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Accident Prediction at Urban Roundabouts in New Zealand – Some Initial Results

Nathan J. Harper and Roger C.M. Dunn

ABSTRACT

Roundabouts are becoming increasingly popular as a choice of intersection control in New Zealand (NZ) due to operational efficiency and safety benefits; in particular roundabouts are used instead of priority control types such as Stop and Give Way controls. Recent revisions of Transfund's Project Evaluation Manual (PEM) utilise accident prediction models to give a better estimate of the true accident frequency of an intersection. At present these prediction models are based solely on traffic volumes.

This paper details the initial findings of research to develop more advanced urban roundabout accident prediction models that will enable more accurate evaluation of urban roundabout accident benefits. It is planned that these models will predict vehicle accidents on urban roundabouts in NZ in relation to traffic volumes and geometric variables – it is proposed that the inclusion of geometric variables will greatly improve the accuracy of these equations. Accident prediction model forms and findings from the United Kingdom, Australia, and NZ are outlined.

A considerable database has been collated including traffic movement volumes, geometric site characteristics, and accident data for 95 urban roundabouts throughout NZ. Some initial results from the database are presented and discussed.

It is envisaged that these new accident prediction models based on traffic volumes and geometric layout variables will be incorporated into a future amendment of the PEM, which uses benefit / cost analyses to determine road improvement priorities in NZ.

1.0 INTRODUCTION

Roundabouts are becoming increasingly popular as a choice of intersection control in New Zealand (NZ) due to operational efficiency and safety benefits. The well-proven operational safety performance of roundabouts has encouraged their use; in particular they have been installed instead of priority control types such as Stop and Give Way intersection controls, and have replaced traffic signals in some situations. Roundabouts in NZ are generally designed in accordance with the Austroads (1993) Guide to Engineering Practice Part 6 – Roundabouts.

Roundabouts have been extensively used in the UK and Australia for some time, are popular in Europe and are being increasingly used in the USA.

2.0 ROUNDABOUT SAFETY

2.1 TYPES OF URBAN ROUNDABOUTS

Wilke and Koorey (2001) classified NZ urban roundabouts into three general categories– mini-, single-lane, and multi-lane. They did not consider motorway rotary interchanges. This classification system has also been adopted in this study (Harper and Dunn 2003).

Many of the roundabouts in NZ have been converted from other control types, and therefore their layout is often restricted by space.

2.2 VEHICLE SAFETY

Many international studies indicate that modern roundabouts are much safer than other forms of intersection control, with substantial reductions in crash rates and more importantly a reduced overall crash injury severity in comparison with other signalised or unsignalised control types (Austroads 1993; Kennedy et al. 1998; Persaud et al. 2000; TRL 2003; USDoT 2000). The operational safety performance of roundabouts has been well documented in a number of major international studies; the most significant work has been in Australia and the UK (Arndt 1998; Kennedy et al. 1998; Maycock and Hall 1984).

The comparatively good operational safety performance of roundabouts has been attributed to a number of contributing factors as follows (Austroads 1993; USDoT 2000):

– Reduced relative speeds of conflicting flows
– Elimination of serious crossing vehicle conflicts
– Reduced and more spatially separated vehicle conflict points
– Simplified driver decision-making
– Clearer indication of the drivers right of way

These safety performance factors are further described in Harper and Dunn (2003).

Roundabouts rely heavily on sight distance for safe and efficient operation, however some NZ observations have suggested that high sight distances may actually negatively affect the safety operation of the roundabout. This appeared to be particularly true for vulnerable users such as pedestrians, cyclists, and motorcyclists which are not as visible as other road users (Hughes 2002). Studies in the UK have shown that accidents did increase with longer sight distances (Kennedy et al. 1998; Maycock and Hall 1984).

2.3 CYCLIST SAFETY

While the installation of roundabouts has been shown to significantly reduce overall accident rates, cyclists face an increased risk of accidents. For example, NZ studies have shown that cycle accidents account for 6% of crashes at roundabouts compared to 1% at traffic signals, and 4% at priority controlled intersections (Traffic Design Group 2000). Hughes (2002) pointed out that while cyclists are involved in a higher proportion of roundabout crashes, the total injury accident rate at roundabouts is lower than for other intersection control types.

To further complicate matters, cyclists have a much higher under-reporting rate than motorists (Wilke and Koorey 2001). Another NZ 'before and after' study showed that cycle crashes reduced 29% after the installation of roundabouts, however, the 'regression to the mean' effect was not taken into account (LTSA 1995). In general, cyclists find roundabouts difficult to negotiate safely, as vehicles fail to give way to them (Austroads 1993; Wilke and Koorey 2001).

