High rate of crashes at roundabouts involving cyclists may be reduced with careful attention to conflict paths.

Cumming, Bob[1]

Road Safety Audits Pty Ltd, Suite 8, 79 Manningham Rd, Bulleen, Vic 3105, Australia

Email for correspondence: bob.cumming@rsaudits.com.au

Abstract

Victoria has a high rate of cyclist involvement in crashes at roundabouts (whole state- 24%; inner suburban- 49%). Many researchers have identified that cyclists circulating on the outer edge or in circulating bicycle lanes may contribute to crashes. The predominant crash type is entering drivers striking circulating cyclists. Video research and post-crash interviews have suggested the relevance of the “looked but failed to see” (LBFTS) phenomenon, where drivers look towards cyclists (or motor-cyclists) but do not see them.

All 2005-2009 crashes at roundabouts in Victoria are analysed based on crash type and region. 82% were entering-circulating crashes - consistent with the findings of others.

130 commuter cyclists were observed negotiating roundabouts, with regard to lane positioning. Only five entered from the middle of driving lanes and none remained there through the roundabout. Predominant behaviours were: 62% “straight-lining” from kerbside to near the island, then back to kerbside - allowing highest speeds to be maintained; and 32% “edge-riding” – riding near the outer edge from entry to exit. It is argued that these cyclist behaviours increase crash risk by creating a more complex conflict environment, in which the cyclist may not be seen by drivers scanning only where cars would be located.

Assuming that cyclists maximise their visibility by riding where cars would be, strategies are suggested to encourage cyclists to move to primary position prior to roundabout entries and remain there: bicycle logos to cue cyclists to merge to primary position and ride through roundabouts in the middle of lanes, and to warn drivers that cyclists will be there; and slowing devices for cars to assist safe merging with cyclists. Examples of implementation are provided.

Key words: roundabouts; cyclists; conflict points; “looked but failed to see”; LBFTS; roundabout crash analysis.

1. Introduction

Although installing a roundabout typically improves road safety, this benefit does not always extend to cyclists (Austroads, 2011; Daniels et al, 2008; FHWA, 2000). During the period 2005-2009 24% of all reported injury crashes at roundabouts in Victoria involved cyclists (Cumming, 2011). Of these 497 crashes state-wide, 27% occurred in seven inner-suburban municipalities, where 49% of crashes at roundabouts involved cyclists. This paper considers the high rate of roundabout crashes involving cyclists and suggests design changes which could be used to reduce such crashes, particularly at inner urban roundabouts.

1.1. Roundabout designs

Patterson (2010) presents a review of roundabout design practice from an Australian perspective. A major point of difference is that UK, Sweden, New Zealand and Australia favour tangential entries which keep speeds high to increase capacity, while Germany, France, Denmark and Netherlands favour radial entries for greater safety - with greater deflections to slow vehicles and entry angles closer to 90º to improve visibility. German roundabout design rules prohibit cyclists on the outside edge of circulating areas, which they regard as dangerous.

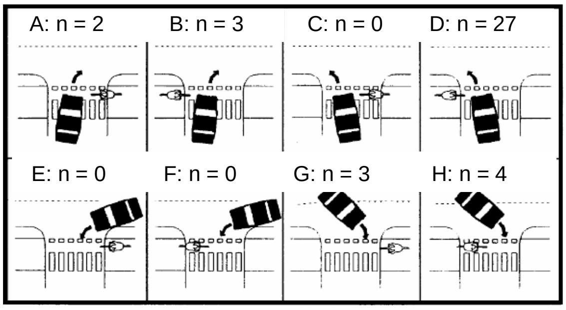
Patterson (2010) concludes that Austroads and VicRoads recommendations for adding bicycle lanes to roundabouts appear to conflict with published safety research.

