/Travis	Christchurch
192	Cashel/Stanmore	Christchurch
193	Cashmere/Colombo/Centaurus/Dyers Pass	Christchurch
210	Claridges/Highsted	Christchurch
213	Clyde/Ilam	Christchurch
262	Deans/Riccarton	Christchurch
282	Dyers/Ferry/Tunnel	Christchurch
294	Ensors/Opawa	Christchurch
324	Frankleigh/Lyttelton/Sparks	Christchurch
331	Gayhurst/McBratneys	Christchurch
334	Glandovey/Idris	Christchurch
347	Grahams/Waimairi	Christchurch
362	Halswell Junction/Shands	Christchurch
389	Hendersons/Sparks	Christchurch
399	Hereford/Stanmore	Christchurch
405	Highsted/Sawyers Arms	Christchurch
411	Hoon Hay/Sparks	Christchurch
437	Kerrs/Woodham	Christchurch
497	Marshlands/Prestons	Christchurch
498	Marshlands/QEII	Christchurch
505	Memorial/Russley	Christchurch
509	Merrin/Withells	Christchurch
556	Roydvale/Wairakei/Wooldridge	Christchurch
564	St Martins/Waltham/Wilsons	Christchurch
567	Staveley/Withells/Woodbury	Christchurch
111	Bexley/Pages	Christchurch
336	Gloucester/Linwood	Christchurch
9630	Albert / Pahiatua / Te Awe Awe	Palmerston North
9635	Gillespies / Botanical / Tremaine	Palmerston North
9690	Victoria / Broadway	Palmerston North

Mid-block Sites

SiteID	Location	Centre
554	Colombo/Carlyle/Moorhouse	Christchurch
539	Tuam/Colombo/Durham	Christchurch
517	Gloucester/Colombo/Manchester	Christchurch

SiteID	Location	Centre
500	Armagh/Colombo/Manchester	Christchurch
501	Armagh/Oxford/Colombo	Christchurch
502	Beresford/Union/Oram	Christchurch
504	Cashel/Manchester/Madras	Christchurch
506	Edgeware/Caledonian/Sherborne	Christchurch
508	Riccarton/Mona Vale/Deans	Christchurch
510	Ferry/Aldwins-Ensors/Manning	Christchurch
512	Ferry/Cathrine/Palinurus-Rutherford	Christchurch
514	Ferry/Graftons/Aldwins-Ensors	Christchurch
516	Ferry/Heathcote/Oak	Christchurch
518	Gloucester/Durham/Colombo	Christchurch
520	Hereford/Colombo/Manchester	Christchurch
522	Hereford/Durham/Colombo	Christchurch
524	Lincoln/Barrington-Whiteleigh/Clarence South	Christchurch
526	Lincoln/Dickens/Wise	Christchurch
528	Marriner/Esplanade/Burgress-Wakefield	Christchurch
530	Normans/Strowan/Searells	Christchurch
532	Opawa/Reeves/Vincent East	Christchurch
534	Riccarton/Clarence-Straven/Mandeville	Christchurch
536	Riccarton/Matipo/Division	Christchurch
538	Tuam/Colombo/Manchester	Christchurch
540	Wairakei/Grahams/Greers	Christchurch
542	Wairakei/Jennifer/Pitcairn	Christchurch
544	Wakefield/Marriner/Wiggins	Christchurch
550	Barrington/Athelston/Kniver	Christchurch
552	Barrington/Frankleigh-Milton/Athelstan	Christchurch
556	Colombo/Cashmere-Centaurus/Wherstead	Christchurch
557	Colombo/Dundas/Welles	Christchurch
558	Colombo/Holly-Canon/Edgeware	Christchurch
559	Colombo/Kilmore/Salisbury	Christchurch
560	Colombo/Purchas/Holly-Canon	Christchurch
562	Colombo/Sandyford-Byron/Carlyle	Christchurch
564	Colombo/Stanley/Wordsworth	Christchurch
566	Farrington/Raleigh/Eastling	Christchurch
568	Main/Augusta/Taupata	Christchurch
570	Main North/Halliwell/Sawyers	Christchurch
572	Main North/Harewood-Papanui/Langdons-Mary	Christchurch
574	Marine Parade/Beresford/Hawkes	Christchurch
575	Papanui/Bealey/Clare	Christchurch
576	Papanui/Blighs/Frank	Christchurch
578	Papanui/Frank/Horner	Christchurch