2.4 PEDESTRIAN SAFETY

A NZ study have shown that 1% of pedestrian crashes occur at roundabouts, compared to 4% at traffic signals, and 1% at priority controlled intersections (Traffic Design Group 2000). However pedestrian volumes at traffic signals are likely to be higher than at roundabouts, thereby giving a biased result.

Another NZ 'before and after' study showed that the installation of roundabouts reduced pedestrian crashes by 48%, although the 'regression to the mean' effect was not taken into account (LTSA 1995).

Austroads (1993) gives advice on the safety of pedestrians at roundabouts.

3.0 ROUNDABOUT STUDIES

3.1 UK STUDIES

The UK has been at the forefront of roundabout studies; indeed modern roundabouts have been shaped by their experiences. Maycock and Hall (1984) undertook a landmark study of 84 four-leg roundabouts in the UK, and analysed accidents by type and road user involvement. Accident prediction models were developed, related to traffic flow and roundabout geometry for the five main accident types: entering-circulating, approaching (rear end and sideswipe), single vehicle, other (including exiting-circulating), and pedestrian.

Maycock and Hall's (1984) models used a product of conflicting flow functions for the traffic volume variables and used an additional exponential form for the geometric and other variables. The simplest expression of this model is below, where A is the accidents per year per leg, Q is the relevant flow function for the particular crash type (Q_c is an additional circulating flow function for entering vs. circulating crashes only), G_i are the geometric and other variables, and k, α, β and the b_i are coefficients to be estimated.

$$A = kQ^{a}\,(Q_c{}^{b})\exp\sum(b_iG_i)$$

The geometric and other variables considered significant to accident prediction were (Maycock and Hall 1984):

- Entry path curvature
- Entry width
- Approach half width correlation
- Ratio of inscribed circle diameter to central island diameter
- Proportion of motorcycles
- Angle between approach leg and the next leg clockwise
- Approach width
- Approach curvature

Maycock and Hall (1984) also further developed relationships between geometry and accident rates, which are briefly summarised in Harper and Dunn (2003).

Kennedy et al. (1998) developed similar accident prediction models based on traffic flow, road features, layout, geometry, and land use for 200 three-leg and 100 four-leg mini- roundabouts in the UK. Their key findings related to mini-roundabouts are summarised in Harper and Dunn (2003).

3.2 AUSTRALIAN STUDIES

Arndt (1998) studied relationships between geometry and accident rates on 100 roundabouts in Queensland. His accident prediction models included estimated speed variables, which interestingly, were found to be more significant than traffic volumes. The five major accident types were: single vehicle, approaching rear-end, entering/circulating, exiting/circulating, and sideswipe (Arndt 1998). Approach curvature, central island diameter, maximum decrease in speeds between successive geometric elements, separation between legs, and length of horizontal geometric element were all found by Arndt (1998) to have a major impact on accident rates. Arndt (1998) developed further relationships between roundabout geometry and safety performance – these are summarised in Harper and Dunn (2003).

A recent Austroads study by McLean (2001), gave a basic roundabout accident rate of 0.13 crashes per 10^6 vehicles entering the intersection based on studies in Victoria - this model form is contrary to the multiplicative forms developed by others (Kennedy et al. 1998; Maycock and Hall 1984; Turner 2001).

3.3 NZ STUDIES

Turner (1995) did extensive work on traffic volume based accident prediction models at common urban intersection types. This was updated and extended to include link models enabling network analyses (Turner 2001). These updated models predict injury crashes based solely on traffic flows, and are an integral component to the recent accident rate and Weighted Accident Procedure (WAP) revisions for NZ's Project Evaluation Manual (PEM) (Transfund 2002).

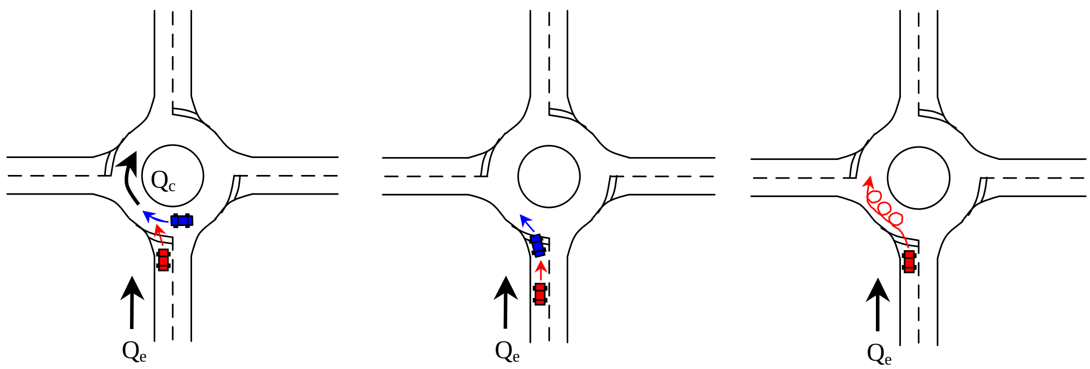
Turner (1995; 2001) created accident prediction models for major signalised and unsignalised intersection types including urban roundabouts, which are the focus of this research project. These models are based on a common multiplicative model form where A is the injury accidents per year, q_1 is the relevant vehicle flow for the crash type (q_2 is a conflicting vehicle flow included where appropriate), and b_0, b_1 and b_2 are parameter values (Turner 2001). The traffic flow exponents (b_1 & b_2) are allowed to vary, instead of being fixed at 0.5 as proposed by many researchers (Turner 1995).

