CYCLE SAFETY – REDUCING THE CRASH RISK

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ABSTRACT

Cycling is a sustainable mode of travel and is an alternative to private motor-vehicles in urban areas, particularly for trips under 6 km. While there are a number of benefits of promoting more cycling, including health benefits to cyclists, reduced emissions, reduced parking demand and less traffic congestion, the risk of having a crash while cycling is typically higher than while travelling as a driver or passenger in a motor-vehicle. There is also a perception that cycling is unsafe, particularly on busy roads.

This paper presents research findings from two NZ Transport Agency (formerly Land Transport NZ) studies focused on understanding and reducing the risk of cycle crashes. Progress on a third study on this topic (for Austroads) is also presented. The first study focuses on the relationship between motor vehicle flow, cycle flow and crashes. The key finding of this study is that as cycle volumes increase the risk per individual cyclists reduces; the ‘safety in numbers’ effect.

The second study focuses on what factors and interventions influence cycle safety, other than cycle flows. This study involved the development of crash models for on-road cycle facilities at intersections and along road links in New Zealand, and looks at factors such as kerbside parking demand and presence of a flush (painted) island. It also presents the safety benefits/disbenefits of off-road cycle paths and motor-vehicle speeds from a collection of international studies.

The Austroads study, on the effectiveness of cycle facilities at intersections looks at the relationship between the various cyclists facilities installed at traffic signals and crash savings. Data on cycle facilities and other treatments, crash occurrence and traffic flows are being collected from around New Zealand and for a number of Australian states.

INTRODUCTION

The benefits of cycling as a mode of transport are widely understood and recognised across the globe. As such, cycling forms an integral element of the transport system to provide a genuine alternative travel choice and contributes to healthier lifestyles, benefiting both individuals and society as a whole. Many governments (including Australia and New Zealand) have set targets to increase the levels of cycling in their respective countries. Yet, for most, cycling accounts for only a small proportion of all daily travel.

When creating a transport network that supports and encourages cycling the aim is to provide a high quality network that is direct, convenient, safe, attractive and comfortable. Although planning for bicycles has become more common place over the last three decades, allocating road space for cycling has often not been seen as a priority, and as a result the final design of schemes does not always achieve all of the aims of developing high quality cycling networks. This in turn can often result in lower levels of cycling. Research by Hallet et al. (2006) and Transport for London (TfL) (2004) provided case studies where cycle facilities have been implemented and supported by promotion and education have resulted can improve safety and increase levels of cycling.

Although there are many guidance documents available for the design of cycle facilities, there is a currently very little content on the effectiveness of different types of treatments, particularly at intersections. The existing primary source of guidance for cycle planning in Australia and New Zealand is Austroads Guideline for Traffic Engineering Practice (GTEP) Part 14. This guide provides information on the types of facilities that are available, but provide little or no research on the safety benefits of each type of facility. Although it is important that cycle facilities are designed to be direct, convenient, attractive and comfortable, creating a safer environment is expected to realise the most gain in numbers of people cycling.

Other key factors that are critical to cycle safety are traffic volumes and speeds. The Institution of Highways & Transportation in the UK indicated that traffic volume and speed reduction can improve cycle safety (IHT) (1996), combined with cycle facilities the benefits can even be greater; although at low speeds and traffic volumes (eg. local streets) cycle facilities are often not required. Driver behaviour can also have a significant impact on the use of cycle routes and facilities. The level of experience of the cyclist using facilities also has a major impact how and when routes are used.

This paper presents recent research on the safety of cyclists on New Zealand roads. It examines cycle safety on roads with and without cycle facilities and the impact of various road features including flush (painted medians) and kerbside parking. Finally it profiles research that is in progress to look in more detail at the safety impact of cycle facilities at intersections across New Zealand and Australia. But first a short review of relevant literature on cycle safety.

