Cycle Safety: Reducing the Crash Risk

October 2009

Shane Turner
Shane Binder
Aaron Roozenburg
Beca Infrastructure, PO Box 13-960, Christchurch

NZ Transport Agency research report 389

ISBN 978-0-478-35232-0 (PDF)
ISBN 978-0-478-35233-7 (paperback)
ISSN 1173-3764 (PDF)
ISSN 1173-3756 (paperback)

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

Turner, SA, AP Roozenburg, SI Binder. 2009. Cycle safety: reducing the crash risk. *NZ Transport Agency research report 389.* 104pp.

Keywords: bicycles, crash prediction models, crash, cycle facilities, cyclists, modelling, New Zealand, paths, prediction, reporting rates, roads, tracks

An important note for the reader

The NZ Transport Agency is a Crown entity established under the Land Transport Management Act 2003. The objective of the Agency is to undertake its functions in a way that contributes to an affordable, integrated, safe, responsive and sustainable land transport system. Each year, the NZ Transport Agency funds innovative and relevant research that contributes to this objective.

The views expressed in research reports are the outcomes of the independent research, and should not be regarded as being the opinion or responsibility of the NZ Transport Agency. The material contained in the reports should not be construed in any way as policy adopted by the NZ Transport Agency or indeed any agency of the New Zealand Government. The reports may, however, be used by New Zealand Government agencies as a reference in the development of policy.

While research reports are believed to be correct at the time of their preparation, the NZ Transport Agency, and agents involved in their preparation and publication, do not accept any liability for the use of the research. People using the research, whether directly or indirectly, should apply and rely on their own skill and judgement. They should not rely on the contents of the research reports in isolation from other sources of advice and information. If necessary, they should seek appropriate legal or other expert advice.

Acknowledgments

The research team would like to acknowledge Tim Hughes from the NZ Transport Agency, who provided a list of road sections in Christchurch with cycle facilities and data on these road sections.

We would also like to acknowledge Peter Kortegast (formerly of Nelson City Council) and Sandi Morris of Palmerston City Council, who provided data on cycle facilities in their respective cities.

Abbreviations and acronyms

ACC	Accident Compensation Corporation
BIC	Bayesian Information Criterion
CCC	Christchurch City Council
CHIRP	Cycle Hazard and Incident Reporting (Programme)
CAS	Crash Analysis System
Empirical Bayes Method	A method used to undertake before-and-after studies to determine change in crashes resulting from changes to roading features (eg installation of cycle lanes)
IHT	Institution of Highways and Transportation (UK)
LTNZ	Land Transport New Zealand (now merged with Transit to form the NZ Transport Agency)
NZTA	NZ Transport Agency
OECD	Organisation for Economic Co-operation and Development
SWOV	Stichting Wetenschappelijk Onderzoek Verkeersveiligheid (Institute for Road Safety, the Netherlands)

Contents

Executive summary

Introduction

Cycling is a sustainable mode of travel and an alternative to motor vehicle trips, particularly for shorter trips (less than 5km). Government transport strategies, including the New Zealand Transport Strategy and *Getting there – on foot, by cycle,* encourage the development of cycling and walking plans and infrastructure improvements that encourage more 'active' mode trips. While health and transport benefits are likely to result from promoting more cycling, the risk of having a crash while cycling is typically higher than while travelling as a driver or passenger in a motor vehicle. This is of concern to cyclists, potential cyclists and organisations involved in road safety.

The challenge for transport engineers and planners is to create a transportation environment that is as safe as possible for cyclists. This can be achieved through a series of measures, including, where practical, reducing traffic volumes and speeds, building on-road cycle lanes and intersection facilities, and constructing of off-roadway cycle paths. The safety benefit of most of these measures has not, to date, been quantified in New Zealand. Internationally, the research is also limited, particular in terms of the direct relationship between crashes and various roadway features and traffic conditions. This study extends previous work on the relationship between crashes and volumes of cycles and motor vehicles to the development of crash prediction models for on-roadway cycle facilities at intersections and along road links. The effects of speed and off-roadway paths have been assessed based on overseas research.

Historically, off-roadway paths and quiet streets were the primary components of most cycle networks. In many cities, including most of the large Australasian cities, the focus is still on getting cyclists off busy arterial routes and onto off-roadway paths and local low speed streets. However, the disadvantage to many cyclists of off-roadway paths and local roads is that they are often not as direct as arterial roads, which is likely to be less attractive to many 'confident' cyclists, given the longer travel times experienced by cyclists compared to motor vehicles. Issues also arise at each end of the cycle path, where cyclists normally have to use arterial routes to access their destinations. As cycling volumes grow, it will become increasingly more important to provide on-roadway facilities for cyclists. A key element of this study is to understand and quantify the safety effect of cycle lanes, car parking and other improvement measures, such as intersection treatments and flush medians, on cycle safety, particularly on higher volume routes. We appreciate that in many cities, this requires the reallocation of road space to cycle facilities, which may not be popular with some stakeholders. In such discussions, the evidence of safety gains for such improvements is particularly important and is a key driver for this research project, which was undertaken in 2006.

On-roadway cycle safety (crash prediction models)

Crash prediction models have been developed for on-roadway cycle lanes at intersections (traffic signals) and along mid-block road links using a sample of sites from Christchurch, Hamilton and Palmerston North. The study looked at ‘cycle v motor vehicle crashes’ and ‘all crashes’, and the relationship each type has with traffic volume, cycle volume and a number of roadway factors. The mid-block models were also separated into ‘turning (in and out of driveways and minor side-roads)’ crashes and ‘non-turning’ crashes. Table XS1 shows the models that were prepared and the key variables that feature in each model.

Table XS1 Crash prediction models

Crash type	Equation (crashes per approach)	Error structure	GoF[a]
Cyclist mid-block crashes	$A_{UCMN\ 0} = 1.05 \times 10^{-2} \times Q^{0.25} \times C^{0.16} \times L^{0.45} \times \phi_{FLUSHMEDIAN}$ $\phi_{FLUSHMEDIAN} = 0.63$	NB[b] k=1.7[c]	0.05
All mid-block crashes	$A_{UAMN\ 0} = 2.36 \times 10^{-4} \times Q^{0.84} \times L^{0.30}$ $\times \phi_{NO\_PARKING}$ $\phi_{NO\_PARKING} = 0.25$	NB k=1.4	0.17
Cyclist mid-block turning crashes	$A_{UAMN\ 1} \times 1.37 \times 10^{-3} \times Q^{0.56} \times L^{0.54} \times$ $\phi_{FLUSHMEDIAN}$ $\phi_{FLUSHMEDIAN} = 0.48$	NB k=1.3	
All mid-block turning crashes	$A_{UAMN\ 1} = 1.37 \times 10^{-3} \times Q^{0.56} \times L^{0.10}$ $\times \phi_{NOPARKING}$, $\phi_{NO\,PARKING} = 0.25$	NB k=0.8	0.09
Cyclist mid-block non-turning crashes	$A_{UCMN\ 2} = 2.28 \times 10^{-4} \times Q^{0.31} \times C^{0.50} \times L^{0.27}$	Poisson	0.31
All mid-block non-turning crashes	$A_{UAMN\ 2} = 4.39 \times 10^{-5} \times Q^{0.97} \times L^{0.42}$ $\times \phi_{NOPARKING}$, $\phi_{NO\,PARKING} = 0.25$	NB k=1.6	0.17
Cyclist signalised crossroad product of link	$A_{UCXT\ 0} = 6.16 \times 10^{-3} \times Q^{0.17} C^{0.03} \times$ $\phi_{CYCLANE}$ $\phi_{CYCLANE} = 1.41$	Poisson	0.25
All signalised crossroad product of link	$A_{UMXT\ 0} = 3.71 \times 10^{-4} \times Q^{0.67}$	Poisson	0.05

a GoF (Goodness of Fit statistic) indicates the fit of the model to the data. A value of less than 0.05 indicates a poor fit, whereas a high value indicates a good fit.

b NB = negative binomial

c *k* is the gamma distribution shape parameter for the negative binomial distribution.

Table XS1 shows that traffic volume (*Q*) is an important variable in all models and that cycle volume (*C*) is an important variable in all ‘cycle v motor vehicle’ crash types. Length (*L*) is also an important variable in mid-block crashes, with safety improving as the lengths between major intersections (roundabouts and traffic signals) increase.

The presence of a flush (or painted) median (FLUSHMEDIAN) reduces cycle-related crashes for mid-blocks (by 37%), particularly where turning traffic is involved (52%), according to the models. This is likely to be a result of the extra space that cyclists and motor vehicles have to take evasive action if a crash is likely. The availability of space is a key issue for cyclists, which is reflected in this result. This, of course, is difficult to achieve on busy arterial roads, and providing (more) room for cyclists is a trade-off that needs to be made in balance with the requirements of other road users. Where cycle volumes are high and carriageways are typically wide, as occurs in Christchurch, this is not as difficult to justify as in cities like Auckland, where carriageways and lane widths are typically narrower and cycle volumes are lower.

The absence of parking is a key factor for the 'all crashes' mid-block models. The overall reduction is 75%, indicating that parking does have a major effect on crash rates. While parking is not the key safety factor, routes where parking is little used (ie where a parking lane is marked, but the proportion of parking spaces that are used is low) have crash rates between 30% and 120% higher than for sections with average parking rates (these models are provided in appendix A). This could be a result of cyclists using the parking shoulder for most of their trip and having to pull out into the traffic lane to go around parked cars. This movement may catch motor vehicle drivers unawares, leading to a potential conflict. This finding needs further research to confirm the behaviour of cyclists and motor vehicles in such circumstances.

The presence of a cycle lane does not feature as a key discrete variable for the mid-block sections, where flush medians and 'no parking' zones appear to be more important variables. However, crash prediction models have been developed that include the presence of a cycle lane (see appendix A) and it was found that crash rates were typically 20–30% higher on those routes with cycle lanes. This did not compare well with overseas research, which typically shows a reduction in all crashes. A 'before and after' study was undertaken and it was found that a 10% reduction in all crashes was found at those sites that have had cycle lanes installed. The difference is likely to be the result of more cyclists using the roadway as a result of the cycle lane going in compared with untreated sites (we only had 'after' cycle counts) and a bias toward treating routes which had a history of cycle crashes. Even the crash reduction of 10% seems low compared to overseas research, and this may be caused by the increase in cyclists and by some of the older cycle lanes included in the study being below standard, particularly in terms of width. The traffic signal model also showed that cycle facilities increased the crash rate. Further research is underway on the effect of various cycle facilities at intersections.

The overseas research indicates that the number of crashes decreased when on-roadway cycle lanes were installed; the reduction of cyclist crashes generally varied from 35% to 50%, although one source did report an increase in cyclist crashes. Total (cycle and motor vehicle) crashes were found to decline by 6.5% to 35%. This compares with the 10% of 'all crashes' that are saved in this study. It was also found that narrower cycle lanes were three to four times less safe than wider cycle lanes, which may be a factor in several of the sites used in this study.

Safety of cycle paths

Research on the safety aspects of off-roadway facilities is not available in New Zealand. The research findings that are available internationally are presented. The factors that should be considered when selecting either on-roadway or off-roadway facilities are discussed.

Studies conducted to compare the event rates for on- and off-roadway cycling have shown that shared-use footpaths are much less safe than other on- or off-roadway cycling options, with a wide amount of data indicating that cycling on the footpath is 1.8 to 2.5 times more dangerous than cycling on the roadway, and 8 to 11 times more dangerous than cycling on an off-roadway track (with very few or no driveways or vehicle crossings). In Denmark, before-and-after studies of off-roadway cycle paths were undertaken over a period of three years. The results showed that cyclist casualties increased by 48% following introduction of off-roadway cycle paths. In addition, vehicles, moped riders and pedestrians suffered more crashes, with an overall rise in casualties of 27%.

These footpath dangers arise principally from conflicts with motor vehicles, pedestrians and other cyclists.

In order to reduce these conflicts and make an off-roadway path safer, the three most important factors to accommodate appear to be:

- the number of motor vehicle crossings on the path and the priority at each crossing
- the visibility and pavement marking at crossings and underpasses
- the width of the off-roadway path.

The research also indicated that better footpath maintenance could improve the safety experience of footpath cyclists, as well as the distance from adjacent roadways, and the speed limit and number of lanes on adjacent roadways.

A British study analysed five types of cycle path crossings with minor roads and found that priority at such crossings was a major hazard for cyclists, followed by side-road motor vehicles blocking the cycle path. Cyclists remaining on the major roadway (as opposed to the off-roadway path) had fewer problems at the junctions with minor roads.

Speed and volume reduction measures

The Danish Ministry of Transport recommends that a desirable speed for motor vehicles where cyclists and motor vehicles use the same traffic lanes is less than 40km/h. This is supported by a number of other overseas studies. A Bicycle Federation of American report found that when vehicles travelling at 32km/h strike pedestrians and cyclists, only about 5% are killed and most injuries are slight. At 48km/h, 45% are killed and many are seriously injured. When cars were travelling at 64km/h, 85%of the pedestrians and cyclists are killed. Another study found that more than half of all cycle fatalities were found to be on roads with posted speed limits greater than 35mph (56km/h) even though less than 20% of all collisions occurred on roads with higher speeds. The Austrian city of Graz adopted a 30km/h speed limit for all residential areas except major roads (about 75% of all roads in Graz or 800 km), resulting in the number of cycle crashes dropping despite the number of cycle trips per day increasing. These studies support the view that reducing speed does improve cycle safety.

New Zealand has found that the crash rate per cyclist reduces as the cycle volume increases; the 'safety in numbers' effect. Conversely, if the cycle volume remains constant but the motorist volume is decreased, the expected crash rate per cyclist decreases and vice versa. This research can be used to calculate the safety effects of changes in both cycle and motor vehicle volumes in the New Zealand context, either up or down, for urban mid-block sections, traffic signals and roundabouts.

Treatment evaluation

A number of engineering treatments can be applied by engineers and other professionals to improve cycle safety. These treatments are typically grouped into a 'Five-Step Hierarchy' of measures:

1. reducing motor vehicle traffic volume
2. reducing motor vehicle traffic speeds
3. intersection treatment and traffic management
4. reallocation of carriageway/corridor space (eg on-roadway facilities)
5. separating cycle facilities (eg off-roadway routes)

The results from this study and from the international literature enable the effectiveness of various measures under each of these hierarchy categories to be quantified. The research undertaken is of variable quality and, in some areas, is not conclusive, and so should be used with caution. Nevertheless, the research does provide engineers and other planners with some evidence of the effectiveness of the various measures, which, along with the different implementation costs, can assist in the selection of an appropriate treatment to improve cycle safety.

Overall, this research and the literature that has been reviewed indicates that significant crash savings can be achieved for cyclists by implementing one or more of the measures specified. It needs to be acknowledged that different types of cyclists use our roads and that their needs vary. Young cyclists and new (novice) cyclists are likely to prefer off-roadway facilities, or low-volume and low-speed roads. More confident cyclists are also likely to ride on busy roads as they place a higher premium on using more direct routes, and their safety can be compromised if on-roadway facilities are not provided.

Abstract

Cycling is a sustainable mode of travel and an alternative to motor vehicle trips, particularly for shorter trips. However, the risk of crashing while cycling is typically higher than while travelling in a motor vehicle. To create a safer environment for cyclists, traffic engineers and transport planners can select a number of safety countermeasures. These include changes to the road layout, such as reducing traffic volumes and speeds; installing cycling lanes and paths; and conducting enforcement and education programmes focused on drivers and cyclists.

The crash benefits to cyclists of reducing traffic volumes and speeds, and constructing cycle lanes and intersection treatments have been investigated during 2006 and quantified based on overseas research and data collected within Christchurch, Palmerston North and Nelson. It was found that cycle lane facilities provided a reduction in cycle crashes of around 10%. No suitable New Zealand data is available on the safety of cycle paths and speed reduction measures, so the discussion focuses on international research findings.

1 Introduction

1.1 Background

Cycling is a sustainable mode of travel and an alternative to motor vehicle trips, particularly for shorter trips (less than 5km). Government transport strategies, including the New Zealand Transport Strategy (Ministry of Transport 2008) and *Getting there – on foot, by cycle* (Ministry of Transport 2006), encourage the development of cycling and walking plans, and infrastructure improvements that encourage more 'active' mode trips. Additional funding is also being provided in the national land transport programme specifically for active modes.

While promoting more cycling is likely to bring many benefits, the risk of having a crash while cycling is typically higher than while travelling as a driver or passenger in a motor vehicle. However, recent research by Turner et al (2006) demonstrates that a 'safety in numbers' effect for cyclists is commonly seen. At the traffic signals, roundabouts and mid-block sections considered in the research, the crash risk per cyclist reduced at higher cycle volumes. For several of the models, the crash risk per cyclist at higher average daily traffic cycle volumes was several magnitudes lower than at low volumes.

While this is reassuring, it remains that when a motor vehicle driver or passenger chooses to switch to cycling, their crash risk will generally increase, particularly when travelling on low-volume cycle routes or high-volume motor vehicle routes.

The challenge is to create an environment for cyclists that is as safe as possible. This can be achieved through a series of measures, including, where practical, reducing traffic volumes and speeds on high cycle volume routes, building on-roadway cycle lanes and intersection facilities, and constructing off-roadway cycle paths. The safety benefit of most of these measures has not been quantified. The relationship between cycle crash risk and traffic volumes has already been established. This study will extend the work by Turner et al (2006) to consider crash rates for on- and off-roadway cycle facilities.

1.2 Objectives

The purpose of this research is to establish the additional crash risk reductions that can be achieved by reducing traffic speed, and installing cycle lanes, cycle paths and intersection cycle facilities. This study has a number of objectives, including:

- calculating the safety benefit (reduction in crashes) of installing cycle lanes on urban routes (collectors and arterials with residential and commercial land use)
- assessing the safety benefit of installing various cycle facilities (eg approach lanes and forward waiting areas) at traffic signals and roundabouts
- comparing the crash risk of cyclists using on-roadway (cycle lane) and off-roadway (cycle path) facilities. (the cycle path analysis also investigates the crash risk at road crossings)
- assessing the safety benefit to cyclists of installing traffic calming or speed reduction measures.

This research is necessary, as many road safety specialists expect that a large mode shift from motor vehicles to cycling will lead to a significant increase in crashes. The research by Turner et al (2006) shows that a 'safety in numbers' effect occurs and that the crash risk drops significantly as cycle volumes increase. However, in most cases, the crash risk still remains higher than that of motor vehicle drivers and passengers. This research will examine what impact various cycle facilities can have on reducing the crash risk further.

1.3 Report structure

An international literature review has been carried out to establish what overseas research is available on the safety benefits of on- and off-roadway cycle facilities (chapter 2).

The report then summarises available data on cycle crashes in New Zealand, including data from the New Zealand Crash Analysis System (CAS), data reported from St. John's Ambulance, data extracted from the Accident Compensation Corporation (ACC) and public hospital databases, and data from the 0800 CYCLECRASH system (Nelson/Tasman) and other council reporting systems, such as the Cycle Hazard Incident Reports (CHIRP) system in Christchurch.

This is followed by a description and initial analysis of the data collected for this study, including crash traffic volumes and layout variables. The safety benefits and drawbacks of cycle facilities have then been assessed for on-roadway cycle lanes and intersection treatments using two analysis methods:

- crash prediction models
- Empirical Bayes Analysis.

The report also contains four appendices:

- Appendix A outlines the crash prediction model parameters.
- Appendix B explains the predictor variables and model parameters.
- Appendix C lists the subscripts used to name the models.
- Appendix D gives a list of works recommended for further reading on this topic.

1.4 Terminology

The terminology used to describe cycle facilities varies greatly internationally, and the terms 'lane', 'path' and 'track' have differing uses. The terminology used in this report is derived from that used in *The cycle network and route planning guide* (Land Transport New Zealand (LTNZ) 2004). The main terminology used here is:

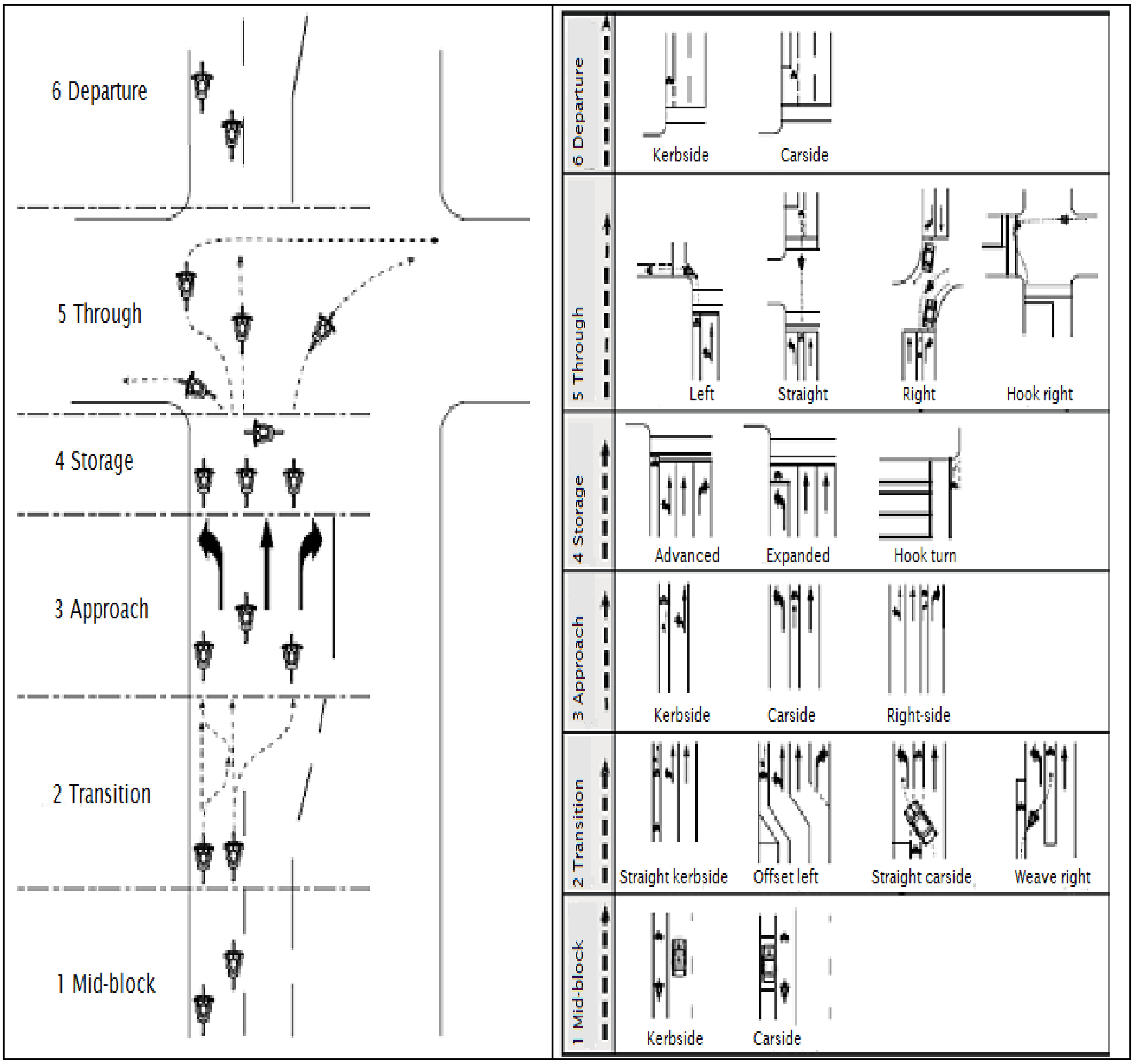
- **cycle lane:** a lane marked on a roadway with a cycle symbol, which can only be used by cyclists
- **cycle path:** an off-roadway path for cyclists. Cycle paths are further broken down:
  - **(shared-use) footpath:** a path immediately adjacent to or in very close proximity to the roadway which is typically shared with pedestrians, and may frequently cross driveways and side roads. It may also be known as a sidewalk overseas
  - **(off-roadway) track:** a cycle path typically segregated from a roadway facility, typically with longer distances between cycle crossings; eg a rail trail, a coastal or river path, or a path along the route of a motorway. It can be an exclusive cycle path, a shared-use path or

a separated path. Cycle tracks can include non-paved recreational tracks for mountain bikers but these facilities were not included in this research

- **cycle crossing:** a crossing of the road network by a cycle path.

A wide variety of terminology is also used in describing cycling facilities specifically at intersections. Cumming (2000) divided the model intersection for cyclists into six elements (see figure 1.1), although not all intersections have every element (eg many intersections lack storage for cyclists). Cumming's terminology is commonly used in New Zealand and has therefore been adopted through this report. This system simplifies a complex design problem into a number of smaller and more manageable design elements. Cumming also identified terminology for different types of the six model elements at intersections (also shown in figure 1.1).

Figure 1.1 Six elements and types of cycle facilities at intersections (adapted from Cumming 2000)



2 Literature review

2.1 Introduction

2.1.1 Legislation

When interpreting the outcomes of international studies into cycle facilities, it is important to consider the legislative and regulatory environment. In many countries and states, cycle lane and cycle path use is mandatory if they are present. In New Zealand, the Road User Rule (Ministry of Transport 2004) does not forbid cyclists from using general traffic lanes where an adjacent dedicated facility is present, except on motorways. This is not typical worldwide; for example, cycle facility use is mandatory in:

- The Netherlands
- Denmark
- Germany (if a bike lane sign is displayed)
- France (if required by local authorities)
- Ireland
- the Canadian Province of Quebec
- The States of Alabama, California, Hawaii, Maryland, New York, Oregon (if required by local authorities) and Pennsylvania (if indicated by a sign).

The United Kingdom has both advisory cycle lanes (use not required) and mandatory cycle lanes (use required) (Organisation for Economic Co-operation and Development (OECD) 1998). Motor vehicles are not allowed to park or drive in the mandatory lanes, but no such restrictions exist for the advisory lanes, which can provide more of a psychological space for cyclists instead of a legal space.

As different users benefit from different types of facilities and some facilities are less suitable for different groups (LTNZ 2004), mandatory use can influence the literature. A number of organisations and individuals internationally are opposed to specific provision for cyclists and argue for cyclists to be treated as 'vehicles.' This opposition possibly stems from mandatory use, whereas New Zealand has no such requirements.

Internationally, priority rules also differ. For example, Sweden has special rules for cyclists crossing the road, where the cyclist must take the speed and distance of the oncoming vehicles into consideration before crossing. In the Netherlands, cyclists must always give way to motorists at intersections without right of way regulations, except in special residential areas (*woonerven*) (OECD 1998). In New Zealand, cyclists are treated as vehicles if they are using the roadway; in other circumstances, they are treated more like pedestrians (for example on shared-use paths and mid-block signalised crossings). In other words, a cyclist on a shared-use path adjacent to a roadway must give way to traffic on intersecting crossroads and accesses, just as a pedestrian would.

2.1.2 Cyclist skill levels and needs

The type of users of a facility is an important consideration when examining cyclist safety. *The cycle network and route planning guide* (LTNZ 2004) groups cyclists into three main skill levels:

- child/novice
- basic competence
- experienced.

The type of facility that cyclists in each group prefer is an important. The purpose of a cycle trip also influences facility selection. Table 2.1 shows cyclists' skill levels and typical preferences (LTNZ 2004).

Table 2.1 Cyclist skill levels and preferences (adapted from LTNZ 2004)

Skill level	Characteristics	Preferences
Child/novice	Depending on their age, children have serious knowledge, perceptual and cognitive limitations in relation to roads. They can be unpredictable, do not have a good appreciation of road hazards and are generally unfamiliar with road rules. However, children as young as eight do not pose as high a risk as adolescents, as younger children have a reduced tendency for deliberate risk-taking behaviours.	These cyclists most commonly ride to schools and shops, and for recreation near their homes. They cannot safely interact with traffic apart from on traffic-calmed neighbourhood roads. They prefer full separation from other traffic if travelling along busier roads, and grade separation or traffic signals for crossing them.
Basic competence	Cyclists can achieve basic competence at about 10 years of age with appropriate training. Their utility trips generally extend further to intermediate and high schools.	These cyclists can ride on quiet two-lane roads, manoeuvre past parked cars, and merge across and turn right from beside the centre line. On busier roads, they prefer cycle lanes and facilities at intersections. They usually lack the confidence to defend a lane in narrow situations.
Experienced	These cyclists have usually learnt by long experience how best to interact assertively with traffic. They typically make longer commuting trips, sports training rides and cycle touring journeys.	They do not require specific cycle facilities, but instead require enough room for faster/busier situations. They will defend a lane where they do not have enough room, and will not usually divert to a cycle path.