1.2. Crash analyses and crash types

Elvik and Vaa (2004) reviewed 34 studies from Northern Europe, Australia and the US about the effect on crashes of converting an intersection into a roundabout. Roundabouts reduced injury crashes by 10 to 40%. The reduction in serious injury crashes was generally greater than for less serious injury crashes. For cyclists, however, roundabouts did not have the same crash reduction effect. (Campbell et al, 2006; Herslund & Jørgensen, 2003; Jørgensen & Jørgensen, 1994; Schoon & van Minnen, 1993). After researching 91 Belgium roundabouts, Daniels et al (2008) concluded that installation of a roundabout increased cyclist injuries by 27% and serious or fatal bicycle crashes by 41%. Most researchers agree that entering drivers failing to give way to circulating cyclists is the most common crash type involving cyclists.

Schnull et al (1993) found that bicycle lanes and tracks increase risk over no treatment. Similarly, a UK study by Allott and Lomax Ltd. (1991) showed that many crashes occur when cyclists ride within the outer 1.5m of roundabouts. Flared entries and wide circulating lanes are also identified as increasing cyclist risk. Hyden & Varhelyi (Sweden, 2000) encourage small single-lane roundabouts, with cyclists merging with cars into a single traffic stream well before roundabout entries.

Figure 1: Bicycle-car collisions, by type at a sign-controlled T-intersection. (Figure reversed for an Australasian left-driving audience)



1.3. Cyclist behaviour

Video research conducted at roundabouts has shown that a large proportion of cyclists ride on the outside edge of the circulating lane and that the outside edge is dangerous. (Arnold et al, 2010 (California); Hyden & Varhelyi, 2000 (Sweden); Sakshaug et al, 2010 (Sweden)). In order to encourage cyclists to control the lane, all three articles suggest terminating bicycle lanes well before roundabouts. Arnold et al (2010) suggest installing “Cyclists Allowed Full Use of Lane” signs on roundabout approaches.

1.4. “Looked but failed to see” phenomenon

Reflecting after roundabout crashes, it is not uncommon for the cyclist to report that they saw the driver look, and for the driver to state that they looked, but that “the cyclist came from nowhere” (Herslund & Jorgensen, 2003). Such a scenario is described in the literature as a “looked but failed to see” (LBFTS) crash.

LBFTS crashes occur when a driver looks in the general direction of an oncoming hazard but does not notice it or give way. These commonly involve two-wheeled vehicles (Koustanaïa et al 2007). Figure 1, reversed for a left-driving audience, illustrates long-term European video research examining turning drivers crossing a two-way cycle path beside an intersection. The highest count is (D), with 27 collisions between left-turning drivers and cyclists from the left. This compares to a count of zero (C) for collisions with cyclists from the right. Hidden cameras observed how left turning drivers scanned to the left much less frequently and later than those turning right. (Summala et al 1996). While the pictured example is not from roundabout research, it supports the idea that drivers are checking the dominant traffic flow path for a gap to fill rather than scanning the whole intersection for all possible hazards. Applying this idea to roundabouts, if approaching drivers are checking only the flow of cars for a gap, they may overlook cyclists riding near the kerb.

After conducting in-depth interviews with cyclist and driver survivors of LBFTS crashes Herslund & Jørgensen (2003) confirmed that car drivers look in the direction of cyclists without perceiving them. Herslund & Jørgensen videoed cars and cyclists at roundabouts and noted that bicycles are often located in drivers' peripheral vision. They suggest that experienced drivers use fast search strategies such as concentrating on where cars usually are, so may be more prone to LBFTS collisions than less experienced drivers. Their gap selection research showed that while drivers allowed 4.6 seconds (mean, standard deviation 0.16) for cars, gaps for bicycles were only 3.3 seconds, with 12% entering with gaps of less than 2 seconds, suggesting that some drivers may be failing to see cyclists altogether. They conclude that cyclists are less likely to be overlooked if they merge with cars and enter roundabouts from where car drivers search for cars.

