IMPROVED MULTI-LANE ROUNDABOUT DESIGN FOR CYCLISTS: THE C-ROUNDABOUT

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ABSTRACT

Multi-lane roundabouts are viewed by cyclists as a hazardous element of the road network to be avoided if possible. International literature review, cyclist crash statistics and cyclists themselves confirmed that the desired outcome is a roundabout design which reduces traffic speed and allows cyclists to use the road as equals with other vehicular users. Lower vehicle speeds should address critical 'entering vehicle versus circulating cyclist' crashes, and also at roundabout exits which is the other main safety concern for cyclists.

The design of a roundabout that reduces car speeds to 30 km/h rather than the conventional 50 km/h requires a significantly confined geometry. The result of this 12-month research project[1] is the Cyclist Roundabout, or C-Roundabout, which requires larger vehicles to straddle two traffic lanes. A roundabout in Auckland has demonstrated this is viable even in locations with heavy volumes of trucks.

The main safety benefit to all users is that it slows down the maximum speeds of vehicles to around 30 km/h. It is also a compact design that offers an economic way to increase the number of traffic lanes through a roundabout and improve its capacity. A C-Roundabout now needs to be constructed and road trialled.

1. BACKGROUND

The aim of this research was to develop a design solution for multi-lane roundabouts that is more amenable to cyclists. Large roundabouts are generally considered by cyclists to be a significant obstacle (crash statistics reflect this), and therefore would also be discouraging to people whom otherwise might contemplate taking up this healthy activity. For the purposes of this research, the definition of a 'multi-lane roundabout' is a roundabout that accommodates more than one lane of traffic on the circulating carriageway.

There is no adequate on-road design available for cyclists to ride through roundabouts, and this seems to be a deficiency in design standards. Available Austroads design guides (Austroads 1993, 1999) only provide for off-road facilities and no on-road alternatives are offered. Off-road bypasses for roundabouts are already well documented in various guidelines, including Austroads (1999) Part 14 "Bicycles", and have been shown by some studies to reduce cyclist crash numbers (Swedish National Road and Research Institute 2000). However unless they are grade separated from the circulating carriageway (often very expensive, and for tunnels a personal security issue), additional delays and inconvenience to cyclists are inevitable, and are a deterrent to their use. Generally, only low numbers of cyclists are likely to use off-road facilities provided at roundabouts (Sharples 1999). They are usually more appropriate for younger cyclists and novices.

The purpose of this research was to develop an on-road design that is both safe as well as attractive to cyclists, and will ideally have benefits to other roundabout users as well. To achieve this, the improved design needs to reduce vehicle speeds without adversely affecting junction capacity. The intention of the design was to:

[1] *A full copy of this report can be downloaded from: www.ltsa.govt.nz/research/reports/287.pdf*

- Achieve a low speed environment (particularly vehicle entering speeds) of around 30 km/h or less, which is amenable to on-road cyclists mixing with circulating traffic.
- Improve visibility of circulating cyclists, by way of radial approaches and lower vehicle approach speeds that will improve driver perception of bike users.
- Potentially reduce the number and severity of crashes by all roundabout users, by way of this reduced speed environment.
- Potentially have little or no effect on capacity of these junctions.

The result of this work is the C-Roundabout, a new concept in roundabout design.

2. LITERATURE REVIEW

A literature review was undertaken that included sources from New Zealand, Australia, the UK, the USA, and several other European countries including The Netherlands and Finland. Major topics investigated were:

- Cyclist crashes at roundabouts
- Vehicle speed and crash statistics
- Vehicle speed and comprehension of cyclists
- Cyclist numbers and crash statistics
- Capacity implications of low speed roundabout designs
- Sideswipe crashes
- On-road design solutions used overseas

Roundabouts are generally safer for cyclists than priority junctions (Schoon and Van Minnen 1994), but cyclists are over-represented by a significant factor in injury statistics (Harper and Dunn 2003, Campbell 2005). Multi-lane types are considered to be relatively hazardous for cyclists compared to traffic signals (Allott and Lomax 1991, Campbell 2005), and are of sufficient concern to cyclists to justify improvements. There appears to be no satisfactory design solution that is available overseas.

There are indicators that a roundabout design which reduces the speed differential between cyclists and car traffic will improve cyclist safety. Lower vehicle speeds have the potential to reduce both numbers and severity of all user crashes (C.R.O.W. 1993, Davies et al 1997, Department For Transport UK 2004, Swedish National Road and Transport Research Institute 2000), will improve driver recognition of cyclists (Rasanen and Summala 2000, Summala et al 1996), and should also assist cyclists to undertake their manoeuvres by enabling them to better establish their road presence.

The predominant cyclist crash pattern at roundabouts in New Zealand and overseas is the ‘entering vehicle versus circulating cyclist’ type (Allott and Lomax 1991, Harper and Dunn 2003). At sites with higher numbers of cyclists, drivers are more likely to be careful and cyclist crash rates have been shown to be lower (Beca 2005, Davies et al 1997, Department For Transport UK 2004).