2.2 Cycle facility safety

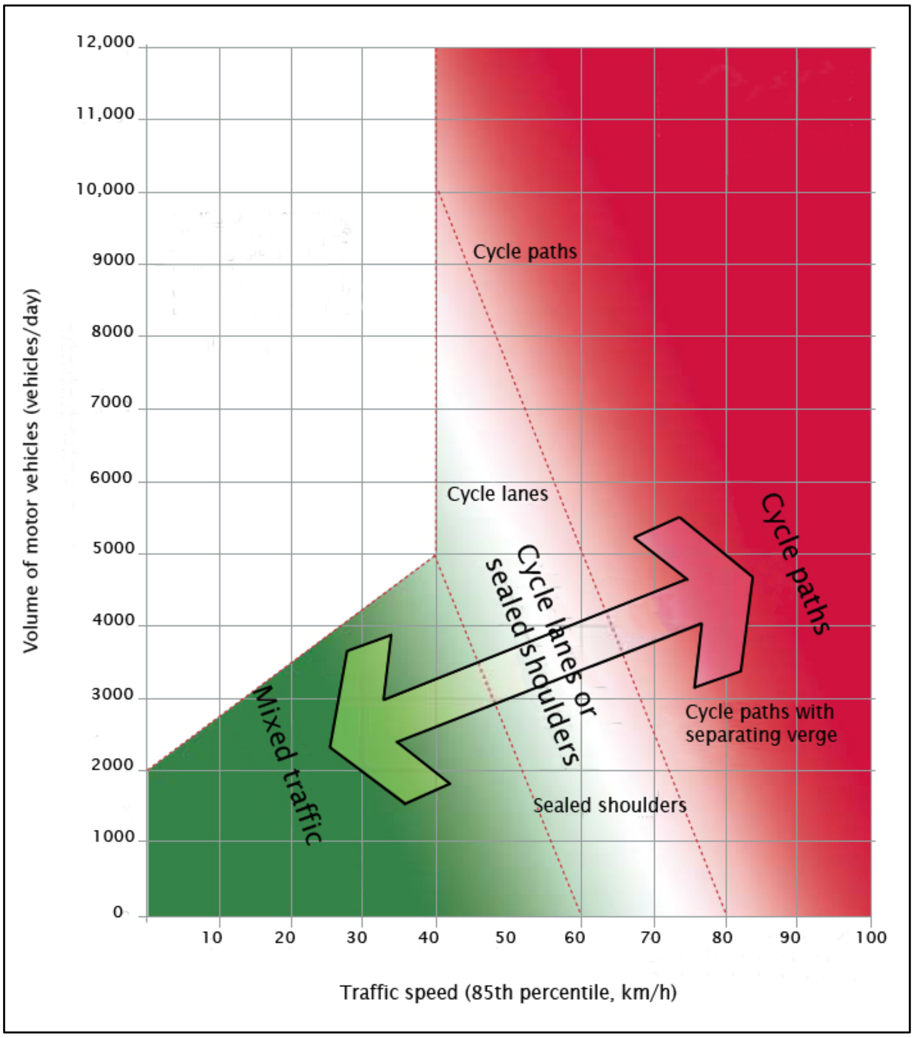
Facilities for cyclists are a highly debated topic in the international literature. A number of studies have been formulated to prove the advantages or disadvantages of particular facilities based on the personal positions of the authors. The centre of this argument is based on the provision of on- or off-roadway cycling networks.

Some authors advocate that cyclists should all behave as motor vehicles, as in most instances, the local traffic regulations allow this. Forester (2001) advocates this position. He states that the counterargument for off-roadway facilities is that they are supposedly safer, which encourages people to take up cycling. Forester argues that the basis of this argument incorrectly assumes that the high cycling rates in the Netherlands are attributed to an off-roadway cycling network, which does not take account of other important factors.

In the past, off-roadway paths and the use of quiet streets were advocated as the core cycle network because of the safety issues of cyclists and motor vehicles using the same space. More recently, processes have been developed to determine whether on- or off-roadway facilities should be provided based on traffic volumes and speeds (LTNZ 2004). Figure 2.1 shows the appropriate cycle facilities recommended for a mix of traffic volumes and speeds in the *Cycle network and route planning guide* (2004). Planners now have more awareness of how appropriate different types of facilities are to different types of cyclists.

However, some argue that traffic volumes and speeds are not the only measures to decide the cycle facilities. The London *Cycling design standards* (Transport for London 2005) provides the processes to decide appropriate cycle facilities and consider traffic calming options. Figure 2.2 shows that the two main options are either better mixed cycling conditions on calmed roads with limited space and low/slow traffic flows, or better segregation on high/fast traffic flows. It also recommends cycle lanes should be considered as the first option where both on-roadway cycle lanes and off-roadway cycle paths are appropriate.

Figure 2.1 Preferred separation of bicycles and motor vehicles according to traffic speed and volume (adapted from LTNZ 2004)

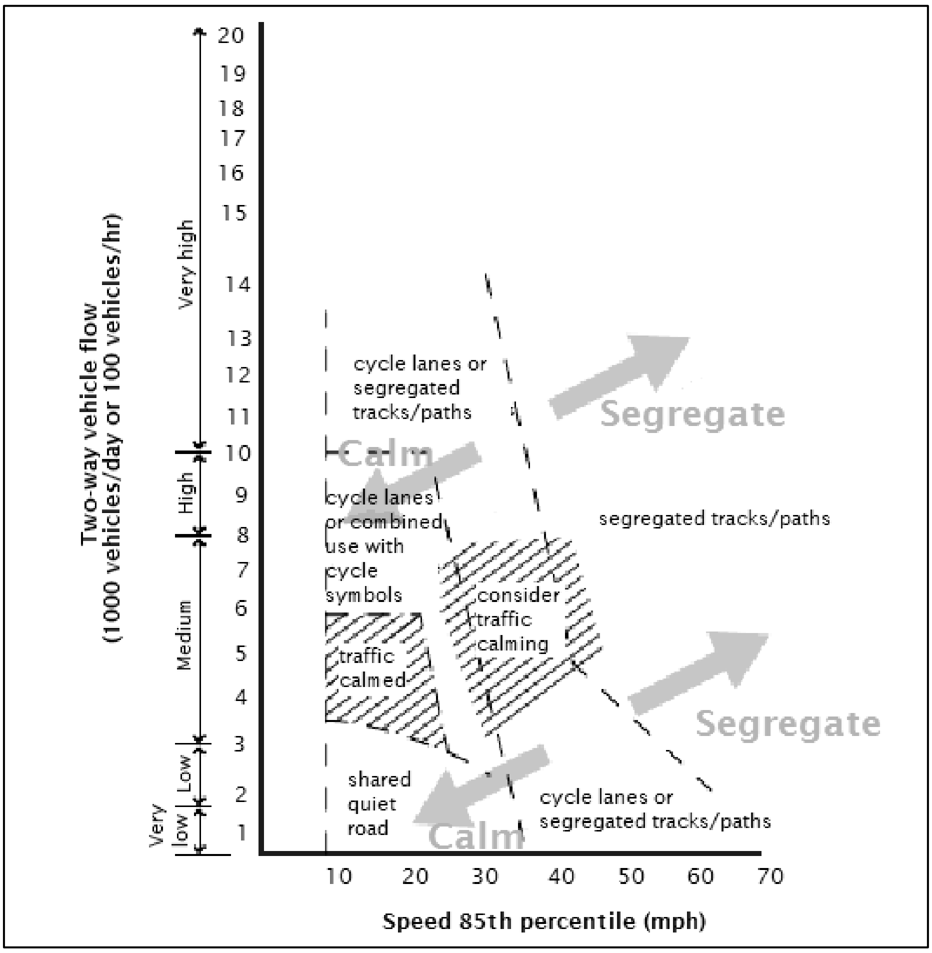


Notes to figure 2.1:

a This diagram is to be applied to urban roads and is not appropriate for rural or non-urban roads.

b Combinations of low speeds and high traffic volumes are very rare. When these conditions occur, segregation may be desirable in order to minimise conflicts.

Figure 2.2 Cycle facilities based on motor traffic volumes and speeds (adapted from Transport for London 2005)



Notes to figure 2.2:

a Each route will need to be judged in the light of its specific situation.

b Cycle lanes or tracks will not normally be required in traffic calmed areas.

c Congested traffic conditions may benefit from cycle lanes or tracks.

d Designs should tend to either calm traffic or segregate cyclists.

2.3 On-roadway cycle facilities

2.3.1 Cycle crash analysis

Munster et al (2001) reported that on-roadway cycle crashes in New Zealand occurred mostly in a location not specifically allocated for cycling. Forty-eight percent of crashes occurred in the traffic lane, 32% on the shoulder and 13% on the footpath. Only 7% occurred in a cycle lane.

Turner et al (2006) also interviewed casualties at Christchurch Hospital and those who had made an ACC claim. Of the 192 cyclists surveyed who had an injury crash on the road, 73% involved a motor vehicle, 3% involved a pedestrian and the remainder were cycle-only crashes. Crashes that occurred off the roadway were not included in the study.

Few studies of the safety benefits of on-roadway cycle facilities have also been carried out internationally. Where crash benefits have been reported, the crash benefits, in many instances, only consider a single site and are based on a simple before-and-after analysis of reported crashes.

Kaplan (1976) undertook a detailed study of cyclist crash rates with a large number of respondents for the categories (all crashes and serious crashes) regarding incidents that occurred on lanes and bike routes. As expected, the rate for crashes occurring on minor streets was somewhat lower than those incidents occurring on major streets. This is probably a result of less exposure to high speed and/or high-volume traffic for cyclists using minor streets rather than major streets.

2.3.2 Conflict studies

Other studies use conflict study techniques to investigate the safety benefits. An example of such a conflict study is Hunter et al (1999). This study compared the safety of cycle lanes with wide kerbside lanes through a conflict study. This comparative analysis was based on videotapes of almost 4600 cyclists in three US cities. The majority of the sites were on commuter routes and two of the sites were located near university campuses. Cycle lanes were marked with both dashed and solid lines, and some were mixed parking/cycle lanes.

Hunter et al defined a conflict as an interaction between a cyclist and motor vehicle, pedestrian or other cyclist such that at least one of the parties had to change speed or direction to avoid the other. Of the 188 mid-block conflicts observed, 71% were cyclist/motor vehicle, 10% cyclist/cyclist, and 19% cyclist/pedestrian. Almost all of the cyclist/cyclist conflicts occurred in cycle lanes, typically where one cyclist manoeuvred around a slower moving cyclist.

At mid-block locations, Hunter et al reported that significantly more motor vehicles encroached into the adjacent traffic lane when passing cyclists in wide kerbside lanes (17%) than cyclists in cycle lanes (7%). It should be noted that 26% of 'wide' kerbside lanes were less than 4.3 metres wide. These encroachments rarely resulted in a conflict with another vehicle.

Compared with those in cycle lanes, cyclists in wide kerbside lanes experienced more cycle/pedestrian conflicts and fewer cycle/cycle conflicts. The scale of response by cyclists or motor vehicle by facility type did not reveal any differences. Overall, 98% of the conflicts were coded as minor, with differences by facility type. Motor vehicle conflicts associated with cycle lanes included illegal parking in the lane, entering/exiting on-street parking, and a driver or passenger entering/exiting a parked or stopped vehicle. Motor vehicle actions more associated with wide kerbside lane conflicts included turning right (left in the New Zealand context) in front of a cyclist after passing, and other actions such as failing to give way, improperly turning right and not allowing cyclists enough room.

At intersections, Hunter et al reported that 93% of the intersection conflicts were coded as minor, with no differences by facility type.

Conflicts at cycle lanes involved the cyclist having to stop or swerve for vehicular traffic. Conflicts at wide kerbside lanes involved passing stopped or slow-moving vehicles on the right (left in the New Zealand context) and encounters with pedestrians. Hunter et al reported that motor vehicles were often illegally parking in cycle lanes. This often caused conflicts in the cycle lanes.

Hunter (1998) carried out another conflict study focusing on red painted shoulders for cyclists in Florida, again using video conflict techniques. Eighty percent of cyclists used the shoulders. Hunter found that vehicles encroached more severely into the opposing traffic lane when they were passing cyclists at sites without red shoulders. Hunter also found that the distance between passing motor vehicles and cyclists was greater without red shoulders, which was a statistically significant result. It was noted that cyclists who were surveyed considered the red shoulders too narrow.

Hunter and Stewart (1999) also used video conflict study techniques to examine how well a cycle lane operates when adjacent to parking. It was found that few conflicts arose between pedestrians, cyclists and motor vehicles. It was reported that cyclists would ride closer to the kerb at locations where parking turnover was low or when vehicles were passing them. Conflicts observed were minor in nature.

Vandebona and Kiyota (2001) conducted a similar study in Sydney, observing where the level of stress exhibited by cyclists on the roadway. The level of stress was measured through five noticeable physical manifestations. These stress indicators were:

- riding on the footpath
- riding on the left edge of the lane
- frequent changing of lane position
- looking behind in mid-blocks
- indication of loss of balance.

Four sites were monitored to compare the level of stress exhibited by cyclists. This study found parked cars caused a high level of stress.

Crashes involving cyclists commonly occur at intersections. Herslund and Jørgensen (2003) investigated 'looked-but-failed-to-see-errors' in traffic in Denmark using conflict studies. These errors result in crashes where a car driver who is supposed to give way to a cyclist collides with the cyclist on the priority road. It was found that more experienced drivers are more likely to be involved in this type of crash than less experienced drivers. Two possible reasons for this error were discussed:

- A driver could be focused on a particular location where other motor vehicles may be present and missing cyclists in their peripheral vision.
- A driver may be focused on another motor vehicle when looking for a suitable gap.

2.3.3 Before-and-after crash analysis

Herrstedt et al (1994) carried out a study on the layout of cycle lanes on the approaches to intersections. They carried out a before-and-after study of the construction of cycle lanes on 37 road segments. Following construction of the cycle lanes, cycle crashes declined by 35% at intersections. The study did not take changes in typical crash rates into account as they had no control group. In a comparative study, they found that wider cycle lanes (1.2m or wider) were three to four times safer than narrower cycle lanes.

Coates (1999) also performed a before-and-after analysis of crashes at locations where cycle lanes had been marked at mid-block locations; it would seem likely that the cycle lanes used in his research were mandatory (as opposed to advisory). The data collected in Oxford in the United Kingdom where 25km of cycle lanes had been constructed in the previous 20 years. Nearly 18km of cycle lanes were introduced in two phases at 11 sites in 1981 and 10 sites in 1986. These cycle lanes were predominantly located on significant radial routes. Three years' worth of before-and-after data was used for the first phase sites, but the second phase sites used six years' worth of data.

Coates compared the number of crashes before and after the cycle lanes were installed. The figures indicated a 4% reduction in total crashes at the first phase sites and a 9% reduction at second phase sites. When considering cycle crashes only, the first phase sites had a 29% increase and the second phase sites a 2% decrease. During this period, cycle crashes throughout Oxford increased by 20% and 17% respectively. He notes that cycling volumes increased to 20% of all traffic in the early 1980s and has since stayed constant.

Table 2.2 shows the number of crashes mid-block before and after the construction of cycle lanes in Coates' study. It shows that cycle lanes reduce the number of crashes mid-block by about 30%. Coates attributes the increase in the number of crashes involving cyclists riding into the back of parked vehicles to a problem with drivers parking on the lanes and a false sense of security that the cycle lanes provide to cyclists.

Table 2.2 Crashes at mid-block locations where cycle lanes were installed (Coates 1999)

Crash type	Before	After
Cyclist pulls out from side of the road to turn right, crossing or entering the path of a motor vehicle	16	7
Motor vehicle conflicts with cyclists while overtaking	17	12
Cyclist riding into the back of a parked vehicle	2	10
Car door opens into path of cyclist	9	3
Vehicle pulls out from kerb into path of cyclist	4	2
Vehicle travelling in opposite direction crosses carriageway into path of cyclist	0	1
Pedestrian steps into cycle lane in path of cyclist	0	1
Total	**51**	**36**

Coates also investigated the before-and-after rate of crashes at intersections following the marking of the mid-block cycle lanes. Cycle lanes were not marked across intersections. Table 2.3 shows the number of intersection crashes before and after the construction of mid-block cycle lanes.

Table 2.3 Crashes at intersections along routes where installed (Coates 1999)

Crash type	Before	After
Vehicle turns left into intersection across path of cyclist	8	10
Vehicle turns right into intersection across path of cyclist	7	13
Vehicle turns left out of intersection into path of cyclist	4	5
Vehicle turns right out of intersection into path of cyclist	17	20
Cyclist turns right out of intersection into path of vehicle approaching from the right	6	0
Cyclist turns right into intersection across path of vehicle approaching from the opposite direction	1	3
Cyclist turns right out of intersection into path of vehicle approaching from the left	2	1
Cyclist turns left out of intersection into path of vehicle approaching from the right	2	3
Total	**47**	**55**

Coates concluded that providing cycle lanes mid-block worsened crashes at intersections, producing a very small increase in the number of crashes. This conclusion did not, however, take increasing cycle volumes into account.

The Danish Road Administration (1994a) carried out a study at four signalised intersections where the stop line for motorists was recessed by five metres. Twenty to thirty metres before these intersections, cycle paths joined the roadway and became cycle lanes of reduced width. These lanes were separated from motorised traffic by a white rumble strip. Behavioural and conflict studies were carried out before and after the motor vehicle's stop line was recessed. This study focused on conflicts in which a motor vehicle turning right (turning left in the New Zealand context) approaches the intersection at the same time as a cyclist is riding straight ahead. Such conflicts were analysed from video recordings.

After the alteration, the time between the cyclist leaving the potential conflict area and a vehicle reaching the same area increased at three of the locations and remained unchanged in the fourth. Prior to alteration, 12–24% of drivers turned right directly in front of a cyclist. After implementation, only 3% to 6% did. The study concluded, on the basis of these results, that at three of the intersections, the behaviour of drivers improved.

Jensen (2000a) reported on the success of new layouts at signalised intersections in five Danish municipalities. Four different layouts were applied at 11 signalised intersections in 1991–1993. These layouts consisted of narrowed cycle lanes to the limit lines, 'slalom' cycle lanes, staggered limit lines, markings of cycle crossings and profiled strips. Figure 2.3 and figure 2.4 show two of these four different layouts.

Figure 2.3 Layout with 'slalom' cycle lane to stop line, staggered stop lines and marked cycle crossing (Jensen 2000a)

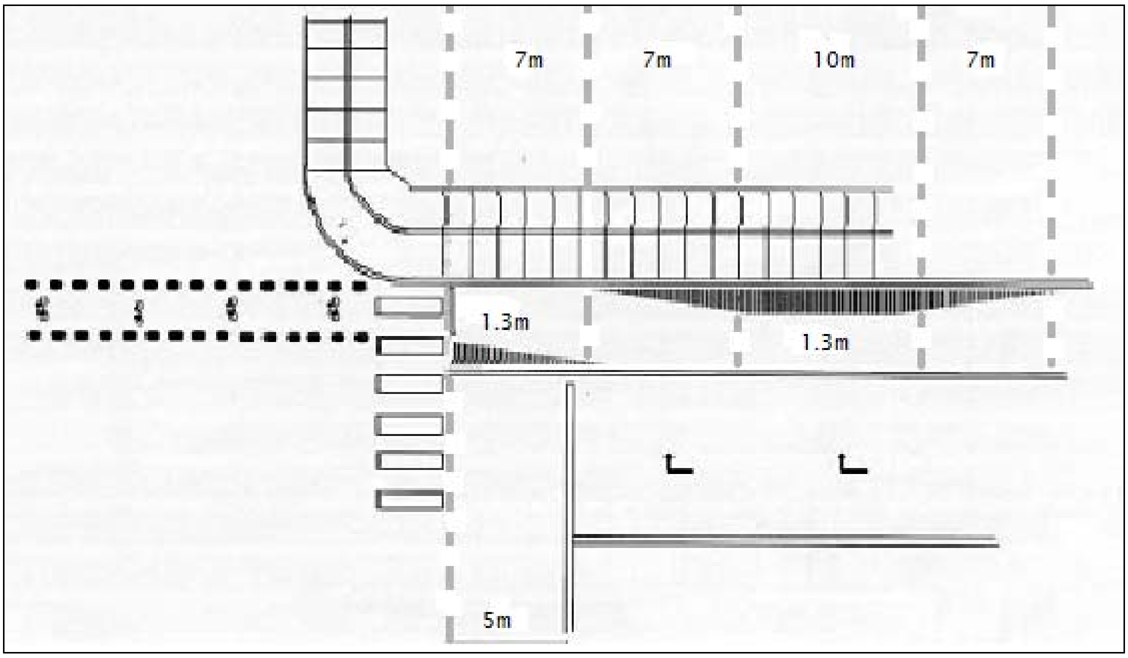
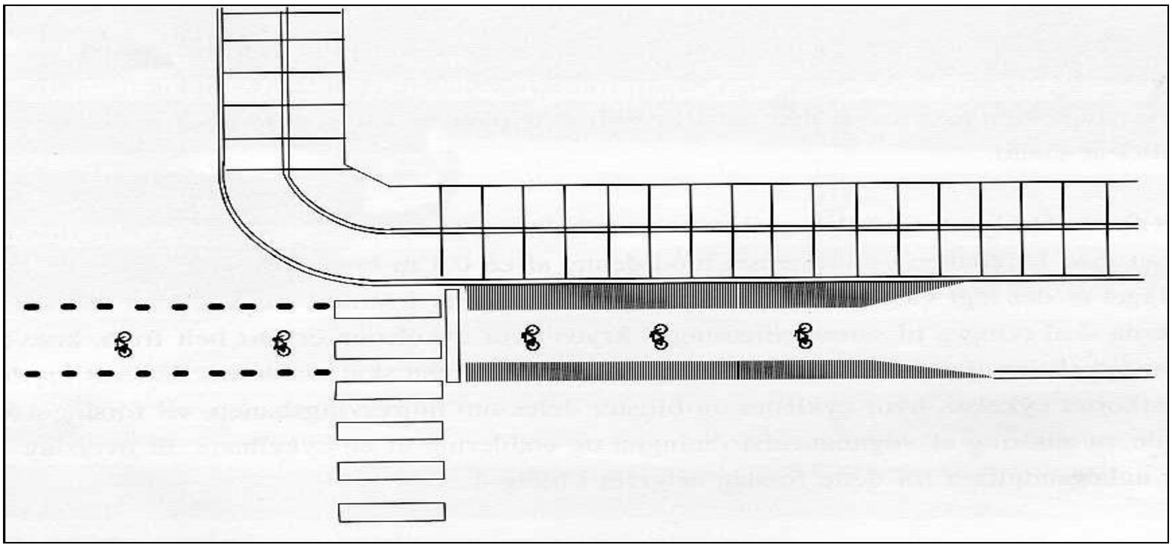


Figure 2.4 Layout with narrowed cycle lane and marked cycle crossing (Jensen 2000a)



The before-and-after study used crashes reported to police. The study considered the five years (maximum) before and after a new layout was introduced, and control groups of signalised intersections were located in the same municipalities as the new layouts. Table 2.4 compares the expected and observed numbers of crashes at intersections with the new layouts applied. In Denmark, it is compulsory for cyclists and moped riders to use cycle paths and cycle lanes if these are provided, which is important to take into account when considering the results of this study.

Table 2.4 Comparison between expected and observed crashes at intersections with new layouts (Jensen 2000a)

Intersection Number	Group 1[a]		Group 2[b]		Group 3[c]		Group 4[d]	
	Exp.	Obs.	Exp.	Obs.	Exp.	Obs.	Exp.	Obs.
1	0	0	0	2	7.2	11	3.7	7
2	0	0	4.1	2	4.1	4	12.8	12
3	0	0	1.4	0	1.4	1	2.1	7
4	0	2	6.8	6	1.0	1	2.9	7
5	1.0	1	14.8	20	8.2	8	20.1	24
6	0	1	3.9	3	12.6	13	36.5	33
7	0	0	2.0	0	10.2	5	12.8	15
8	-	-	1.6	3	3.1	3	6.8	4
9	-	-	0.0	0	0	1	2.6	8
10	0	0	4.7	4	0	2	2.6	3
11	0	0	0.8	0	3.1	0	8.5	10
Total	**1.0**	**4**	**40.0**	**40**	**50.8**	**49**	**111.4**	**130**

Notes to table 2.4:

a Group 1 crashes involved at least one cyclist or moped rider on the road section before the stop line.

b Group 2 crashes involved at least one cyclist or moped rider coming from an entry (in the intersection after the stop line).

c Group 3 crashes involved at least one cyclist or moped rider coming from other entries.

d Group 4 crashes did not involve cyclists or moped riders.

Table 2.4 shows that the new layouts in Jensen's study did not considerably change the number of crashes involving cyclists.

2.3.4 Observation studies

Ryley (1996) examined non-kerbside approach cycle lanes and the effect of different signal timings on the value of advanced stop lines in the UK by observation. Advanced stop lines in the UK allow cyclists to stop in a storage box in front of motor vehicles at signalised intersections and typically include a mandatory cycle lane approaching the storage box.

Ryley found that a large proportion of cyclists used a kerbside cycle lane approach to turn left or go straight ahead. Few cyclists used the complete length of the kerbside cycle lane up to the advanced stop line to turn right. Ryley reported that some cyclists used part of the kerbside cycle lane up to the stop line to turn right, but not the entire lane. Some cyclists turning right were observed to use part of the cycle lane and then move out before the storage area; others ignored the cycle lane altogether.

VicRoads (2000) also undertook a behaviour study. This study not only investigated cyclist behaviour but also motorist behaviour before and after the installation of storage boxes at signalised intersections in St Kilda Road, Melbourne. The stopping locations of cyclists and motor vehicles were recorded to assess if behaviour changed. These storage boxes were not connected to cycle lanes, which stopped prior to the intersections.

Before the marking of the storage boxes, cyclists were observed to stop on the pedestrian crosswalk or just forward of it. After the marking of the storage boxes, 40% of cyclists stopped in the box. However, 67% of stopping motorists also stopped in the storage box. The authors of the VicRoads study believed this was because the box was placed behind the original limit line.

2.4 Off-roadway cycle paths

2.4.1 Cycle paths in New Zealand

A cycle path is a path where cyclists are segregated from motor vehicles, either adjacent to a roadway, or completely independent (such as a rail trail or a foreshore trail). Internationally, many of these paths are specifically for cyclists. In New Zealand, the paths are almost always shared with pedestrians. In many countries, it is common for cycle paths to be adjacent to roadways, even urban roads with low speed limits; in New Zealand, on-roadway cycle lanes are more likely to be provided. This is because of New Zealand traffic legislation, where cyclists on segregated paths adjacent to roadways do not have priority over motor vehicles leaving and entering driveways and side-roads, as is the case in many other countries. Therefore caution should be exercised when attempting to transfer the results of overseas studies to New Zealand conditions. Off-roadway cycle path safety research generally covers footpaths adjacent to roadways; very limited data is available on cycle tracks away from roadways.

2.4.2 Off-roadway cycle path safety

2.4.2.1 Studies of cycle crashes on off-roadway paths

Bach et al (1988) undertook a before-and-after study of 105 new off-roadway path segments in Denmark between 1978 and 1981. The total study length was 64km of urban one-way paths; in Denmark, these paths are cycle-only facilities separated from the roadway and footpath by kerbs (this study looked only at one-way paths but Denmark has some two-way paths where some cyclists ride opposite to the motor vehicle traffic in the adjacent roadway). The results showed that cyclist casualties increased 48% following the introduction of off-roadway paths; moped riders and pedestrians also suffered more crashes (table 2.5). The overall casualties increased by 27%.

Table 2.5 Cycle crashes on off-roadway paths in Denmark (Bach et al 1998)

Crashes	Between intersections		At intersections	
	Before (no off-roadway paths)	After (with off-roadway paths)	Before (no off-roadway paths)	After (with off-roadway paths)
All cycle crashes	46	49	71	105
Cycle v vehicle	29	19	55	82
Cycle v other	17	30	16	23
All mopeds	23	32	23	38
Moped v vehicle	12	13	19	20
Moped v other	11	19	4	18
All pedestrian	32	43	43	56
Pedestrian v vehicle	28	24	35	40
Pedestrian v other	4	19	8	16
All vehicle	108	108	169	213
All vehicles	28	34	53	66
Vehicle v other	80	74	116	147
Totals	**134**	**154**	**187**	**251**

Leden (1989) has undertaken a field survey of 14,000 school children between ages of 6 and 16 in Finland. The results showed that for children cycling, the risk of colliding with a motor vehicle was 2.7 times higher at intersections with a cycle track (which the child used) than at roadway-only intersections. The risk was highest when cycle crossings were 8–15m from intersections and when traffic signals were present. The overall risk of collision is 0.5 crashes/100,000km on the carriageway but 1.3 crashes/100,000km on a cycle track, rising to 2.8 when roadways and cycle tracks have concurrent green signals at junctions.

The American Association of State Highway & Transportation Officials (1999) also strongly warns against off-roadway footpaths in the US, and states that using or providing a footpath as a shared-use path is unsatisfactory for a variety of reasons. Sidewalks are typically designed for pedestrian speeds and manoeuvrability, and are not safe for higher speed bicycle use. Conflicts are common between pedestrians travelling at low speeds (exiting stores or parked cars, etc.) and cyclists, as are conflicts with fixed objects (eg parking meters, utility poles, sign posts, bus benches, trees, fire hydrants and mail boxes).