SiteID	Location	Centre
580	Selwyn/Coronation/Somerset	Christchurch
584	Stanmore/Draper-Swains/Alexandra-Vogel	Christchurch
586	Victoria/Kilmore/Salisbury	Christchurch
588	Victoria/Salisbury/Dorset	Christchurch
590	Waimairi/Maidstone/Tudor	Christchurch
594	Waimairi/Riccarton/Bowen	Christchurch
5507	Alexandra/Caro/Collingwood	Hamilton
5514	Alexandra/Hood/Collingwood	Hamilton
5521	Barton/Bryce/London	Hamilton
5528	Cambridge/Hillcrest/Masters	Hamilton
5535	Commerce/High/Kent	Hamilton
5542	Commerce/Keddel/Lake	Hamilton
5549	Fifth/Peachgrove-/John	Hamilton
5556	Grey/Cook/Clyde	Hamilton
5563	Lyndon/De Vere-Comries/Wake	Hamilton
5570	Rawhiti/Ken/Lake	Hamilton
5577	Victoria/Bryce/London	Hamilton
5584	Victoria/Hood/Collingwood	Hamilton
5591	Ward/Victoria/Worley	Hamilton

Appendix E Confidence intervals for generalised linear models

Confidence and prediction intervals for generalised linear accident models

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Abstract

Generalised linear models, with "log" link and either Poisson or negative binomial errors, are commonly used for relating accident rates to flows. This paper adds to the toolkit for such models. It describes how confidence intervals (for the true accident rate at a given flow) and prediction intervals (for example, for the number of accidents at a new intersection with a given flow) can be produced using spreadsheet technology.

Running head: Confidence intervals for accident models

Key words and phrases: Generalised linear model; negative binomial; Poisson

1 Introduction

Generalised linear models have gathered recognition in recent years (Maycock and Hall, 1984; Hauer et al., 1988; Maher and Summersgill, 1996) as useful tools for relating numbers of accidents, of a specifed type, to vehicle flow. For the single flow model, the true mean number of accidents μ is modelled as $\beta_0 x^{\beta_1}$, where x denotes the flow. The distribution of the observed number of accidents, for a given flow, is assumed to be either Poisson, or more generally, negative binomially distributed about this mean value. The negative binomial distribution occurs naturally when we allow for variation of safety M between intersections, with a given flow, to be modelled by a gamma distribution, and then variation of the number of accidents Y within an intersection, with safety M, to be modelled by a Poisson distribution with mean M. A detailed description of these models has been given in the companion paper (Wood, 2002), where methods for assessing goodness of fit were described.

Once goodness of fit is established for a model it is of interest to provide confidence intervals (for model parameters) and prediction intervals (for dependent variables); this is routinely carried out when working with linear models. Such intervals provide information about the extent of variation in these quantities. In this context the intervals of interest, for a given flow, are:

i) A confidence interval for μ, the true accident rate

ii) a) For a Poisson model, a prediction interval for y, the accident rate at a new intersection

b) For a negative binomial model, a prediction interval for m, the safety of a new intersection, and a prediction interval for y, the accident rate at a new intersection.

The purpose of this paper is to provide formulae, in Section 2, which enable construction of these intervals, and to illustrate their use with real accident data in Section 3. The required calculations can be carried out on a spreadsheet. All exposition is in terms of models with a single flow; models with more than one flow are handled in an extended, but similar, fashion. Notation and terminology used in this paper are as in Wood (2002).

Standard texts, for example McCullough and Nelder (1989), discuss confidence intervals for generalised linear model parameters; the author, however, has not found the approach discussed here in the literature, other than in Maher and Summersgill (1996). Here we clarify, amplify and extend that work.

Specifically, approximate confidence and prediction intervals appropriate for a given flow are developed. We caution that the confidence level necessarily decreases if we wish to make statements about many flow values. For this, so-called simultaneous (and necessarily wider) confidence bands are needed. The development of simultaneous confidence bands is a topic of current research; the work of Sun et al. (2000) produces such confidence bands for the mean in a generalised linear model.