LITERATURE REVIEW

A number of studies have been conducted to investigate the safety benefits of cycle facilities. It is acknowledged by most that the risk of being involved in a crash while cycling is typically higher than while travelling in a motor-vehicle, and the key concern is the severity of injuries to cyclists. However, research by Jacobson (2003) and Turner et al. (2006) demonstrates that there is a ‘safety in numbers’ effect for cyclists. As cycle volumes grow the research indicates that the individual risk to a cyclist of being involved in crashes reduces. The other vital aspect is to consider in terms of safety is the ‘perception of safety’ which as previously discussed can be very different to the actual safety of cycle routes and facilities.

Some studies use conflict study techniques to investigate the safety benefits. An example of such a conflict study is Hunter et al. (1998). This study compared the safety of cycle lanes with wide kerb side lanes through a conflict study. This comparative analysis was based on videotapes of almost 4,600 cyclists in three U.S. cities. 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.

Coates (1999) performed a before-and-after analysis of crashes at locations where cycle lanes had been marked at mid-block locations and concluded that providing cycle lanes at mid-block locations negatively impacted on crashes at intersections with a very small increase in the number of crashes. This conclusion did not, however, take into account increasing cycle volumes.

Other studies that have been conducted internationally, quantifying the safety benefits of cycle facilties provided the following results:

- that conditions for cycling can be improved by reducing motor vehicle volumes and speeds as this reduces the potential crashes and improves cyclists’ comfort (Turner et al, 2006);
- that while a numerical expected crash reduction corresponding to a reduction in motor vehicle volumes has not been quantified, a reduction in motor vehicle speeds is expected to result in a change of -0.1% to 0.3% (Wisconsin DOT 1998 and Jensen 2000) in cycle crashes for every 1 km/hr reduced;
- that the addition of an advanced limit line for cyclists is expected to lead to a -27% change in cyclist crashes and a -40% change in all crashes (Elvik 2004). These figures are based upon the amalgamation of research from different countries evaluated by Elvik and Vaa (2004) and provide the best estimates of crash reduction factors based on these studies; and
- that traffic management strategies like traffic calming have been shown to reduce cyclist crashes by -36% (Davies 1997) and total crashes by -40% (Zein 1997).

Hunter et al (1996) discovered that half of bicycle-motor vehicle collisions in the US occurred at intersections in their study of pedestrian and cycle crashes in the early 1990’s. A previous Australian study reflected the fact that many of the collisions on safety of cyclists at intersections in Australia by Green et al (2002) investigated cycle crashes for a two year period between 1998 and 1999 and reported that 39 cyclists were killed in Australia in 1999. In New Zealand, most on-roadway cycle crashes occur in locations not specifically allocated for cycling; only 7% of crashes occurred in a cycle lane, Munster (2001). Marked cycle lanes also have been shown in the US to result in fewer cyclist/pedestrian conflicts and fewer motor vehicles encroach into the neighbouring lane when passing a cyclist in a marked cycle lane.

Elvik and Vaa (2004) found that an advanced stop bar for cycle lanes at intersections leads to a decrease of 27% for cycle injury crashes and a 40% reduction in total crashes. In addition, Elvik and Vaa (2004) also found that adding cycle lanes through a signalised intersection reduce cycle crashes by 12% but increases overall crashes by 14%. Construction of grade-separated crossings has a major decrease of 30% of total crashes.

Work conducted by Carter et al. (2006) built upon this study to develop a macro- level bicycle intersection safety index (Bike ISI) in the USA that would allow engineers, planners, and other practitioners to use known intersection characteristics to prioritize intersection approaches with respect to bicycle safety proactively. The project collected a significant amount of data with regards to the types of facilities available including the number of lanes on each leg, lighting, sight distance and number of driveways. The results of the report by Carter et al (2006) provided a guideline for countermeasures that could be employed to improve safety at signalised intersections but did not include modelled results.

A before and after study by Herrstedt et al. (1994) carried out a study on the layout of cycle lanes, on the approaches to intersections. Following the construction of the cycle lanes, cycle crashes declined by 35% at intersections. The study did not take into account changes in typical crash rates as there was no control group.

Jensen (2000) reported on the success of new layouts at signalised intersections in five Danish municipalities. Four different layouts were applied at 11 signalised intersections in 1999-1993. These layouts consisted of narrowed cycle lanes to the limit lines, 'slalom' cycle lanes, staggered limit lines, markings of cycle crossings and profiled strips.