A UK design guide has indicated that excessive visibility can result in higher approach and entry speeds than desirable for junction geometry (The Highways Agency 2005), and recommends limiting visibility on approach roads to no further back than 15 metres from roundabout limit lines. However, this is contrary to Austroads (1993) recommendations that suggest desirable visibility from 40m back (equivalent to the stopping sight distance for a car travelling at 50 km/h), and this topic therefore justifies further research.

The ‘turbo-roundabout‘ from The Netherlands is a potential alternative treatment for multi-lane roundabouts at main-road junctions with lower-volume roads (Fortuijn 2003), but further research is recommended before application in New Zealand. It includes the use of an off-road facility that can give priority to cyclists at road crossing points, which is of interest and also deserves further attention.

3. CRASH ANALYSIS IN AUCKLAND

Bicycle crashes at multi-lane roundabouts in the Auckland region were reviewed – in Auckland City, Waitakere City, Manukau City and North Shore City. A total of 59 Police Crash Reports at 58 sites for the ten-year period 1995 to 2004 were reviewed. Of these some 39 involved injury to the cyclist. **Figure 3.1** shows a summary diagram of all crashes.

The crash type most reported to police is the ‘entering vehicle versus circulating cyclist’, which comprises some 68% of total crashes and 69% of all injury crashes at multi-lane roundabouts in Auckland. The only other common type of crash that features with respect to injuries are the ‘exiting vehicle versus circulating cyclist’ and ‘sideswipe circulating vehicles versus circulating cyclist’.

Night-time accidents are an issue for cyclists due to the fact that they are less visible - some 25% of the cyclist crashes at Auckland multi-lane roundabouts occurred in dark conditions. This highlights the importance of good streetlighting at these locations, and for cyclists to use correct night-time equipment.

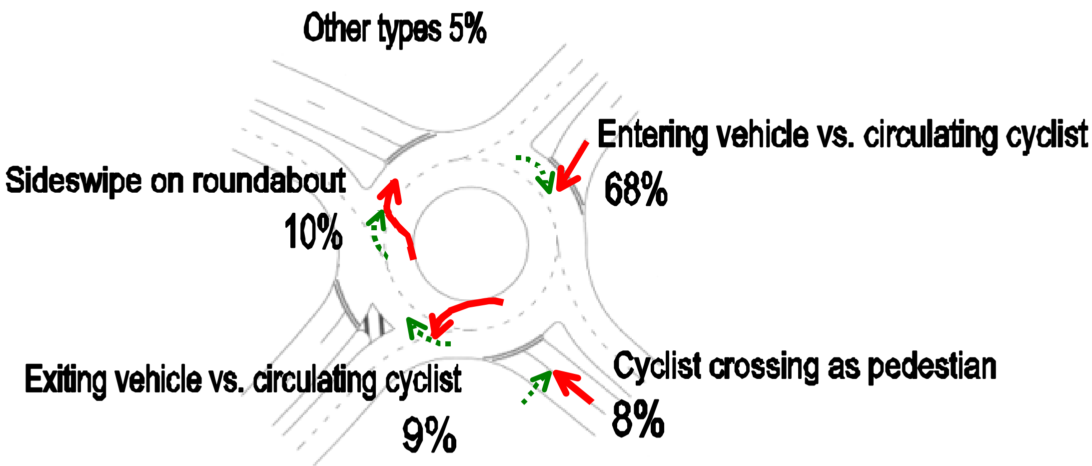

Figure 3.1 Summary Diagram of crash data for cyclists at multi-lane roundabouts in the four Auckland cities (non-injury and injury) 1995 to 2004 (59 reported crashes).

4. CYCLIST SURVEY

A survey was undertaken to assess the level of concern cyclists have with multi-lane roundabouts, identify their main perceived safety issues, and get some preliminary feedback on the concept of low-speed on-road designs. In summary, overwhelming support was received for the latter.

A survey form was drafted in Excel format and distributed via email as well as a downloadable website link, to cyclist organisations and retail outlets in the Auckland Region. A total of 195 responses were received.

Based on the above survey, the following conclusions have been made:

- Experienced cyclists predominantly responded to the survey, and they generally view multi-lane roundabouts as a reasonably significant obstacle that is to be avoided if conveniently possible. High vehicle speeds and making right-turns are particular issues.
- The most important safety issues as perceived and experienced by cyclists relate to 'entering motorist versus circulating cyclist', 'exiting motorist versus circulating cyclist', and 'cyclists entering the roundabout'. **Figure 4.1** shows a summary of the incidents reported by cyclists.
- Education for cyclists making right-turns at multi-lane roundabouts is recommended. A significant proportion of cyclists would use the kerbside approach lane when making a right turn, which is not advisable. They are either unaware that it is best practise for them to use the right-hand lane (Franklin 1997), or are wary of doing so. Roundabout designs that reduce traffic speeds should be more conducive to this aim.
- The overwhelming majority of experienced cyclists (85%) would prefer to use the road rather than at-grade bypasses.
- About 87% of respondents agreed that a multi-lane roundabout design that reduces maximum vehicle speeds to around 30 km/h is the most desirable on-road outcome for cyclists. This confirmed the aim of this research.