This paper can be read in two ways. A reader interested in the practical construction of confidence and prediction intervals should skim Section 2, then work carefully through the examples of Section 3, referring to Section 2 and the appendix for formulae as needed.

For the reader interested in the underlying theory, careful reading of Section 2 and the appendix is recommended.

2 Confidence and prediction bands

A confidence interval for the true mean, for both the Poisson and negative binomial models, is developed in Section 2.1. In Section 2.2 a prediction interval for a predicted number of accidents at a new site is derived for the Poisson model, while in Section 2.3 prediction intervals for safety and predicted number of accidents at a new site are produced for negative binomial models.

2.1 Confidence band for μ

The generalised linear model we have described uses a "log" link function; the logarithm of μ is linear in the model parameters β_0' and β_1, since $\eta = \log \mu = \log \beta_0 + \beta_1 \log x = \beta_0' + \beta_1 \log x$, for the single flow model. Standard generalised linear model theory gives that asymptotically the estimates b_0' and b_1, of β_0' and β_1 respectively, have a bivariate normal distribution (Dobson, 1990), in particular

$$\begin{bmatrix} b_0' \\ b_1 \end{bmatrix} \sim N\left(\begin{bmatrix} \beta_0' \\ \beta_1 \end{bmatrix}, I^{-1}\right),$$

so they are unbiased, with covariance matrix the inverse of the information matrix I. It follows that $\hat{\eta} = b_0' + b_1 \log x$ has asymptotically a normal distribution and since $\hat{\eta} = \log \hat{\mu}$, where $\hat{\mu} = e^{b_0'} x^{b_1}$, $\hat{\mu}$ has an approximately lognormal distribution.

3

This enables us to write down an approximate 95% confidence interval for η, when the flow is x, as

$$b_0' + b_1 \log x \pm 1.96\sqrt{\text{Var}(b_0' + b_1 \log x)},$$

whence a 95% confidence interval for $\mu = e^\eta$ is given by

$$\left(e^{b_0'+b_1 \log x - 1.96\sqrt{\text{Var}(b_0'+b_1 \log x)}},\ e^{b_0'+b_1 \log x + 1.96\sqrt{\text{Var}(b_0'+b_1 \log x)}}\right)$$

The lower boundary here is closer to the estimate $\hat{\mu}$ of μ than is the higher boundary, reflecting the right skewed lognormal distribution of the estimate $\hat{\mu}$. Here

$$\begin{aligned}\text{Var}(b_0' + b_1 \log x) &= \text{Var}(b_0') + 2\log x\text{Cov}(b_0', b_1) + (\log x)^2\text{Var}(b_1) \\ &= I_{11}^{-1} + 2\log x I_{12}^{-1} + (\log x)^2 I_{22}^{-1}\end{aligned}$$

Illustrative real examples are given in Section 3.

There are two ways to find the components of I^{-1}. If the model is fitted using a statistical package then options are generally available which output the covariance matrix I^{-1} of the paramaters. On the other hand, if using the first principles method described in (Wood, 2002, A.3) then the required covariance matrix is $(X'WX)^{-1}$, where X is the design matrix and W a diagonal matrix.

A final remark in this subsection: the log-normal distribution of $\hat{\mu}$ discussed can be approximated by a normal distribution, or

$$\hat{\mu} \sim N\left(\mu_0 = \mu, \sigma_0^2 = \mu^2\text{Var}(\hat{\eta})\right)$$

(as in Maher and Summersgill (1996), Equation (14)). This approximate sampling distribution for $\hat{\mu}$ is fundamental in the sequel.

2.2 Poisson model

We consider the case of the Poisson model and an interval for a predicted number of accidents, y. Under the model, given a true mean accident rate of μ, the conditional distribution of accidents Y is Poisson with mean μ. A confidence interval for the number of accidents Y, however, must now accommodate the approximately normal variation in $\hat{\mu}$, our estimator of μ, as $N(\mu_0, \sigma_0^2)$. Table 1 summarises the variables involved.