Studies conducted by Pedler and Davies (2000) concluded that cycle crossings with priority for cyclists across minor roads appeared to work satisfactorily in some circumstances, but by no means all. Among all the options, crossings where cyclists have no priority caused the least confusion. However, this does not mean that they are necessarily the correct design in all cases. The sites that appeared to cause most confusion or where the priorities were most misunderstood were crossings with partial priority for both cyclists and motor vehicles. This research is discussed further in section 2.5.

A study by the Danish Road Administration (1994b) analysed cycle crossing safety at priority (give way and stop) controlled intersections. Five intersections were studied before and after modification of the crossing design. These modifications included bringing the cyclists and motor vehicles closer together as they approached the intersection. On the approaches to the intersection, a solid painted line separated the cycle lane from the roadway. At the intersection, the cyclists and the motor vehicles were separated again to enable the cyclist to leave the conflict area before vehicles entered it or to give the cyclist enough time to perform a slight evasive action if the vehicle proceeded. Different surfacing and colour also highlighted the conflicting area. Results included more careful motorist behaviour, earlier reactions by cyclists (to the approaching intersection) and a reduction in the number of serious conflicts at the intersections.

Petrisch et al (2006), in a study on the safety of off-roadway cyclists using footpaths in Florida in the USA, developed a crash prediction model for cyclist v motor vehicle crashes that identified the following factors as having the greatest significance regarding the safety of cycling on footpaths:

- the width of the footpath
- the effective distance between the footpath and the roadway
- the posted speed limit on the adjacent roadway
- the number of lanes on the adjacent roadway.

Some other factors also affecting off-roadway safety referenced by Petrisch include:

- the amount of motor traffic crossing the footpath
- the type of off-roadway treatment
- the extent to which cyclists using the footpath need to cross into motor vehicle traffic
- the quantity and nature of the undisciplined traffic using the footpath
- the speed of the cyclists using the footpath
- the skill and knowledge that these cyclists can apply to avoiding collisions with all traffic.

In a British study of 98 cycle path crashes over five years, Rainbird (1979) concluded that consistency in layout and markings for off-roadway paths, including crossings, was important to reduce cycle crashes. Principal crash types were collisions at road junctions and underpasses caused by poor visibility, head-on collisions and loss of control.

2.4.2.2 Shared-use paths: cycle v pedestrian conflict and perceptions

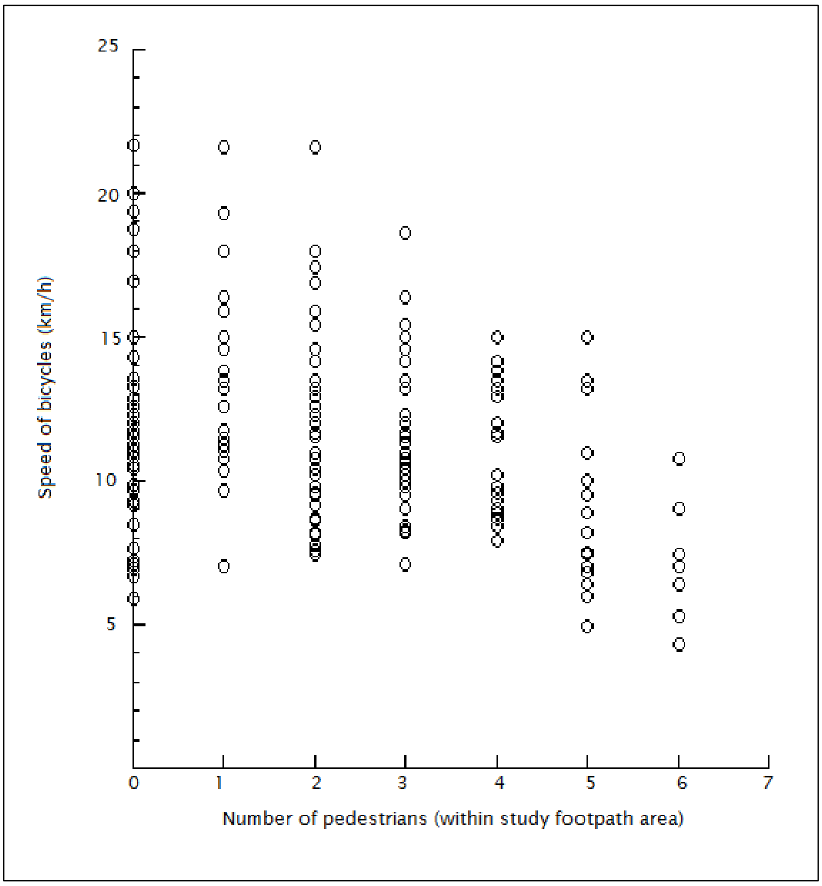
Kiyota et al (2000) investigated the conflicts between cyclists and pedestrians on shared paths in Japan. In Japan, cyclists are legally permitted to ride on footpaths. The technique evaluated shared-use paths based on the level of risk perceived by subjects who reviewed video recordings of pedestrian and cyclist conflicts in a shared space. These videos were analysed further to measure flow levels and spacing between pedestrians and cyclists.

Kiyota et al found that the perceived risk was directly related to spacing between cyclists and pedestrians (see table 2.6). Cyclist speed was found to decrease with increasing density of pedestrians despite the increased perceived danger (see figure 2.5).

Table 2.6 Relationship between perceived risk and spacing (Kiyota et al 2000)

Spacing between users when passing	Probability that pedestrians perceive danger
75cm	0.86
100cm	0.39
125cm	0.06
150cm	0.01

Figure 2.5 Cycle speed and pedestrian volume (Kiyota et al 2000)



2.4.3 Conflict studies: cycle path road crossings

Pedler and Davies (2000) used conflict study techniques to investigate sites where paths adjacent or in close proximity to roadways intersected crossroads. The study investigated a variety of crossing arrangements, most with priority for cyclists. Pedler and Davies used video cameras to monitor 1512 cyclists at five different cycle crossings of minor roads. The study team also interviewed 223 cyclists at the sites. From the video surveys, all traffic movements were recorded and classified by manoeuvre.

The study found that the majority of intersections observed were non-hazardous. It was reported that in most circumstances, both drivers and cyclists observed who had priority. In most cases where the priority was not observed, it was found that the cyclist stopped at the kerb line to let vehicles pass.

Pedler and Davies also found that higher flows of motor vehicles intersecting the cycle path crossing led to more conflicts. They also noted that higher flows of cyclists using the crossing increased the likelihood of drivers giving way to cyclists and being more alert to cyclists at the crossing. It was reported that some cyclists who continued to travel along the major road had fewer problems than those on the footpath.

Munster et al (2001) studied the role of roadway features in cycle crashes not involving a motor vehicle on public roads, cycle tracks and footpaths. From a mail-out survey with 335 responses, they found that 51% involved crashes off the roadway. They concluded, based on hospital and ACC data, that cycle-only crashes appeared to be twice as frequent as crashes with motor vehicles.

2.5 Comparative studies between shared-use cycle paths and lanes

2.5.1 UK studies

Pedler and Davies (2000) analysed five types of cycle crossings intersecting with with minor roads and found that that cycle paths with priority for cyclists across minor roads appeared to work reasonably satisfactorily in some circumstances, but some hazardous interactions were also observed. Cyclists remaining on the major roadway (as opposed to riding on the adjacent footpath) had fewer problems at the junctions with minor roads. The majority of cyclists, however, used the cycle path, particularly the less confident cyclists such as children. Pedestrians also used the crossing, appearing to benefit from the set back 'give way' lines and raised crossing. No pedestrian–cyclist conflicts were observed on the crossings.

At the first two sites, the cycle path crossing was a raised 'bent-out' cycle crossing from the major road and the cyclist had priority, as shown in figure 2.6. The survey results showed that most cyclists were observed on cycle paths.

Figure 2.7 shows that the crossing at the third site was straight (not bent-out) and cyclists had partial priority over the side-road traffic.

Cyclists give way to drivers turning in from the major road but have priority over drivers turning out of the minor road. The crossing is on a hump and is straight, but provides no area for entering drivers to stop if cyclists are on the crossing, as is provided when the cycle crossing is set back.

A conflict often arises when drivers turning out of the minor road do not stop behind the humped cycle crossing but instead stop on the crossing, obstructing the cyclist's route. Motor vehicles turning into the minor road, however, have priority over cyclists crossing the minor road. If this situation arises, cyclists have to give way to the driver turning into the minor road. The reasons for drivers blocking the cycle path are likely to be the need to improve their view of traffic on the major road (including the cycle path) and, in busy traffic conditions, to move forward to take advantage of gaps in the traffic. The majority of conflicts, therefore, were caused by motor vehicles stopping on the cycle crossing.

Figure 2.6 Bent cycle path crossing facilities (Pedler and Davies 2000)

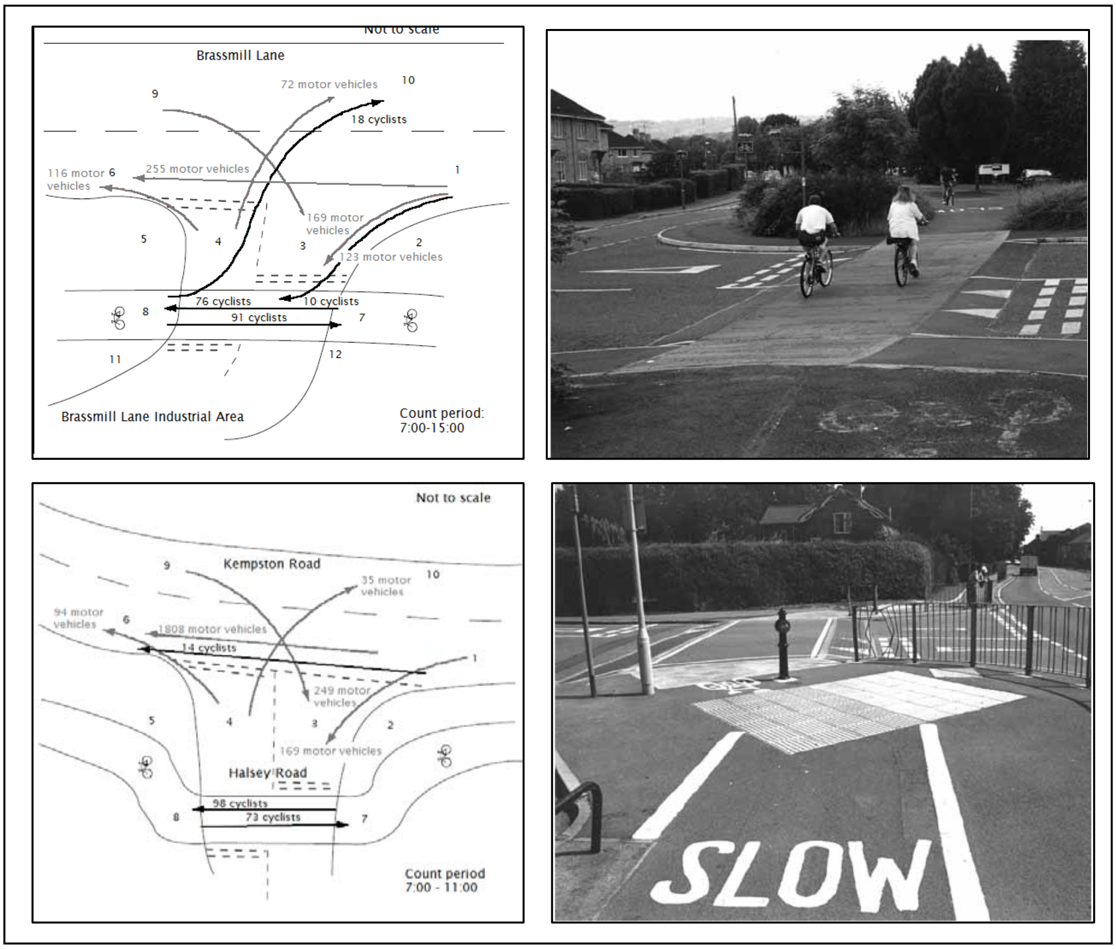


Figure 2.7 Continued raised cycle path crossing along a major road (Pedler and Davies 2000)

Figure 2.8, however, also highlighted a conflict between the vehicle stopped at the minor road waiting to pull out and cyclists moving from 13 to 14 in the bus lane at the fourth site. Motor vehicles were pulling out beyond the mouth of the junction into the bus lane to wait for a gap. At the minor road, therefore, motor vehicles conflicted with both cyclists on the cycle path and cyclists on the roadway. However, it was noticeable that the cyclists on the roadway who were affected by an obstructing car were less affected than cyclists on the cycle path. The cyclists on the roadway made less of a deviation in their path than the cyclists on the path.

Figure 2.8 Continued cycle path at an intersection (Pedler and Davies 2000)

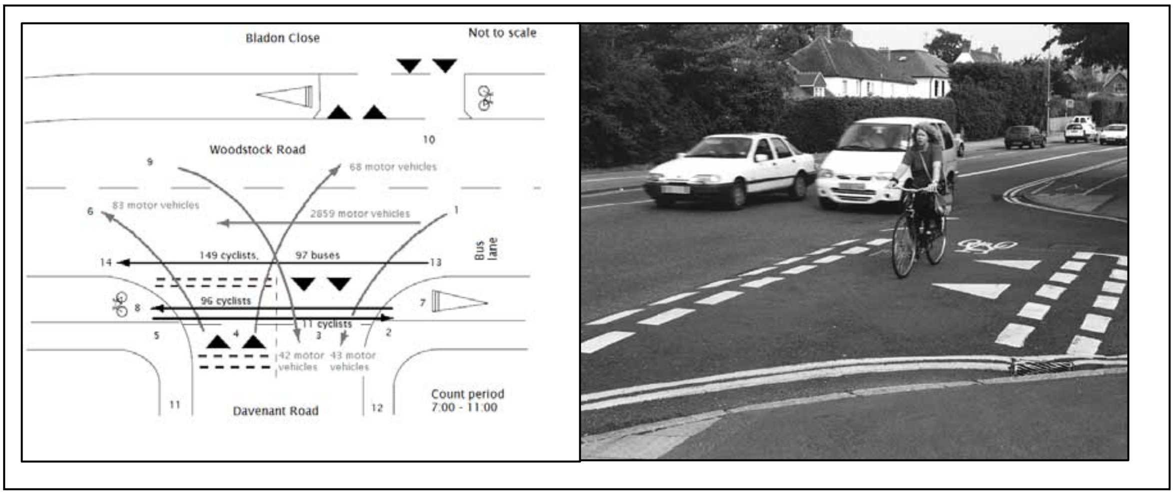
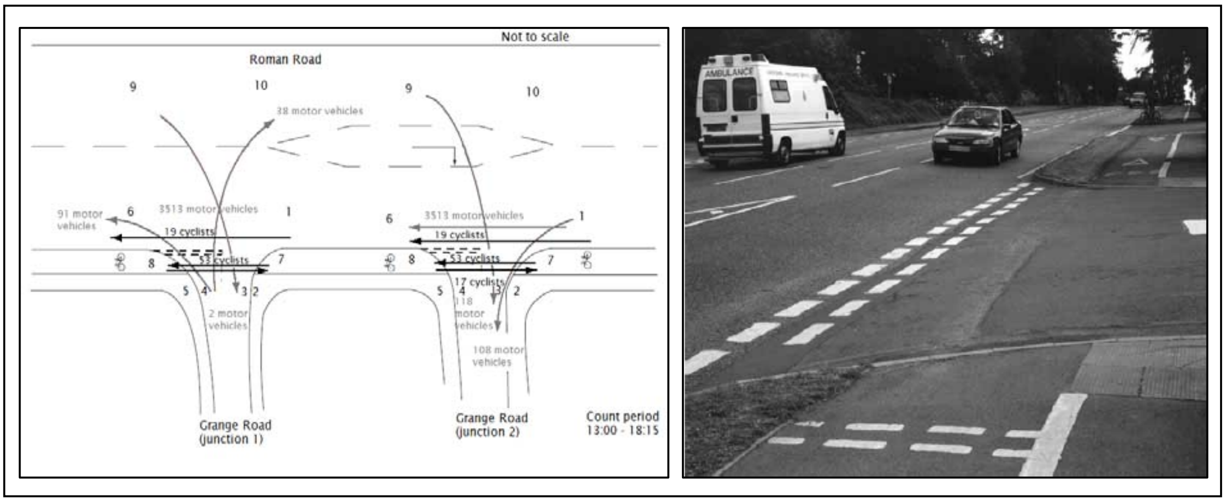


Figure 2.9 shows that the fifth site had no bent-out crossing and cyclists had to give way to vehicles.

Figure 2.9 Discontinued cycle paths at intersection (Pedler and Davies 2000)



The majority of conflicts resulted from motor vehicles stopping on the cycle crossing and obstructing cyclists' paths. Observations showed that cyclists were very aware of the conflicts that might arise and were extra vigilant when approaching the crossings. This is likely to be because motor vehicles have full priority when turning into and out of the minor road. Priority for motor vehicles is also the standard situation in New Zealand, although some locations abroad give priority to cyclists. None of the conflicts in this study were classified as potentially dangerous.

Crossings where cyclists have no priority caused the least confusion. However, this does not mean that they are necessarily the correct design in all cases. The sites that appeared to cause most confusion or where the priorities were most misunderstood were crossings with partial priority for both cyclists and motor vehicles. Vehicles exiting had to give way but vehicles entering did not, as they had no room to queue.

Some cyclists used the major road carriageway in preference to the cycle path. The percentage doing so varied considerably between sites. Cyclists remaining on the major road carriageway had fewer problems at the junctions but simple comparisons may be misleading.

Most problems were observed at sites with straight-through crossings, largely caused by poor visibility to the right from the minor road, and by high flows of traffic on the major road. In these conditions, drivers tended to pull forward and obstruct the crossing. Because of right-of-way constraints, it was not possible to deflect the cycle path at these sites to provide queuing space for incoming and outgoing vehicles. At all sites, a significant percentage of cyclists were unsure or wrong about the traffic priorities on the crossing. However, in most cases, this made them more cautious.

A comparison between the cycle crossings emphasises the need for sites to have good visibility. In addition, other factors such as high vehicle flows on the major and minor roads increase interaction and reduce the perceived safety of the crossing. Prestwich Place (figure 2.7) and Davenant Road (figure 2.8) both have an alternative parallel bus lane for cyclists to use. The low flows of motor vehicles out of Prestwich Place and the good visibility for all road users encourage cyclists to use the cycle path. Davenant Road has more motor vehicle turning movements, a good on-roadway alternative route and confusion about whether vehicles will give way. Therefore, cyclists feel safer using the road.

Transport for London (2004) reports on cycle crashes at seven sites in York in the UK, where a combination of several types of cycle facility were implemented. This study found that the number of cycle crashes reduced by approximately 50% at specific locations and routes. The report did not discuss the cycle volumes, any comparisons with control sites or what previous facilities were installed. Table 2.7shows the reductions for each of the seven types of facility installed. Reductions of 100% (cycle track and advanced limit lines) can be discounted as unrealistic.

Table 2.7 Cycle facilities & crash reduction rates for York, UK (Transport for London 2004)

Facility	Cycle crashes per year		Measured reduction rates (%)
	Before	After	
On-roadway cycle lanes	12.0	5.2	-57%
Shared-use footpath	3.6	2.6	-28%
Signalled intersections	2.9	0.5	-83%
Cycle track*	4.9	0.0	-100%
Cycle lane	1.7	0.5	-70%
Advance stop line at signals**	1.0	0.0	-100%

* Definition of ‘cycle track’ unclear from study.

** Advanced stop line includes storage box.

Harland and Gercans (1993) evaluated changes in cycle safety in centres where cycle route experiments were implemented in the 1970s and early 1980s. These cycle routes consisted of segregated paths, shared-use paths, quiet streets, and new links across barriers such as rivers and rail lines. Harland and Gercans found that significant numbers of cyclists transferred from the main roads to the new routes. Overall, the number of cyclist casualties in the towns studied did not change, with casualties on the minor roads increasing and casualties on the major roads decreasing, as shown in table 2.8.

Table 2.8 Cyclist casualties before & after cycle facility construction (Harland and Gercans 1993)

Town	Area	Number of casualties					
		A and B roads			C and unclassified roads		
		Before	After	Change %	Before	After	Change %
Cambridge	Experiment	67	71	6	72	121	68
	Control	277	309	12	250	279	12
Exeter	Experiment	68	43	-35	74	69	-7
	Control	71	69	-3	81	75	-7
Kempston	Experiment	14	7	-50	13	15	15
	Control	103	74	-28	72	52	-28
Nottingham	Experiment	112	130	16	84	94	12
	Control	150	183	22	192	167	-13
Southampton	Experiment	38	24	-37	31	36	16
	Control	190	175	-8	274	257	-6
Stockton	Experiment	14	17	21	15	21	40
	Control	13	29	123	16	6	-83

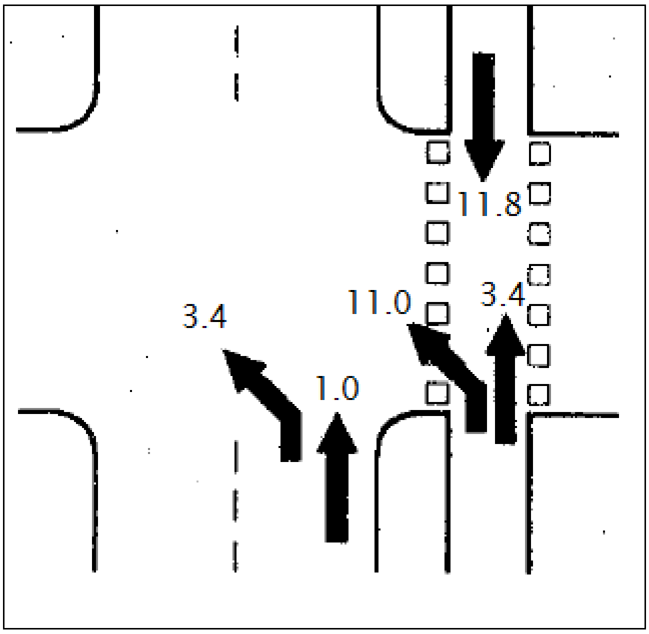
2.5.2 Northern European studies

Elvik and Vaa (2004) suggest that no statistically significant change occurs in the total number of crashes (motor vehicle, cyclist or pedestrian) when off-roadway paths are constructed, whereas the construction of cycle lanes leads to a decrease of 10% for cycle injury crashes and a 30% reduction in total crashes. It should be noted that Elvik and Vaa define a cycle lane as being separated from motorised traffic by a kerb or 'traffic segregator,' which is a common practice in some Scandinavian countries but not in New Zealand. However, the crash change rates quoted in Elvik and Vaa are amalgamated from a number of studies in multiple countries, some of which do not use this type of separation.

An advanced stop line for cycle lanes at intersections leads to a decrease of 27% for cycle injury crashes and a 40% reduction in total crashes. Adding cycle lanes across a signalised intersection reduces cycle crashes by 12% but increases overall crashes by 14%. Construction of grade-separated crossings has a major decrease of 30% of total crashes.

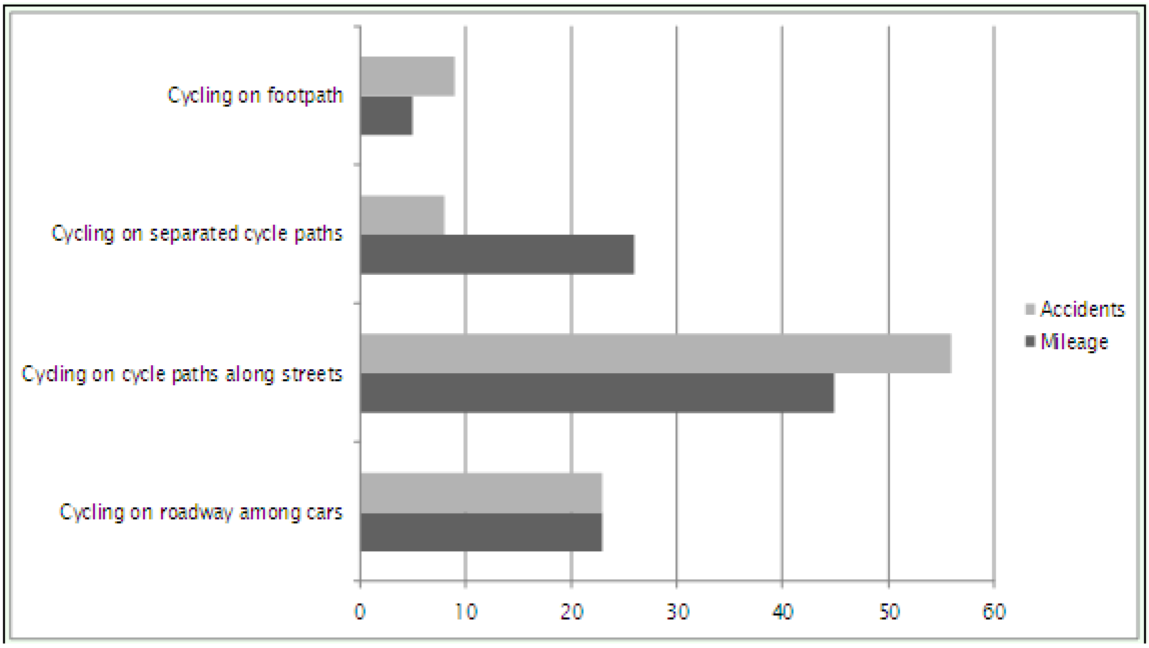
Linderholm (1984) in the University of Lund, Sweden, found that the risk of cycle v vehicle crashes was 11.9 times greater for cyclists riding on the left-hand footpath, and 3.4 times higher for cyclists on the right-hand footpath, compared with cyclists riding in the normal position on the roadway, as shown in figure 2.10 below.

Figure 2.10 Relative risk of cycle and vehicle crashes (adapted from Linderholm 1987)



In Finland, Pasanen (1999) collected samples of cyclist data in Helsinki. The results obtained were consistent with other studies: it is safer to cycle on streets amongst cars than on two-way cycle paths along side streets. The data presented did not include information on cycle volumes so the number of cyclists exposed on each cycling facility cannot be compared. Figure 2.11 shows that 45% of the cycling kilometres in Helsinki are on cycle paths along side streets, but 56% of injury crashes happen to cyclists on these paths.

Figure 2.11 Cycle use and crashes on different facilities in Helsinki, Finland (Pasanen 1999)

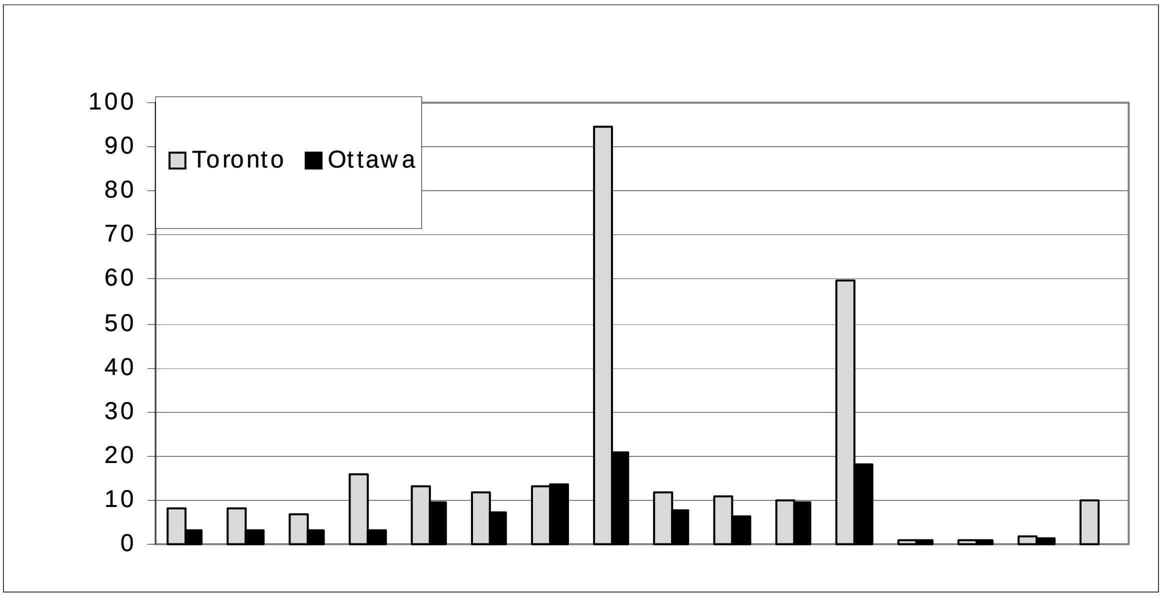


Stichting Wetenschappelijk Onderzoek Verkeersveiligheid (SWOV – the Dutch Institute for Road Safety) (2004) summarised research on the safety effects of cycle paths and cycle lanes (Dutch cycle lane and path design is similar to Danish). This summary referred to a study by Welleman and Dijkstra (1988) that showed segregated cycle paths adjacent to major roadway facilities were safer for cyclists than on-roadway painted cycle lanes, and that cycle lanes were less safe than no cycle facilities (ie shared traffic). It is important to note that the study did not consider the number of cyclists using the facility or the type of adjacent land use. The cycle lane types in the sample set were also diverse: narrow and wide cycle lanes, with or without parking, had all been used in the one sample set. The same report also found that at intersections, cycle paths were less safe for cyclists than cycle lanes or no cycle facilities.