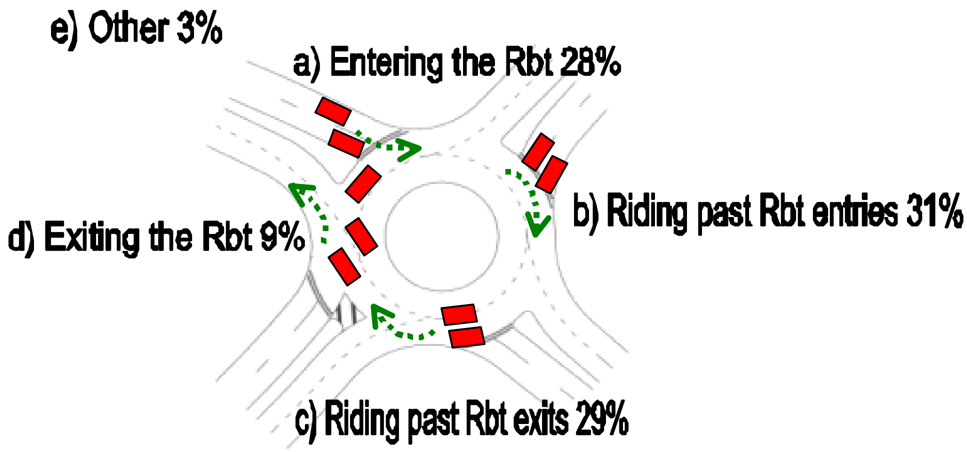

Figure 4.1 Summary diagram of incidents as reported by cyclists in the survey.

5. LOW SPEED DESIGN OPTIONS

Identified design options to achieve a reduction in roundabout traffic speed include:

- The application of confined roundabout geometry and thermoplastic roadmarking. The research undertaken in this report indicates that maximum path radii in the order of 30 to 40m is required for the desired 30 km/h environment (described further in Section 6).
- Vertical deflection devices on roundabout approaches. Although an economic alternative to roundabout redesign, these are potentially contentious to install on bus routes and there are some issues with emergency and heavy vehicles.
- The 'turbo-roundabout' as used in The Netherlands (Fortuijn 2003). The layout assumes two opposing single-lane exits, and it includes mountable lane dividers on the circulating carriageway that are an uncertain element with respect to the safety of two-wheeled road users. It also appears to require relatively significant land area, and so therefore may not be useful for confined urban areas such as in Auckland City.

As the second two options had limitations of some sort, the focus of this research was directed towards the first approach. In practice it was difficult to achieve confined geometry and still allow for larger vehicles to enter alongside other traffic, and this led to the C-Roundabout concept.

6. NEGOTIATION SPEED AND GEOMETRIC DESIGN

The aim of this project was to design a roundabout configuration that reduced the speed differential between cyclists and cars. This will enable cyclists to take up full lanes and safely mix with vehicle traffic without holding up traffic, and in order to do this, requires these users be travelling at similar speeds. This reduction of vehicle speed at roundabout entries is also expected to improve driver recognition of cyclists and reduce the chance of a conflict (Rasanen and Summala 2000, Summala et al 1996), which is particularly important given the prevalence of 'entering vehicle versus circulating cyclist' type injury crashes.

For an assumed average cyclist speed of around 20 km/h (from author Duncan Campbell's riding experience), vehicle speeds of around 30 km/h are estimated to be acceptable for them to competently mix with traffic. In addition, at this speed any injuries incurred from a collision are expected to be coincidentally reduced.

The target of this study was the *85th percentile speed of unimpeded car drivers entering the roundabout*, i.e. those not having to give way to circulating vehicles already on the roundabout, or held up for any other reason such as queued or turning vehicles. It is supposed that it is predominantly this group of drivers that is more likely to collide with circulating cyclists on the roundabout.

A brief review of overseas literature was undertaken along with some field surveys of roundabouts in Waitakere and Auckland City. These indicated that for roundabout design:

- Provision of a 30 metre maximum path radius approximately achieves the desired 30 km/h speed environment.

- A 40 metre maximum path radius achieves a marginally higher speed environment than desirable. However, it is surmised that if drivers have to undertake "S" manoeuvres to achieve this then vehicle speeds may be acceptable (such as for some straight-through alignments). This tendency is best understood when considered from a driver comfort point of view. Undertaking two opposing turns of the wheel in quick succession is more demanding (and uncomfortable) than what might otherwise be simply the negotiation of a single radius curve. **Figure 1** in the Appendix demonstrates this for the straight-through vehicle path.