Variable description	Variable notation	Distribution
Accident rate, given true rate μ	$Y\vert\mu$	Poisson(μ)
Estimator of true mean accident rate	$\hat{\mu}$	$N(\mu_0, \sigma_0^2)$

Table 1: The two levels of variation, first in μ, then in Y given μ, to be considered when forming a prediction interval for y in the Poisson model.

The marginal distribution of Y is thus a mixture of Poisson distributions, on the mean, by a normal distribution. It can be shown that the distribution of Y, supported by $\{0, 1, 2, \ldots\}$ has mean μ_0 and variance $\sigma_0^2 + \mu_0$. (The key to this calculation is the observation that a central moment of a mixture is the mixture of the central moments of the distributions being mixed.) Our intuition does tell us that this variance should depend on that of $\hat{\mu}$, namely σ_0^2, and also should increase as μ_0 increases, since Poisson distributions with larger mean have greater variance. This is captured in the expression $\sigma_0^2 + \mu_0$.

Chebyshev's inequality (Feller, 1966), namely

$$P(|Y - \mu_Y| \geq t\sigma_Y) \leq \frac{1}{t^2} \quad \text{for } t > 0,$$

is a most useful result and can be used to produce a prediction interval. When the interval is one-sided (so for low mean values) Chebyshev's one-sided inequality (Feller, 1966, Section V.7, Example (a)), namely

$$P(Y - \mu_Y \geq t\sigma_Y) \leq \frac{1}{1 + t^2} \quad \text{for } t > 0,$$

provides a tighter interval. A formula, exploiting the discreteness of the distribution of Y, however, has been developed and offers a slight strengthening of this approach. It is described in the appendix and its use illustrated in Section 3. Further tightening of this confidence interval is doubtless still possible, for example, by making use of third and higher moments.

2.3 Negative binomial model

We now develop intervals for safety and predicted number of accidents, for the negative binomial model; there are three mixtures involved. We first study construction of a prediction interval for intersection safety M, which rests on a mixing process analogous to the Poisson case. We then see that the negative binomial conditional distribution of Y, given μ and k, is a mixture, as is the marginal distribution of Y.

Prediction interval for safety m

Here we find a prediction interval for m, the underlying intersection safety described in Hauer et al. (1988), as the flow x varies. We answer the question "If we selected another intersection with flow x, where would m lie?" Table 2 summarises the variables involved.

Variable description	Variable notation	Distribution
Safety, given true rate μ	$M\|(\mu, k)$	$\text{Gamma}(k, \mu/k)$
Estimator of true mean accident rate	$\hat{\mu}$	$N(\mu_0, \sigma_0^2)$

Table 2: The two levels of variation, first in μ, then in M given μ and k, needed when producing a prediction interval for safety m, for the negative binomial model.

Here we mix gamma distributions with a normal; it can be shown that the marginal distribution of M has mean μ_0 and variance $\sigma_0^2 + (\sigma_0^2 + \mu_0^2)/k$. If we assume approximate normality (this will improve as μ increases) and recalling that k is estimated as $\hat{k}$ during the fitting process, an approximate 95% prediction interval for intersection safety m is

$$\hat{\mu} \pm 1.96\sqrt{\hat{\mu}^2\text{Var}(\hat{\eta}) + \frac{\hat{\mu}^2\text{Var}(\hat{\eta}) + \hat{\mu}^2}{\hat{k}}}$$

Estimates $\hat{\mu}$ and $\text{Var}(\hat{\eta})$ can be readily evaluated, as described earlier. Simulation tests, using typical parameter values, have shown this to provide a satisfactory prediction interval approximation.

Prediction interval for number of accidents y

Here we find a prediction interval for the number of accidents y at an intersection, randomly chosen from those with flow x. The relevant variables are summarised in Table 3.

Variable description	Variable notation	Distribution
Accident rate, given safety m	$Y\|m$	Poisson(m)
Safety, given true rate μ	$M\|\mu, k$	Gamma($k, k/\mu$)
Estimator of true mean accident rate	$\hat{\mu}$	$N(\mu_0, \sigma_0^2)$

Table 3: The three levels of variation involved in forming a prediction interval for y in the negative binomial model; first in μ, then in M given μ and k, and finally in Y given m.