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 a storage box to stop 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 nearside cycle lane up to the stop line to turn right, but not the entire lane. Some right turning cyclists were observed to use part of the cycle lane and move out before the storage area while others ignored the cycle lane altogether.

Green et al (2002) 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 there was a change in behaviour. These storage boxes were not connected to cycle lanes, which stopped prior to the intersections.

CRASH PREDICTION MODELS FOR CYCLISTS

The models developed for cycle versus motor-vehicle crashes in this paper have been produced using generalised linear modelling methods. Generalised linear models were first introduced to road crash studies by Maycock and Hall (1984), and extensively developed in Hauer et al (1989). These models were further developed and fitted using crash data and traffic counts for motor-vehicle crashes in New Zealand by Turner (1995).

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

Equation 1 $$A = b_0 x_1^{b_1} x_2^{b_2},$$

Where,

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

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

Equation 2 $$\eta = \log A = \log b_0 x_1^{b_1} x_2^{b_2} = \log b_0 + b_1 \log x_1 + b_2 \log x_2$$

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

FLOW-ONLY CRASH PREDICTION MODELS FOR CYCLISTS

Table 1 shows the models developed by Turner et. al. (2006). The models are based solely on the volume of motor vehicles and cycles using each facility and are only for cycle accidents that involved a motor vehicle. It has been estimated that approximately 73% of on-road cycle accidents involve motor vehicles and only 49% of total cycle accidents occur on-road.

Table 1: Crash prediction models for Cyclists Accidents (Flow-only)

Crash Type #	Equation (crash per approach)	Error Structure	Significant Model
Signalised Crossroads			
Same Direction (codes A, E, F & G)	$A = 7.49 \times 10^{-4} \times Q_e^{0.29} \times C_e^{0.09}$	Poisson	Yes
Right-turn-against (code LB)	$A = 4.41 \times 10^{-4} \times q_7^{0.34} \times c_2^{0.20}$	NB (K=1.3)*	Yes
Roundabouts			
Entering versus circulating (HA, LB, KB & KA)	$A = 2.40 \times 10^{-5} \times Q_e^{0.79} \times C_c^{0.32}$	NB (K=0.8)*	Yes
Mid-Block			
All non-intersection Accidents	$A = 1.73 \times 10^{-7} \times Q^{1.38} \times C^{0.23} XL$	Poisson	Yes

*K is the Gamma shape parameter for the negative binomial (NB) distribution.
Crash Codes are those used in CAS (NZ Crash Analysis System)

Where:

- A = Annual number of crashes for an approach or mid-block section
- Q_e = Motor vehicle flow entering the intersection for an approach
- C_e = Cycle flow entering the intersection for an approach
- q_7 = Motor vehicle flow turning right from the opposing approach
- c_2 = Cycle flow entering the intersection from an approach and travelling straight
- C_c = Circulating cycle flow at an approach
- Q = Total two-way motor vehicle flow for the link
- C = Total two-way cycle flow for the link

L = Length of the link in kilometres

The model exponents in Table 1 for cyclists flows are a lot lower than 1.0 indicating that there is a 'safety in numbers' effect for cyclists. While the number of cycle crashes increases with increased cycle volumes, the crash rate per cyclist reduces significant as volumes increase. For example if the volume of straight though cyclists doubles from 200 to 400 cyclists per day at an intersection the number of 'right turn against' crashes involving cyclists (assuming right traffic volume is unchanged at 1,500 vehicles per day) will only increase by 15% (from 0.015 to 0.018 crashes per year). In terms of risk per cyclist, this results in a drop in the individual risk of 43%.

MODELS FOR ON-ROAD CYCLE FACILITIES

The benefits of cycle facilities were assessed using two methods, 1) cross-sectional studies, or crash prediction models and 2) before and after studies, in which an empirical Bayes approach is used. The results from these two methods are summarised below.