2.5.3 USA and Canada

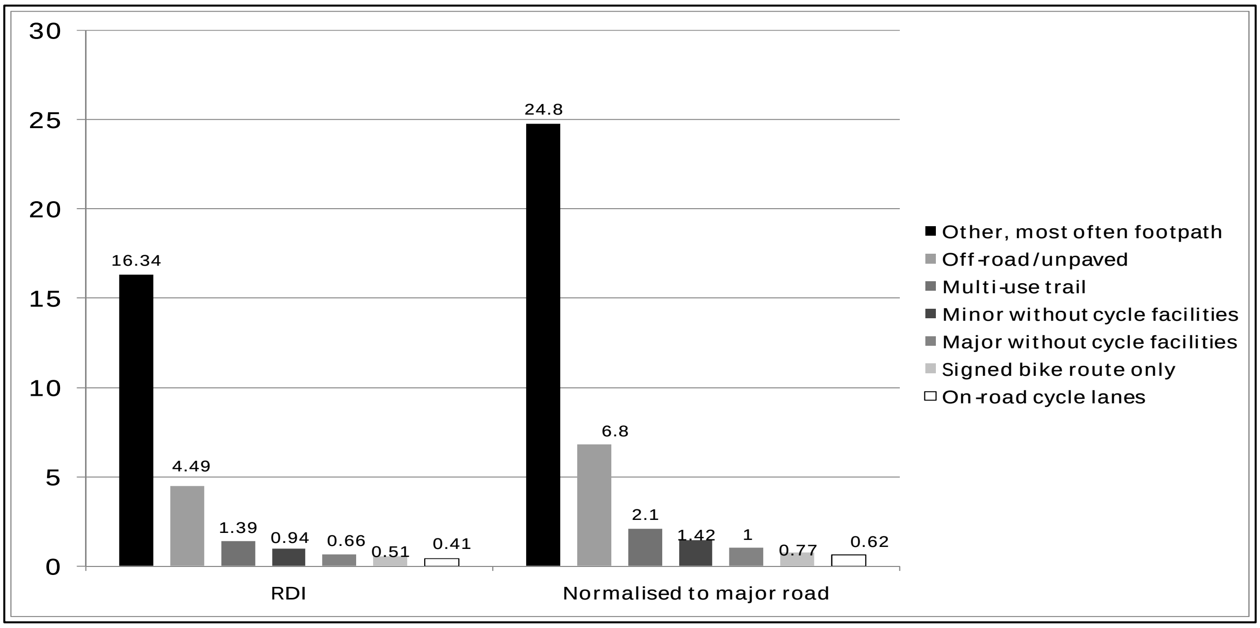
Aultman-Hall and Adams (1998) attempted to understand off-roadway cycle crashes in further detail. Their footpath data was collected in Ottawa and Toronto. Figure 2.12 shows that the conflict rate for cycling on the footpath was significantly higher than for on-roadway lanes or off-roadway paths. The research also indicated that better footpath maintenance could improve the safety of footpath cyclists.

Figure 2.12 Relative event rates of cycle accidents in Canada (Aultman-Hall and Adams 1998)



In a study conducted on adult cyclists in the US, Moritz (1998) found that the relative danger index was 24.8 times as high for footpath riding as for major streets without bicycle facilities (data included all crashes, not just cycle v motor vehicle collisions). The study indicated that cyclists are less safe on the footpath even when cyclists have right of way, as shown in figure 2.13.

Figure 2.13 Relative Danger Index (RDI) of various cycling facilities (Moritz 1998)



RDI = % crashes/% miles ridden. Higher values indicate a higher level of danger.

Wachtel and Lewiston (1994) compared the safety of on-roadway cycling (with or without cycle lanes) to cycling on shared footpaths, basing their study in Palo Alto, California. This study used the numbers of cyclists travelling along the footpath adjacent to a number of major routes and the numbers of cyclists travelling along the routes on the roadway. It compared the numbers of these cyclists on both types of facility and the number of reported crashes on each. This study found that cycling on shared footpaths was 1.8 times less safe than cycling on the roadway. Table 2.9 presents the risk ratios by age, gender and direction of travel.

Table 2.9 Risk ratio of cycling on footpaths and on the roadway (Wachtel and Lewiston 1994)

Category	Footpath			Roadway			Risk ratio	*p*
	Cyclists observed	Crashes reported	Risk	Cyclists observed	Crashes reported	Risk	Footpath to roadway	
All cyclists	971	41	1.4	2005	48	0.8	1.8	0.01
≤17 years old	693	21	1.0	740	9	0.4	2.5	0.03
≥18 years old	278	20	2.4	1265	39	1.0	2.3	0.01
Female	295	9	1.0	557	13	0.8	1.3	
Male	676	32	1.6	1448	35	0.8	2.0	0.01
With traffic	656	13	0.7	1897	43	0.8	0.9	
Against traffic	315	28	3.0	108	5	1.5	1.9	

2.6 Perceived cycle safety

Loveday (2000) investigated cyclists' perceptions of safety, types of cycling routes used, cyclist involvement in crashes within the last year and crash locations. Table 2.10 summarises this data. Loveday then conducted a discriminant function analysis to determine whether cyclists had been involved in a crash or not.

Table 2.10 Perceived safety level, usage and percentage of crashes for different cycle facilities (using data from Loveday (2000))

Cycle facility type	Mean frequency of use	Perceived safety level*			Cycle crashes
		Mean	Mode	Range	%
None	3.3	2.5	2	1.4–3.7	44
On-roadway with cycle lane or signage	2.4	3.3	4	2.5–4.2	3
Off-roadway cycle paths	2.7	3.7	4	2.8–4.7	25
Off-roadway shared-use paths	1.7	3.2	4	2.1–4.2	14
Off roadway-cycle tracks	1.5	3.6	4	3.0–4.2	6

* 1 = lowest level of perceived safety; 5 = highest level of perceived safety

Loveday found that cyclists' crashes could be predicted by frequency of cycling and greater use of off-roadway cycling paths. This was despite the fact that the perceived level of safety of off-roadway cycle paths was high.

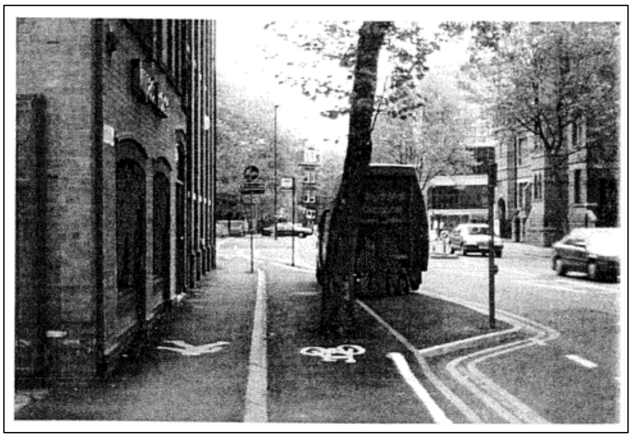
McClintock and Cleary (1996) analysed the safety of cycle facilities introduced in parts of the Greater Nottingham area since the early 1980s as part of this experiment. The results of user surveys were also reported. The cycle facilities introduced in Nottingham consisted of quiet back streets signed as dedicated cycle routes, as well as segregated paths, shared-use paths and signalised mid-block crossings of the road network.

McClintock and Cleary reported that the safety and perceived safety of the off-roadway facilities was highly dependent on the quality and type of facilities. As an example of a good quality of cycle path that improved safety, they used Clifton Lane, a cycle path adjacent to the main road with adequate width, good visibility, and very few driveways and crossings (see figure 2.14).

Figure 2.14 Clifton Lane cycle path (McClintock and Cleary 1996)

McClintock and Cleary also gave Castle Boulevard as an example of a cycle facility that had negative impacts on cycle safety (shown in figure 2.15). This facility had a high number of crossings and driveways (10), poor visibility, inadequate width and was shared with pedestrians. At this facility, large increases in crashes were reported at driveways, despite 90% of cyclists continuing to cycle along the roadway. An increased number of cyclists rode on the footpath in adjacent parts of the network.

Figure 2.15 Castle Boulevard cycle facility (McClintock and Cleary 1996)



According to a 2002 Marketing & Communications Research perceptional survey reported in the Queensland Cycle Strategy (2005), cyclists in Queensland generally feel safer riding off-roadway on cycle paths or on footpaths (see table 2.11). Also, the presence of bike lanes significantly increased the perception of safety by cyclists who ride on roadways.

Table 2.11 Safety perception of cycle facilities (adapted from Queensland Cycle Strategy (2005))

Cyclists' perceptions (n = 134)	On roadway with cycle lanes (%)	On roadway with no cycle lanes (%)	Off-roadway cycle path (%)	Off-roadway on footpath (%)
Very safe	27	9	76	49
Somewhat safe	36	18	17	37
Somewhat unsafe	19	32	4	6
Very unsafe	3	38	0	4
Don't know	15	4	3	4

In Christchurch, the level of satisfaction of on- and off-roadway cycle facilities on Tennyson Street and Lyttelton Street was surveyed in 2004 (Christchurch City Council (CCC) 2004). Approximately 90% of cyclists in Tennyson St (off-roadway cycle paths) and 91% of cyclists in Lyttelton St (on-roadway cycle lanes) were satisfied with the overall layout. While 96% of cyclists in Tennyson St were satisfied with the overall appearance of the street, 89% of cyclists in Lyttelton St were satisfied (table 2.12).

Table 2.12 Satisfaction level of Christchurch cycle facilities (adapted from CCC 2004)

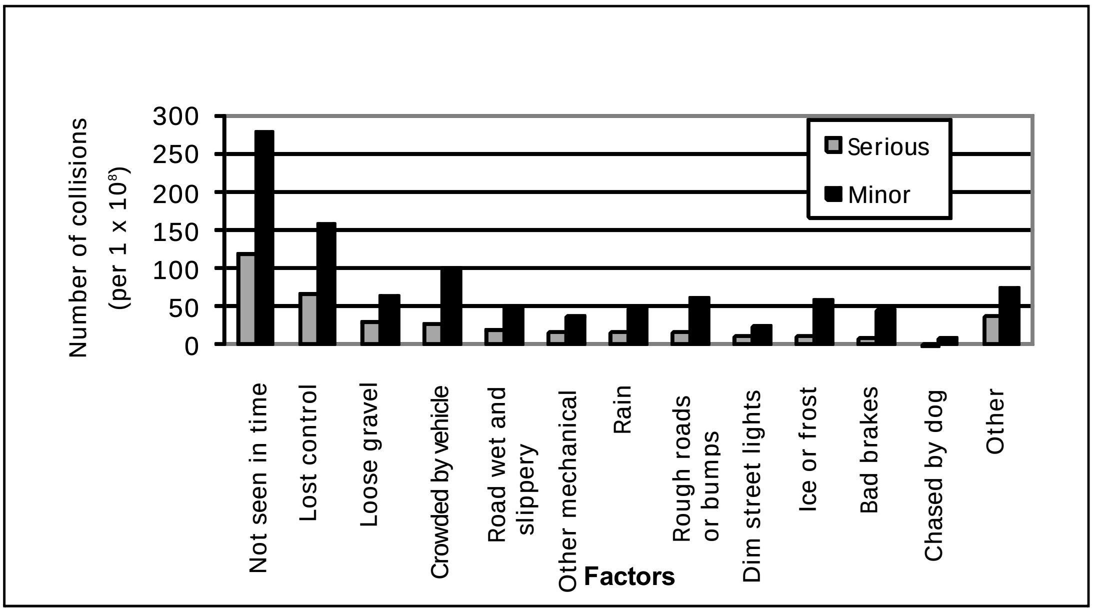
Response	Tennyson Street cyclists* %	Lyttelton Street cyclists** %
Layout		
Very satisfied	53.00	52.67
Quite satisfied	37.50	38.67
Neither satisfied nor dissatisfied	3.00	7.33
Quite dissatisfied	4.50	1.33
Very dissatisfied	2.00	–
Appearance		
Very satisfied	53.00	54.67
Quite satisfied	43.00	34.67
Neither satisfied nor dissatisfied	1.50	10.67
Quite dissatisfied	1.50	–
Very dissatisfied	1.00	–

* n = 200

**n = 150

A study by the Christchurch Cycle Safety Committee (1991) was undertaken to obtain more data on cycle collisions than was available from the police (reported crash data). Questionnaires were distributed to adult cyclists, school students, and medical practices and hospitals in Christchurch. Figure 2.16 shows the contributing factors found in adult cyclists' collisions. 'Not seen in time' was the greatest contributing factor of both serious and minor injury collisions.

Figure 2.16 Contributing factors to adult cyclists' serious and minor collisions (Christchurch Cycle Safety Committee 1991)



2.7 Traffic calming/speed reduction/volume reduction

A variety of traffic calming techniques and devices are used internationally. These techniques have the common goal of reducing traffic speeds and hence improving safety. A number of studies have specifically looked at the crash savings of traffic calming, which showed varying degrees of benefits. Only a few studies separate cycle crashes from the overall number of crashes in evaluating the benefits.

Zein et al (1997) conducted a study into the safety effects of traffic calming in Vancouver, Canada. The study involved a before-and-after analysis of four neighbourhood areas where traffic calming had been implemented. On average, a 40% reduction in the total number of crashes involving all modes was achieved. Between sites, the magnitude of the benefits varied greatly depending on individual site characteristics. Zein et al reported that cyclist safety did not improve significantly following implementation of traffic calming.

Davies et al (1997) filmed 15 traffic-calmed sites in the UK, representing a variety of lane widths and narrowings. The study found that at the central islands without cycle bypasses, where the lane width was 3.5m–4.3m, most drivers overtook cyclists at or within 20m of the narrowings. The location where drivers overtook cyclists did not vary with the lane width. The presence of cycle lanes did not appear to affect the percentage of drivers overtaking cyclists. It was also observed that motor vehicle encroachment into cycle lanes was high at sites where the remaining width for motor vehicles was less than 3.0m. Oncoming motor vehicles did not wait for cyclists but passed them at the narrowing.

Crashes at traffic calming sites were also investigated. Crashes for all vehicle types and crashes involving cyclists either decreased or remained at the same level at each of the sites. Overall, at the sites studied, crashes involving cyclists decreased from an average of 1.51 crashes per year to an average of 0.96 crashes per year (36%). The proportion of serious and fatal crashes also decreased. These results were not statistically significant. Data on changes in motor vehicle and cycle flows were not available.

Hoenig (2000) separated cycle crashes from the overall crash statistics in a study of the effect of citywide traffic calming in Austria. Hoenig reported that in 1992, the city of Graz, with a population of 240,000, adopted ‘Gentle Mobility’. This involved adopting a 30km/h speed limit for all residential areas except major roads. This lower speed limit applied to 75% of all roads in Graz (800km). A limit of 50km/h applied to the remainder of the roads. In addition to an information campaign, the speed limits were closely enforced. The number of cycle crashes dropped in Graz following the introduction of the programme in 1992 (see figure 2.17), despite an increase in the number of cycle trips per day (see figure 2.18).

Figure 2.17 Cycle crashes per year in Graz, Austria (Hoenig 2000)

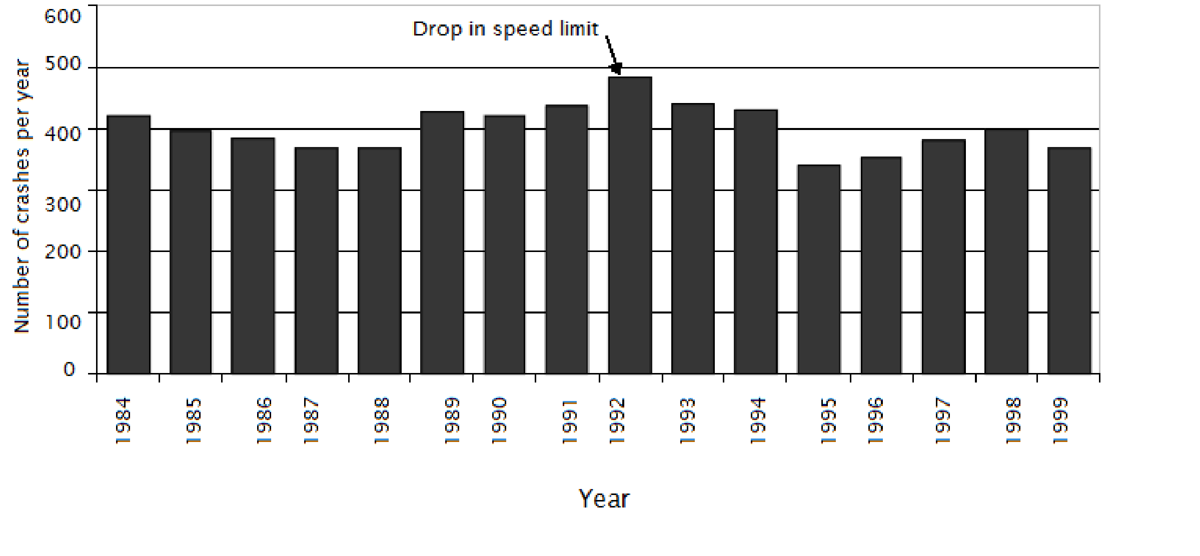
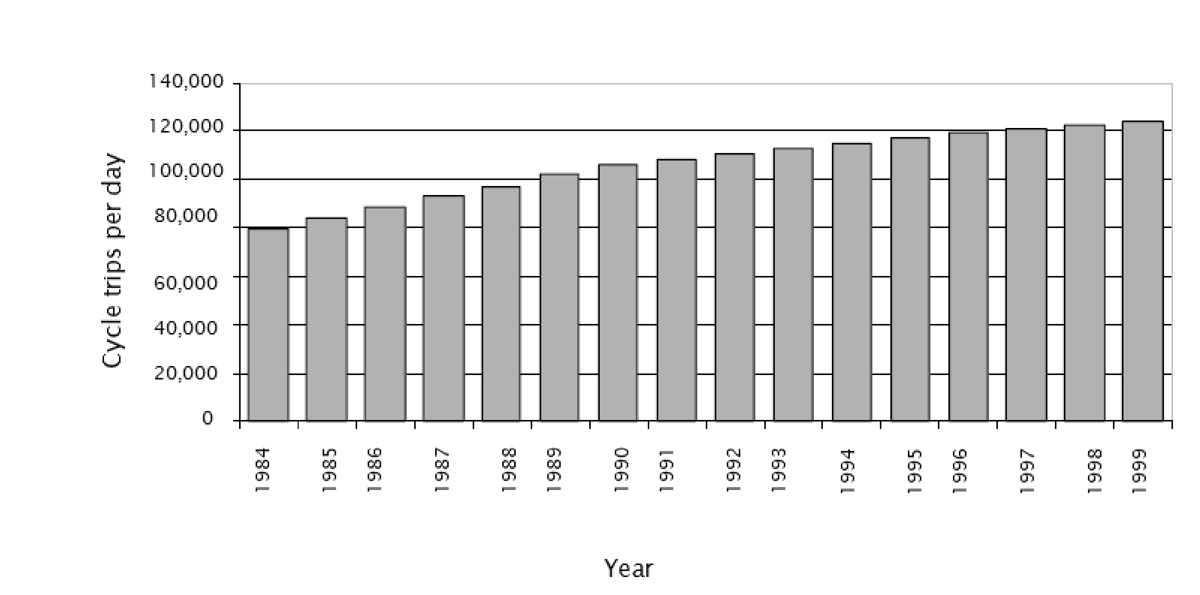


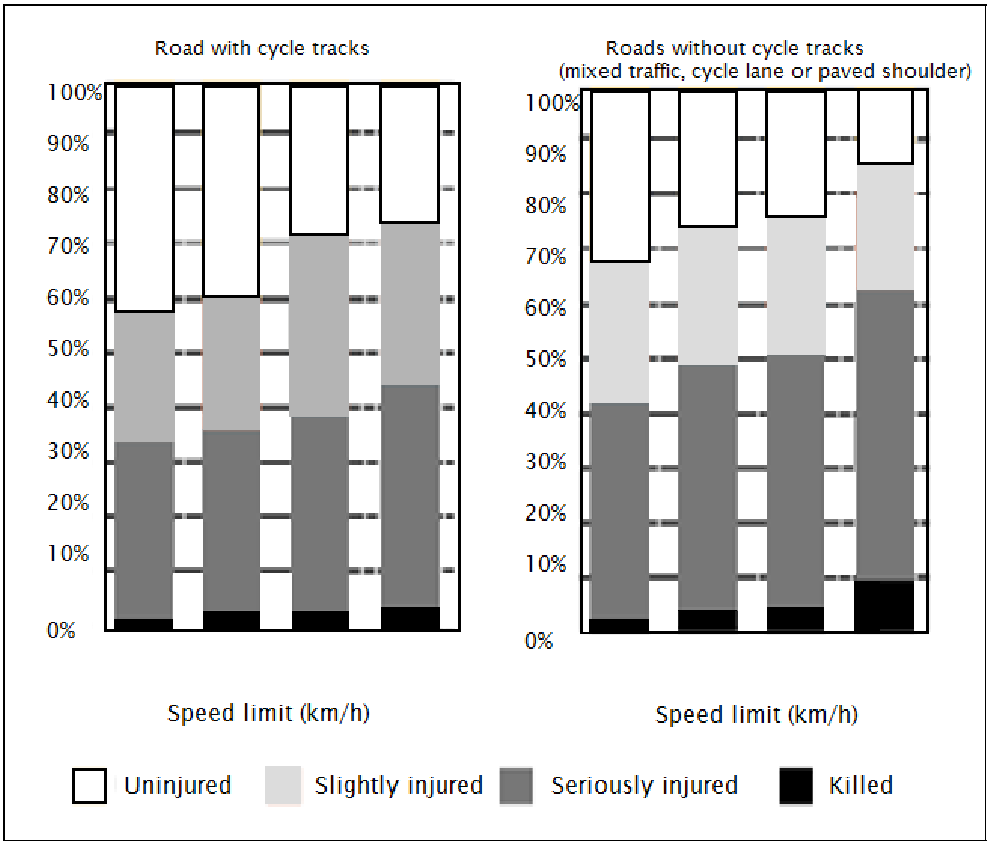
Figure 2.18 Cycle trips per day in Graz, Austria (Hoenig 2000)



One major benefit of traffic calming, from a cycling perspective, is the reduction in motor vehicle speeds, which may not reduce the quantity of crashes but does reduce their severity. In the Cross- and Fisher study (1977), more than half of all fatalities were on roads with posted speed limits greater than 35mph (56km/h), even though less than 20% of all collisions occurred in that fast traffic.

The Danish Road Directorate publication (Jensen 2000b) recommended that a desirable speed for cars where cyclists and cars use the same traffic lanes is less than 40km/h. Figure 2.19 shows the severity of cyclists involved in crashes with cars at different speed limits (note that Danish cycle tracks are separated from both pedestrian and motor vehicle traffic by kerbs). It indicates that severe cycle injuries were more likely on roadways without cycle tracks. It also shows that crashes in higher speed limits cause more severe injuries to cyclists.

Figure 2.19 Severity of cyclists at different speed limits (Jensen 2000b)



The Bicycle Federation of America report (1993) showed a relationship between pedestrians' and cyclists' injuries and motor vehicle speeds in the United Kingdom. The report found that when vehicles travelling at 20mph (32km/h) struck pedestrians and cyclists, only about 5% were killed and most injuries were slight. At 30mph (48km/h), 45% were killed and many seriously injured. When cars were travelling at 40mph (64km/h), 85% of the pedestrians and cyclists were killed.

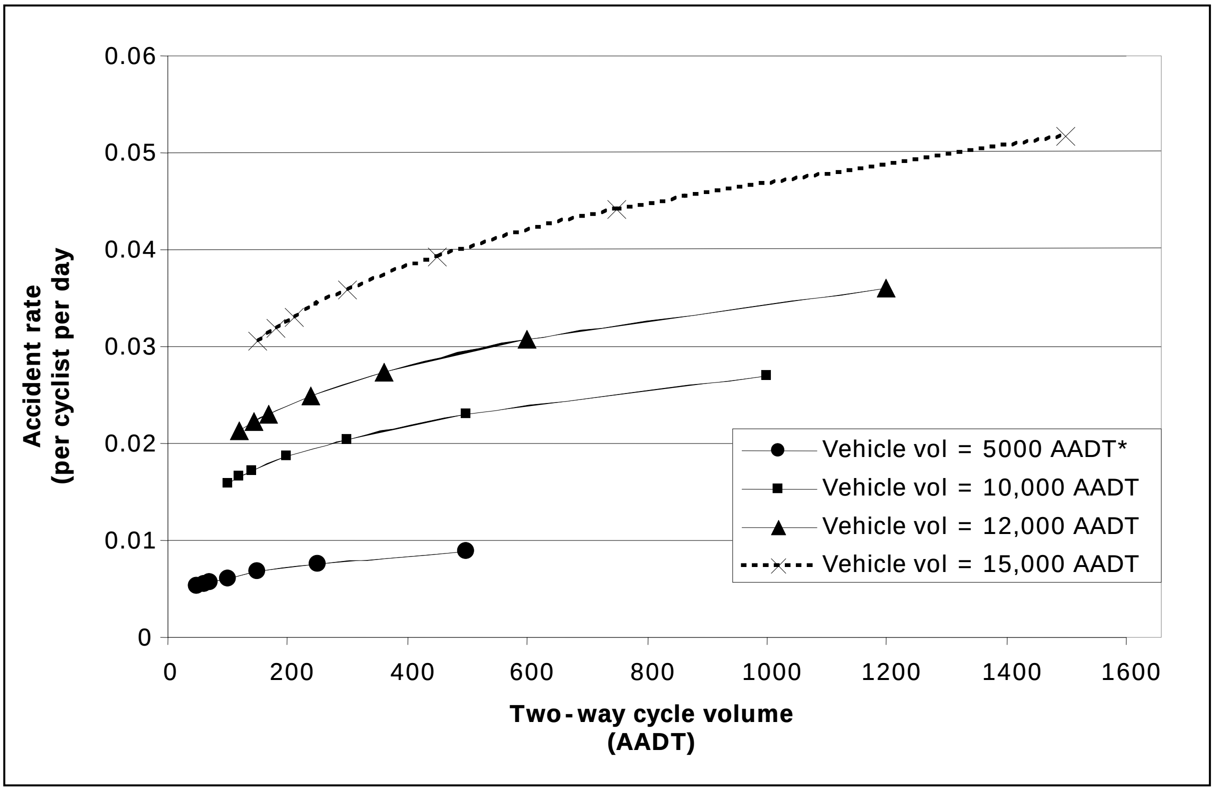
The Wisconsin Department of Transportation (1998) also undertook a study on cyclists' injuries and motor vehicle speeds between 1989 and 1998. The study showed that while the total injury rate was similar at all speed limits, fatal and severe injury crash rates increase dramatically where speed limits are higher (table 2.13). The study also showed that the cyclist injury rate was lower at a speed limit less than 40km/h.

Table 2.13 Injury rates by speed of motor vehicle, 1989–1998 (Wisconsin Department of Transportation 1998)

Posted speed (km/h)	Crashes per 1000 cyclists		
	Fatal injury rate	Severe injury rate	Total injury rate
40– 48	3.0	150	941
56–72	10.3	227	943
88	63.2	356	953

Turner et al (2006) derived crash prediction models for this report's predecessor and found a pronounced 'safety in numbers' effect in the models. Using the crash prediction model for mid-block locations, generic motorist and cyclist volumes can be used to demonstrate the impacts on the expected crash rate of varying motor vehicle and cycle volumes. As shown in figure 2.20, an increase in the proportion of cyclists to the overall traffic volume causes an increase in expected crashes at mid-block locations, but the crash rate increases at a decreasing rate. That is to say, the crash rate per cyclist goes down as the cycle volume increases.