The model builds the distribution of accidents across all sites with flow x, first as a mixture of the Poisson within site variation $Y|m$ by the gamma across site variation $M|\mu, k$, well known to be negative binomial with parameters k and $p = k/(\mu + k)$, as described in (Wood, 2002, p.425). Second, we must now recognise that μ itself is unknown, so the accident rate is really a mixture of negative binomial $Y|k, p$ variables by a normal distribution on μ.

The marginal distribution of Y, the number of accidents at a site with flow x, having support in $\{0, 1, 2, \ldots\}$, can be shown to have mean μ_0 and variance $\sigma_0^2 + (\sigma_0^2 + \mu_0^2)/k + \mu_0$. All quantities can be found during model fitting, as earlier. Note that as k increases the variance shrinks to that found in the Poisson case. Chebyshev's one-sided inequality, or the slightly stronger method of the appendix, can be used to produce a prediction interval for y.

3 Examples

Illustrations of each of the intervals described are now given, using two New Zealand accident datasets.

3.1 Poisson model

A Poisson model was used to relate loss-of-control accidents to incoming flow at 289 arms of both priority and uncontrolled T-intersections throughout New Zealand, yielding $b_0' = -4.5260$ and $b_1 = 0.2883$. The grouped G^2 method described in (Wood, 2002, Section 4.3) was used to test the goodness of fit of the model; there was no evidence of poor fit. In order to find a confidence interval for μ, the covariance matrix $(X'WX)^{-1}$ was obtained as a bi-product of the fitting process, as

$$I^{-1} = \begin{bmatrix} 2.6724 & -0.5140 \\ -0.5140 & 0.1018 \end{bmatrix}$$

For a flow of $x = 600$, for example, this gives $\text{Var}(b_0' + b_1 \log x) = 0.2615$, whence an approximate 95% confidence interval for μ is $(0.0251, 0.1865)$. The full confidence band, as x varies, is shown (long dashes) around the fitted curve (solid line) in Figure 1.

For each flow, $\mu_0 = \hat{\mu}$ and $\sigma_0^2 = \hat{\mu}^2\text{Var}(\hat{\eta})$ were then calculated, as described in Section 2.2. The formula given in the appendix was then applied, yielding the 95%

band for a predicted y value, shown as the stepped line in Figure 1. (The 90% band was everywhere $\{0\}$, so the horizontal axis in the figure.)

Figure 1 here

Figure 1: A Poisson model (solid line) relates accident rate to flow for the loss-of-control data. A 95% confidence band for the true accident rate μ is shown with the dashed lines, while a 95% prediction band for the number of accidents y at at new site is shown with the stepped line.

3.2 Negative binomial model

Rear-end accidents at 392 arms of signalised crossroads throughout New Zealand were related to flow using the negative binomial model, producing $b_0' = -16.3141$, $b_1 = 1.6330$ and $\hat{k} = 0.60$. Goodness of fit of the model was tested using the method presented in (Wood, 2002, Section 4.4), revealing no evidence of poor fit. Again, the covariance matrix for b_0' and b_1, $(X'WX)^{-1}$ was obtained as

$$I^{-1} = \begin{bmatrix} 8.4048 & -0.9347 \\ -0.9347 & 0.1042 \end{bmatrix}$$

allowing construction of a 95% confidence band for μ, as described for the Poisson model. For example, for $x = 10000$, we find $\hat{\mu} = 0.2798$ and $\text{Var}(\hat{\eta}) = \text{Var}(b_0' + b_1 \log x) = 0.0296$, whence an approximate 95% confidence interval is $(0.1998, 0.3920)$. The full confidence band is shown (long dashes) around the fitted curve (solid line) in Figure 2.

The variance of M, for a given flow, was then calculated as $\sigma_0^2 + (\sigma_0^2 + \mu_0^2)/k$, as described in Section 2.3. Continuing this example, for $x = 10000$, and recalling that $\hat{k} = 0.60$, this provides a 95% prediction interval for m of $(0, 1.005)$. The full prediction band is shown (short dashes) in Figure 2.

Finally, the variance of a predicted Y is calculated using the formula given in Section 2.3, for each flow level, and the formula described in the appendix used to calculate the upper limit of the prediction interval. For example, for $x = 10000$ and using $\hat{\mu}_i$, $\text{Var}(\hat{\eta}_i)$ and $\hat{k}$ as before we find that $\{0, 1, 2\}$ provides a 90% interval. The full prediction band is shown in Figure 2 (stepped horizontal lines).