$$A = b_0 q_1^{\ b1} (q_2^{\ b2})$$

Turner (1995; 2001) disaggregated total accidents into major crash types that frequently occur at intersections, including roundabouts. He found that individual crash types were best related to the product of the conflicting turning movements involved in that particular accident type, and he created different model forms to reflect this. For example, Turner (1995; 2001) determined that rear end crashes occur in the vehicle movement entering the intersection, and therefore the models only include the entering flow. For roundabouts these major accident types included: loss of control crashes, rear end crashes, entering vs. circulating (often referred to as right angle) crashes, and other (pedestrian and cycle) crashes as illustrated in Figure

1 (Turner 2001). These disaggregated conflicting flow accident models were not directly included in the PEM (Transfund 2002) revisions, but are referred to for unusual applications and unbalanced major and minor traffic volume situations.

Turner (1995; 2001) also established that <u>total</u> urban roundabout accidents were best related to the product (as opposed to the sum) of the major (q_1=Q_1) and minor (q_2=Q_2) intersecting street average two-way daily traffic volumes. This category encompasses all injury crash types that occur within 30m of the roundabout, and are the only roundabout models included in the PEM (Transfund 2002) for use in the economic evaluation of safety benefits. No models were developed for three-leg roundabouts, however Turner (2001) recommended using 75% of the four-leg model.



$A = b_0 Q_e^{b1} Q_c^{b2}$	$A = b_0 Q_e^{b1}$	$A = b_0 Q_e^{b1}$
Entering vs. Circulating	***Rear End***	***Loss of Control***

Other - Pedestrian and Cycle - $A = b_0 Q_e^{b1}$

Figure 1 – Turner's (2001) Models for Major Accident Types at Roundabouts

Turner (1995; 2001) stated that his volume based models were reasonably accurate for overall network analyses, but not appropriate for accident prediction at individual sites. Also, his models are considered most appropriate for 'normal' sites that do not have unusual geometric features that may contribute to vehicle crashes (Transfund 2002).

The WAP, developed by Turner (2001), enabled volume based accident prediction models developed for generic intersection types to be combined with site-specific crash history to give a relatively accurate estimate of the true underlying accident rate of an individual site. In this way, the accident history is a substitute for the influence of site geometry and layout on accident rates. This method enables road safety projects to be undertaken on known unsafe sites without a significant crash history, and therefore sites can be proactively treated before accidents occur.

The weighted accident rate is based on the following Empirical Bayes method of statistical analysis, where A_W is the weighted accident rate, A_T is the typical accident rate (from the prediction model), A_S is the site specific accident rate (from the accident history), and w is the weighting factor (Transfund 2002):

$$A_W = wA_T + (1-w)A_S$$

The weighting factor w allows the weighted accident rate to be biased toward either A_W or A_T, depending on the relative statistical confidence in each data source.

4.0 CURRENT STUDY OF ACCIDENT PREDICTION

4.1 MAIN OBJECTIVE

The main objective of this research project is to extend the previous NZ work (Turner 2001) and to develop more advanced urban roundabout accident prediction models. These models will predict vehicle accidents on urban roundabouts in NZ in relation to traffic volumes and geometric layout variables – it is proposed that the inclusion of geometric variables will greatly improve the accuracy of these equations.

4.2 DATA COLLECTION AND CATEGORISATION

Three sources of data for 95 urban roundabouts (of varying layouts) throughout NZ have been recently collated to develop the accident prediction models: traffic data, crash data, and geometric data.

- ***Traffic Data -*** The traffic turning counts for this study have been obtained from a variety of different sources around NZ including both local road controlling authorities and independent consultants.
- ***Crash Data -*** Injury crash records (fatal, serious, and minor) within 50m of the identified sample sites for the five-year period 1998-2002 were obtained from the Land Transport Safety Authority Crash Analysis System (CAS) database.