The conclusion, that prior to entering roundabouts drivers tend to look mainly for cars and thus miss circulating cyclists, is shared by many researchers. (Herslund & Jørgensen, 2003; Hyden & Valhelyi, 2000; Jørgensen and Jørgensen, 1994; Räsänen and Summala, 1998, 2000; Summala et al, 1996). In a videoed simulator study examining eye movement of drivers approaching and entering roundabouts with circulating cyclists and with and without bicycle lanes, Lund (2008) observed that drivers are more attentive to cyclists at roundabouts without bicycle lanes (and with circulating cyclists in the middle of the lane). Being simulator-based, this research was able to effectively control for many temporal-spatial variables which typically confound research comparing different treatments. However, its conclusions assume cyclists without bicycle lanes ride in the middle of the lane – which is not always correct.

Although many researchers have identified that cyclists riding in the outer edge of roundabouts or parallel to other vehicles appear to increase crash risk compared to cycling in the middle of lanes, a gap exists concerning why. This paper suggests a theory about why cycling away from the expected car trajectory may increase crash risk. Where other researchers conclude that cyclists should merge with cars and travel through roundabouts in the middle of the lane, this paper goes a step further by suggesting infrastructure measures to encourage such behaviour by cyclists.

2. Analysis of Crash Data

Victoria's official crash data (VicRoads, 2010) was analysed for the 5 year period 2005-2009. Bicycle casualty crashes accounted for 9% of all crashes in Victoria, but were higher for inner-urban Melbourne[1] with 18%. While crashes at roundabouts accounted for only 3% of all crashes, they disproportionately involved bicycles, with the proportion of roundabout crashes involving cyclists being 24% (47% inner urban).

During the period 2005-2009, 162 reported crashes at roundabouts within these municipalities involved cyclists – 47% of the 346 total reported crashes. Some characteristics of these 162 crashes include:

-	25% resulted in serious injuries		
-	Speed limits:	30-50 km/h - 69%	60 km/h+ - 31%
-	Serious injuries: by speed limit	28%	21%

Interestingly, serious cyclist injuries were more common at roundabouts on lower speed roads.

[1] Melbourne, Darebin, Maribyrnong, Moonee Valley, Moreland, Port Phillip, Stonnington & Yarra local government areas.

Australian definitions for classifying accidents (DCAs) do not include roundabout-specific categories. Each DCA was assessed and reclassified into roundabout crash-types as listed in Table 1(a).

Table 1: Roundabout crash types

(a) Conversion of DCAs to roundabout crash types		**(b) %age freq. of crash types**		**(c) Crashes involving a bicycle: percentage frequency of crash types by region**			
DCAs	Roundabout Crash-Type	Not involving a bicycle	Involving a bicycle	Victoria - non-Melb LGAs	Outer Metro LGAs	Inner Metro LGAs	Melbourne LGA
110,111,113,114,116,117, 119,121,123,124	Entry-circulating	37	82	88	77	85	68
134-139,153	Exit-circulating	2	4	2	4	5	16
120,150,170-179,180-189	Loss of control	32	4	3	4	4	4
130-132	Rear end	19	3	3	3	2	0
133	Lane side swipe	1	3	2	4	2	8
100-109	Pedestrian	6	0	0	0	0	0
147-148	Bike from driveway or footpath	0	4	2	8	0	4
All other DCAs	Others	2	1	0	1	1	0
Total number of roundabout crashes		1587	497	132	203	137	25

All crashes at roundabouts were reclassified into roundabout crash-types and grouped based on whether or not a bicycle was involved. It can be seen form Table 1(b) that the frequency distribution of crash types is quite different between the two groups. For those involving bicycles, the entering-circulating crash type dominates (82%) with no other crash type accounting for more than 4%. This is consistent with the findings of other researchers (Turner et al, 2006 & Jurisich et al, 2010). It is assumed that most of these involve an entering car striking a circulating cyclist.

Crashes involving cyclists were further broken down by region. Table 1(c) shows crash-type frequencies by region. The main regional differences are that outer metropolitan areas have more crashes involving bicycles from driveways or footpaths and Melbourne CBD has more exiting-circulating and lane side-swipe crashes – all of which occurred at multi-lane roundabouts.