Figure 2 here

Figure 2: A negative binomial model (solid curve) relates accident rate to flow for the rear-end data. A 95% confidence band for the true accident rate μ is shown (long-dashes) and a 95% prediction band for the safety m (short dashes), while a 90% prediction band for the number of accidents at a new site is shown (stepped horizontal lines).

4 Summary

Approximate confidence intervals for the true mean have been presented (Section 2.1) for Poisson and negative binomial generalised linear accident models. An approximate prediction interval for a predicted accident rate has been developed (Section 2.2) for the Poisson model. The form of this interval for the negative binomial model has also

11

been presented (Section 2.3), together with a prediction interval for a predicted safety. Examples hve been used (Section 3) to illustrate the ideas.

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Appendix

A strengthening of the one-sided Chebyshev inequality, exploiting the integer support of Y and appropriate for the typically low mean values ($\mu < 1$) encountered in accident modelling, is presented. It provides a formula for the upper limit of a one-sided prediction interval for y. In the remainder, Y is a random variable taking values in $\{0, 1, 2, \ldots\}$, with mean μ and variance σ^2. Table 4, in summary form, shows the prediction $100(1-\alpha)\%$ interval as μ varies.

μ interval	$100(1-\alpha)\%$ prediction interval
$0 \le \mu \le \alpha$	$\{0\}$
$\alpha < \mu \le 0.5$	$\{0, 1, \ldots, \lfloor \mu + \sqrt{\mu^2 - (\mu^2 - \sigma^2)/\alpha} \rfloor\}$
$0.5 < \mu < 1$	$\{0, 1, \ldots, \lfloor \mu + \sqrt{1 + \mu^2 + (\mu^2 + \sigma^2 - \mu(1+2\alpha))/\alpha} \rfloor\}$

Table 4: Upper limits for the prediction interval for y, as μ varies ($\lfloor x \rfloor$ denotes the largest integer less than or equal to x).

The reasoning behind these formulae follows now. We let $p_i = \Pr(Y = i)$ for $i = 0, 1, \ldots$. Then

$$\mu = \sum_{i=0}^{\infty} ip_i = \sum_{i=1}^{\infty} ip_i \geq \sum_{i=1}^{\infty} p_i = 1 - p_0$$

So if $0 \leq \mu \leq \alpha$, $p_0 \geq 1 - \mu \geq 1 - \alpha$ whence $\{0\}$ serves as a $100(1-\alpha)\%$ prediction interval.

Now suppose that $\alpha < \mu \leq 0.5$. It is always the case that

$$\sigma^2 = p_0(0-\mu)^2 + \sum_{i=1}^{x-1} p_i(i-\mu)^2 + \sum_{i=x}^{\infty} p_i(i-\mu)^2$$

where $x \geq 1$ is the largest positive integer such that $\Pr(Y \geq x) \geq \alpha$. At least probability $1 - \mu$ sits at zero and at least probability α sits to the right of and including x. By placing the maximum possible balance of the probability, $\mu - \alpha$, at the domain point closest to μ, namely zero, we can conservatively find x as the largest solution of

$$\sigma^2 \geq (1-\mu)\mu^2 + (\mu-\alpha)\mu^2 + \alpha(x-\mu)^2$$

or, with manipulation, the largest solution of

$$x^2 - 2\mu x + \frac{1}{\alpha}(\mu^2 - \sigma^2) \leq 0$$

The larger root of this quadratic is $\mu + \sqrt{\mu^2 - (\mu^2 - \sigma^2)/\alpha}$, from which the result follows.

When $0.5 < \mu < 1$ we follow the same path, but must place the balance of probability at the closest domain point to μ, now 1, so must find the largest integer x for which

$$\sigma^2 \geq (1-\mu)\mu^2 + (\mu-\alpha)(1-\mu)^2 + \alpha(x-\mu)^2$$

or $\mu + \sqrt{1 + \mu^2 + (\mu^2 + \sigma^2 - \mu(1+2\alpha))/\alpha}$, so demonstrating the result.