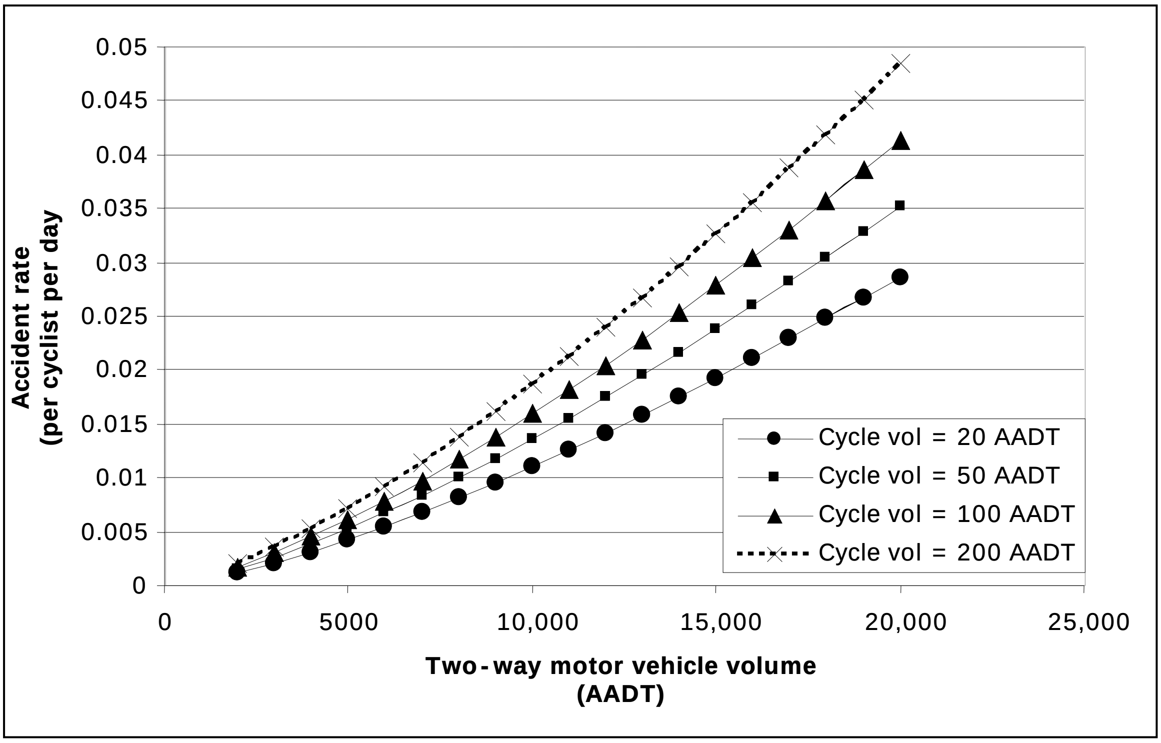
Figure 2.20 Crash rate with constant motorist and changing cyclist volumes (Turner et al 2006)



* AADT = annual average daily traffic

Conversely, if the cycle volume remains constant but the motorist volume is decreased, the expected crash rate per cyclist decreases as well, as shown in figure 2.21. This type of modelling is discussed further in section 4.2.

Figure 2.21 Crash rate with constant cyclist and changing motorist volumes (Turner et al 2006)



Jacobsen (2003) also found that the likelihood that a cyclist will be struck by a motorist is inversely proportional to the amount of cycling in the area, which was consistent across communities of varying size in North America and Europe.

3 Crash data

3.1 Reporting of crashes

3.1.1 Current reporting systems in New Zealand

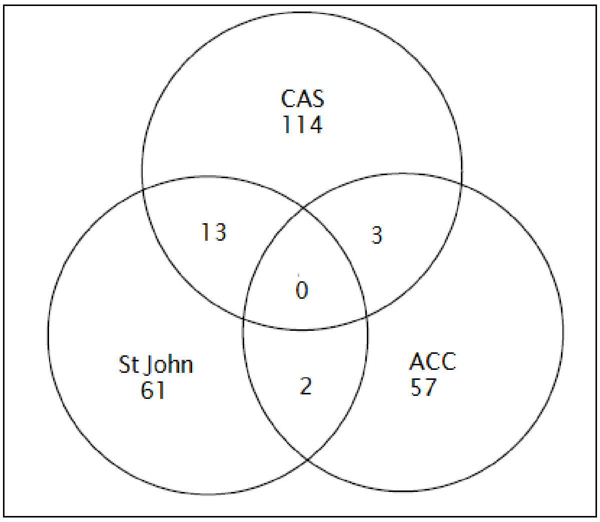
Knowing where and how cycle crashes occur on a network is an essential tool for improving the safety of cycling. Nationally, the only system that provides this information is the Ministry of Transport's Crash Analysis System (CAS). This system includes crashes that occur on the road network and are reported to the police. No national system collects data for off-roadway cycle crashes, although some local authorities use crash reporting cards or online crash entries. Unfortunately, the reporting rate for these methods is also generally low. New systems have been introduced by some councils to improve reporting rates, such as Nelson/Tasman's 0800 CYCLECRASH system (Parfitt and Kortegast 2005); however, these do not have coverage outside their regions.

3.1.2 Under-reporting of cycle crashes

Under-reporting occurs when a crash is not reported to the New Zealand Police and therefore is not entered into the CAS database. Turner et al (2006) found that the reporting rate for all traffic crashes in New Zealand is low, especially for crashes involving only minor injuries. It was stated that the ratio of reported cycle injury crashes to ambulance calls is approximately 54%. Since 1998, it has been a legal requirement in New Zealand for cycle crashes to be reported to the police. However, cycle crashes have not always been entered in the CAS database when a motor vehicle is not involved.

Using cycle crash data for Christchurch for 2001 from CAS, ACC and St John's Ambulance for 2001, Turner et al (2006) found that for every cycle crash reported in CAS, an additional 0.92 appeared in the St John and ACC databases. This study carried out a data-matching exercise to determine whether crashes appeared in duplicate (see figure 3.1).

Figure 3.1 Duplication in reporting of cycle crashes in Christchurch in 2001



A study of cyclists with 1400 responses from adult cyclists and 3500 responses from school children found that the reporting rate for all cyclist collisions is approximately 21% (Christchurch Cycle Safety Committee 1991).

Internationally, the reporting rate for crashes has also been found to be low. In Denmark, only about 10% of crashes with slight personal injuries and 50% of the serious crashes involving cyclists are reported to the police. In the Netherlands, a comparison of hospital survey data and the reported crash data showed that reported crashes accounted for only 20% of all crashes by those interviewed (OECD 1998).

A study by the Royal Society for the Prevention of Accidents (2005) suggested that 60–90% of 'bicycle only' crashes go unreported. The under-reporting of cycle crashes could have an negative impact on encouraging people to cycle because fewer recorded crashes results in a low level of investment in cycle remedial schemes, thereby inadequately addressing risks to cyclists. However, currently no system is in place to test if all crashes in the UK are reported.

A related study conducted on the under-reporting of cycle crashes in Sheffield, UK (Allatt 2006) concluded that 71% of all cycle crashes go unreported, especially those on off-roadway paths. Allat also noted a higher incidence of cycle-only crash under-reporting, which suggests that the full extent of crash patterns is not fully understood. Millar (2005) also reported that a very high proportion of crashes (41%) occurred off the roadway and many were not captured by crash databases, in this case, Scotland's STATS19. A majority (57%) of the off-roadway crashes occurred on cycle tracks, forest tracks and mountain bike tracks.

3.1.3 Addressing crash under-reporting

Normally, all collisions on our roads should be reported to the police. The police typically complete a collision report and submit it to the NZ Transport Agency (NZTA). However, it is estimated that only 10% of cycle collisions are reported.

In response to concerns about the under-reporting of cycle collisions through normal channels, the CCC initiated its own Cycle Hazard and Incident Reporting system, known as 'CHIRP'. Freepost cards are available from cycle shops, council libraries, service centres etc. Cyclists can fill out the cards identifying collisions they have had or hazards they have identified. The CHIRP card is intended to be a simple method of capturing information on cycle collisions and hazards that would normally go unreported.

The 0800CYCLECRASH system at Nelson was conceived as another way to get around the problem of under-reporting of cycle crashes. This enables the public to report injury and non-injury crashes which involve cyclists, as well as other related incidents that are not reported to or recorded by the police. The crash details received through this system are put into the CAS database as non-police reported crashes. Crashes are subsequently coded as injury, non-injury and conflict to differentiate them from actual collisions. So far, 184 crashes have been reported in the Nelson/Tasman region since the start of the 0800CYCLECRASH system. It is estimated that the 0800CYCLECRASH dataset contains a third of all cycle injury crashes in the Nelson region, and combining this dataset with CAS covers half of all cycle injury crashes (Turner 2006).

The various reporting rates for cycle crashes are not conclusive as to the level of under-reporting in CAS; however, it is clear that the reporting rate for cycle crashes is low, especially for crashes that:

- involve minor injuries
- do not involve a motor vehicle
- occur off the roadway.

3.2 On-roadway cycle crashes

The CAS database is the primary database providing crash statistical information for on-roadway cycle crashes. Crashes recorded in this database are compiled when the police attend and complete a traffic crash report, which is then supplied to NZTA to enter the data.

The crash data includes the location and time of crash, a description of the crash (which is later coded using 'movement codes') and crash causes. This database will be used as the sole source of crash data for cycle crashes occurring on-roadway in this study.

To determine where reported crashes involving cyclists commonly occur in urban areas, figure 3.2 was produced for selected crash locations.

Figure 3.2 Reported on-roadway cycle crash locations in New Zealand (1999–2003)

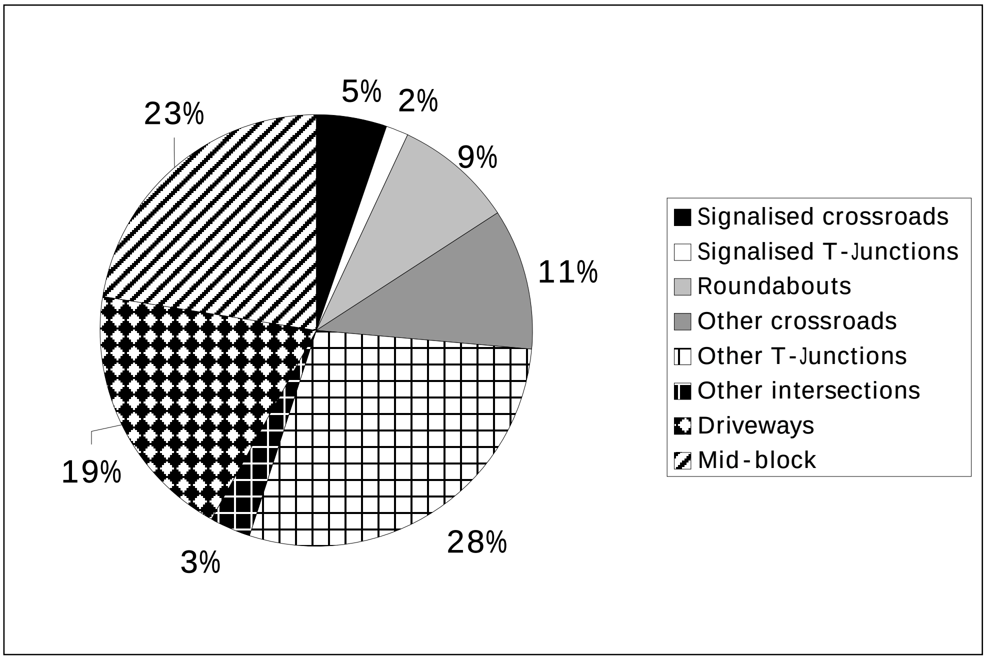
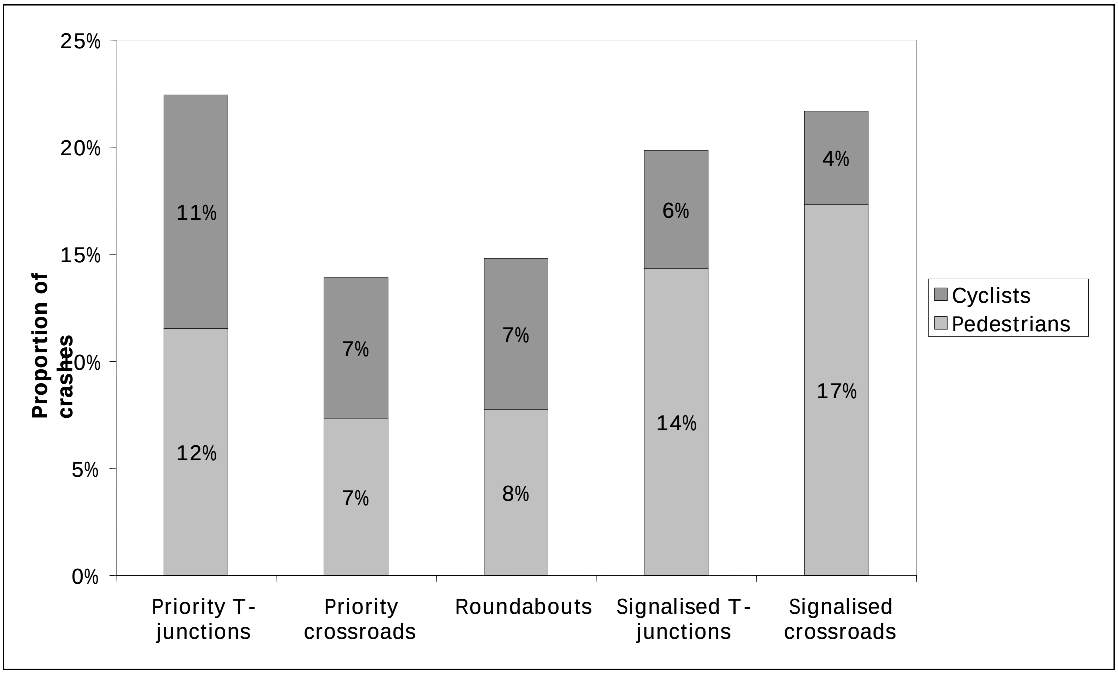


Figure 3.2 shows that the majority of reported urban cyclist crashes (53%) occur at intersections. The remaining crashes occur at driveways and other mid-block locations. The proportion of crashes at each intersection type is affected by the frequency of that intersection type, the number of cyclists using each intersection type and the relative safety of cyclists at that intersection type. Figure 3.3 shows the proportion of all injury crashes involving cyclists (and pedestrians) at each urban intersection type. This shows that a disproportionate proportion of crashes at priority T-junctions involve cyclists compared with signalised intersections and roundabouts.

Figure 3.3 Proportion of injury crashes at different types of intersection



3.3 Off-roadway cycle crashes

The data available for off-roadway crashes is of a very limited nature. The chief contributing factor for this is the gross under-reporting of cycle crashes that occur on off-roadway cycle paths and tracks. A study conducted by Munster et al (2001) showed insufficient data related to off-roadway cycle crashes in New Zealand. The main reason for this is because it is not necessary for crashes involving cyclists only to be reported to the police.

In many countries, it is common for cycle paths to be adjacent to roadways, even urban roads with low speed limits, whereas in New Zealand, on-roadway cycle lanes are more likely to be provided. This is because of New Zealand traffic legislation, where cyclists on segregated paths adjacent to roadways do not have priority over motor vehicles leaving and entering driveways and side roads, as is the case in many other countries. Therefore caution should be exercised when attempting to transfer the results of overseas studies to New Zealand conditions.

4 Data collection and modelling process

4.1 Data collection

4.1.1 General notes

This section outlines the site locations, cyclist count data collection and crash data. Some of the data was collected in previous studies. Cycle count data was collected from Christchurch, Palmerston North and Hamilton. These cities were chosen because they have significant numbers of cyclists using their urban road network.

Data on cycle counts was available in most centres, but generally, it was not in a suitable format for developing crash prediction models. To develop crash prediction models, detailed counts need to be available specifying the number of cyclists performing each turning and crossing manoeuvre. Such data enables various crash models to be developed for each type 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. This data was collected as part of a previous Beca study (Turner 2006).

4.1.2 Christchurch City count data

Cycle counts are collected by the CCC as part of its intersection count programme (this data is available in an electronic form) and in a separate cycle count programme. The separate cycle counts are generally more accurate than those collected simultaneously 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.

Additional cycle counts were collected in Christchurch. The counts were collected between 21 July and 24 October 2003, and included over 1640 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. Longer duration counts were also 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 as discussed below in section 4.1.5.

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

4.1.3 Hamilton City count data

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

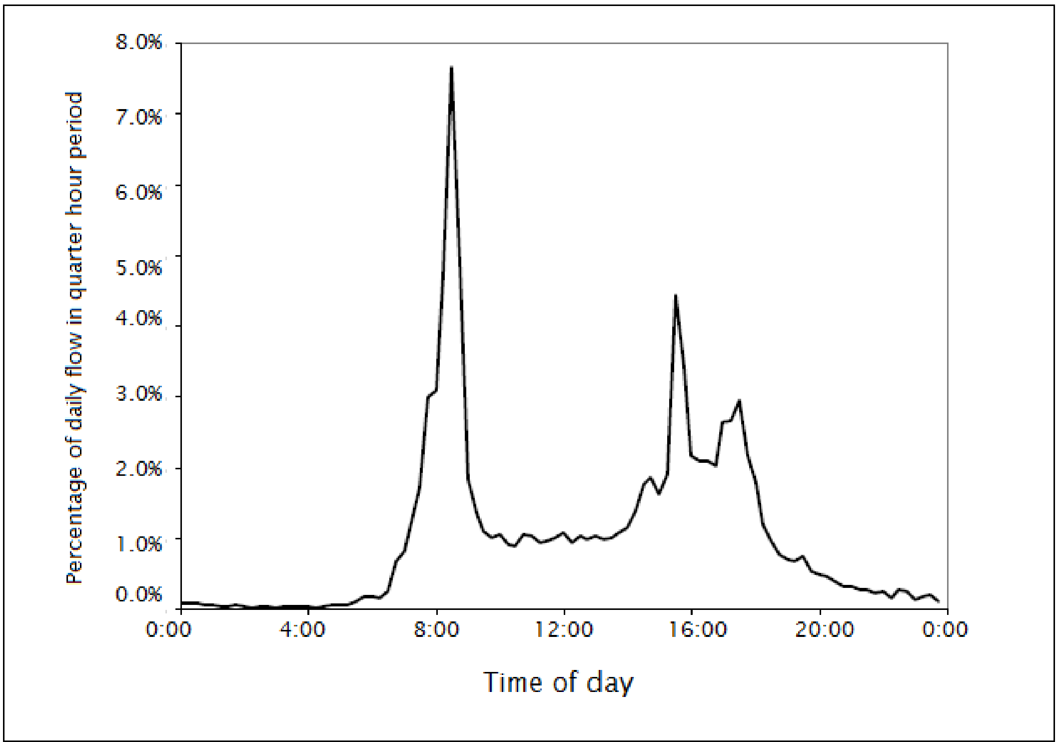
4.1.4 Palmerston North City count data

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 the lower holiday flows into account, correction factors were applied (section 4.1.5).

4.1.5 Cycle correction factors

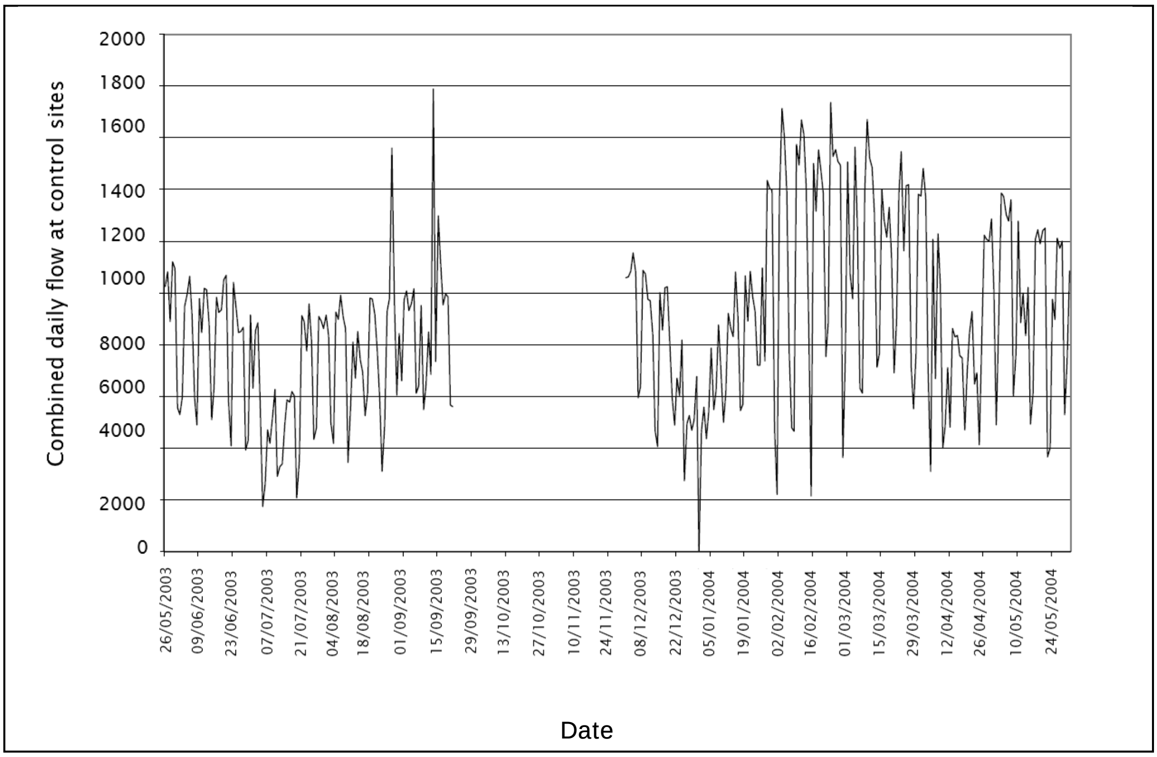
Because the counts that were undertaken were of fairly short duration and did not cover long periods of each day, correction factors were required to determine the daily average flow. Also, cycle flows are highly variable depending on such things as the weather, school holidays, day of the week, types 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 4.1.

Figure 4.1 Daily cycle profile flow by quarter hour



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 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 4.2.

Figure 4.2 Total daily cycle flow at control sites (June 2003–May 2004)



No continuous count data was 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, differences in weather between the cities could not be taken into account. Future studies should establish profiles for other cities.

4.2 Crash prediction model analysis

4.2.1 Selecting functional form

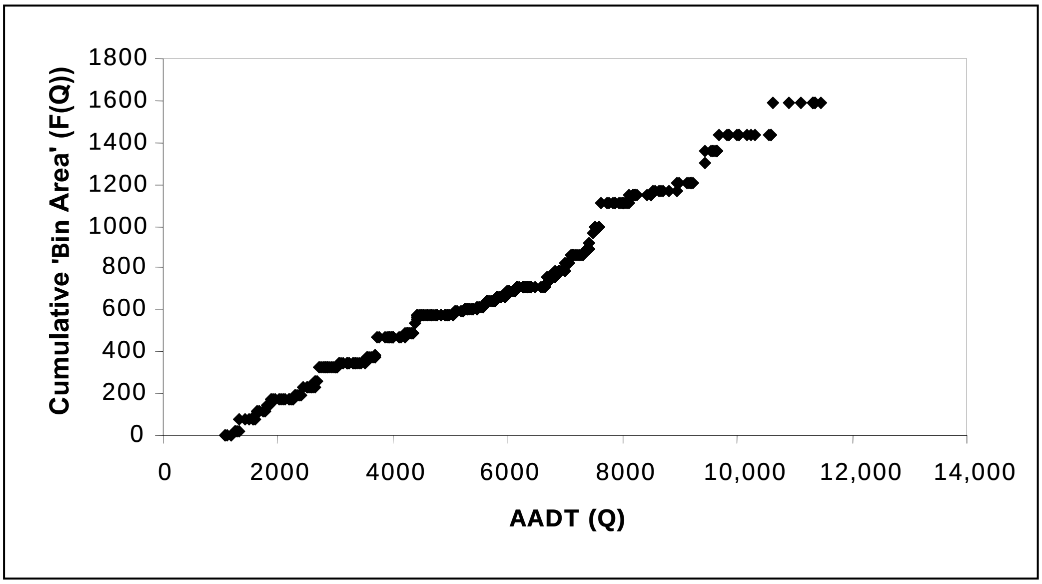
The process begins by listing the critical variables influencing the cycle crash rate, together with a clear procedure describing how they should be measured. Data is then collected for all such variables.

Each variable is integrated into the functional form of the model using Hauer and Bamfo's (1997) integrate–differentiate method. If the functional form does not match the relationship between the predictor variable and crashes, then the fit of the model is likely to be poor and the model cannot be trusted to predict the change in crashes for a change in the predictor variable.

The integrate–differentiate method starts by first determining the empirical integral function. This is determined by the following steps (Hauer and Bamfo 1997):

1. Sort the crash and predictor variable data by the predictor variable of interest, eg flow (*Q*).
2. Determine the 'bin width' of each data point. The bin width in this example is the difference between the next higher and next lower flow divided by two.
3. Calculate the 'bin area': this is the bin width multiplied by the crash count.
4. Calculate the sum of all bin areas from the lowest value of the predictor variable up (see figure 4.3).

Figure 4.3 Example showing the estimate of the integral function



Assuming that a function f(Q) exists for the relationship between the predictor variable (*Q*) and crashes (*A*), then the definite integral of f(Q) from *Q*=0 to *Q*=*x*, (ie the area under the curve f(Q)) will be the integral function, F(Q). The summing of the bin areas to determine the empirical integral function is therefore an estimate of the integral function.

By inspecting the relationship in figure 4.3, the relationship can be inferred by comparing it with the graphs in figure 4.4,which has been taken from Hauer and Bamfo (1997). In the case of figure 4.3, the relationship is unclear. To determine which functional form may be suitable, the empirical integral function can be transformed for each applicable form. In the case of the power function, this can be done by plotting the natural log of flow against the natural log of the integral function (see figure 4.5).

Figure 4.4 Corresponding functional form (f(x)) and integral function (F(X)) (Hauer and Bamfo 1997)

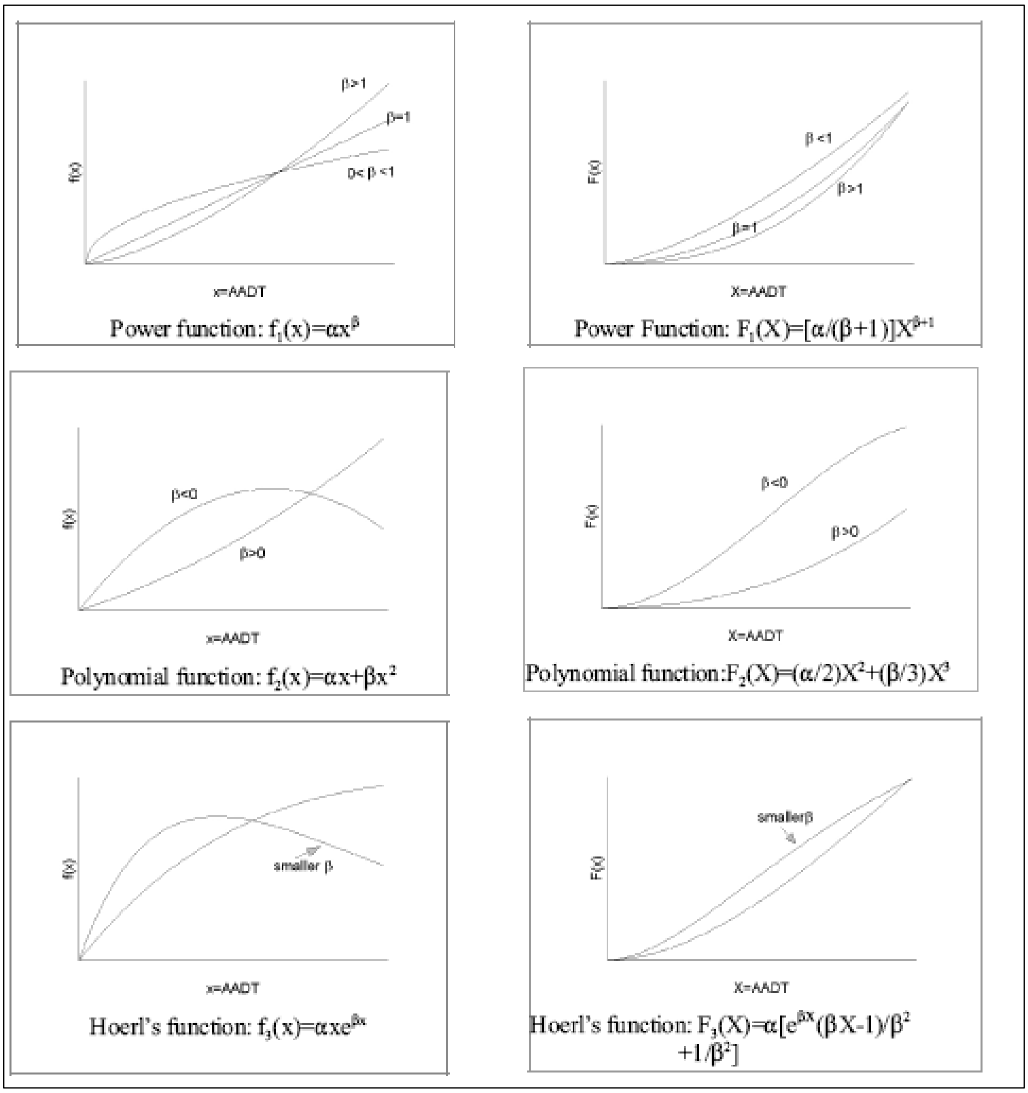


Figure 4.5 Transformed F(Q) indicating that a power function is the appropriate relationship

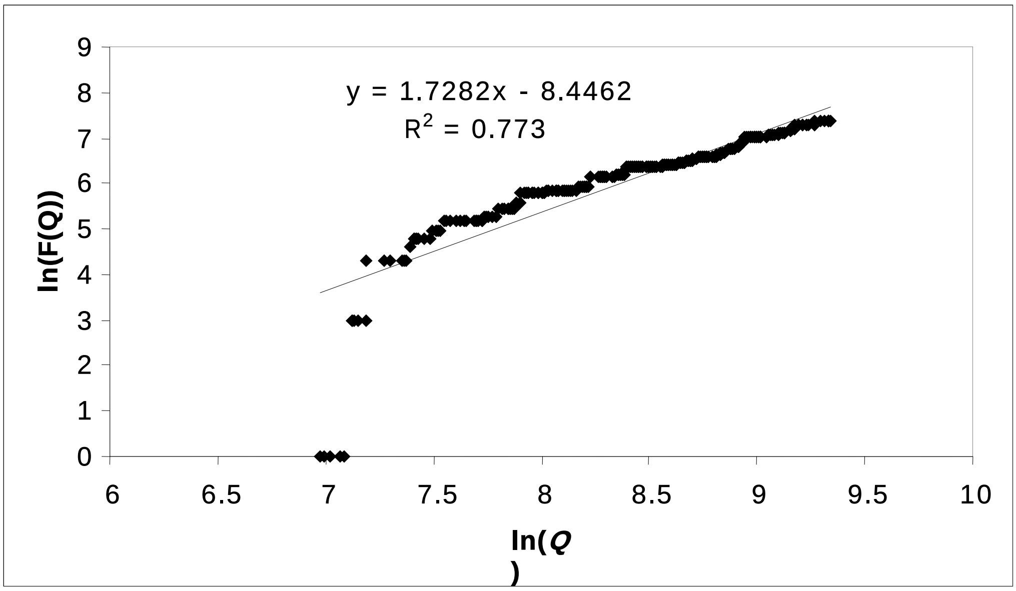


Figure 4.5 shows a linear trend, indicating that the power function is the appropriate functional form. If a linear trend is not observed, then this functional form is inappropriate.