3. Observation of driver behaviour at roundabouts

In January 2010, from a concealed location the author observed approximately 50 motorists at two 1-lane roundabouts in Melbourne inner suburbs, one with bicycle lanes continuing to the hold lines, focusing on (1) observable driver head and eye movements; and (2) vehicle trajectories. It was observed that: (1) most drivers diverted their eyes from the road ahead to the right and not to the left; (2) most looked to the right only very briefly; and (3) most drove across bike lanes to reduce their deviation and maintain speed, on entry or exit or both. No cyclists were present during these observations. It is expected that when drivers see cyclists present, driving across bicycle lanes would be much reduced.

What is in motorists' minds as they approach roundabouts? It is theorised that motorists approach roundabouts with the goal of slowing as little as possible and with assumptions that: (1) they probably won't stop, (2) only conflicts from the right need be considered, and (3) potential conflicts can be assessed with a brief glance to the right. Bicycle lanes without cyclists can be used to reduce deflection to help maintain higher speeds.

4. Observation of cyclist behaviour at roundabouts

4.1. Procedure & Results

In December 2011, over 200 cyclists were observed at three inner suburban Melbourne roundabouts during a morning commuter peak period (Figure 2). All three roundabouts had bicycle lanes on approaches, most terminating prior to entries. Two of the roundabouts were located on a popular CBD commuter route and one direction of travel (toward the CBD) was dominant for cyclists - shown with arrows. The third was not on a "cyclist arterial" route, but was located near a university.

Figure 2: Roundabouts where cyclists were observed

(a) Canning St & Pigdon St, Carlton North, Vic

(b) Canning St, Barkly St & Faraday St, Carlton, Vic

(c) Faraday St & Cardigan Street, Carlton, Vic

About one-third of cyclists arrived and travelled through roundabouts in large groups, so lane positioning was not clearly observable. Observations of the other 130 cyclists are summarized in Table 2. Cyclist lane positioning was noted at entry, while circulating and while exiting. Behaviours differed significantly between the three roundabouts, apparently influenced by the presence of circulating bicycle lanes at one roundabout.

Just five cyclists entered the roundabout from "primary position"[2], and none of these remained in primary position while circulating and exiting. Approximately two thirds were observed to start from the left side of the road and sweep across to the right side of the lane then back, presumably to minimise deflection and maintain speed. Approximately one third entered from the left and travelled in "secondary position"[3] through the roundabout, some travelling parallel with cars.

[2] "Primary position" is in the centre of the lane. This contrasts with "secondary position" near the left edge of the road (effectively creating a second traffic stream within one lane). These terms are widely used in UK cycling instruction and manuals and by the UK Department for Transport.

Table 2: Summary of observations of individual (and small group) cyclists.

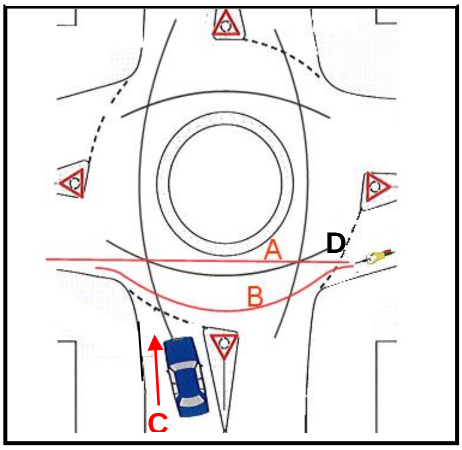
	Roundabout							
	Canning & Pigdon		Canning/Faraday/Barkly		Faraday/Cardigan		Total	
Approach characteristics Roundabout characteristics	bike lane small, poor vis to left		bike lane large, marked circ bike lane		bike lanes small, one lane			
	Count	%	Count	%	Count	%	Count	%
Left entry, circulate & exit	13	19	23	59	8	38	44	34
Left entry, circulate middle or right	53	76	16	41	12	57	81	62
Middle entry	4	6	0	0	1	5	5	4
Total	70	100	39	100	21	100	130	100

Few of the cyclists observed appeared to look around when transitioning from terminating bicycle lanes or to consider the possibility that their path might conflict with parallel vehicles – both prior to entering roundabouts and when crossing roundabout exits.