NON-FLOW CRASH PREDICTION MODELS

In Turner et. al. (2009) the traffic signals and mid-block models by Turner etal. (2006) were expanded to include additional variables for intersection and mid-block facilities respectively. Variables, such as parking frequency and turnover and the density of access points were considered. The study sample size consisted of 44 signalised crossroad intersections (so 176 approaches) and 97 mid-block sections of various length (L). 54 of the intersection approaches and 44 of the links had cycle facilities. Table 2 shows a selection of the accident prediction models produced. Table 3 defines each of the predictor variables (other than those defined above).

Table 2: Accident prediction models for Cyclists Accidents

Accident Type	Equation (accidents per approach)	Error Structure	Significant Model
Signalised Crossroads #			
All Cycle Accidents – Flow only	$A = 8.86\times10^{-3} \times Q_e^{0.14} \times C_e^{0.04}$	P	No
All Cycle Accidents – Including Cycle Lanes Variable	$A = 6.16\times10^{-3} \times Q_e^{0.17} \times C_e^{0.03} CyLane$ $CyLane = 1.41$	P	Yes
Mid-Block			
All Cycle Accidents – Flow Only	$A = 8.60\text{x}10^{-3} \text{x } Q^{0.25} \text{x } C^{0.17} \text{x } L^{0.37}$	NB (K=1.6)	Yes
All Cycle Accidents – Including Flush Median Variable	$A = 1.05\text{x}10^{-2} \text{x } Q^{0.25} \text{x } C^{0.16} \text{x } L^{0.45} \text{ x Flush}$, Flush = 0.63	NB (K=1.7)	Yes
All Cycle Accidents – Including Cycle Lanes Variable	$A = 7.11\text{x}10^{-3} \text{x } Q^{0.25} \text{x } C^{0.19} \text{x } L^{0.38} \text{ xCyLane}$, CyLane = 1.21	NB (K=1.6)	Yes
All Cycle Accidents – Including Speed Variable	$A = 2.04\text{x}10^{-3} \text{x } Q^{0.23} \text{x } C^{0.18} \text{x } L^{0.37} \text{ x } S^{0.40}$	NB (K=1.6)	Yes

# there were insufficient accidents to break down into the two major accident types (same direction and right-turn against)
P = Poisson models, so no 'k' value.

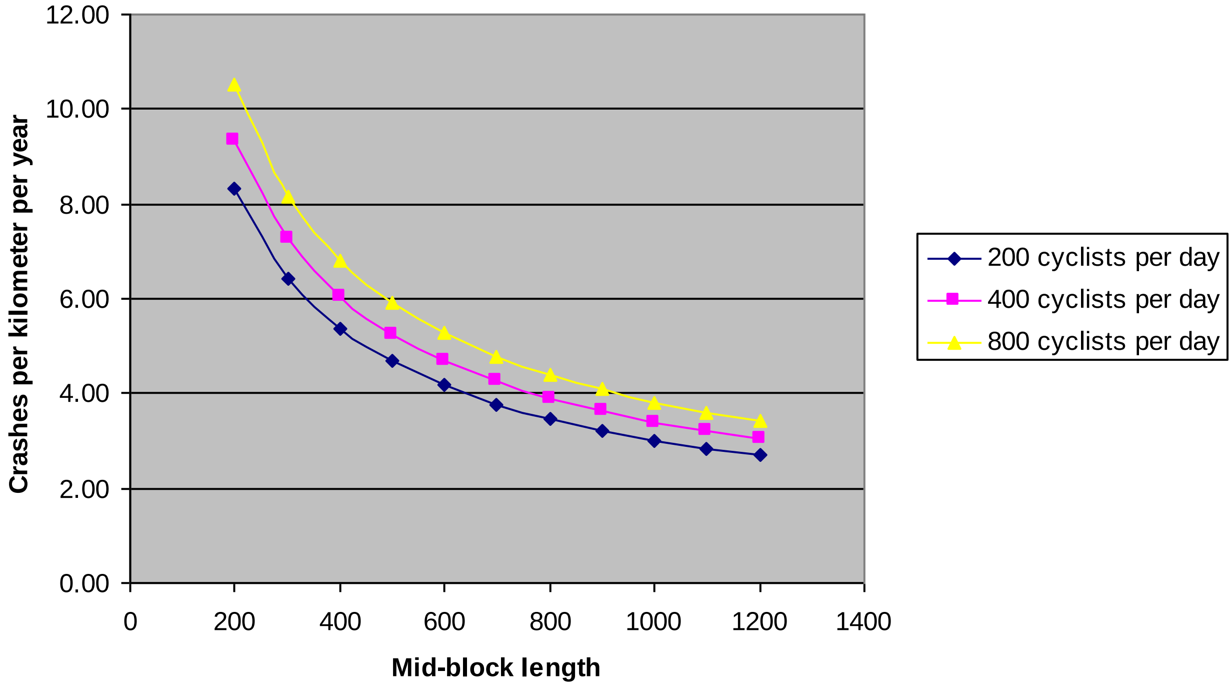
Table 3: 'Non-Flow' Variables for Cycle Accident Prediction Models#