  However, significant discrepancies have been identified between the CAS records and the Traffic Crash Reports (TCR's). Subsequently the sample of 289 recorded crashes was "cleansed" by scrutinising each TCR, and categorising each crash into common roundabout accident types. As a result, nine crashes were eliminated as they were not located on the approach roads (such as a supermarket car park crash) or where the TCR suggested that the spatial location of the accident was miscoded. It was decided to categorise 38 crashes as "Other" and to eliminate them from the analysed database, as although they were on the approach roads, the crash was not directly attributable to the normal operation of the roundabout. These included crashes at access ways, when car doors were opened into the path of cyclists, and where vehicles were involved in car parking or making U-turn manoeuvres.
- ***Geometric Data -*** Aerial photographs of sample sites (with available traffic data as described above) have been obtained from local road controlling authorities, and are presently being used to take reasonably accurate scale measurements of the site geometric characteristics. One of the objectives of this study is to investigate potential relationships between the geometric characteristics of each approach and the crash records. However, it is not planned to include other potential key variables that may be applicable to accident prediction such as driver sight distance, approach grade, road lighting, and vehicle speeds.

Sites have been included in the sample if they are existing roundabouts that have not been significantly altered in the last 5 to 6 years (to ensure consistent geometry), and have relevant and recent traffic movement counts. Candidate sites are also within an urban speed limit area and have a reasonably standard layout. Urban is defined as those sites with a speed limit of 70km/h or less, but will mostly be 50km/h sites (Transfund 2002). Data on the three general roundabout layout types has been collected with the aim to compare their relative safety performance: mini- (with drive over islands), single-lane, and multi-lane (including mixed single- / multi-lane layouts). No restriction was made on the number of approach roads at each site. As shown in Table 1, the majority of the database sites are four-leg roundabouts; only one is a six-leg roundabout.

The lack of existing roundabouts with movement count data that have not been significantly altered in the last 5 to 6 years, forces the use of 'convenience sampling' in order to obtain a useful sample size. 'Convenience sampling' introduces some bias into the study as the chosen sites may already have abnormally high crash histories, which may be the reason that they have been studied and traffic counts recorded.

5.0 SOME RESULTS AND DISCUSSION

5.1 LOCATION OF SITES

As noted above, the 242 crashes in the database of NZ urban roundabouts was analysed and tabulated to show some general trends. Table 1 shows the location of the 95 urban roundabouts by the number of intersecting approach legs, and the resulting basic accident frequency.

Table 1 – Location of Database Sites by Number of Approach Legs and Crash Frequency

Road Controlling Authority	*Number of Roundabout Approach Roads*				Total No. of Sites	Total Crashes	Accident Frequency *(Acc/Yr)*
	3-Leg	4-Leg	5-Leg	6-Leg			
Auckland City	2	10	3	1	16	48	0.60
Christchurch City		27			27	72	0.53
Dunedin City		1			1	3	0.60
Hamilton City		1			1	4	0.80
Hutt City	1	5			6	12	0.40
Manukau City		5			5	14	0.56
North Shore City	2	4			6	13	0.43
Palmerston North City	2	12			14	25	0.36
Timaru District		1			1	4	0.80
Waitakere City	6	7	2		15	46	0.61
Whangarei City	1	2			3	1	0.07
All Sites	**14**	**75**	**5**	**1**	**95**	**242**	**0.51**

The Waitakere City (0.61) and Auckland City (0.60) regions have the highest accident frequencies – the high 'outlier' values of Hamilton City (0.80), Timaru District (0.80) and Dunedin City (0.60) have a sample size of only one. Palmerston North City (0.36), and Hutt City (0.40) have the lowest crash frequencies, possibly due to lower traffic volumes in these cities. Whangarei City has an unusually low accident frequency (0.07), with only one crash recorded over the three sample sites during the five-year analysis period.

The average overall crash frequency of 0.51 crashes per urban roundabout per year in NZ is low when compared to UK studies. Kennedy et al. (1998) gave an overall frequency of 1.06 accidents per year for mini-roundabouts, and Maycock and Hall (1984) gave a considerably higher result of 3.31 accidents per year for conventional four-leg sites. It should be noted that exposure to traffic has not been accounted for in any of these basic accident frequencies.

These results may be biased, as four-leg roundabouts dominate the database with 75 out of the total 95 sites in the sample.

5.2 MAJOR CRASH TYPES AND INVOLVEMENT

For the purposes of this study, cyclists travelling on the roundabout have been classified as vehicles – however, they have been considered to be pedestrians when they walk their bicycles across the roadway. Pedestrian crashes have been categorised according to the direction the vehicle was travelling in, namely entering or exiting the roundabout.

The major vehicle accident types (with the exception of entering vs. circulating accidents) are further disaggregated into sub-types. This disaggregation has been based on a subjective assessment of the TCR, namely at what stage the accident occurred in the vehicle's negotiation of the roundabout (entering, circulating, or exiting).

Table 2 shows the relative proportions of crashes for the four major vehicle accident types and pedestrian accidents.