- Larger maximum path radii than the above do not achieve the low speed environment that is desired for cyclists, especially outside peak hour periods when traffic speeds will be higher.

7. THE FROST ROAD / CARR ROAD INTERSECTION IN AUCKLAND

The single-lane Frost Road / Carr Road roundabout in an industrial area of Mt Roskill in Auckland was redesigned in 1999 to improve its capacity. One of its approaches was amended to provide for two entry lanes of reduced width (5.3m kerb to kerb), which large trucks straddle rather than travel alongside other vehicles (see **Figures 7.1** and **7.2**). This approach is marked for two lanes some 100 metres upstream of the roundabout. From observations as well as a review of the site's crash history, this has shown to be a practical concept and is the basis for the C-Roundabout design.

Figure 7.1 Semi-trailer straddling both entry lanes while entering the Frost Road / Carr Road roundabout from the Carr Road approach.

Figure 7.2 View of smaller vehicles approaching the roundabout from Carr Road. Kerb to kerb width is just 5.3 metres.

8. THE C - ROUNDABOUT DESIGN CONCEPT

Our research showed that adult commuter cyclists (whom are generally more able and confident riders), would prefer to stay on the road rather than use some kind of off-road facility – provided that vehicle speeds could were around 30 km/h or less. The C-Roundabout uses confined geometry to achieve this low speed environment, and consequently requires larger vehicles such as trucks or buses to travel through single file. Cyclists are not provided with a separate facility, instead are they expected to travel through as if they were a car user – speed differential between cyclists and car traffic is expected to be in the order of 10-15 km/h, or less in busy peak hour periods. A C-Roundabout now needs to be constructed and road-trialed to prove the concept in practice.

Typical layout drawings for a four-way C-Roundabout is attached as an Appendix. In order to achieve the 30 km/h speed environment, the roundabout entry width is narrowed to 5.4 metres so that larger vehicles do not attempt to enter alongside other vehicles (see **Figure 8.1**). These narrow lanes also encourage cyclists to travel in the centre of the lane, which is desirable for their safety. In turn, circulating carriageway width can be reduced which helps to facilitate an overall speed reduction on the roundabout. A C-Roundabout with dual lane approaches and additional left-turn slip lanes for improved capacity is shown in **Figure 8.2**.

The design process was an iterative one involving differing combinations of central island diameters and approach angles for side roads. The 20 metre central island diameter as shown in Figure 1 of the Appendix was chosen because, for a four-way junction, it provides an optimum configuration for the desired maximum path radii as recommended in Section 6. This being for around 30 metres for left-turn movements, and 40 metres for straight-through movements with an "S" type alignment. Smaller island diameters are feasible when used in conjunction with curvature on approach roads, as used in the example shown in **Figure 8.3**.

Unless there are a substantial proportion of trucks (which is usually not the case), the capacity of the C-Roundabout compared to a standard multi-lane configuration is not expected to be significantly affected. Except where roundabout diameters are substantially larger, circulating traffic speeds during peak hour have been observed to be low irrespective of geometry. Gap acceptance behaviour that might depend upon opposed vehicle speeds, will therefore not be affected during capacity conditions.

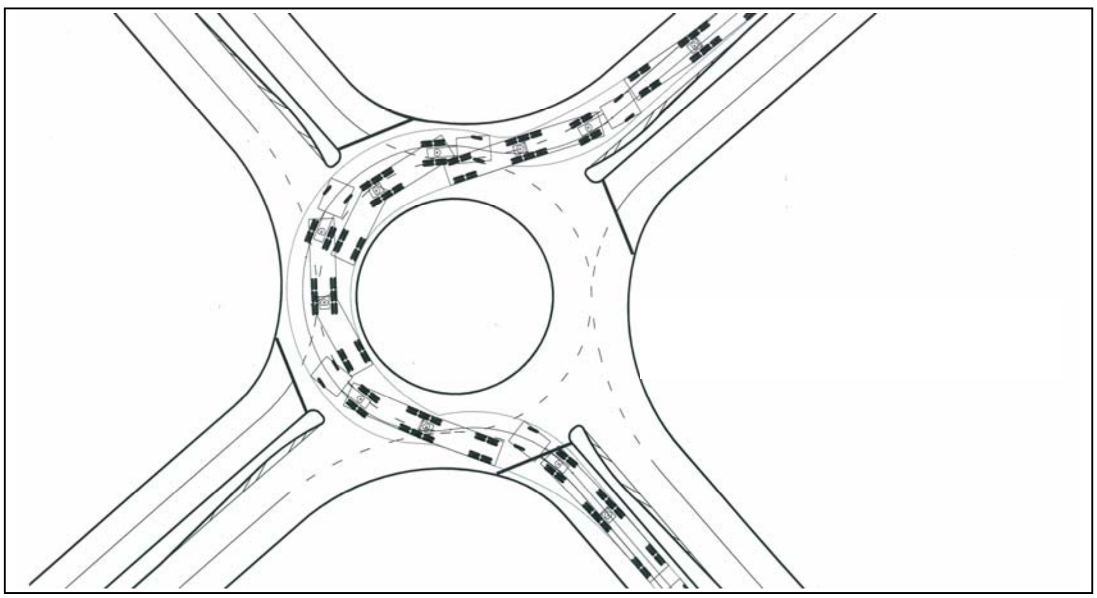

Figure 8.1 "B" train undertaking a right-turn at the C-Roundabout with a 20 metre central island diameter. At 20 metres long this is the maximum length vehicle permitted on New Zealand Roads without a special permit. Note that a large mountable section for the central island is not essential here.