Functional forms that have been used in this study are the power function (equation 4.1), the exponential function (equation 4.2) and Hoerl's function (equation 4.3).

$$A = b_0 x_1^{b_1} \quad \text{(Equation 4.1)}$$

$$A = b_0 e^{x_1 b_1} \quad \text{(Equation 4.2)}$$

$$A = b_0 x_1^{b_1} e^{x_1 b 2} \quad \text{(Equation 4.3)}$$

where:

A = annual mean number of crashes

x_1 = a continuous flow or non-flow variable

b_0, b_1 and b_2 = model parameters.

4.2.2 Determining a parsimonious variable set

Once the functional form has been determined, generalised linear models are then developed using either a negative binomial or Poisson distribution error structure. Generalised linear models were first introduced to road crash studies by Maycock & Hall (1984), and extensively developed by others (eg Hauer et al 1989). These modelling techniques were further developed in the New Zealand context for motor vehicle only crashes by Turner (1995).

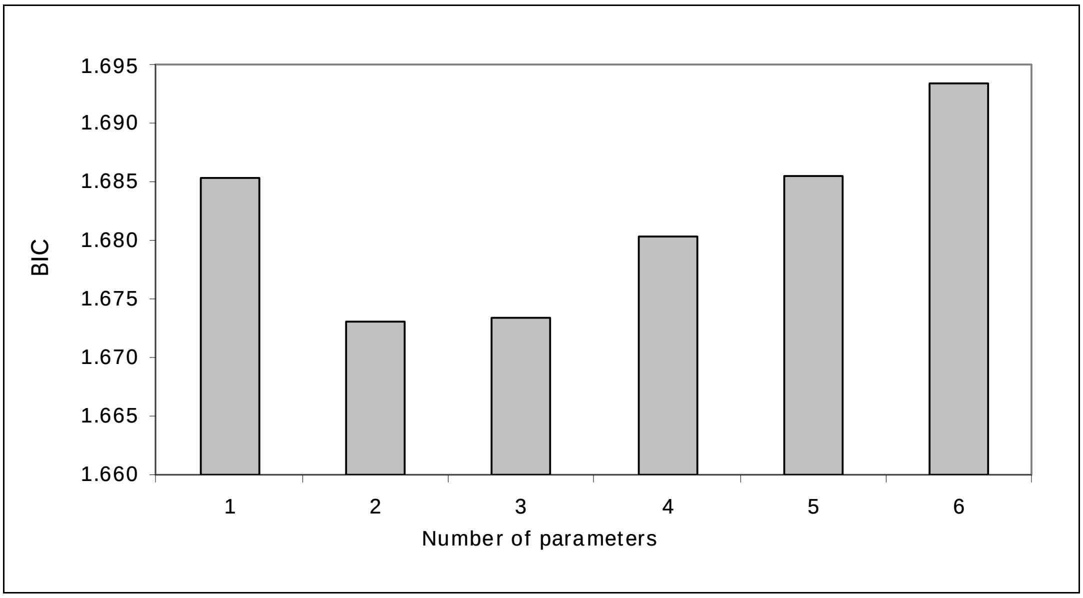
Software has been developed in Minitab in order to fit such models (eg to estimate the model coefficients); this can be readily done, however, in many commercial packages such as GENSTAT, LIMDEP or SAS.

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

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

The model with the lowest BIC is typically the preferred model form. Addition of a new variable to a model always provides an improved fit, though this may be slight and therefore not reduce the BIC. Figure 4.6 illustrates the case where the BIC indicates that the parsimonious number of parameters is two. However, if the analyst considers that a three-parameter model includes an important variable not contained in the two-parameter model, then he/she could justifiably select the model with three parameters, depending on the outcome of quality of fit testing (see section 4.2.1.3).

Figure 4.6 The Bayesian Information Criterion (BIC) for various numbers of parameters



Modelling every possible combination of variables to determine which has the lowest BIC would be time-consuming and inefficient. The process used instead involves all non-flow variables being modelled with the main flow variable. The variables in the resulting models that maximise the log-likelihood (and therefore minimise the BIC) are then added together into a new model with more variables, and the BIC is tested. This is done for a number of combinations of variables (but not all combinations) as often the variables can be correlated, meaning that the 'best' two variables may not result in a better model. The correlation can be checked by producing a correlation matrix of the variables.

4.2.3 Goodness of fit

The BIC provides us with a model, but the model may still not fit the data well. The usual methods for testing goodness of fit of generalised linear models involve the scaled deviance G^2 (twice the logarithm of the ratio of the likelihood of the data under the larger model to that of the data under the smaller model) or Pearson's χ^2 (the sum of squares of the standardised observations). These do not work in our situation because of the 'low mean value' problem; our models are being fitted to data with very low means. This difficulty was first pointed out by Maycock and Hall (1984).

Wood (2002) developed a 'grouping' method for overcoming the low mean value problem. The central idea is that sites are clustered and then aggregate data from the clusters is used to ensure that a grouped scaled deviance follows a χ^2 distribution if the model fits well. Evidence of a good of fit is provided by a p-value. If this value is less than 0.05, say, this is evidence at the 5% level that the model does not fit well. Software has been written in the form of Minitab macros in order to run this procedure.

The goodness of fit is often calculated for a number of the better models as indicated by BIC. This is because although the best model, as indicated by the BIC, may have a crash rate that follows the modelled negative binomial distribution more closely at each combination of variables, some combination may make the model fit poorly (ie the true crash rate is very different from our prediction). The quality of fit would indicate that this is a poorly fitting model. As the goodness of fit is the best overall arbiter of the worth of the model, a model with a poorer BIC (but a better fit) may be selected as the preferred model.

4.2.4 Model interpretation

Once models have been developed, in some simple cases, the relationship between crashes and predictor variables can be interpreted. Caution should always be exercised when interpreting relationships within some multiple predictor variable models, as two or more variables can be highly correlated. However, the modelling process described in the previous sections usually means that variables in the 'preferred' models are not highly correlated because the method acknowledges that adding a variable correlated to those already in an existing model does not improve the fit of the model compared to the addition of important non-correlated variables. Likewise, functional forms that deviate from a power function are also difficult to interpret. In these situations, it is always best to plot the relationship.

In models with a power function form where the variables are not correlated, an assessment of the relationship can be carried out. For a typical model with a power-function form and two continuous variables (such as flows or speeds), the model takes the form shown in equation 4.5.

$$A = b_0 x_1^{b_1} x_2^{b_2} \qquad \text{(Equation 4.5)}$$

where:

A	=	annual mean number of crashes;
x_1 , x_2	=	continuous flow or non-flow variables
b_0, b_1 and b_2	=	model parameters.

In this model form, the parameter b_0 acts as a constant multiplicative value. If the number of reported injury crashes is not dependent on the values of the two predictor variables (x_1 and x_2), then the model parameters b_1 and b_2 are zero. In this situation, the value of b_0 is equal to the mean number of crashes. The value of the parameters b_1 and b_2 indicate the relationship that a particular predictor variable has (over its flow range) with crash occurrence. Five types of relationship exist for this model form, as presented in figure 4.7 and discussed in table 4.1.

Figure 4.7 Relationship between crashes and predictor variable *x* for different model exponents (b_1)

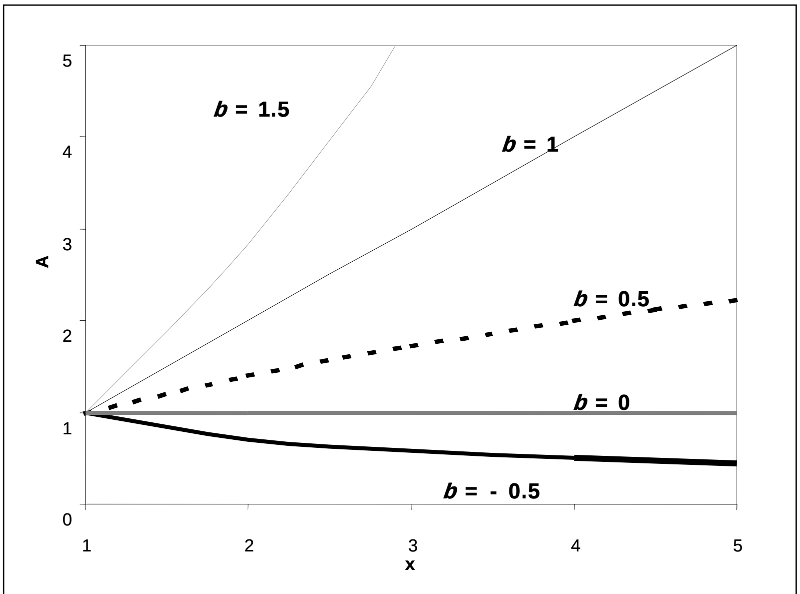


Table 4.1 Relationship between predictor variable and crash rate

Value of exponent	Relationship with crash rate
$b_i > 1$	For increasing values of the variable, the number of crashes will increase at an increasing rate
$b_i = 1$	For increasing values of the variable, the number of crashes will increase at a constant (or linear) rate
$0 < b_i < 1$	For increasing values of the variable, the number of crashes will increase at a decreasing rate
$b_i = 0$	The number of crashes will not change with increasing values of the variable
$b_i < 0$	For increasing values of the variable, the number of crashes will decrease

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

In the case of models including a covariate (here, discrete variables with a small number of alternatives), a multiplier (Φ) for different values of the variable is produced, and it is easy to interpret the relationship. This factor indicates how much higher (or lower) the number of crashes is if the feature is present. A factor of 1 indicates no effect on crash occurrence.

5 On-roadway crash models

5.1 Introduction

The following sections present the crash prediction models developed for the following cyclist crash types:

- mid-block crashes
- mid-block turning crashes
- mid-block non-turning crashes
- signalised crossroad product of link
- signalised crossroad 'right turn against' crashes
- other signalised crossroad crashes.

For each crash location, models were developed separately for crashes involving cyclist v motor vehicle interactions and crashes involving all motor vehicle classes. All crash types are included in both datasets. The models were developed in accordance with the process outlined in chapter 4.

5.2 Mid-block crashes

5.2.1 Cyclist v motor vehicle crashes

Ten models were developed for this crash type before settling on a preferred model (see appendix A for the models calculated for this and all other crash types). Appendix B outlines the full set of predictor variables and model parameters that were calculated for each of the ten models. Equation 5.1 presents the preferred model form, which includes the total two-way flow for both motor vehicles and cyclists, the length of the mid-block section and a covariate for the presence of a flush median.

$$A_{UCMN0} = 1.05 \times 10^{-2} \times Q^{0.25} \times C^{0.16} \times L^{0.45} \times \phi_{FLUSH\ MEDIAN} \quad \text{(Equation 5.1)}$$

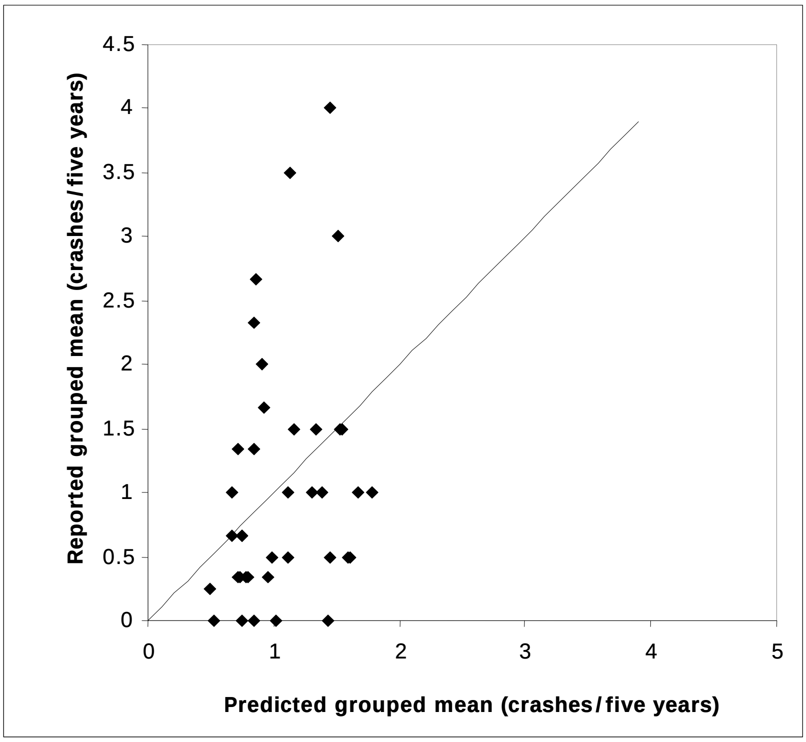
where:

A_{UCMN0}	=	annual number of mid-block crashes involving cyclists only (subscript denotes model type – see Appendix C);
Q	=	total two-way motor vehicle flow for the link
C	=	total two-way cycle flow for the link
L	=	length of mid-block in kilometres
$\Phi_{FLUSHMEDIAN}$	=	factor to multiply the crash prediction by if a flush median is present. This factor is $\Phi_{FLUSHMEDIAN}$ = 0.63.

Equation 5.1 implies that the presence of a flush median mid-block can reduce cyclist crashes by 37%. The safety benefit provided by flush medians to cyclists may be caused by the extra width that flush medians provide to motorists to avoid cyclists travelling on the side of the carriageway.

Equation 5.1 has a p-value of 0.05, indicating a model with good fit (values below 0.05 indicate a poor model). The goodness of fit can be illustrated by comparing the predicted mean number of crashes and the reported number of crashes for 'grouped' (approach) data (as outlined in Wood (2002)). Figure 5.1 presents this comparison between 'grouped' reported and predicted crashes for the preferred model. A poor fit is illustrated by a group that has different predicted and reported numbers of crashes (where the plotted point is furthest from the 45 degree line). If we have no evidence of poor fit, this gives us valid grounds for increased confidence in the model. Figure 5.1 indicates a generally good fit for most approach groups. However, the model appears to underestimate crashes at sites with higher traffic volumes.

Figure 5.1 Relationship between predicted and reported crashes for A_{UCMN0}



A number of other models were developed but were less than ideal. These included non-flow variables with significant relationships, such as:

- effective width of the kerbside lane, including the vehicle lane and cycle lane, where present
- the presence of a cycle lane
- mean motor vehicle speed along each mid-block section.

The models show that crashes increase with increasing traffic volume, mid-block length, effective width and mean motor vehicle speed. One model suggests that the presence of a cycle lane increases crashes by 21%, as shown in equation 5.2, which includes a covariate for the presence of a cycle lane.

$$A_{UCMN0} = 7.11 \times 10^{-3} \times Q^{0.25} \times C^{0.19} \times L^{0.38} \times \phi_{CYCLANE} \qquad \text{(Equation 5.2)}$$

where:

A_{UCMN0}	=	annual number of mid-block crashes involving cyclists only (subscript denotes model type – see appendix C)
Q	=	total two-way motor vehicle flow for the link
C	=	total two-way cycle flow for the link
L	=	length of mid-block in kilometres
$\Phi_{CYCLANE}$	=	factor to multiply the crash prediction by if a cycle lane is present. This factor is $\Phi_{CYCLANE} = 121$.

The increase in the crash rate with the presence of a cycle lane is counter-intuitive and counter to other research. The data used in the crash prediction model, however, is biased, which complicates the outcome. High crash frequency sites have historically been a high-priority location for cycle lane construction, so it is unlikely that sites with cycle lanes and sites without cycle lanes will have the same background crash rate. The before-and-after studies using the same locations with and without cycle lanes, as discussed in section 5.9, remedy this problem.

5.2.2 All crashes

Ten models were developed for this crash type before settling on a preferred model. Appendix B outlines the full set of predictor variables and model parameters that were calculated for each of the 10 models. Equation 5.3 presents the preferred model form, which includes the total two-way flow for motor vehicles, the length of the mid-block section and a covariate for parking prohibition.

$$A_{UAMN0} = 2.36 \times 10^{-4} \times Q^{0.84} \times L^{0.30} \times \phi_{NOPARKING} \qquad \text{(Equation 5.3)}$$

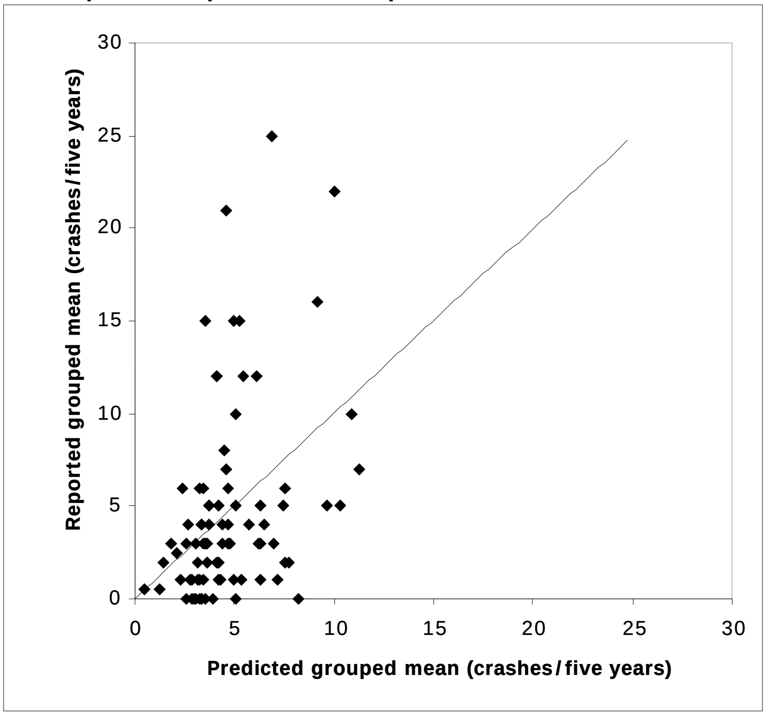
where:

A_{UAMN0}	=	annual number of mid-block crashes involving all vehicle types (subscript denotes model type – see appendix C)
Q	=	total two-way motor vehicle flow for the link
L	=	length of mid-block in kilometres
$\Phi_{NOPARKING}$	=	factor to multiply the crash prediction by if the mid-block length does not allow parking. This factor is $\Phi_{NOPARKING}$ = 0.25.

Equation 5.3 implies that all crashes occurring in mid-blocks can be reduced by 75% by removing parking from mid-block sections. The reduction in crashes by removing parking may be caused by removing conflicting movements of the parking manoeuvre with the carriageway traffic.

Equation 5.3 has a p-value of 0.17, indicating a model that fits well. Figure 5.2 presents the comparison between the predicted and reported number of crashes for the preferred model. Figure 5.2 indicates a generally good fit for most approach groups. However, the model appears to underestimate crashes at sites with higher traffic volumes.

Figure 5.2 Relationship between predicted and reported crashes for A_{UAMN0}



5.3 Mid-block turning crashes

5.3.1 Cyclist v motor vehicle crashes

For this crash type, 18 models were developed. Appendix B outlines the full set of predictor variables and model parameters that were calculated. Equation 5.4 presents the preferred model form, which includes the total two-way flow for motor vehicles, the length of the mid-block section and a covariate for the presence of a flush median.

$$A_{UCMN\ 1} = 3.50 \times 10^{-2} \times Q^{0.19} \times L^{0.54} \times \phi_{FLUSH\ MEDIAN} \qquad \text{(Equation 5.4)}$$

where:

A_{UCMN1}	=	annual number of mid-block turning crashes involving cyclists v motor vehicles (subscript denotes model type – see appendix C)
Q	=	total two-way motor vehicle flow for the link
L	=	length of mid-block in kilometres
$\Phi_{FLUSHMEDIAN}$	=	factor to multiply the crash prediction by if a flush median is present. This factor is: $\Phi_{FLUSHMEDIAN} = 0.48$.

Equation 5.4 suggests that the presence of a flush median mid-block can reduce interactions between turning cyclists and motor vehicles by more than 50%. Again, this reduction may be a result of the extra width that flush medians afford to motorists to avoid cyclists travelling on the side of the

carriageway. The flush median also allows right-turning traffic, both cycles and motor vehicles, to be separated from through-traffic, further reducing the likelihood of interactions.

5.3.2 All crashes

For this crash type, nine models were developed. Appendix B outlines the full set of predictor variables and model parameters that were calculated. Equation 5.5 presents the preferred model form, which includes the total two-way flow for motor vehicles, the length of the mid-block section and a covariate for parking prohibition.

$$A_{UAMN\ 1} = 1.37 \times 10^{-3} \times Q^{0.56} \times L^{0.10} \times \phi_{NOPARKING} \qquad \text{(Equation 5.5)}$$

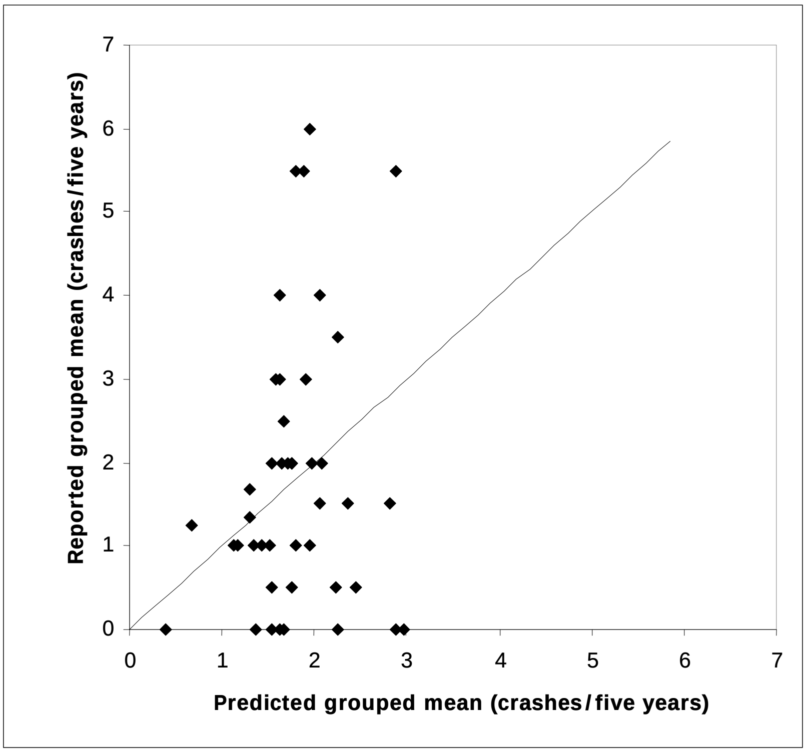
where:

A_{UAMN1}	=	annual number of mid-block turning crashes involving all vehicle types (subscript denotes model type – see appendix C)
Q	=	total two-way motor vehicle flow for the link
L	=	length of mid-block in kilometres
$\Phi_{NOPARKING}$	=	factor to multiply the crash prediction by if the mid-block length does not allow parking. This factor is $\Phi_{NOPARKING}$ = 0.25.

Equation 5.5 implies that all turning crashes occurring in mid-blocks can be reduced by 75% by removing parking from mid-block sections, which is very similar to equation 5.3. Equation 5.5 has a *p*-value of 0.09, indicating a model with good fit.

Figure 5.3 presents the comparison between the predicted and reported number of crashes for the preferred model. Figure 5.3 indicates a generally good fit, except for higher crash rates.

Figure 5.3 Relationship between predicted and reported crashes for A_{UAMN1}



5.4 Mid-block non-turning crashes

5.4.1 Cyclist v motor vehicle crashes

For this crash type, ten models were developed. Appendix B outlines the full set of predictor variables and model parameters that were calculated. Equation 5.6 presents the preferred model form, which includes the total two-way flow for motor vehicles, cyclists, and the length of the mid-block section.

$$A_{UCMN\ 2} = 2.28 \times 10^{-4} \times Q^{0.31} \times C^{0.50} \times L^{0.27} \qquad \text{(Equation 5.6)}$$

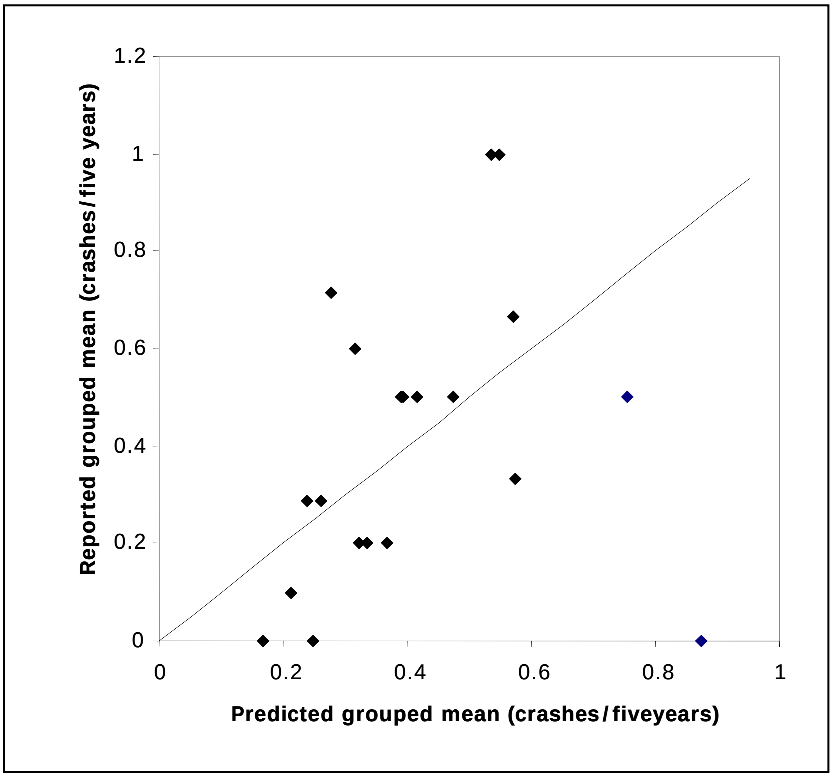
where:

A_{UCMN2}	=	annual number of mid-block non-turning cyclists v motor vehicle crashes (subscript denotes model type – see appendix C)
Q	=	total two-way motor vehicle flow for the link
C	=	total two-way cycle flow for the link
L	=	length of mid-block in kilometres.

Equation 5.6 indicates that crashes increase with increasing motor vehicle flow, cycle flow and mid-block length. Equation 5.6 has a p-value of 0.31, indicating a model with good fit.

Figure 5.4 presents the comparison between the predicted and reported number of crashes for the preferred model and indicates a generally good fit.