4.2. Discussion

At many inner suburban roundabouts, bicycles can follow an almost straight line and pass through the roundabout with negligible speed reduction. This behaviour was observed of many cyclists. At one of the roundabouts (Figure 2-(a)), the eastern leg entry had very poor visibility. Drivers from the eastern leg must give way to circulating cyclists from the northern leg (which has much better visibility to its right). Crash history (VicRoads 2010) check showed seven crashes at this location during the five years 2005-2009 involving northern leg cyclist conflicts with vehicles from the eastern leg. Thus, the observed cyclist behaviour of "straight-lining" at speed through this roundabout correlates with a history of crashes there. Where drivers who must give way have poor sightlines, the cyclist behaviour of "straight-lining" at speed appears to contribute to their risk.

Figure 3: Conflict locations for drivers to consider with cyclist entry from kerb-side.



The lack of looking around for other vehicles suggests an assumption that parallel car drivers will give way to cyclists.

However, if drivers assume that cyclists will continue in secondary position while cyclists assume that drivers will give way, cyclists are likely to be at risk.

Figure 3 illustrates the predominant paths of the cyclists observed: path (A) for "straight-lining" (potentially fast-moving) cyclists and path (B) for "edge-riding" (generally slower) cyclists;

Considering the point of view of an entering driver (blue car): In addition to the car conflict path (D), there are three new conflict paths for an entering driver to be aware of and monitor: paths (A) and (B), and location (C) where parallel surprise cyclists may arrive from behind.

Cyclists' range of behaviours when approaching and negotiating a roundabout create a much more complex environment than if they all followed primary position, path (D), when entering and circulating.

If a driver approaching a 1-lane roundabout assumes and attends to just one conflict path (D), there are many other locations where cyclists may be that the driver will overlook.

If a driver looks to the right and sees an empty space along the car path D, they may enter the roundabout - with complete ignorance of the possibility of these three cyclist conflict paths. The secondary position cyclist entry point lies in the peripheral vision of the entering driver looking towards primary position.

Possible issues for cyclists following paths (A), (B) & (C) are listed in Table 3.

Cyclist lateral positioning entering and circulating roundabouts has a strong effect on the chances of cyclists being seen by entering drivers. Bicycle circulating lanes and/or bicycle lanes on approaches ensure that cyclists enter from secondary position which reduces their chances of being seen by entering drivers.

As bicycle lanes remove cyclists from the path that most drivers check before entering roundabouts, any feelings of safety which they provide is at the cost of real safety. Cyclist safety is better served by cyclists following in the centre of the paths that cars follow. Therefore, bicycle lanes should not be installed in or near roundabouts.

Table 3: Issues for cyclists travelling through roundabouts along observed cyclist paths

(A) "Straight-lining" issues
1. Approaching from a kerbside location outside the "criterion 2" sight triangle used by roundabout designers. 2. Cycling through locations where an entering driver is less likely to look. 3. Cycling through locations where cyclist is more likely to be obscured by or blend with vegetation, poles or trees. 4. Possible conflict with parallel driver from behind. 5. Entry at speeds too high for being seen by the driver to their left.
(B) "Edge-riding" issues
1. Approaching from a kerbside location outside the "criterion 2" sight triangle used by roundabout designers. 2. Cycling through locations where an entering driver is less likely to look. 3. Cycling through locations where cyclist is more likely to be obscured by or blend with vegetation, poles or trees. 6. Cycling near the hold line allows minimal time for evasive action by a cyclist if a driver fails to stop at the line. 7. As the relevant conflict point is 2-3m closer to the roundabout entry, if struck by a slowing driver, driving speed will be higher, so injuries more severe. 8. Ambiguity at exits if the cyclist is continuing and a parallel driver exiting. Who should give way?
(C) "Parallel Surprise Cyclist" issues
2. Cycling through a location where a driver to their right is less likely to look. 9. High chance of being squeezed or "cut off" by a driver accelerating to the left (particularly if turning left).