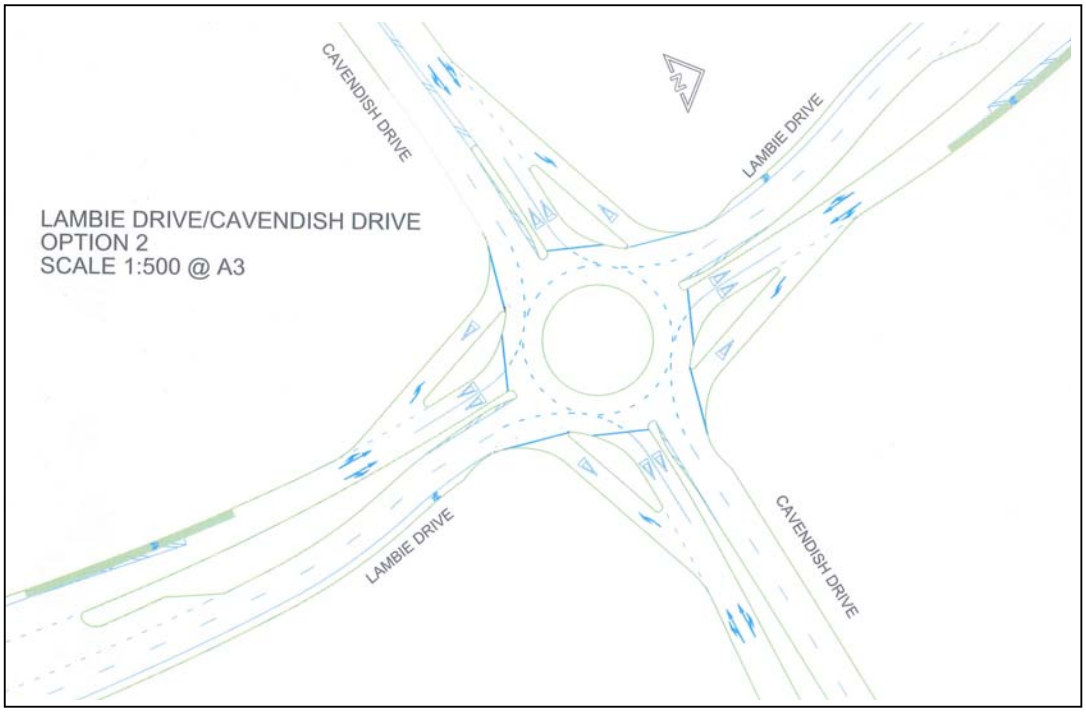

Figure 8.2 A C-Roundabout option in Manukau City, Auckland, that includes left-turn slip-lanes for additional roundabout capacity (central island diameter is 20 metres as in Figure 8.1). Note the Lambie Drive approaches are dual-lane and are shown with merge areas upstream of roundabout entries.