Figure 5.4 Relationship between predicted and reported crashes for A_{UCMN2}



5.4.2 All crashes

For this crash type, nine models were developed. Appendix B outlines the full set of predictor variables and model parameters that were calculated. Equation 5.7 presents the preferred model form, which includes the total two-way flow for motor vehicles, the length of the mid-block section and a covariate for parking prohibition.

$$A_{UAMN\ 2} = 4.39 \times 10^{-5} \times Q^{0.97} \times L^{0.42} \times \phi_{NOPARKING} \qquad \text{(Equation 5.7)}$$

where:

A_{UAMN2} = annual number of mid-block non-turning crashes involving all vehicle types (subscript denotes model type – see appendix C)

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

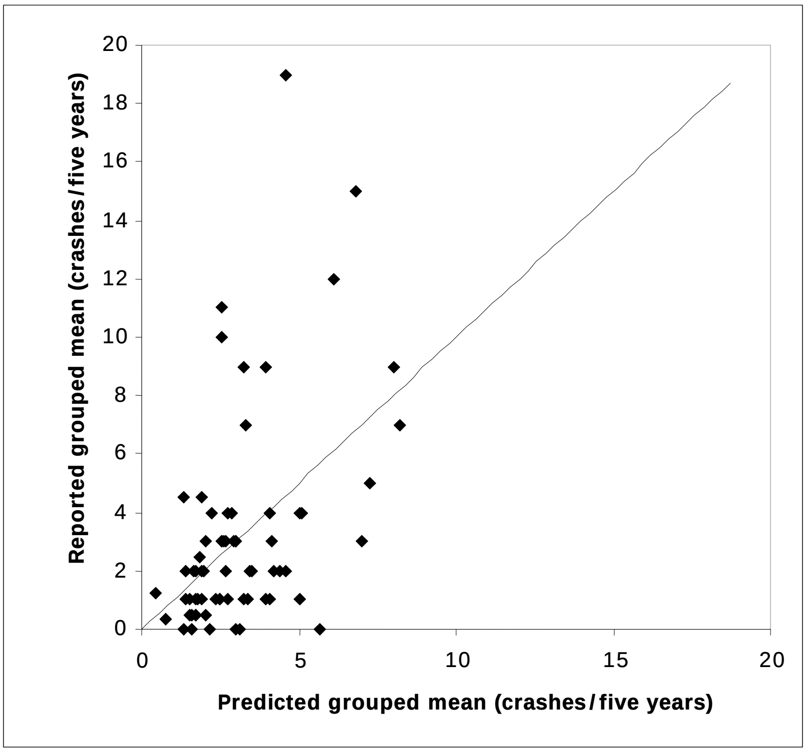
L = length of mid-block in kilometres

$\Phi_{NOPARKING}$ = factor to multiply the crash prediction by if the mid-block length does not allow parking. This factor is $\Phi_{NOPARKING}$ = 0.25.

Equation 5.7 implies that all crashes occurring mid-block can be reduced by 75% by removing parking from mid-block sections, which is very similar to both equations 5.2 and 5.4. Equation 5.7 has a *p*-value of 0.17, indicating a model that fits well.

Figure 5.5 presents the comparison between the predicted and reported number of crashes for the preferred model and indicates a generally good fit, except for higher crash rates.

Figure 5.5 Relationship between predicted and reported crashes for A_{UAMN2}



5.5 Signalised crossroad product of link

5.5.1 Cyclist v motor vehicle crashes

For this crash type, five models were developed. Appendix B outlines the full set of predictor variables and model parameters that were calculated. Equation 5.8 presents the preferred model form, which includes the total two-way flow for motor vehicles and cyclists, and a covariate for the presence of a cycle lane.

$$A_{UCXT\ 0} = 6.16 \times 10^{-3} \times Q^{\ 0.17} \times C^{\ 0.03} \times \phi_{CYCLANE} \qquad \text{(Equation 5.8)}$$

where:

A_{UCXT0} = Annual number of signalised crossroad crashes involving cyclists only (subscript denotes model type – see appendix C)

Q = total two-way motor vehicle flow for the approach

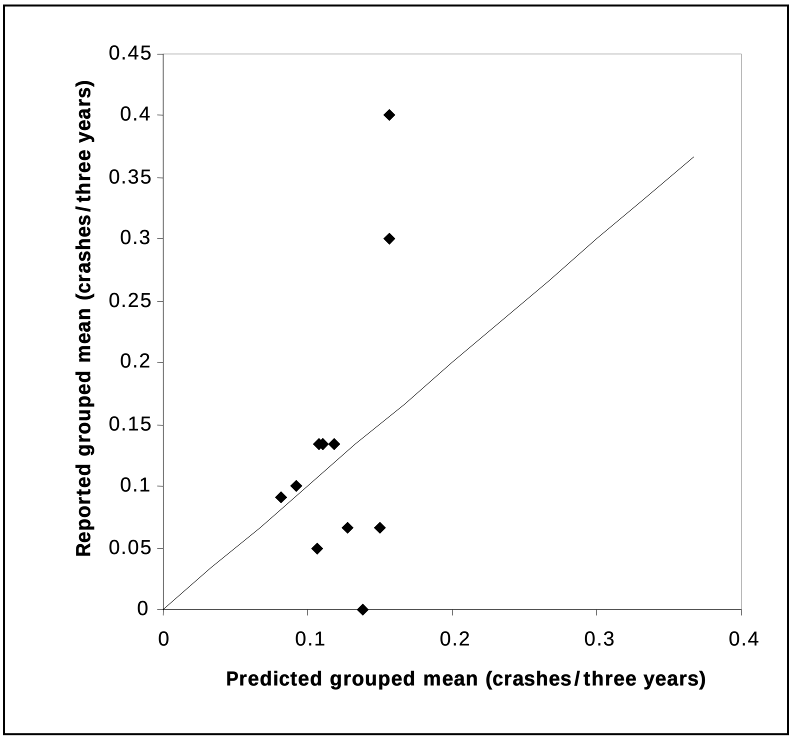
C = total two-way cycle flow for the approach

$\Phi_{CYCLANE}$ = factor to multiply the crash prediction model by if a cycle lane is present. This factor is $\Phi_{CYCLANE}$ = 1.41.

Equation 5.8 implies that the presence of a cycle lane at a signalised intersection can increase crashes involving cyclists by 41%. The dataset used to build this model only included 21 crashes, which may indicate that the model does not represent the situation well. The cycle flow has a very low coefficient, which suggests that changes in cycle flow have little effect on crashes. Equation 5.8 has a *p*-value of 0.25, indicating a model with good fit.

Figure 5.6 presents the comparison between the predicted and reported number of crashes for the preferred model and indicates a generally good fit, except for higher crash rates. Note that the crash rate in this figure (and in figure 5.7) give the crash rate over three years rather than over five years, as is the case for the other models.

Figure 5.6 Relationship between predicted and reported crashes for A_{UCXT0}



5.5.2 All crashes

For this crash type, four models were developed. Appendix B outlines the full set of predictor variables and model parameters that were calculated. Equation 5.9 presents the preferred model form, which includes only the total two-way flow for motor vehicles.

$$A_{UMXT0} = 3.71 \times 10^{-4} \times Q^{0.67} \qquad \text{(Equation 5.9)}$$

where:

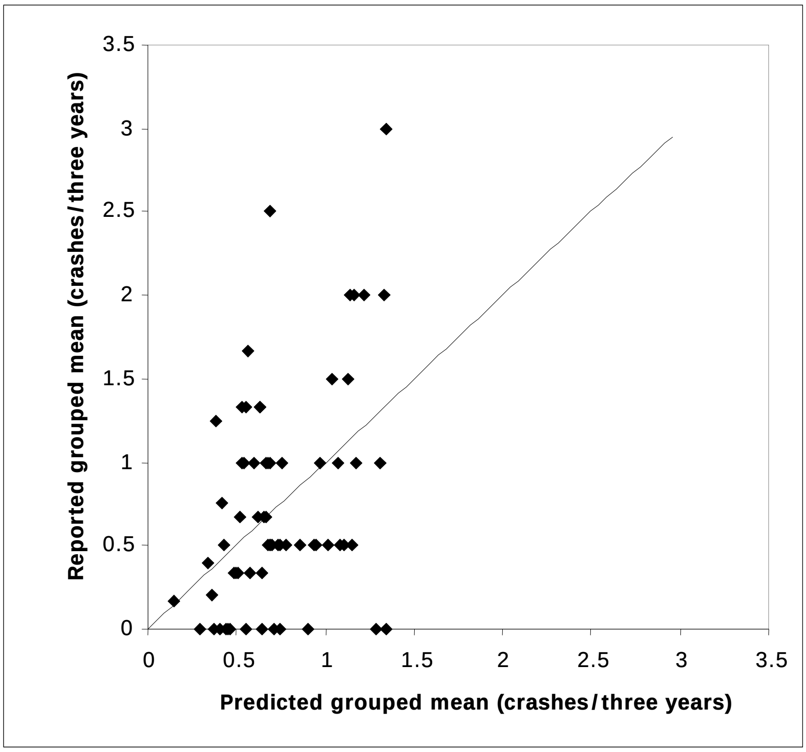
A_{UMXT0} = annual number of crashes involving motor vehicles at signalised crossroads (subscript denotes model type – see appendix C)

Q = total two-way motor vehicle flow for the approach.

Equation 5.9 implies that motor vehicle crashes at signalised intersections increase with increasing motor volumes. Equation 5.9 has a p-value of 0.05, indicating a model with good fit.

Figure 5.7 presents the comparison between the predicted and reported number of crashes for the preferred model and indicates a generally good fit, except for higher crash rates.

Figure5.7 Relationship between predicted and reported crashes for A_{UMXT0}



5.6 Signalised crossroad 'right turn against' crashes

The dataset for 'right turn against' crashes involving cyclists that occurred at signalised crossroads, contained only five crashes. A dataset containing less than 20 crashes is thought to be insufficient to build crash models, so no models can be presented for this crash type.

5.7 Other signalised crossroad crashes

The dataset for other crashes involving cyclists that occurred at signalised crossroads contained only 16 crashes. A dataset containing less than 20 crashes is thought to be insufficient to build crash models, so no models can be presented for this crash type.

5.8 Summary

This section summarises the models for each crash type. The typical mean annual numbers of reported injury crashes involving cyclists can be calculated using volume counts, and data for various non-flow variables, such as visibility, speed and geometry, and the crash prediction models in table 5.1. The total number of crashes can be predicted by summing the individual predictions for each crash group. Where traffic volumes or non-flow variable data are unavailable then the total number of crashes can be estimated using the model outlined in chapter 4. However, we strongly recommend the use of the crash models by type, particularly where volumes of cyclists are likely to be high.

Table 5.1 Crash prediction models

Crash type	Equation (crashes per approach)	Error structure	GoF[a]
Cyclist mid-block crashes	$A_{UCMN\ 0} = 1.05\times10^{-2}\times Q^{0.25}\times C^{0.16}\times L^{0.45}\times\phi_{FLUSHMEDIAN}$ $\phi_{FLUSHMEDIAN}=0.63$	NB[b] k=1.7[c]	0.05
All mid-block crashes	$A_{UAMN\ 0} = 2.36\times10^{-4}\times Q^{0.84}\times L^{0.30}\times\phi_{NOPARKING}$ $\phi_{NO\ PARKING}=0.25$	NB k=1.4	0.17
Cyclist mid-block turning crashes	$A_{UCMN\ 1} = 3.50\times10^{-3}\times Q^{0.19}\times L\times\phi_{FLUSHMEDIAN}$ $\phi_{FLUSHMEDIAN}=0.48$	NB k=1.3	
All mid-block turning crashes	$A_{UAMN\ 1} = 1.37\times10^{-3}\times Q^{0.56}\times L^{0.10}\times\phi_{NOPARKING}$ $\phi_{NO\ PARKING}=0.25$	NB k=0.8	0.09
Cyclist mid-block non-turning crashes	$A_{UCMN\ 2} = 2.28\times10^{-4}\times Q^{0.31}\times C^{0.50}\times L^{0.27}$	Poisson	0.31
All mid-block non-turning crashes	$A_{UAMN\ 2} = 4.39\times10^{-5}\times Q^{0.97}\times L^{0.42}\times\phi_{NOPARKING}$ $\phi_{NO\ PARKING}=0.25$	NB k=1.6	0.17
Cyclist signalised crossroad product of link	$A_{UCXT\ 0} = 6.16\times10^{-3}\times Q^{0.17}\times C^{0.50}\times\phi_{CYCLANE}$ $\phi_{CYCLANE}=1.41$	Poisson	0.25
All signalised crossroad product of link	$A_{UMXT\ 0} = 3.71\times10^{-4}\times Q^{0.67}$	Poisson	0.05

Notes to table 5.1:

a GoF (Goodness of Fit statistic) indicates the fit of the model to the data. A value of less than 0.05 indicates a poor fit, whereas a high value indicates a good fit.

b NB = negative binomial

c k is the gamma distribution shape parameter for the negative binomial distribution.

5.9 Empirical Bayes analysis

The empirical Bayes method is a 'hybrid' approach that uses elements of both the conventional and Bayesian methods. It is not considered controversial and, in a sense, is not a true Bayesian method, as it does not rely completely on a subjective evaluation of the prior distribution.

In crash prediction modelling (where crashes have a negative binomial distribution), the prior distribution is generated using data from a number of typical sites, the conventional crash prediction models or base models. This method allows both sources of information, ie typical crash rates for the population of sites and the local crash history, to be used in generating crash predictions.

The empirical Bayes method detailed in this section relies on a number of assumptions:

- The annual crash counts at a particular site are Poisson distributed about a constant true crash rate (m) over the crash period.
- The crash counts for each year of the crash period are independent of each other.
- The true crash rate (m) varies from site to site.
- The prior distribution of m is described by a gamma probability density function.

Further details on this method can be found in Persuad and Lyon (2006).

The before-and-after study (Empirical Bayes analysis) was undertaken for mid-block sections where cycle lanes had been installed, and where the 'after' period was at least five years. Forty-four of the 97 sections used in the cross-sectional study met these criteria. An empirical Bayes method was used in this analysis to enable 'regression to the mean' to be taken into account in the comparison. Based on the crash history and adjusting for regression to the mean, it was estimated that 46 crashes would occur along the 44 road sections in the five-year 'after' period, if no treatment (ie cycle lane addition) was undertaken. It was assumed that no other changes (raised median, parking, change in roadway width, etc) occurred for these sections.

Based on the observed 'after' period and again adjusting for regression to the mean, it was estimated that the crash frequency had dropped to 41.6 crashes in the five years following installation of the cycle lanes (treatment). This corresponds to a drop of 4.4 reported injury crashes in the 'after' period resulting from the installation of cycle lanes, or a 10% reduction. However, it should be noted that a number of the cycle lanes observed in the study were substandard, and the rate of reduction is likely to be greater for high standard facilities.

6 Off-roadway cyclist safety

6.1 Footpath safety

Certain elements of off-roadway cycle paths have been recognised as having potentially higher crash risks, particularly, where they intersect with motor vehicle facilities and where motor vehicle traffic exits from driveways over footpaths. Shared-use footpaths have been singled out as being areas of high risk because of the high frequency of crossings and the potential for limited visibility. These risks are further compounded by New Zealand road rules requiring cyclists to give way to pedestrians and motor vehicles on side-roads. A wide amount of data compares the safety of cycling on the footpath with that of riding on any other facility, ranging from 1.8 to 2.5 times more dangerous than cycling on the roadway, and 8 to 11 times more dangerous than cycling on an off-roadway track (these rates may not necessarily account for the number of cycle crossings, the volume of pedestrians, or the available width on and adjacent to the path or track). Given the research, the provision of shared-use footpaths alongside roadways is not recommended.

6.2 Cycle track safety

Cycle tracks have dangers somewhat similar to footpaths, although the nature of crossings along tracks can lead to fewer potential conflicts. These conflicts arise principally with:

- motor vehicles
- pedestrians
- mobility scooters and wheelchairs
- other cyclists.

In order to reduce these conflicts and make an off-roadway path safer, the three most important factors to accommodate appear to be:

- the number of motor vehicle crossings on the path, their motor vehicle volume, and the priority at each crossing
- the visibility and pavement marking at crossings, corners and underpasses
- the width of the off-roadway path.

In the case of motor vehicle crossings (primarily side-roads instead of driveways) on a cycling facility adjacent to a roadway, it appears two preferable treatments are possible: either eliminating the cycle path in favour of a cycle lane, or a 'bent-out' treatment that provides motor vehicle space between the cycle crossing and the adjacent intersection (refer to section 2.5.1 and figure 2.6). For all cycle crossings, it is important to clarify priority to all users, be it for motor vehicles or cyclists; giving cyclists no priority appears to cause the least confusion but is not always the preferential treatment. In high-traffic or high crash locations, grade-separated crossings should be considered, as they lead to a strong decrease in crashes when fully used.

Figure 6.1 Good practice: mid-block signalised cycle path crossing (Christchurch)

Off-roadway paths should further be designed with sufficient forward visibility for their users, considering all users from slow-moving pedestrians to mobility scooters to high-speed experienced cyclists. Path visibility is critical at cycle crossings, underpasses and corners but should be considered for the entire length of a facility (such as in figure 6.1). Driveways present a major hazard for cyclists, as visibility sightlines are often not provided in their construction. This lack of visibility is compounded by the lack of on-site turning within properties, creating the need for motor vehicles to reverse out over the shared footpath.

Proper pavement marking and signage is also critical along paths to segregate potentially conflicting traffic flows, especially at the limited visibility locations discussed previously. Appropriate markings include those to:

- divide opposing directions of traffic
- separate user groups of differing speeds (for example, pedestrians, roller-skaters and cyclists; see figure 6.2)
- designate priority at pathway intersections
- provide advanced warning of unexpected geometric changes (curves, underpasses, intersections etc).

Finally, an off-roadway path should have a design width that can accommodate the expected user mix and allow for safe passing by users at different speeds (see figure 6.3). A ‘clear zone’ on both sides of the path should also be considered to allow for informal passing and recovery for errant cyclists.

Figure 6.2 Good practice: wide, well-delineated shared-use track (Wellington)

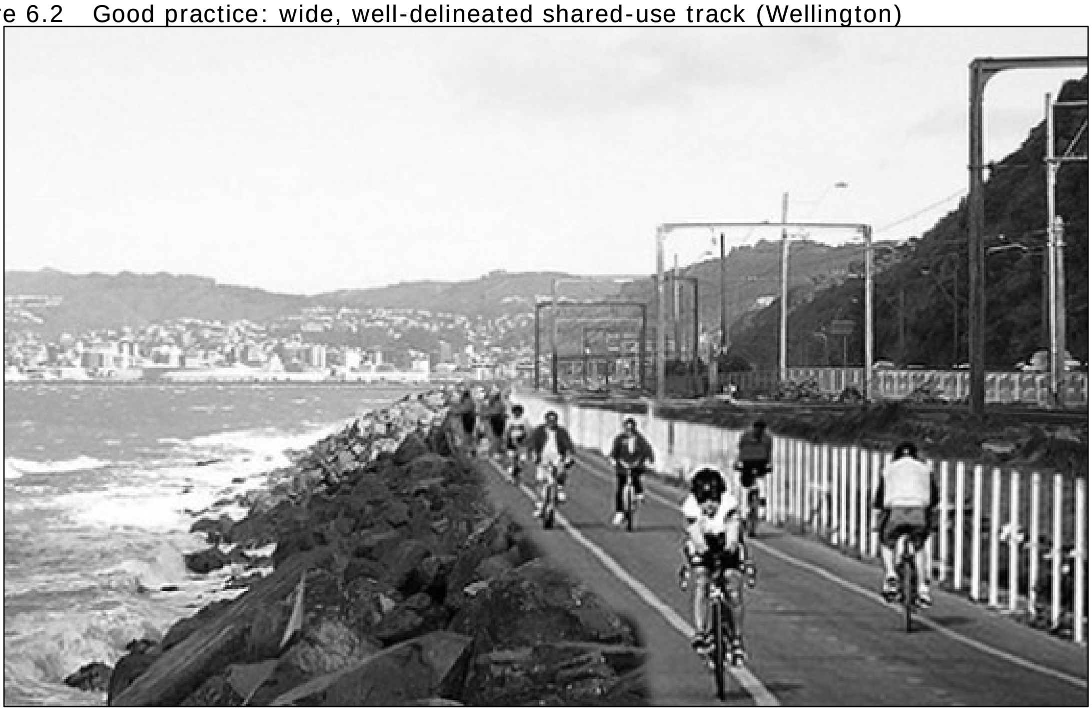


Figure 6.3 Good practice: well-delineated segregated cycle path (Tauranga)

Additional considerations from overseas research include:

- the effective distance between the off-roadway path and any adjacent roadway
- the posted speed limit and the number of lanes on this adjacent roadway
- the extent to which cyclists using the off-roadway path need to cross into motor vehicle traffic (for instance, in advance of intersections)
- the level of conflicting pedestrian traffic
- proper footpath maintenance.

7 Treatment hierarchy

The UK's Institution of Highways and Transportation (IHT 1996) proposed a 'Five-Step Hierarchy' of measures to improve safety for cyclists in this order:

1. reducing motor vehicle traffic volume
2. reducing motor vehicle traffic speeds
3. intersection treatment and traffic management
4. reallocation of carriageway/corridor space (eg on-roadway cycle lanes)
5. separating cycle facilities (eg off-roadway cycle tracks).

The research presented or referenced in this report indicates that safety benefits can be gained from all five elements of the treatment hierarchy, and in most cases, we can quantify their actual safety impact. Perhaps the most continuous area is the safety of off-roadway or segregated facilities. Each element of the hierarchy is discussed in turn below.

It is clear from the research that conditions for cycling can be improved by reducing motor vehicle volumes (measure 1) and speeds (measure 2) as this reduces the exposure to crashes (with less traffic) and the risk of more severe crashes (with lower speeds). In addition, the research by Turner et al (2006) indicates that a 'safety in numbers' effect occurs when cycle volumes grow. While cycle crashes increase as cycle volumes grow, the individual risk to cyclists reduces significantly. Research referenced in this report allows the actual effect of volume and speed changes to be quantified.

Improvements to intersections and traffic management (measure 3) can have similarly marked effects on cycle crash rates. For example, research findings quoted in Elvik and Vaa (2004) indicate that the addition of an advanced limit line for cyclists is expected to lead to a 27% reduction in cyclist crashes and a 40% reduction in all crashes. Benefits are also provided for other intersection treatments in this publication. This project did not provide a reduction factor for intersection cycle facilities and the crash modelling indicated that the number of cycle crashes may indeed increase; further research with a larger sample set is required to provide a specific result for New Zealand. Traffic management strategies like traffic calming have been shown to reduce cyclist crashes by 36% (Davies et al 1997) and total crashes by 40% (Zein 1997).

Regarding the reallocation of carriageway space (measure 4), different measures can lead to a reduction cycle crash rates. Addition of a flush median can reduce cycle crash rates by 37–50% (models U_{CMN0} and U_{CMN1}), while removal of on-street parking was found to reduce crash rates by up to 75% in three models (U_{AMN0}, U_{AMN1} and U_{AMN2}). The research also indicates that the addition of on-roadway mid-block cycle facilities can result in a reduction in all crashes of around 10%, although this result was not conclusive, as the crash models did indicate an increase in crashes. Elvik and Vaa (2004) indicate that the benefit may be higher, possibly as high as 35%. Further work is required, using a larger sample set and more variables to confirm this result.

The safety impact of off-roadway cycle paths (measure 5) varies considerably. Most of the research indicates that shared footpaths with multiple access and road crossings is less safe than on-roadway facilities, and that such off-roadway facilities should be avoided. While no relevant New Zealand research has been done on this topic, this is likely to be even more of a safety concern in New Zealand, where the road user rules require cyclists to give way to motor vehicles crossing these off-roadway facilities. This is not the case in many of the countries where other research has been undertaken, and this research still indicated an increase in crashes. Where cycle paths are not alongside roadways and/or have very few accesses and side-road crossings, the research has indicated they are safer than on-roadway facilities. The design of such facilities (eg width, particularly if shared with pedestrians) and the design of any vehicle crossings (eg who has priority and how the side-road is controlled) is critical.

8 Conclusion

8.1 Summary

8.1.1 Methodology

This study set out to quantify the safety benefit to cyclists from various cycle safety improvement measures, including cycle lanes, improving intersections for cyclists, off-roadway cycle paths, speed reduction (or traffic calming) measures and reducing traffic volumes. These measures fit within the five-step hierarchy of cycle improvements proposed by the IHT. Measures at the top of the hierarchy are typically applied first, depending on the type of site being treated.

1. reducing motor vehicle traffic volume
2. reducing motor vehicle traffic speeds
3. intersection treatment and traffic management
4. reallocation of carriageway/corridor space (eg on-roadway cycle lanes)
5. separating cycle facilities (eg off-roadway cycle tracks).

Data was collected from three cities, Christchurch, Hamilton and Palmerston North, to examine the effect of cycle facilities and other on-roadway features. Two methods, before-and-after studies and crash prediction modelling (using generalised linear modelling), were used to quantify the effects of traffic volume (refer to Turner et al 1996), on-roadway mid-block cycle facilities, intersection cycle facilities, flush medians, and presence and use of parking. The safety benefits of other factors were assessed from international literature, including off-roadway facilities and vehicle speed.

8.1.2 Safety of on-roadway cycle facilities

Most of the effort in this research project went into quantifying the safety effects of on-roadway features such as cycle lanes, flush medians and parking on cycle-related crashes and all crashes. Table 5.1 shows the crash prediction models that were developed for mid-block routes and intersections. The following discussion summarises the key findings that can be inferred from the crash prediction models.

Traffic volume (*Q*) was found to be an important variable in all models and cycle volume (*C*) was an important variable in all 'cycle v motor vehicle' crash types. Length (*L*) is also an important variable in mid-block crashes, with safety improving as the lengths between major intersections (roundabouts and traffic signals) increases.

The presence of a flush (or painted) median (indicated by the subscript FLUSHMEDIAN) reduces cycle-related crashes for mid-blocks (by 37%), particularly where turning traffic is present (52%), according to the models. This is likely to be a result of the extra space that cyclists and motor vehicles have to take evasive action if potential for a collision arises. The availability of space is a key issue for cyclists, which is reflected in this result. This, of course, is difficult to achieve on busy arterial roads, and providing (more) room for cyclists is a trade-off that needs to be made in balance with the needs of other road users. Where cycle volumes are high and carriageways are typically wide, as occurs in Christchurch, this is not as difficult to justify as it is in cities like Auckland, where carriageways and lane widths are typically narrower and cycle volumes are lower.

The absence of parking is a key factor for models looking at all mid-block crashes. The overall reduction is 75%, indicating that parking does have a major effect on crash rates. Routes that have low parking usage rates (ie where a parking lane is marked but the proportion of parking spaces that are used is low) have crash rates between 30% and 120% higher than sections with average parking rates, although this was a less crucial factor (these models are provided in appendix A). This could be because cyclists use the parking shoulder for most of their trip but then have to pull out into the traffic lane to go around parked cars. This movement may catch motor vehicle drivers unawares, leading to a potential conflict. This finding needs further research to confirm the behaviour of cyclists and motor vehicles.

The presence of a cycle lane does not feature as a key discrete variable for the mid-block sections, where the presence of a flush median and/or 'no parking' appear to be more important variables. However, crash prediction models have been developed that include the presence of a cycle lane (see appendix A) and it was found that crash rates were typically 20 to 30% higher on those routes with cycle lanes. This did not compare well with overseas research, which typically shows a reduction in all crashes. A before-and-after study found that a 10% reduction in all crashes was found at those sites that have had cycle lanes installed. The difference is likely to be the result of an increase in cyclists as a result of the cycle lane going in compared with untreated sites (we only had 'after' cycle counts) and a bias toward treating routes which had a history of cycle crashes. Even the crash reduction of 10% seems low compared to overseas research; this may be caused by the increase in cyclists and because some of the older cycle lanes included in the study are below standard, particularly in terms of width. The traffic signal model also showed that cycle facilities increased the crash rate. Further research is being undertaken on the effect of various cycle facilities at intersections.

The overseas research indicates that the number of crashes decreased when on-roadway cycle lanes were installed; the reduction of cyclist crashes generally varied from 35% to 50%, although one source did report an increase in cyclist crashes. Total (cycle and motor vehicle) crashes were found to decline by 6.5% to 35%. This compares with the 10% of 'all crashes' that are saved in this study. It was also found that narrower cycle lanes were three to four times less safe than wider cycle lanes, which maybe a factor in several of the sites used in this study.

8.1.3 Safety of cycle paths

Data on the safety aspects of off-roadway facilities is not readily available in New Zealand. The data sources that are available internationally are presented. The factors that should be considered when selecting either on- or off-roadway facilities are discussed.

Studies conducted to compare the crash rates for on- and off-roadway cycling have shown that footpaths are much less safe than other on- or off-roadway cycling options, with data indicating that footpath cycling is 1.8 to 2.5 times more dangerous than cycling on the roadway, and 8 to 11 times more dangerous than cycling on an off-roadway track (with very few or no driveways or vehicle crossings). In Denmark, before-and-after studies of off-roadway cycle paths were undertaken over a period of three years. The results showed that cyclist casualties increased 48% following introduction of off-roadway cycle paths. In addition, vehicles, moped riders and pedestrians suffered more crashes, with an overall rise in casualties of 27%. These footpath dangers arise principally from conflicts with motor vehicles, pedestrians and other cyclists.

In order to reduce these conflicts and make an off-roadway path safer, the three most important factors to accommodate appear to be:

- the number of motor vehicle crossings on the path and the priority at each crossing,
- the visibility and pavement marking at crossings and underpasses, and
- the width of the off-roadway path.

The research also indicated that better footpath maintenance could improve the safety of footpath cyclists, as well as the distance from adjacent roadways, and the speed limit and number of lanes on adjacent roadways.

A British study analysed five types of cycle path crossings with minor roads and found that priority at such crossings was a major hazard for cyclists, followed by side-road vehicles blocking the cycle path. Cyclists remaining on the major road (as opposed to the off-roadway path) had fewer problems at the junctions with minor roads.