Variable	Description
CyLane	A covariate that indicates a cycle lane. At intersection it is a cycle lane provided up to and including the limit lines and usually a straight through cycle lane.
Flush	A covariate that indicates that a flush median is provided along a road section
No Parking	This covariate is used if there is no parallel parking permitted next to the kerb. None of the study sections had angled parking.
Parking Utilisation	Parking utilisation along each mid-block section was categorised as very low, low, medium or high. Parking utilisation is a combination of the proportion of the mid-block with parking and turnover of that parking.
As	This is the number of minor side-roads along the mid-block section
Ar	This is the number residential access points along the mid-block section.
Ao	This is the number of educational, commercial and industrial access points along the mid-block section.
Speed (S)	Mean speed of motor vehicles along each mid-block section.
W & We	'W' is the width of the kerbside traffic lane. 'We' is the effective width of kerbside lane, including vehicle lane plus cycle lane, where present.
Lns	This is the number of through motor vehicle lanes in each direction

Some of these variables have not shown up as important in the modelling undertaken to date

Figure 1 shows the relationship between mid-block road segments of varying road length and crashes at cycle volume of 200, 400 and 800 per day (using all cycle accidents –flow only models) and traffic volume of 15000 vpd. The increased risk to cyclists when the mid-block length reduces from 600m to 300m (with 400 cyclists per day) is 55% (7.25 crashes per km compared to 4.68 crashes per km). This indicates that transport engineers need to pay particularly attention to cycle safety when intersections are closely spaced. This is also the case with other mid-block models, even when other road features, including cycle lanes are present (refer to Table 2).

Figure 1 - Cycle Crashes per Km based on Mid-block Length



'BEFORE AND AFTER' STUDY (EMPIRICAL BAYES) FOR MID-BLOCKS

The crash prediction models indicate that cycle lanes actually increase cycle crashes. Other researchers (Elvik and Vaa, 2004) have shown that cycle safety actually improved with cycle lanes, and we expected the same. So in order to examine this more closely and explore whether there was bias in the selection of sites for treatment a 'before and after' study was undertaken for the mid-block road sections that now have cycle facilities. Only 44 of the mid-block sections had cycle lanes installed (i.e. treated sections).

An empirical Bayes method was used in this analysis, to enable regression-to-the-mean to be taken into account in the comparison. Further details on this method can be found in Persuad and Lyon (2006). Based on the accident history and adjusting for regression-to-the-mean, it was estimated that 46 accidents would occur along the 44 treated mid-block sections in the five-year 'after' period, if no treatment (i.e. cycle lane) had been undertaken. 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 'after' period following treatment. This corresponds to a drop of 4.4 reported injury crashes in the 'after' period due to the installation of cycle lanes; a 10% reduction.