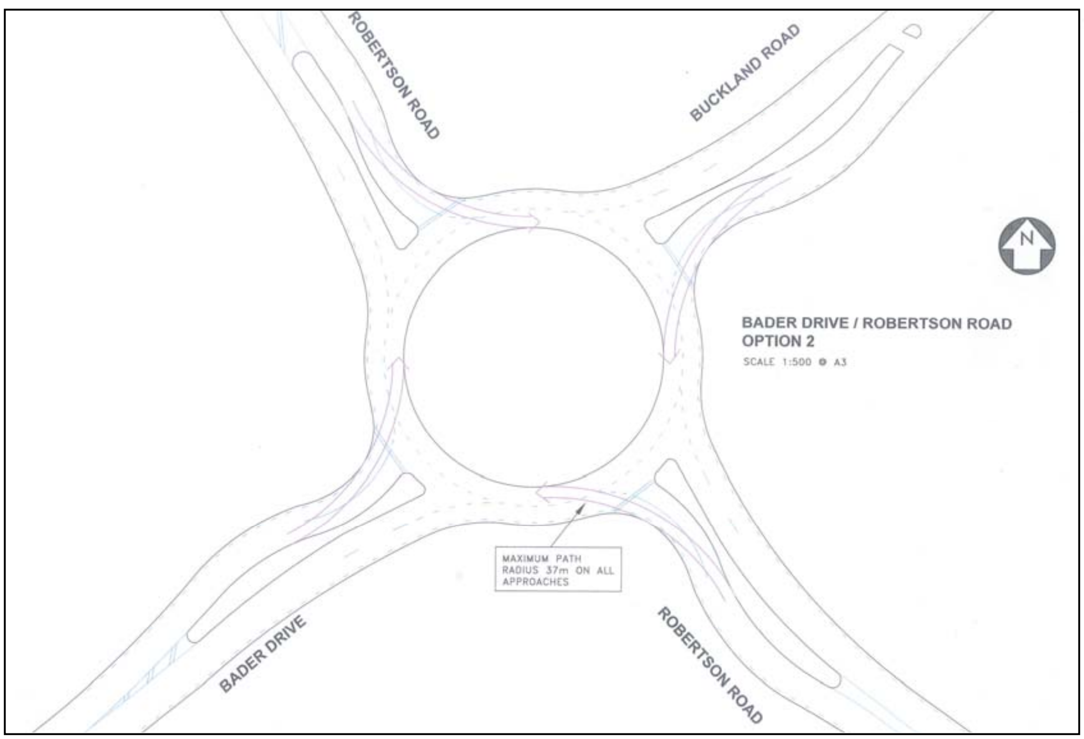

Figure 8.3 An alternative C-Roundabout scheme in Manukau City, Auckland, that retains the existing 45 metre diameter central island. Note a slower entry configuration is achieved by using curvature on the approach roads. Though less ideal than a smaller diameter configuration (as higher vehicle circulating speeds will result), it would be more economical to construct here and still goes some way in addressing critical 'entering vehicle versus circulating cyclist' crashes. Trucks still have to travel through single-file.

9. OPPORTUNITIES FOR APPLYING THE C – ROUNDABOUT CONCEPT

9.1 Benefits of a C-Roundabout

The C-Roundabout concept is applicable to any new multi-lane roundabout design, and would substantially improve the road environment for cyclists. The following benefits are also attributed to other road users:

- Pedestrians – the lower speed environment means that any pedestrian facilities in the vicinity of the roundabout should be safer. This includes zebra crossings, traffic signals and informal crossing points at roundabout throat islands.
- Vehicle drivers – even though well-designed roundabouts generally have a good safety record in terms of injury-related crashes, a lower speed environment means that any crashes that do occur will be less severe. Motorcyclists can especially benefit, as they are also a vulnerable road user group.

However, it is recognised that these benefits alone may not justify relatively expensive reconstruction of an existing multi-lane roundabout. For economic reasons many Road Controlling Authorities may find the C-Roundabout more realistically viable for:

- Smaller intersections or single-lane roundabouts being upgraded for capacity reasons. The C-Roundabout concept can achieve compact designs compared to a typical multi-lane arrangement, and for this reason may potentially be the best economic solution available for a capacity improvement. This represents the greatest opportunity for the C-Roundabout as perceived by the authors.
- Treating existing multi-lane roundabouts on particularly important cyclist routes.
- New intersections in green field developments.

9.2 Example of a Roundabout Reconfigured to a C-Roundabout

An extensive search was undertaken for existing roundabouts in Auckland City that might be feasible for reconfiguring to a C-Roundabout. It was perceived that a capacity improvement project would be a wise use of funds, and could also double as a road trial. Although several sites were identified, the Merton Road / Morrin Road / Felton Mathew Avenue roundabout in St Johns (see **Figure 9.1**) has an existing geometry that is very close to the C-Roundabout layout as shown in the Appendix, and therefore would be very economic to construct.

Currently this roundabout has separate left-turn lanes on three of its four approaches, but does not allow for two straight-through lanes of traffic in any direction (effectively it has only circulating lane). Roundabout geometry is also such that through vehicle speeds of around 50 km/h would not be uncommon. Queues on Merton Road were observed to extend for some distance on both approaches during peak hour (see **Figure 9.2**). By providing two straight-through traffic lanes, a C-Roundabout configuration is expected to reduce delays for these vehicles especially.

A scheme drawing is shown in **Figure 9.3** that shows what is required. The proposed design will improve the capacity of the roundabout and also make it more cyclist friendly at little cost, estimated at around $100,000. Unfortunately Auckland City is not currently prepared to invest money at this intersection, as there is a major redevelopment proposed in the vicinity that was perceived could compromise the new design. GHD Ltd is currently seeking another potential site for implementation.

Figure 9.1: Aerial photo of the Merton / Morrin / Felton Mathew roundabout in St Johns, Auckland City.

Figure 9.2: Westbound queues on Merton Road during the morning peak. Note the virtually unused left-turn only lane. With a C-Roundabout design, straight-through vehicles can utilise this lane and thereby reduce delays.