Table 2 – Proportion of Crashes by Major Accident Type, and Sub-Type

Accident Type	**Sub Type**	**Total No. of Crashes**	**% of Total Crashes**
Loss of Control	Entering	19	8%
	Circulating	19	8%
	Exiting	7	3%
Total Loss of Control	***LC***	***45***	***19%***
Rear End	Entering	24	10%
	Circulating	2	1%
	Exiting	13	5%
Total Rear End	***RE***	***39***	***16%***
Sideswipe	Entering	4	2%
	Circulating	6	2%
	Exiting	3	1%
Total Sideswipe	***SS***	***13***	***5%***
Entering vs. Circulating	***EVC***	***109***	***45%***
Pedestrian	Entering	24	10%
	Exiting	12	5%
Total Pedestrian	***PED***	***36***	***15%***
All Crashes		**242**	**100%**

Entering vs. circulating accidents are the largest crash group with 45% of the total, which is greater than the sum total of the other vehicle crash types: loss of control (19%) rear end (16%) and sideswipe crashes (5%). Pedestrian crashes account for 15% of total roundabout accidents.

Loss of control crashes occur more often when entering or circulating (8% each respectively) than when exiting (3%). It should be noted that the loss of control point, either circulating or exiting, is often difficult to distinguish from the TCR information.

As expected, Table 2 shows that rear end entering crashes (10%) are much more prevalent than either rear end circulating (1%) or rear end exiting (5%) accidents. The latter accidents (5%) were much more common than anticipated, and can be attributed to vehicles accelerating off the roundabout and not expecting to stop for stationary vehicles at pedestrian crossings or at other vehicle queues.

Generally, sideswipe crashes are a minor accident type (5%), and are more prevalent at sites with two or more approach lanes (for entering sideswipes) or more than one circulating lane (for circulating and exiting sideswipes).

Table 3 shows the relative involvement of vulnerable road users for the major crash types.

Table 3 shows that 50% of all entering versus circulating (EVC) accidents involve a cyclist, and a further 15% involve a motorcyclist, totalling 64% of EVC crashes for all 'two wheelers'. More importantly, all but one of these crashes involved a vehicle failing to give way to a circulating cyclist or motorcyclist. This disturbing result could be attributed to the low visual impact and small physical size of cycles and motorcycles at roundabouts in relation to other vehicles.

Table 3 – Proportion of Vulnerable Road Users by Major Accident Type

Crash Type	Total Crashes	Ped No.	Ped %	Cyclist No.	Cyclist %	M-cyc No.	M-cyc %	Other No.	Other %
EVC	109		0%	54	50%	16	15%	39	36%
LC	45		0%		0%	2	4%	43	96%
PED	36	36	100%		0%		0%		0%
RE	39	1	3%		0%	3	8%	35	90%
SS	13		0%	5	38%	4	31%	4	31%
All Crashes	**242**	**37**	**15%**	**59**	**24%**	**25**	**10%**	**121**	**50%**

Cyclists (38%) and motorcyclists (31%) are also heavily involved in sideswipe injury accidents. This could also be attributed to the low visual impact and small physical size of two wheelers.

Loss of control and rear end accidents predominantly involves non-vulnerable users or 'other' vehicles in Table 2.

It should be noted that vulnerable road users are more likely to be injured in a crash than non-vulnerable road users. Hence, one would expect vulnerable road users to be over represented in injury crashes compared to other vehicles.

5.3 CRASHES BY NUMBER OF CIRCULATING LANES

Table 4 illustrates the crash severity distribution by number of lanes in the circulating carriageway, average accident frequency (crashes per year), and accident severity ratio (% fatal and serious crashes). As noted in 5.1, exposure to traffic flow has <u>not</u> been accounted for in any of these accident frequencies.

Table 4 – Crash Severity by Number of Circulating Lanes, Accident Frequency, and Severity Ratio

Number of Circulating Lanes	No. of Sites	*Crash Severity* Fatal	Serious	Minor	Total Crashes	Accident Frequency *(Acc/Yr)*	Severity Ratio *(% F+S)*
1	72	1	22	129	152	0.42	15%
2	21	0	7	76	83	0.79	8%
3	2	0	0	7	7	0.70	0%
All Sites	95	1	29	212	242	0.51	12%

Table 4 confirms the hypothesis that multi-lane roundabouts are significantly more dangerous than single-lane roundabouts, as the difference in accident frequency between one (0.42 crashes per year) and two circulating lane roundabouts (0.79 crashes per year) is approximately 47%. The three lane sites also have a high accident frequency (0.70), but the sample size is considered too small to give a reliable result. Conversely, the severity ratio results indicate that while multi-lane roundabouts have more crashes, the accident severity tends to decrease with an increasing number of circulating lanes - falling from 15% for a single-lane to 8% for two lanes, and 0% for three circulating lane sites. However, these statistics are based on only one fatal crash and two sites with three circulating lanes.