DISCUSSION - IMPROVING CYCLE SAFETY

The cross-sectional analysis (accident prediction models) shows that the number of cycle versus motor vehicle accidents increases with increasing motor vehicle volumes (Q), cycle volumes (C) and speed (S). An exponent of 0.40 for the speed variable indicates that a 4 – 7% reduction in cycle accidents could be expected for every 10% reduction in speed, with the largest reductions being in lower speed environments e.g. below 50km/h. Both New Zealand research studies show that there is a 'safety-in-number' effect for cyclists, with the risk for individual cyclists reducing as cycle volumes increase.

The models also show that as the length of the mid-block section increases the number of cycle accidents per kilometer decreases. So the cycle accident rate is higher along shorter road sections, which may be influenced by the closer spacing of major intersections.

The research also indicates that roads with flush (painted) medians have a lower cycle accident rate than roads without, given the same cycle and traffic volumes and length. The mid-block model indicates a 37% reduction in cycle accidents on roads with flush medians.

The effect of cycle lanes and intersection facilities on cycle accident occurrence is still unclear. The cross-sectional analysis indicates that cycle lanes and intersection facilities may increase the number of accidents; possibly by as much as 21% and 41% at mid-block locations and intersections respectively. However the 'before and after' study of mid-block sections indicates a 10% reduction in accidents if cycle lanes are installed. What is unclear from the analysis is the influence of other factors in the cross-sectional analysis. Less than half the mid-block sections and only 25% of the signalised intersection approaches have cycle facilities. It is highly possible that there is some bias, to higher cycle accident sites, in the intersections/mid-blocks that have been treated.

The other factor that may be influencing accidents at the treated sites is that we know from Christchurch City Council (CCC) cycle counts, that routes with cycle facilities have had increasing or static cycle volumes, whereas routes with no facilities cycle volumes have been reducing. Given these influencing factors the results of the 'before and after' study is likely to be the most reliable, which show a reduction in the cycle accidents when these facilities are installed. But greater benefits are likely to be realised from reducing volumes and speeds. Further research on this topic was recommended with a larger sample set, from cities around Australasia. Details on this expanded study follows.

EFFECTIVENESS OF CYCLING FACILITIES AT INTERSECTIONS

A third study on cycle safety, utilising crash prediction models, is currently underway, this time funded by Austroads. This study is focused on the effectiveness in terms of improved safety of cycle facilities at intersections. This study is to utilise a larger sample set of intersections that have cycle facilities across New Zealand and Australia, than were available in Turner et al. (2006 and 2009). The objectives of this study are to:

1. Develop crash prediction models and/or crash reduction factors for various cycle facilities at intersections; and
2. Advise how these models or crash reduction factors can be used to select the most effective cycle countermeasures for a particular signalised intersection.

To date this study has focused on understanding the various intersection treatments that are used in each of the Australian States and New Zealand, the widespread use or otherwise of various treatments and the availability of data for developing the crash prediction models and undertaking 'before and after' assessments.

Following a questionnaire mail-out and workshop the research team has identified the key intersection treatments that are applied at signalised intersections in each State and New Zealand. The key intersection treatments applied by State on the approach to the intersection and in the storage area are shown in Table 4 and 5. Figure 2 shows the various elements of continuity for cyclists through an intersection. The number of facility figures given is indicative only and for some cities only represent a sample of all sites (in Brisbane data was available for one arterial route and in Melbourne only within the City of Yarra).