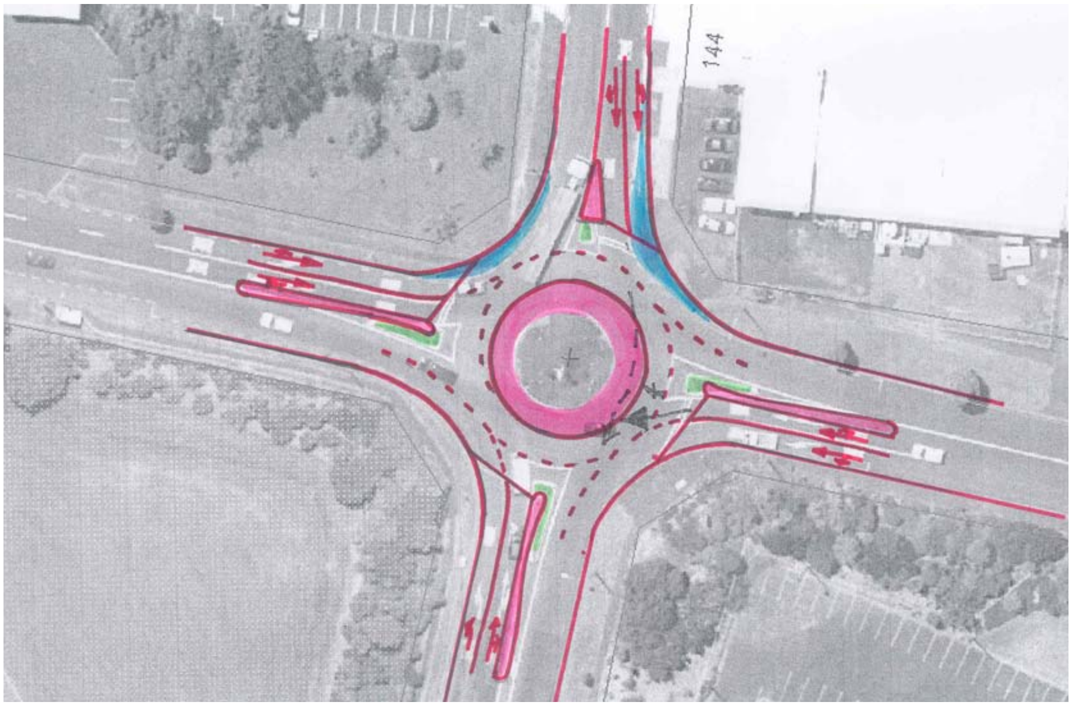

Figure 9.3: Sketch showing a C-Roundabout configuration. The shaded areas depict kerb cutback (shown blue), existing islands to be removed (shown green), and new traffic islands (shown pink).

10. CONCLUSIONS

The main conclusions of this research are:

- Cyclists are over-represented in crashes at roundabouts, and multi-lane types in particular are more hazardous for them than traffic signals. Cyclists view multi-lane roundabouts as a reasonably significant obstacle, and if cycling is to be encouraged then this needs to be addressed. There appears to be no satisfactory design solution that is available overseas.
- Off-road bypasses are an alternative that is generally more appropriate for younger cyclists and novices. More experienced cyclists prefer to stay on the road.
- International literature review, cyclist crash statistics and cyclists themselves confirmed that the desired outcome is a roundabout design which reduces traffic speed and allows cyclists to use the road as equals with other vehicular users. Lower vehicle speeds should address critical ‘entering vehicle versus circulating cyclist’ crashes, and also at roundabout exits which is the other main safety concern for cyclists.
- Options to reduce vehicle speed include confined geometry, vertical deflection devices and the ‘turbo-roundabout’ concept from The Netherlands. This research focussed on the first method.
- Maximum path radii in the order of 30 to 40 metres is required to achieve the desired low speed environment for cyclists, particularly in off-peak periods when vehicle speeds will be higher.
- The Frost Road / Carr Road roundabout in Mt Roskill, Auckland, has demonstrated the feasibility of narrow roundabout approaches that require larger vehicles to straddle both entry lanes. This is the basis for the C-Roundabout concept.
- The C-Roundabout uses confined geometry to achieve a low speed environment, and consequently requires larger vehicles to travel through single file. Cyclists are not provided with a separate facility, instead are they expected to travel through as if they were a car

user – the lower vehicle speeds mean this should be a relatively safe exercise. A C-Roundabout now needs to be constructed and road-trialled.

- The C-Roundabout design concept offers potential safety benefits to all users including cyclists, and can also achieve compact designs. Unless there are substantial volumes of trucks, the capacity of the C-Roundabout compared to a standard multi-lane configuration is not expected to be significantly affected. The author's perceive its main potential is for upgrading existing intersections for capacity reasons, or for green field developments. Reconfiguring existing multi-lane roundabouts is more justifiable for important cyclist routes.
- Further research needs to be undertaken on visibility guidelines at roundabouts, cyclist priority laws in The Netherlands, the use of vertical deflection devices on roundabout approaches, and a review of the 'turbo-roundabout' from The Netherlands.