For the 95 roundabout sample sites, the overall accident frequency is 0.51 injury crashes per year, and the proportion of fatal and serious crashes to total injury accidents is approximately 12%. Compared to the two major UK studies, Kennedy et al. (1998) and Maycock and Hall (1984), the severity results are reasonably similar, at 12.7% and 16%, respectively.

Table 5 illustrates the reported pedestrian, cyclist, motorcycle, and heavy vehicle (truck and bus) crash involvement by number of lanes in the circulating carriageway.

Table 5 – Crashes by Number of Circulating Lanes and Pedestrian, Cyclist, Motorcyclist and HCV Proportions

Number of Circulating Lanes	Total Crashes	Ped No.	Ped %	Cyclist No.	Cyclist %	M-cyc No.	M-cyc %	HCV No.	HCV %
1	152	18	12%	50	33%	12	8%	10	7%
2	83	17	20%	9	11%	12	14%	4	5%
3	7	2	29%	0	0%	1	14%	0	0%
All Sites	**242**	**37**	**15%**	**59**	**24%**	**25**	**10%**	**14**	**6%**

For pedestrians, there is a consistent trend of increasing crashes with an increasing number of circulating lanes - namely, from 12% for a single-lane roundabout to 20% for a two-lane roundabout, and 29% for the three-lane roundabout. This appears to be due to the increased difficulty of pedestrians to cross the roadway with increasing approach lanes and increasing traffic flows. It should be noted that the high percentage for the three-lane sites may not be reliable due to its small sample size. Overall, pedestrians make up 15% of reported injury accidents at roundabouts. This compares reasonably well with Kennedy et al. (1998) who recorded 14.8%. However, considerably lower values were recorded by Traffic Design Group (2000) at 1%, and Maycock and Hall (1984) who recorded 3%.

Cycle crashes show a decreasing trend with an increasing number of circulating lanes, from 33% for single-lanes to 11% for two-lane (and 0% for three lane) roundabouts. This could be attributed to the hypothesis that cyclists find multi-lane sites with their corresponding high traffic volumes difficult to negotiate, and plan their routes to avoid these sites. Overall, cyclists are at significant risk at roundabouts with 24% of all injury accidents. This result is significantly higher than recorded by Traffic Design Group (2000) at less than 6%. In the UK, Maycock and Hall (1984) also recorded a significantly lower result at 8%, as did Kennedy et al. (1998) with 11.6% for three-leg, 9.8% for four-leg roundabouts.

Overall, motorcycle and heavy vehicle crash involvement is relatively steady at 10% and 6%, respectively, over all circulating lane configurations. The motorcycle result could be significant, as although no motorcycle counts were undertaken, the result (10%) is considered disproportionate to the actual motorcycle volume. This motorcycle proportion is similar to Kennedy et al. (1998) who recorded 8.9% for three-leg, and 8.6% for four-leg mini- roundabouts, but is much lower than Maycock and Hall (1984) who recorded 18.8%.

Table 6 illustrates the crash proportions with common crash contributing factors - a wet road surface, rain falling, or occurring in darkness by number of lanes in the circulating carriageway.

Table 6 – Crashes Proportions with a Wet Road Surface, Rain Falling, or Occurring in Darkness by Number of Circulating Lanes

Number of Circulating Lanes	Total Crashes	Wet No.	Wet %	Rain No.	Rain %	Dark No.	Dark %
1	152	36	24%	31	20%	41	27%
2	83	21	25%	15	18%	17	20%
3	7	2	29%	3	43%	2	29%
All Sites	**242**	**59**	**24%**	**49**	**20%**	**60**	**25%**

The wet road surface, rain and dark accident proportions are relatively consistent with differing circulating lanes with 24%, 20% and 25% involvement respectively for all sites. This compares with 31.5%, 16.5% and 33.2% respectively recorded by Kennedy et al. (1998). The only exception to these reasonably consistent results, are the proportion of crashes during rain at sites with three circulating lanes, which accounted for 43% of crashes - however this result may be unreliable due to the low sample size.

5.4 CRASHES BY NUMBER OF APPROACH ROADS

Table 7 illustrates the crash severity distribution by number of intersecting approach roads, average accident frequency (crashes per year), and accident severity ratio (% fatal and serious crashes).

Table 7 – Crash Severity by Number of Approaches, Accident Frequency, and Severity Ratio

Number of Approach Roads	No. of Sites	*Crash Severity*			Total Crashes	Accident Frequency *(Acc/Yr)*	Acc Freq per Leg *(Acc/Yr/Leg)*	Severity Ratio *(% F+S)*
		Fatal	Serious	Minor				
3	14	0	3	18	21	0.30	0.10	14%
4	75	1	25	174	200	0.53	0.13	13%
5	5	0	1	14	15	0.60	0.12	7%
6	1	0	0	6	6	1.20	0.20	0%
All Sites	**95**	**1**	**29**	**212**	**242**	**0.51**	**0.13**	**12%**

Table 7 shows an increasing crash frequency with an increasing number of approach roads, from 0.30 crashes per year for a three-leg, to 0.60 for a five-leg roundabout.