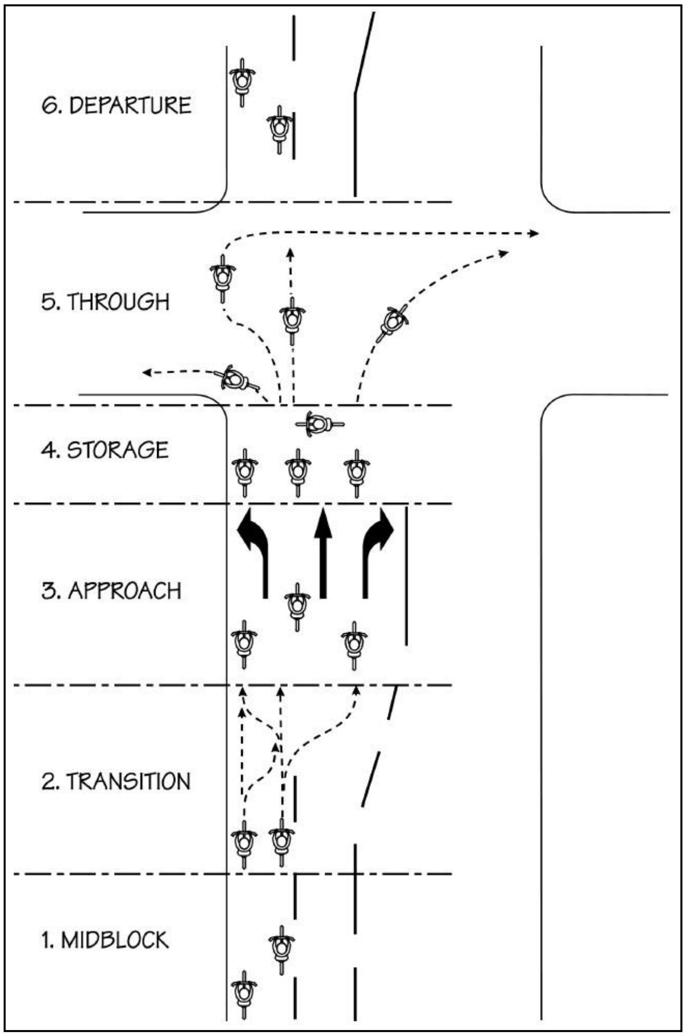
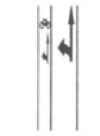
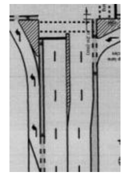


Figure 2 – Six Elements of Continuity through an intersection (Cumming, 2000)

Table 4: Approach treatments used in each City

City	 Kerbside	 Carside		 Rightside	Total
Adelaide	25	49	363	5	**442**
Canberra	50	20	5	0	75
Perth	100	5	100	0	**205**
Melbourne (Yarra)	20	20	5	0	45
Christchurch	100	150	70	5	**325**
Brisbane	16	10	1	0	27
Percentage	**28%**	**23%**	**49%**	**<1%**	**1119**

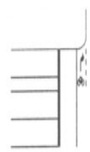
City	 Advanced	 Expanded	 Hook Turn	Other	Total
Adelaide	490	0	0	0	**490**
Canberra	110	0	5	0	115
Perth	0	0	0	0	0
Melbourne (Yarra)	20	30	0	0	50
Christchurch	20	30	10	20	80
Brisbane	22	0	0	5	27
Percentage	**87%**	**8%**	**2%**	**3%**	**762**

Table 5: Storage Treatments used in each City

Table 4 shows that approach treatment are in wide use and that three main treatment types are commonly used, with cycle lanes between the left and through traffic movement making up over 70% of all treatments applied. This table also shows that approach lanes for right turning cyclists are rarely used.

Table 5 shows that the dominate storage treatment used across Australasia is advanced storage boxes, although this preference is dominated by the use of this treatment in Adelaide. Expanded storage boxes are popular in some States and in New Zealand, but are rarely used in others. We understand that in some States there is resistance to the use of expanded storage boxes due to opposition from motor-vehicle drivers. Hook turns are not commonly used/marked, but there was support at the workshop for more use of this treatment, particularly at major signalised intersections, where it is very difficult and often unsafe for cyclists to cross several through lanes to turn right. This treatment is particularly useful for more vulnerable cyclists, such as school children, that need to turn right. The use of hook turns is considered a much more desirable treatment than expanded storage boxes that cross several through lanes to the right turn lane(s).

The research team's investigations have highlighted the lack of cycle count data (particularly turning counts and counts prior to the treatment going in), information about the timing of cycle facilities installation and access to detailed crash reports (from the Police). Often the detailed crash reports are required to check the cycle crashes are coded correctly. The best data on cycle facilities and cycle usage is available in Adelaide and Christchurch. The research team also plans to obtain data, which is likely to be less complete, from Perth and Brisbane and perhaps some of the inner city Melbourne Councils, where cycle facilities are in common use and cycle usage is relatively high.

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