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Appendix F Land Transport New Zealand CAS movement codes

Land Transport NZ Ikiiki Whenua Aotearoa

VEHICLE MOVEMENT CODING SHEET

For use with crash data from **CAS** (Version 2.4 February 2005)

	TYPE	A	B	C	D	E	F	G	O
A	OVERTAKING AND LANE CHANGE	PULLING OUT OR CHANGING LANE TO RIGHT	HEAD ON	CUTTING IN OR CHANGING LANE TO LEFT	LOST CONTROL (OVERTAKING VEHICLE)	SIDE ROAD	LOST CONTROL (OVERTAKEN VEHICLE)	WEAVING IN HEAVY TRAFFIC	OTHER
B	HEAD ON	ON STRAIGHT	CUTTING CORNER	SWINGING WIDE	* BOTH OR UNKNOWN	LOST CONTROL ON STRAIGHT	* LOST CONTROL ON CURVE		OTHER
C	LOST CONTROL OR OFF ROAD (STRAIGHT ROADS)	OUT OF CONTROL ON ROADWAY	OFF ROADWAY TO LEFT	OFF ROADWAY TO RIGHT					OTHER
D	CORNERING	LOST CONTROL TURNING RIGHT	LOST CONTROL TURNING LEFT	MISSED INTERSECTION OR END OF ROAD					OTHER
E	COLLISION WITH OBSTRUCTION	PARKED VEHICLE	CRASH OR BROKEN DOWN	NON VEHICULAR OBSTRUCTIONS (INCLUDING ANIMALS)	WORKMANS VEHICLE	OPENING DOOR			OTHER
F	REAR END	SLOW VEHICLE	CROSS TRAFFIC	PEDESTRIAN	QUEUE	SIGNALS	OTHER		OTHER
G	TURNING VERSUS SAME DIRECTION	REAR OF LEFT TURNING VEHICLE	LEFT TURN SIDE SIDE SWIPE	STOPPED OR TURNING FROM LEFT SIDE	NEAR CENTRE LINE	OVERTAKING VEHICLE	* TWO TURNING		OTHER
H	CROSSING (NO TURNS)	RIGHT ANGLE (70° TO 110°)							OTHER
J	CROSSING (VEHICLE TURNING)	RIGHT TURN RIGHT SIDE	OBSOLETE	TWO TURNING					OTHER
K	MERGING	LEFT TURN IN	RIGHT TURN IN	TWO TURNING					OTHER
L	RIGHT TURN AGAINST	STOPPED WAITING TO TURN	MAKING TURN						OTHER
M	MANOEUVRING	PARKING OR LEAVING	"U" TURN	"U" TURN	DRIVEWAY MANOEUVRE	PARKING OPPOSITE	ENTERING OR LEAVING	REVERSING ALONG ROAD	OTHER
N	PEDESTRIANS CROSSING ROAD	LEFT SIDE	RIGHT SIDE	LEFT TURN LEFT SIDE	RIGHT TURN RIGHT SIDE	LEFT TURN RIGHT SIDE	RIGHT TURN LEFT SIDE	MANOEUVRING VEHICLE	OTHER
P	PEDESTRIANS OTHER	WALKING WITH TRAFFIC	WALKING FACING TRAFFIC	WALKING ON FOOTPATH	CHILD PLAYING (TRICYCLE)	ATTENDING TO VEHICLE	ENTERING OR LEAVING VEHICLE		OTHER
Q	MISCELLANEOUS	FELL WHILE BOARDING OR ALIGHTING	FELL FROM MOVING VEHICLE	TRAIN	PARKED VEHICLE RAN AWAY	EQUESTRIAN	FELL INSIDE VEHICLE	TRAILER OR LOAD	OTHER

* = Movement applies for left and right hand bends, curves or turns

Appendix G Unique identification code for APMs

Each APM developed can be identified by a unique code which gives information on the environment, user type, location, control and type of crashes it predicts. The following table outlines these codes.

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

1,2,3,4,…	Allocated in numerical order to crash types

6th Character – Non-conflicting Flow Variables

(blank)	Flow-only model
(Character)	Variable (for example ‘L’ for lane width)

Predicting Accident Rates for Cyclists and Pedestrians

Land Transport New Zealand
Research Report 289