The high accident frequency for the six-approach site cannot be regarded as reliable due to its small sample size.

It is interesting to note, that the crash frequency per leg results are relatively constant, overall, at 0.13 crashes per year per approach (aside from the six-leg approach). This supports the hypothesis that accident rates can be modelled by individual approaches, and therefore accidents can be predicted on an approach-by-approach basis.

Again, the overall severity ratio (apart from the six-leg site) is relatively consistent within the vicinity of 12% (the average) for all approach configurations.

Table 8 illustrates the reported pedestrian, cyclist, motorcycle, and heavy vehicle (truck and bus) crash involvement by number of approach roads.

Table 8 – Crashes by Number of Approaches and Pedestrian, Cyclist, Motorcyclist and HCV Proportions

Number of Approach Roads	Total Crashes	Ped No.	Ped %	Cyclist No.	Cyclist %	M-cyc No.	M-cyc %	HCV No.	HCV %
3	21	7	33%	5	24%	3	14%	1	5%
4	200	22	11%	53	27%	20	10%	13	7%
5	15	6	40%	1	7%	1	7%	0	0%
6	6	2	33%	0	0%	1	17%	0	0%
All Sites	**242**	**37**	**15%**	**59**	**24%**	**25**	**10%**	**14**	**6%**

The pedestrian crash percentages give unusual results, in that apart from the four-leg roundabouts (11%), the other approach configurations provide extremely high values (33% to 40%). However, due to the large sample size for four-leg sites, the overall result reduces to 15%.

The cyclist crash percentages suggest a decreasing overall trend with an increasing number of roundabout approaches. However the predominant four-leg sites suggest otherwise. As before, this may support the hypothesis that cyclists will avoid five and six-leg sites, as these are likely to be multi-circulating lane, with high traffic flows and therefore are perceived to have increased cyclist risk.

It appears that the overall motorcycle and heavy vehicle crash involvement is relatively steady at 10% and 6% respectively for all intersecting road categories. However this result is not reliable due to the low sample sizes.

Table 9 shows the crash proportions with a wet road surface, rain falling, or occurring in darkness by number of approach roads.

Table 9 – Crashes Proportions with a Wet Road Surface, Rain Falling, or Occurring in Darkness by Number of Approach Roads

Number of Approach Roads	Total Crashes	Wet No.	Wet %	Rain No.	Rain %	Dark No.	Dark %
3	21	7	33%	6	29%	5	24%
4	200	47	24%	38	19%	51	26%
5	15	4	27%	3	20%	3	20%
6	6	1	17%	2	33%	1	17%
All Sites	**242**	**59**	**24%**	**49**	**20%**	**60**	**25%**

Table 9 does not indicate any significant and consistent trends, bearing in mind the small sample sizes of the three, five, and six-leg roundabouts.

6.0 FUTURE RESEARCH

In the future, a quantitative 'cross sectional' analysis of the road safety effects of urban roundabout operation will be undertaken on the project database. More advanced NZ accident prediction models similar to those developed by Maycock and Hall (1984) will be developed for urban roundabouts based on traffic volumes and geometric layout variables. At this stage it is planned to use the Negative Binomial distribution and Generalised Linear Regression techniques, as they are widely regarded as being appropriate analysis methods (Persaud et al. 2000; Turner 2001). It is anticipated that these models will be tested for accuracy with confidence interval and goodness of fit statistics.

The inclusion of geometric variables will:

- Allow more accurate modelling of the crash reduction potential of the installation or replacement of urban roundabouts.
- Ensure accuracy of economic safety benefits of new project proposals.
- Be able to be adapted to a wider range of roundabout sites than the existing traffic volume based models.
- Enable the identification of optimal geometric and layout features that minimise traffic crashes at urban roundabouts.

It is planned to develop guidelines based on NZ roundabout data to promote the best practice geometric layout of urban roundabouts.

It is envisaged that the results from this research project will be included in Transfund NZ's Project Evaluation Manual (2002) to enable the more accurate evaluation of roundabout accident benefits. This in turn is expected to lead to better returns on investment and therefore will be a more effective use of public funding for roads.