8.1.4 Speed and volume reduction measures

The Danish Ministry of Transport recommends that a desirable speed for vehicles where cyclists and vehicles use the same traffic lanes is less than 40km/h. This is supported by a number of other overseas studies. A Bicycle Federation of America report (1993) found that when vehicles travelling at 32km/h strike pedestrians and cyclists, only about 5% are killed and most injuries are slight. At 48km/h, 45% are killed and many are seriously injured. When cars travel at 64km/h, 85% of pedestrians and cyclists are killed. Cross and Fisher (1977) found that more than half of all cycle fatalities occurred on roads with posted speed limits greater than 35mph (56km/h) even though less than 20% of all collisions occurred on roads with higher speeds. The Austrian city of Graz adopted a 30km/h speed limit for all residential areas except major roads (about 75% of all roads in Graz or 800 km), resulting in the number of cycle crashes dropping despite the number of cycle trips per day increasing. These studies support the view that reducing speed does improve cycle safety

New Zealand research by Turner et al (2006) has found that the crash rate per cyclist reduces as the cycle volume increases: the 'safety in numbers' effect. Conversely, if the cycle volume remains constant but the motorist volume is decreased, the expected crash rate per cyclist decreases and vice versa. This research can be used to assess the safety effects of changes in both cycle and motor vehicle volumes in the New Zealand context, either up or down, for urban mid-block sections, traffic signals and roundabouts.

8.2 Areas for future research

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

- **A larger sample size is necessary to confirm the findings of this report.** Ideally, this sample could be expanded to other cities in Australasia with large cycling populations, such as Melbourne and Adelaide in Australia.
- **The reporting rate of cycle crashes could be improved by extending the 0800 CYCLECRASH system** currently in use in the Nelson/Tasman region to a nationwide scale, or at least to one or more other cities with high cycling volumes, eg Christchurch.
- **The disparity in findings on the presence of cycle lanes at mid-block sections must be studied further.** It is possible that the sample set used for this study was biased towards sites with a higher rate of cycle crashes. A larger sample size could potentially negate this bias.
- Two of the signalised intersection categories – 'right turn against' crashes and 'other' crashes – did not have sample sizes large enough from which to develop crash prediction models. **Future research could focus on these intersection-based crashes to narrow the scope of the study.**

- **A study on the safety of off-roadway cycle paths in New Zealand should be undertaken.** This has not been studied well anywhere else in the world. It would be necessary to interview/survey cyclists using rail trails or bike paths in several rural and urban centres, potentially including routes through Hagley Park, along QEII Drive and beside the railway in Christchurch; Evans Bay to Oriental Bay or Hutt Road in Wellington; the North-western Cycleway in Auckland; Nelson's off-roadway cycle path system; or the New Plymouth Coastal Cycleway.
- **More New Zealand research is required on how best to design off-roadway paths (especially shared-use footpaths) for cyclists.** Specific examples of existing facilities that have provided good safety performance should be cited. This research can cascade into updates to the prevailing design standards for cycle paths.
- Giving consideration to existing advice on selecting cycle safety treatments, **a decision tree should be developed to provide advice on suitable treatments** for parts of the road network based on road hierarchy and type of cyclists.

9 References

American Association of State Highway & Transportation Officials (1999) *Guide for the development of bicycle facilities*. Washington DC: American Association of State Highway & Transportation Officials.

Allatt, T (2006) *The extent and implications of cycle accident under reporting*. Leeds, UK: Institute of Transport Studies.

Aultman-Hall, L and M Adams (1998) Sidewalk bicycling safety issues. *Transportation Research Record 1636*. Washington, DC: Transportation Research Board.

Bach, O, O Rosbach and E Jørgensen. 1988. *Cykelstier i byer - den sikkerhedsmaessige effect* (Bicyclists in cities – the effect of safety measures). Copenhagen, Denmark: Vejdirekforatet (Danish Road Administration).

Bicycle Federation of America (1993) Killing speed – a national goal. *Pro Bike News:* 7.

Millar, C (2005) Research to investigate the extent and severity of cycling accidents both on and off road. *Development Department Social Research Research Findings No. 204/2005.* Edinburgh: The Scottish Government.

Christchurch City Council (2004) Item 20: Tennyson Street and Lyttelton Street off-road and on-road cycling facilities – evaluation. *Sustainable Transport and Utilities Committee Agenda. 7 September 2004.*

Christchurch Cycle Safety Committee (1991) Cycle use and collisions in Christchurch. *Transit Research Report No. 7*.

Cross, KD, and GA Fisher (1977) *A study of bicycle/motor vehicle accidents: identification of problem types and countermeasure approaches*. Springfield, VA: National Technical Information Service.

Coates, N (1999) The safety benefits of cycle lanes. *Thirteenth Velo-city International Conference Proceedings, Dublin.*

Cumming, A (2000) A framework for bicycles at intersections. *Fourteenth Velo-city International Conference Proceedings, Munich.*

Danish Road Administration (1994a) Vurdering av nye krydsutformninger for cyklister (Design of urban signalised intersections). *Notat 2.* Copenhagen, Denmark: Vejdirekforatet (Danish Road Administration).

Danish Road Administration (1994b) Cycle paths at non signalised T-junctions. *Notat 8.* Copenhagen, Denmark: Vejdirekforatet (Danish Road Administration).

Davies, DG, TJ Ryley, SB Taylor and ME Halliday (1997) Cyclists at road narrowings. *Transport Research Laboratory Report 241.* Crowthorne, UK: Transport Research Laboratory.

Elvik, R and T Vaa (eds) (2004) *The handbook of road safety measures.* Amsterdam: Elsevier.

Forester, J (2001) The bicycle transportation controversy. *Transportation Quarterly, Vol 55, No. 2:* 7–17.

Harland, G, and R Gercans (1993) Cycle routes*. Transport Research Laboratory Project Report 42.* Crowthorne, United Kingdom: Transport Research Laboratory.

Hauer, E, and J Bamfo (1997) Two tools for finding what function links the dependent variable to the explanatory variables. *Proceedings of the ICTCT 97 Conference, Lund, Sweden.*

Hauer, E, JCN Ng and J Lovell (1989) Estimation of safety at signalised intersections. *Transportation Research Record 1185*: 48–61.

Herrstedt, L, MA Nielsen, L Agústsson, KM Lei Krogsgaard, E Jørgensen and NO Jørgensen (1994) *Safety of cyclists in urban areas: Danish experiences.* Copenhagen: Danish Road Directorate.

Herslund, M, and NO Jørgensen (2003) Looked-but-failed-to-see-errors in traffic. *Accident Analysis & Prevention 35:* 885–891.

Hoenig, M (2000) The Graz traffic calming model and its consequences for cyclists. *Fourteenth Velo-city International Conference Proceedings. Munich.*

Hunter, WW (1998) *An evaluation of red shoulders as a bicycle and pedestrian facility.* Bicycle and Pedestrian Safety Report. Tallahassee, Florida: Florida Department of Transportation.

Hunter, WW, JR Stewart, JC Stutts, HH Huang and WE Pein (1999) Bicycle lanes versus wide curb lanes: operational and safety findings and countermeasure recommendations. *Federal Highway Administration Report. FHWA-RD-99-035.* Washington, DC: Federal Highway Administration.

Hunter, WW, and R Stewart (1999) *An evaluation of bike lanes adjacent to motor vehicle parking.* Bicycle and Pedestrian Safety Report. Tallahassee, Florida: Florida Department of Transportation.

IHT (1996) *Cycle-friendly infrastructure: guidelines for planning and design*. London, UK: Institution for Highways and Transportation, Cyclists' Touring Club, Bicycle Association and Department of Transport.

Jacobsen, PL (2003) Safety in numbers: more walkers and bicyclists, safer walking and bicycling. *Injury Prevention 9:* 205–209.

Jensen, SU (2000a) Cyclist safety at signalised junctions. *Fourteenth Velo-city International Conference Proceedings. Munich.*

Jensen, S (ed) (2000b) *Collection of cycle concepts.* Copenhagen, Denmark: Vejdirekforatet (Danish Road Administration).

Kaplan, J (1975) *Characteristics of the regular adult bicycle* user. Washington, DC: Federal Highway Administration.

Kiyota, M, U Vandebona, N Katafuchi, and S Inoue (2000) Bicycle and pedestrian traffic conflicts on shared pavements. *Fourteenth Velo-city International Conference Proceedings, Munich.*

LTNZ (2004) *Cycle network and route planning guide.* Wellington, New Zealand: Land Transport New Zealand.

Leden, L (1989) The safety of cycling children – effect of the street environment. *Technical Research Centre of Finland Publications 55*. Espoo, Finland: Technical Research Centre of Finland.

Linderholm, L (1984) Signalised intersections function and accident risk for unprotected road users. Lund, Sweden: University of Lund.

Loveday, WA (2000) Bicycling is safe despite what you think: the relationship between safety perceptions of cyclists and cycling incidents and behaviour. *Road Safety: Research, Policing and Education Conference, 26–28 November 2000, Brisbane, Australia*.

Maycock, G, and RD Hall (1984) Accidents at 4-arm roundabouts. *TRRL Report LR 1120.* Crowthorne: UK: Transport & Road Research Laboratories. 60pp.

McClintock, H, and J Cleary (1996) Cycle facilities and cyclists' safety: experience from Greater Nottingham and lessons for future cycling provision. *Transport Policy Vol. 3, No. 1/2:* 67–77.

Ministry of Transport (2004) *Land transport (road user) rule 2004.* Wellington, New Zealand: Ministry of Transport.

Ministry of Transport (2006) Getting there – on foot, by cycle. Accessed 20 August 2009. *http://www.transport.govt.nz/ourwork/Documents/GettingThereA4.pdf*

Ministry of Transport (2008) New Zealand transport strategy. Accessed 20 August 2009. *http://www.transport.govt.nz/ourwork/Documents/NZTS2008.pdf*

Moritz, WE (1998) *Adult bicyclists in the United States: characteristics and riding experience in 1996.* Washington, DC: Transportation Research Board Bicycling Committee.

Munster, D, G Koorey and Walton (2001) Role of road features in cycle-only crashes in New Zealand. *Land Transport New Zealand Research Report No. 211*. Wellington, New Zealand: Land Transport New Zealand.

OECD (1998) Safety of vulnerable road users. *DSTI/DOT/RTR/RS7(98)1/FINAL.* Paris, France: OECD Directorate for Science, Technology and Industry.

Parfitt, M, and P Kortegast (2005) 0800 Cycle Crash ringing hot in Nelson. *Proceedings of the NZ Cycling Conference 2005, Hutt City, New Zealand.*

Pasanen, E (1999) Cycling risks in the City of Helsinki, Finland. Accessed 17 September 2009. *http://www.bikexprt.com/research/pasanen/helsinki.htm*

Pedler, A, and DG Davies (2000) Cycle track crossings of minor roads. *Transport Research Laboratory Report 462.* Crowthorne, UK: Transport Research Laboratory.

Persuad, B, and C Lyon (2006) Empirical Bayes before-and-after safety studies: lessons learned from two decades of experience *Transportation Research Board Annual Meeting, Washington, USA.*

Petrisch, TA, BW Landis, HF Huang and SK Challa (2006) *Sidepath safety model – bicycle sidepath design factors afftecting crash rates.* Lutz, Florida, USA: Sprinkle Consulting.

Queensland Transport (2005) *Queensland cycle strategy implementation report 2003–2005*. Fortitude Valley, Queensland, Australia: Policy Implementation Team, Land Transport & Safety Division, Queensland Transport.

Rainbird, RC (1979) *Accidents on Stevenage cycleways 1972–1977*. London: Hertfordshire County Council and Planning and Transport, Research and Computation.

Royal Society for the Prevention of Accidents (2005) *Cycling Accidents Facts and Figures, June 2005.* Birmingham, UK: Royal Society for the Prevention of Accidents.

Ryley, TJ (1996) Advanced stop lines for cyclists: The role of central cycle lane approaches and signal timings. *Transportation Research Laboratory Report 181.* Crowthorne, UK: Transportation Research Laboratory.

SWOV (2004) *Bicycle facilities on road segments and intersections of distributor roads.* SWOV Institute for Road Safety Research Factsheet. The Netherlands: SWOV.

Transport for London (2004) *A business case and evaluation of the impacts of cycling in London.* London: Transport for London Cycling Centre of Excellence Surface Transport.

Transport for London (2005) Cycling design standards. Accessed 17 September 2009. http://www.tfl.gov.uk/businessandpartners/publications/2766.aspx

Turner, S (1995) *Estimating accidents in a road network.* PhD thesis. Christchurch, New Zealand: School of Engineering, University of Canterbury.

Turner, S (2006) *0800CYCLECRASH system review, August 2006.* Christchurch: Beca Infrastructure Ltd.

Turner, SA, AP Roozenburg and T Francis (2006) Predicting accident rates for cyclists and pedestrians. *Land Transport New Zealand Research Report 289.* Wellington, New Zealand: Land Transport New Zealand.

Vandebona, U, and M Kiyota (2001) Safety perception issues related to pedestrians and cyclists. *Transport Engineering in Australia, Vol. 7, No. 1 and 2*:27–34.

VicRoads (2000) 'Head Start' storage areas at intersections. *Cycle Notes. No. 5 February 2000.* Australia: VicRoads.

Wachtel, A, and D Lewiston (1994). Risk factors for bicycle–motor vehicle collisions at intersections. *Institute of Transportation Engineers Journal September 1994*: 30–35.

Welleman, AG, and A Dijkstra (1988) Veiligheidsaspecten van stedelijke fietspaden (Safety of roads and other traffic in urban areas). *R-88-20.* Leidschendam: SWOV.

Wisconsin Department of Transportation (1998) *Wisconsin bicycle transportation plan 2020.* Madison, WI: Division of Investment Management, Bureau of Planning, Wisconsin Department of Transportation.

Wood, GR (2002) Generalised linear accident models and goodness-of-fit testing. *Accident Analysis and Prevention 34*: 417–427.

Zein, SR, E Geddes, S Hemsing and M Johnsons (1997). Safety benefits of traffic calming. *Transportation Research Record 1578,* Washington, DC: Transportation Research Board, National Research Council.

Appendix A: Crash prediction model parameters

A1 Introduction

This appendix outlines all the crash prediction models developed using the modelling procedure in chapter 5. The model parameters are included in tables in the following section by crash type and have been sorted by their BIC. The preferred model, ie the model that maximises the quality of fit while having a parsimonious number of variables, is highlighted in bold and pale grey fill.

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

Table A.1 Sample parameters for model reconstruction

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

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

$$A = b_0 \times P^{b_1} \times e^{b_2 \times (Qa/100)} \times \phi_{MEL} \quad \text{(Equation A.1)}$$

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

$$A = 3.84 \times 10^{-4} \times P^{0.55} \times e^{0.003 \times (Qa/100)} \times \phi_{MEL} \quad \text{(Equation A.2)}$$

A2 Model parameters

The following section outlines the model parameters for the eight crash categories.

Table A.1 Cyclist mid-block crashes (U_{CMN0})

Predictor variables	Parameters					Multiplier Φ	Error structure	BIC
	b_0	b_1	b_2	b_3	b_4			
Q, L	1.43×10^{-2}	0.29	0.36				k = 1.6	2.861
C, L	8.73×10^{-2}	0.20	0.36				k = 1.6	2.862
Q, C, L	8.60×10^{-3}	0.25	0.17	0.37			k = 1.6	2.902
$Q, C, L, \Phi_{FLUSHMEDIAN}$	**1.05×10^{-2}**	**0.25**	**0.16**	**0.45**		0.63	**k = 1.7**	**2.926**
Q, C, L, W_e	1.65×10^{-3}	0.33	0.11	0.28	0.65		k = 1.7	2.937
$Q, C, L, \Phi_{CYCLANE}$	7.11×10^{-3}	0.25	0.19	0.38		1.21	k = 1.6	2.944
Q, C, L, W	1.15×10^{-3}	0.36	0.15	0.35	0.62		k = 1.6	2.945
Q, C, L, S	2.04×10^{-3}	0.23	0.18	0.37	0.40		k = 1.6	2.949
Q, C, L, Lns	7.38×10^{-3}	0.27	0.17	0.37	-0.05		k = 1.6	2.949
$Q, C, L, e^{(As/100)}, e^{(Ar/100)}, e^{(Ao/100)}$*	8.26×10^{-3}	0.30	0.14	0.50	-0.03		k = 1.7	3.038

*For the last model, b_5 = 0.0 and b_6 = -0.01.

Table A.3 All mid-block crashes (U_{AMN0})

Predictor variables	Parameters					Multiplier Φ	Error structure	BIC
	b_0	b_1	b_2	b_3	b_4			
$Q, L, \Phi_{NOPARKING}$	**0.84**	**0.30**				**0.25**	**k = 1.4**	**5.120**
Q, L	0.71	0.35					k = 1.3	5.171
$Q, L, \Phi_{VERYLOWPARKINGUSE}$	0.76	0.21				1.64	k = 1.3	5.185
Q, C, L	0.66	0.29	0.35				k = 1.3	5.192
$Q, L, \Phi_{CYCLANE}$	0.71	0.36				1.22	k = 1.3	5.209
$C, L, \Phi_{NOPARKING}$	0.34	0.28				0.36	k = 1.3	5.211
$Q, L, e^{(Ar/100)}$	0.78	0.28	0.00				k = 1.3	5.211
$Q, L, \Phi_{FLUSHMEDIAN}$	0.71	0.39				0.85	k = 1.3	5.214
C, L	0.37	0.33					k = 1.2	5.218
$Q, L, e^{(As/100)}$	0.37	0.30	0.02				k = 1.2	5.256

Table A.4 Cyclist mid-block turning crashes (U_{CMN1})

Predictor variables	Parameters					Multiplier Φ	Error structure	BIC
	b_0	b_1	b_2	b_3	b_4			
Q	2.92×10^{-2}	0.15					*k* = 1.0	2.304
Q, L	2.22×10^{-2}	0.21	0.42				k = 1.2	2.319
C, L	2.29×10^{-1}	-0.05	0.41				*k* = 1.2	2.322
Q, L, $\boldsymbol{\Phi_{FLUSHMEDIAN}}$	$\mathbf{3.50\times10^{-2}}$	**0.19**	**0.54**			**0.48**	***k* = 1.3**	**2.329**
Q, L, $\Phi_{VERYLOWPARKINGUSE}$	6.36×10^{-3}	0.30	0.27			1.85	*k* = 1.3	2.340
Q, L, $\Phi_{NOPARKING}$	1.08×10^{-2}	0.28	0.41			0.49	*k* = 1.2	2.353
Q, L, $e^{(As/100)}$	1.98×10^{-2}	0.19	0.38	0.03			*k* = 1.2	2.355
Q, L, $\Phi_{CYCLANE}$	1.90×10^{-2}	0.21	0.44			1.32	*k* = 1.2	2.358
Q, L, W	2.94×10^{-3}	0.31	0.40	0.63			*k* = 1.2	2.363
Q, L, S	8.71×10^{-4}	0.17	0.42	0.93			*k* = 1.2	2.364
Q, C, L	2.81×10^{-2}	0.23	-0.09	0.42			*k* = 1.2	2.365
Q, L, Lns	1.41×10^{-2}	0.25	0.42	-0.13			*k* = 1.2	2.365
Q, L, $e^{(Ar/100)}$	2.09×10^{-2}	0.21	0.42	0.00			*k* = 1.2	2.366
Q, C, L, $\Phi_{FLUSHMEDIAN}$	4.69×10^{-2}	0.21	-0.11	0.55		0.48	*k* = 1.3	2.375
Q, C, L, We	1.10×10^{-3}	0.39	-0.22	0.24	1.33		*k* = 1.3	2.376
Q, C, L, W	3.40×10^{-3}	0.35	-0.10	0.40	0.67		*k*= 1.2	2.408
Q, C, L, S	1.50×10^{-3}	0.19	-0.06	0.42	0.82		*k* = 1.2	2.410
Q, C, L, Lns	1.66×10^{-2}	0.29	-0.10	0.42	-0.15		*k* = 1.2	2.411

Table A.5 All mid-block turning crashes (U_{AMN1})

Predictor variables	Parameters					Multiplier Φ	Error structure	BIC
	b_0	b_1	b_2	b_3	b_4			
Q, L, $\boldsymbol{\Phi_{NOPARKING}}$	$\mathbf{1.37\times10^{-3}}$	**0.56**	**0.10**			**0.25**	***k* = 0.8**	**3.646**
Q, L	7.26×10^{-3}	0.39	0.16				*k* = 0.7	3.648
C, L	$1.09E\times10^{-1}$	0.23	0.14				*k* = 0.8	3.653
Q, L, $\Phi_{VERYLOWPARKINGUSE}$	2.15×10^{-3}	0.48	-0.02			2.05	*k* = 0.8	3.655
Q, L, $\Phi_{FLUSHMEDIAN}$	8.01×10^{-3}	0.40	0.23			0.72	*k* = 0.7	3.687
Q, C, L	4.09×10^{-3}	0.35	0.19	0.17			*k* = 0.7	3.690
Q, L, $e^{(As/100)}$	7.16×10^{-3}	0.39	0.15	0.01			*k* = 0.7	3.694
Q, L, $\Phi_{CYCLANE}$	7.19×10^{-3}	0.39	0.17			1.06	*k* = 0.7	3.695
Q, L, $e^{(Ar/100)}$	5.83×10^{-3}	0.41	0.14	0.00			*k* = 0.7	3.695

Table A.6 Cyclist non-turning crashes (U_{CMN2})

Predictor variables	Parameters					Multiplier Φ	Error structure	BIC
	b_0	b_1	b_2	b_3	b_4			
C	3.90×10^{-3}	0.53					Poisson	1.560
Q	9.95×10^{-4}	0.42					Poisson	1.589
C, L	4.52×10^{-3}	0.54	0.27				Poisson	1.595
Q, C	2.11×10^{-4}	0.30	0.51				Poisson	1.601
Q, L	8.61×10^{-4}	0.46	0.28				Poisson	1.622
Q, C, L	**2.28×10^{-4}**	**0.31**	**0.50**	**0.27**			**Poisson**	**1.635**
C, L, $\Phi_{FLUSHMEDIAN}$	4.71×10^{-3}	0.53	0.27			0.94	Poisson	1.641
C, L, $\Phi_{VERYLOWPARKINGUSE}$	4.79×10^{-3}	0.53	0.30			0.86	Poisson	1.641
C, L, $\Phi_{CYCLANE}$	4.56×10^{-3}	0.54	0.27			0.99	Poisson	1.642

Table A.7 All non-turning crashes (U_{AMN2})

Predictor variables	Parameters					Multiplier Φ	Error structure	BIC
	b_0	b_1	b_2	b_3	b_4			
Q, L, $\Phi_{NOPARKING}$	**4.39×10^{-5}**	**0.97**	**0.42**			**0.25**	**k = 1.6**	**4.224**
Q, L	1.25×10^{-4}	0.86	0.45				k = 1.3	4.261
Q, C, L	3.55×10^{-5}	0.80	0.33	0.44			k = 1.4	4.276
Q, L, $\Phi_{CYCLANE}$	8.34×10^{-5}	0.89	0.46			1.34	k = 1.4	4.290
Q, L, $e^{(Ar/100)}$	3.62×10^{-5}	0.96	0.35	0.00			k = 1.4	4.294
Q, L, $\Phi_{VERYLOWPARKINGUSE}$	8.37×10^{-5}	0.89	0.36			1.37	k = 1.4	4.297
Q, L, $e^{(As/100)}$	1.22×10^{-4}	0.85	0.42	0.02			k = 1.4	4.299
Q, L, $\Phi_{FLUSHMEDIAN}$	1.27×10^{-4}	0.86	0.45			0.97	k = 1.3	4.308
C, L	7.02×10^{-2}	0.43	0.43				k = 1.2	4.332

Table A.8 Cyclist signalised crossroad product of link (U_{CXT0})

Predictor variables	Parameters					Multiplier Φ	Error structure	BIC
	b_0	b_1	b_2	b_3	b_4			
Q_{MOTOR},	1.00×10^{-2}	0.15					Poisson	0.819
Q_{CYC}	3.15×10^{-2}	0.05					Poisson	0.820
Q_{MOTOR}, $\Phi_{CYCLANE}$	6.63×10^{-3}	0.18				1.43	Poisson	0.845
Q_{CYC}, Q_{MOTOR}	8.86×10^{-3}	0.04	0.14				Poisson	0.848
Q_{CYC}, Q_{MOTOR}, $\Phi_{CYCLANE}$	**6.16×10^{-3}**	**0.03**	**0.17**			**1.41**	**Poisson**	**0.874**

Table A.9 Motor vehicle signalised crossroad product of link (U_{MXT0})

Predictor variables	Parameters					Multiplier Φ	Error structure	BIC
	b_0	b_1	b_2	b_3	b_4			
Q_{MOTOR}	**3.71×10^{-4}**	**0.67**					**Poisson**	**2.125**
Q_{MOTOR}, $\Phi_{CYCLANE}$	4.41×10^{-4}	0.65				0.91	Poisson	2.153
Q_{CYC}, Q_{MOTOR}	3.39×10^{-4}	0.03	0.66				Poisson	2.153
Q_{CYC}, Q_{MOTOR}, $\Phi_{CYCLANE}$	4.07×10^{-4}	0.03	0.65			0.90	Poisson	2.181

Appendix B: Predictor variables and model parameters

A:	annual number of crashes
C:	total two-way bicycle flow
L:	length of block in km
Lns:	**n**umber of lanes in one direction on approach
Q:	total two-way motor vehicle flow
S:	mean motor vehicle speed in km/h
W:	width of lane used by cyclists in m
W_e:	effective width of kerbside lane including vehicle and cycle lanes in m
$\Phi_{CYCLANE}$:	factor for the presence of a cycle lane
$\Phi_{FLUSHMEDIAN}$:	factor for the presence of a flush median
$\Phi_{NOPARKING}$:	factor if parking is prohibited on a particular block
$\Phi_{VERYLOWPARKINGUSE}$:	factor if parking is allowed but used very rarely on block
Φ_{MOTOR}:	???? appears in Table A.9
Φ_{CYC}:	???? appears in Table A.9

Appendix C: Models

UAMN1: All vehicles, mid-block turning crashes

UAMN2: All vehicles, non-turning crashes

UCMN1: Cyclist v motor vehicle, mid-block turning crashes

UCMN2: Cyclist v motor vehicle, non-turning crashes

UCMN0: Cyclist v motor vehicle, mid-block crashes

UAMN0: All vehicles, mid-block crashes

UCXT0: Cyclist v motor vehicle, signalised crossroad product of link

UMXT0: All vehicles, signalised crossroad product of link

Appendix D Recommended further reading

The publications listed below have not been referenced in the main body of this report, but they contain useful or interesting information and ideas related to cycle safety and crash prediction modelling.

Allen, JS (2002) Bicycle sidepaths: crash risks and liability exposure. Accessed 17 September 2009. http://www.bikexprt.com/bikepol/facil/sidepath/sidecrash.htm

Antonakos, CL (1994) Environmental and travel preferences of cyclists. *Transportation Research Record 1438.* Washington, DC: Transportation Research Board.

Brude, U, and J Larsson (1993) Models for predicting accidents at junctions where pedestrians and cyclists are involved. How well do they fit? *Accident Analysis and Prevention*, *Vol. 25*: 499–509.

Davies, DG (1999) Integrating cycling with mainstream traffic engineering. *Thirteenth Velo-city International Conference Proceedings, Dublin.*

Harkey, DL, JR Stewart and ER Rodgman (1996) *Evaluation of shared-use facilities for bicycles and motor vehicles.* Tallahassee, Florida: Florida Department of Transportation

Forester, J (1978) The effect of bikelane system design upon cyclists' traffic errors. Accessed 18 September 2009. *http://www.johnforester.com/Articles/Facilities/bikelane.htm*

Forester, J (1992) Setting traffic signal clearance interval for wide streets crossed by bicycle traffic. Accessed 18 September 2009. *http://www.johnforester.com/Articles/Facilities/traffsig.htm.*

Godefrooij, T (2000). Segregation or Integration? – the Dutch approach. *Fourteenth Velo-city International Conference Proceedings, Munich.*

Hunter, WW, JR Stewart, JC Stutts, HH Huang, and WE Pein, (1998) A comparative analysis of bicycle lanes vs. wide curb lanes: final report. *Federal Highway Administration Report FHWA-RD-99-034.* Washington, DC: Federal Highway Administration.

Landis, B (1994) Bicycle interaction hazard score: a theoretical model. *Transportation Research Record 1438.* Washington, DC: Transportation Research Board.

Noland, RB (1995) Perceived risk and modal choice: risk compensation in transportation systems. *Accident Analysis and Prevention, Vol 27 No 4*:503–521.

Sebastian, JR (2000) Integrated and segregated facilities worldwide. Discussion points: integration or segregation workshop. *Fourteenth Velo-city International Conference Proceedings, Munich.*

Simpson, M (1999) The benefits of advanced stop lines and cycle lanes for cyclists, pedestrians and accidents in Edinburgh*. Thirteenth Velo-city International Conference Proceedings, Dublin.*

Wilkinson, WC, B Epperson and R Knoblauch (1994) *The effects of bicycle accommodations on bicycle/motor vehicle safety and traffic operations*. Washington, DC: Bicycle Federation of America for the Federal Highway Administration.