5. Recommendations

These recommendations, illustrated in Figure 4 could be expected to reduce cyclist crashes at single-lane roundabouts[3] by relocating cyclists to where entering drivers scan before entering:

- terminating bicycle lanes prior to roundabout entries;
- strategies to encourage safe cyclist merging to primary position (e.g. "Look, Signal, Merge" signs; bicycle logos with 45° arrows along approaches, and bicycle logos in the middle of lanes at roundabout entries; slowing devices for cars on approaches[4]);
- strategies to encourage cyclists to maintain primary position through roundabouts (such as bicycle logos in the middle of circulating lanes);
- public education & training.

These suggestions are consistent with the advice of other researchers (Allott and Lomax Ltd, 1991; Arnold et al, 2010; Herslund & Jørgensen, 2003; Hyden & Varhelyi, 2000; Sakshaug et al, 2010; and Schnull et al, 1993) and of Bicycle Network Victoria (2012), all of whom recommend ensuring that cyclists are in primary rather than secondary position when

[3] Multi-lane roundabouts have additional issues which are beyond the scope of this paper.
[4] On high speed roads, driver slowing devices and cyclist merge warnings are important to assist safe merging with cyclists.

entering and through roundabouts. Cumming (2011) provides a more thorough description of these suggestions. Figure 4 shows a schematic design for implementing these ideas.

Local governments in Newcastle, NSW, and Darebin, Yarra, Moonee Valley and Mildura in Victoria have begun implementing these ideas. Some examples are shown in Figures 5-8.

After implementation, before and after crash analyses should be undertaken to assess the effectiveness of these measures at reducing cyclist crashes.

It is also suggested that Austroads design guidelines be updated to remove recommendations for circulating bicycle lanes.

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Figure 4: Proposed treatment for bicycle safety at single lane roundabouts.