7.0 CONCLUSIONS

The initial analysis of the project crash database has yielded the following results:

- On average there are 0.51 injury crashes per urban roundabout per year, with a severity ratio of 12%.
- Entering vs. circulating accidents are the most common crash type (45%), and are greater than the sum of the other vehicle crash types: loss of control (19%) rear end (16%) and sideswipe crashes (5%).
- Pedestrians are involved in 15% of the recorded injury crashes.
- Cyclists face a significant crash risk at roundabouts with 24% involvement in injury accidents, and 50% of entering versus circulating crashes involve a cyclist.
- Motorcyclists are involved in 10% of total injury crashes – this is suspected to be disproportionate to the actual motorcycle volume.
- Two wheelers, cyclists and motorcyclists, are involved in 64% of entering vs. circulating crashes.
- Heavy vehicles are involved in 6% of total injury crashes.
- Multi-lane roundabouts are significantly more dangerous than single-lane roundabouts, as the difference in accident frequency between one (0.42 crashes

per year) and two circulating lane roundabouts (0.79 crashes per year) is almost 50%.

- The wet road surface, raining and dark crash proportions are 24%, 20% and 25% respectively.
- The crash frequencies per leg show a relatively constant crash frequency of 0.13 crashes per year, per approach, and support the hypothesis of using accident prediction on an approach-by-approach basis.

Further analyses will be undertaken to develop more advanced accident prediction models for urban roundabouts in NZ based on traffic volumes and geometric layout variables - it is envisaged these results will be incorporated into the PEM (Transfund 2002).

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REFERENCES

Arndt, O. (1998). "Relationship Between Roundabout Geometry and Accident Rates - Final Report." *Report Number ETD02*, Transport Technology Division, Department of Main Roads, Brisbane, Australia.

Austroads. (1993). "Guide to Traffic Engineering Practice Part 6 - Roundabouts." Austroads, Sydney, Australia.

Harper, N. J., and Dunn, R. C. M. "Preliminary Results for Accident Prediction at Urban Roundabouts in New Zealand." *Institute of Transportation Engineers 2003 Annual General Meeting and Exhibit*, Seattle, Washington, USA.

Hughes, T. (2002). "Safety at Roundabouts." Transafe - Issue 8, Transfund New Zealand, Wellington.

Kennedy, J. V., Hall, R. D., and Barnard, S. R. (1998). "Accidents at Urban Mini-Roundabouts." *TRL Report 281*, Transport Research Laboratory, Crowthorne, Berkshire, UK.

LTSA. (1995). "Install Roundabout / Install Traffic Signals at Urban Intersections." Land Transport Safety Authority, Wellington.

Maycock, G., and Hall, R. D. (1984). "Accidents at 4-Arm Roundabouts." *TRRL Laboratory Report 1120*, Transport and Road Research Laboratory, Crowthorne, Berkshire, UK.

McLean, J. R. (2001). "Economic Evaluation of Road Investment Proposals - Improved Prediction Models for Road Crash Savings." Austroads, Sydney, Australia.

Persaud, B. N., Retting, R. A., Garder, P. E., and Lord, D. (2000). "Crash Reductions Following Installation of Roundabouts in the United States." Insurance Institute for Highway Safety, Arlington, Virginia, USA.

Traffic Design Group. (2000). "The Ins and Outs of Roundabouts - Safety Auditors' Perspective." Transfund New Zealand, Wellington.

Transfund. (2002). "Project Evaluation Manual." *Amendment 6 - Sept. 2002*, Transfund New Zealand, Wellington.

TRL. (2003). "Roundabout Design for Capacity and Safety - The UK Empirical Methodology." Software Bureau, Transport Research Laboratory , Crowthorne, Berkshire, UK.

Turner, S. A. (1995). "Estimating Accidents in a Road Network." PhD Thesis, Dept of Civil Engineering, University of Canterbury, Christchurch.

Turner, S. A. (2001). "Accident Prediction Models." *Research Report No. 192*, Transfund New Zealand, Wellington.

USDoT. (2000). "Roundabouts: An Informational Guide." *Publication No. FHWA-RD-00-067*, U.S. Department of Transportation, Federal Highway Administration, Turner-Fairbank Highway Research Center, Virginia, USA.

Wilke, A., and Koorey, G. (2001). "How Safe are Roundabouts for Cyclists?" Transafe - Issue 5, Transfund New Zealand, Wellington.

AUTHOR'S INFORMATION

Nathan J. Harper

Postgraduate Researcher - Department of Civil and Environmental Engineering,
The University of Auckland.
Opus International Consultants Ltd., Level 3, The Westhaven, 100 Beaumont Street, PO Box 5848, Auckland, New Zealand.
Phone: +64 9 355 9500, Fax: +64 9 355 9585
Email: nathan.harper@opus.co.nz

Roger C.M. Dunn

Director of Transportation Engineering & Associate Professor
Department of Civil and Environmental Engineering, School of Engineering, The University of Auckland, Private Bag 92019, Auckland, New Zealand.
Phone: +64 9 373 7599, ext.87714, Fax: +64 9 373 7462
Email: rcm.dunn@auckland.ac.nz