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AUTHOR BIOGRAPHIES

Duncan Campbell (presenting) is a Chartered Professional Engineer and has around ten years' experience in the traffic engineering field. In 2005 he submitted a thesis on this subject (improved multi-lane roundabout design for cyclists) to Auckland University as the final part of a Masters of Engineering (ME) qualification. Most of Duncan's experience has been in traffic design work for Auckland City Councils, including an emphasis on traffic safety and cyclist infrastructure projects.

Ivan Jurisich (presenting) is Principal Traffic Engineer at GHD Auckland (Central Business District Office) and has over 28 years' experience in traffic and transportation engineering. Ivan is one of New Zealand's leading experts in the field of traffic engineering, and is well experienced with roundabout investigation and design projects.

Roger Dunn is the Associate Professor, Director of Transportation Engineering, Dept of Civil and Environmental Engineering, The University of Auckland.

APPENDIX

TYPICAL LAYOUT DRAWINGS FOR A FOUR-WAY C – ROUNDABOUT

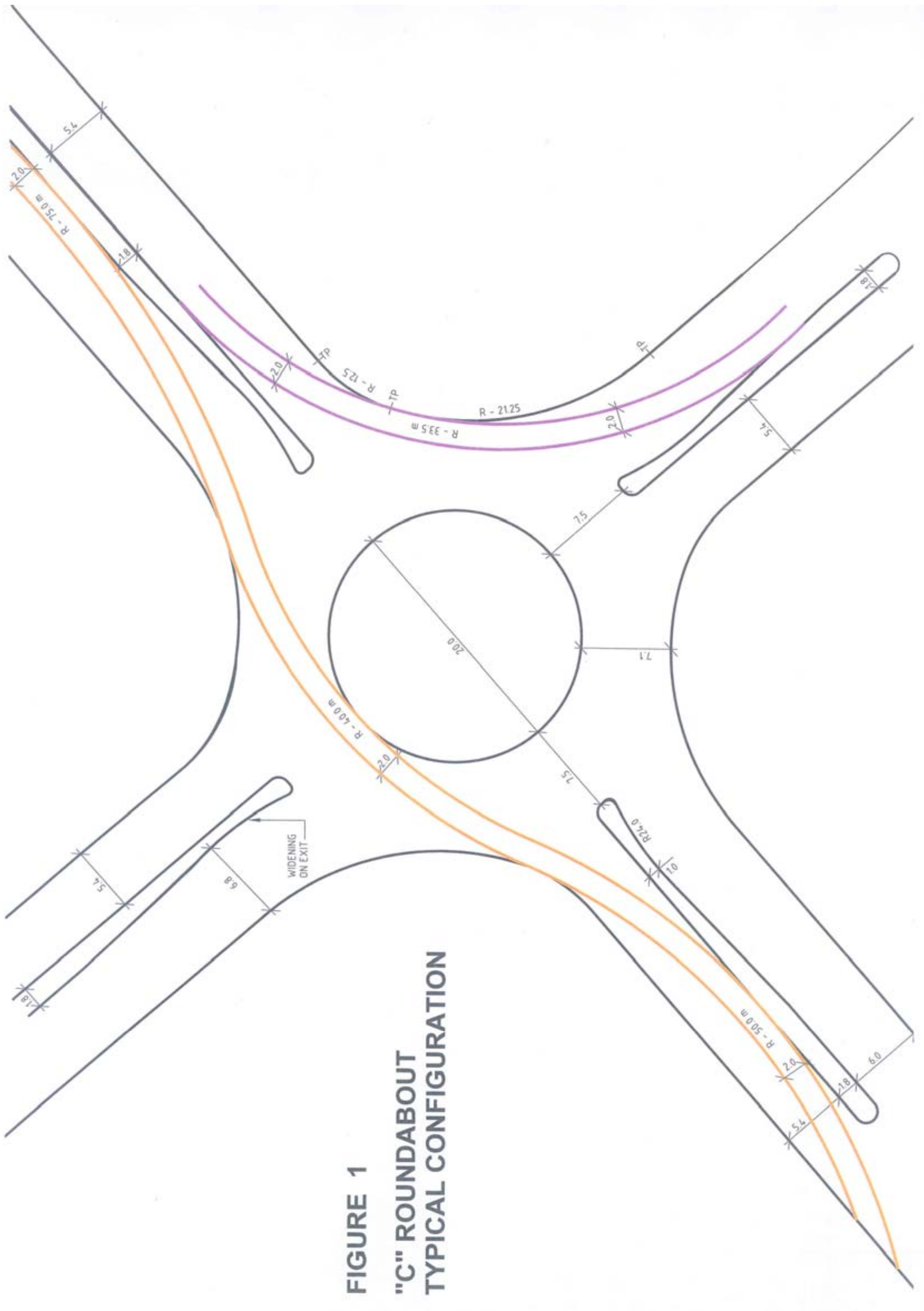

FIGURE 1

"C" ROUNDABOUT TYPICAL CONFIGURATION

FIGURE 2

"C" ROUNDABOUT
ROADMARKING AND SIGNS DRAWING