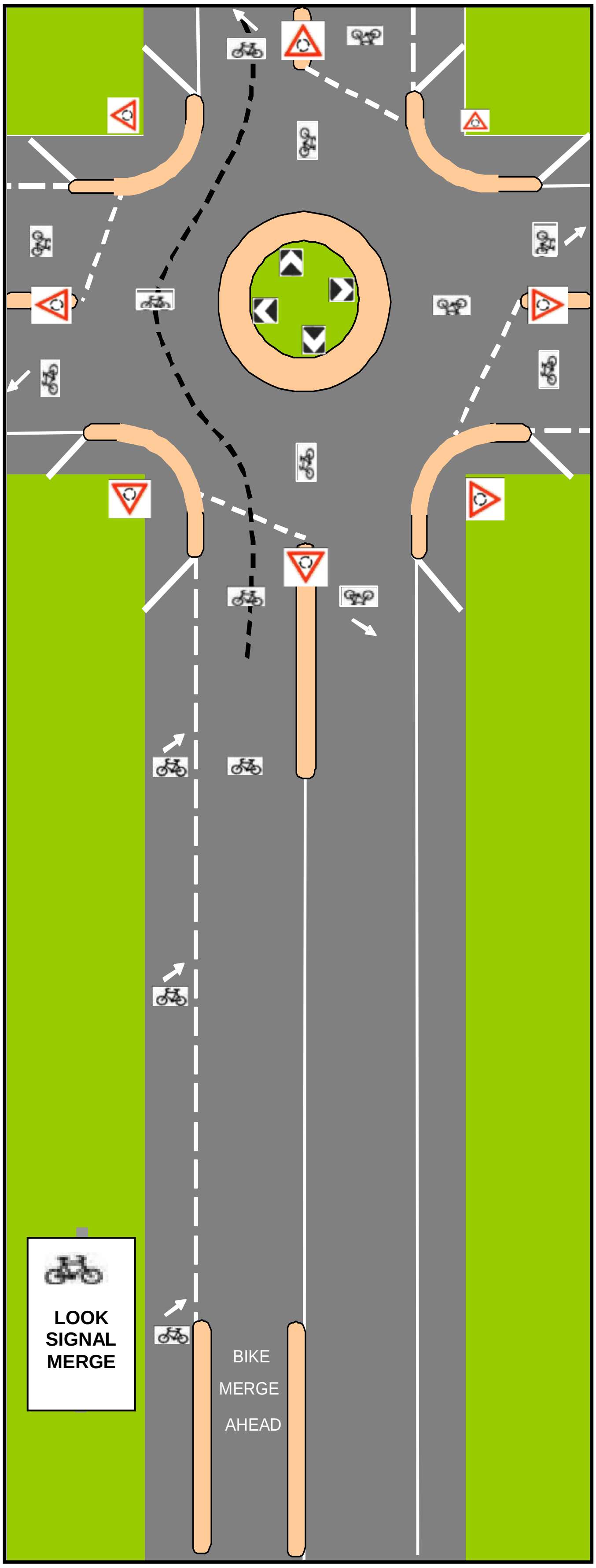
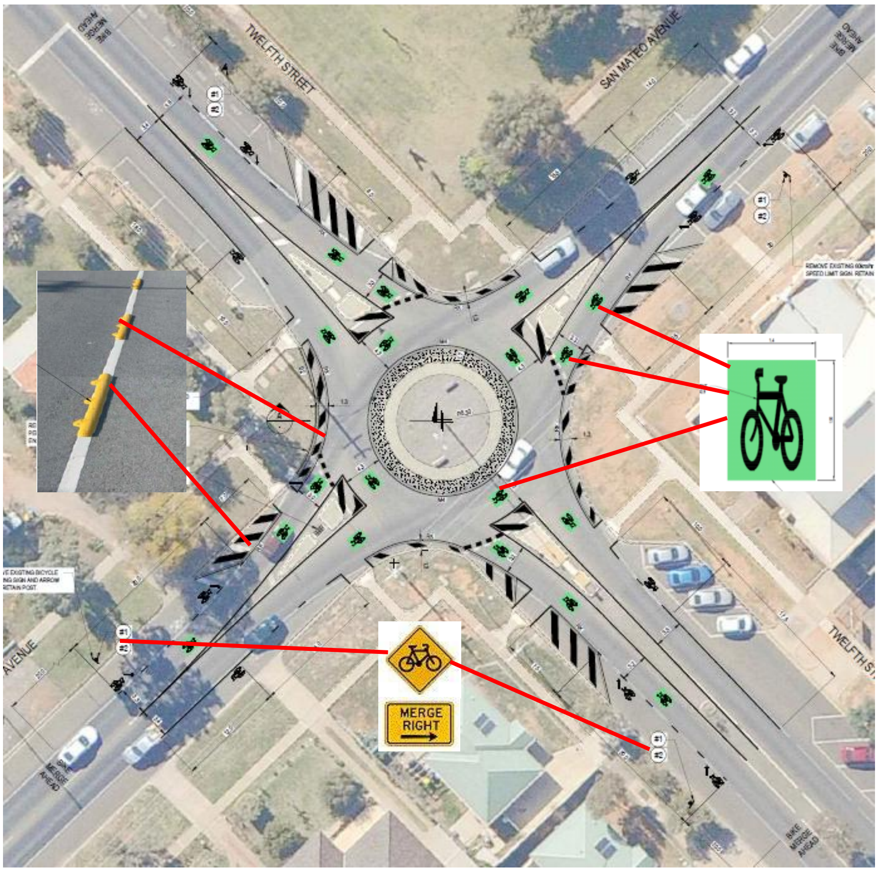


Figure 5: City of Newcastle (NSW)
Prince St & Platt St, Waratah
Designs include bicycle logos in middle of lanes (entry and circulating).
Installed May 2011

Figure 6: City of Darebin (Vic) –Raglan St, Preston & City of Yarra (Vic) Pigdon St, Carlton
Designs include sharrows in the middle of lanes and bicycle symbols with merge arrows.
Installed July 2011 & Feb 2012.

Figure 7: Rural City of Mildura (Vic) –San Mateo Ave & 12th St Design includes: bicycle logos in middle of lanes (entry and circulating); bicycle symbols with merge arrows; Riley Kerb mountable geometry tightening (to allow B-doubles) and approach slowing; BIKE MERGE AHEAD pavement warnings; & “bicycles / merge right” signage. Installed 2012.



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