

Analysing & managing the cyclist-driver interface using “conflict path analysis”

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Abstract

Conflict path analysis considers the microgeography of cyclist travel paths and how travel path choice may affect the level of mutual awareness between road users. Travel paths of bicycles and motor-cycles are both: less visible because vehicles are smaller; and less predictable to drivers because narrow vehicles take a range of positions within lanes and sometimes “share” lanes, so may not be where drivers look. Where awareness of cyclists by drivers required to yield to them is impossible or improbable, crash risks are high. For four road conflict scenarios which particularly affect cyclists, precise travel paths are analysed, considering how they may affect potential driver awareness and countermeasures are proposed to improve likely driver awareness of cyclists. Left turn side-swipes can be reduced by encouraging left turning vehicles to do so from the left edge of the road; Car “dooring” may be reduced with painted safety buffers between parking and bicycle lanes. “Keep Clear” area crashes may be reduced by extending the clear area upstream to remove sightline obstructions. Roundabout strategies to encourage central lane positioning by cyclists include centrally painted bicycle symbols. “Conflict path analysis” is a new analysis system which can usefully assist designers to create safer roads.

Keywords: Roundabouts; cyclists; conflict points; road safety; keep clear; “dooring” of cyclists; conflict path analysis.

Introduction

Conflict points are locations where the travel paths of road users cross. If the trajectories and speeds of two road users lead to them passing a specific conflict point at the same time, then at least one road user must change their speed and/or trajectory in order to avoid a collision. This means that at least one road user must be aware of the other and correctly assess their location, speed and path trajectory.

Road rules specify which of two potentially conflicting road users should yield or give way. Legally, the yielding road user has full responsibility for awareness of all other road users to whom they must yield. In some situations in some road environments, such awareness may be impossible (e.g. due to obstructed sightlines). In others, typical driving habits mean that such awareness is improbable. In both cases, crash risk is high.

“Looked but failed to see” (LBFTS) researchers (Koustanaià et al, 2007) have identified that cyclists and motor-cyclists are particularly at risk from crashes where drivers look in the general direction of the conflicting road user but fail to see them and respond appropriately. Herslund & Jorgenson (2003) suggest that this is because drivers develop selective search strategies, focusing their attention on the parts of the road environment where conflicts are most likely. Because bicycles and motorcycles are smaller than cars they are more likely to be overlooked; because they are narrower, they are able to be located in places other than the centre of driving lanes.

Conflict path analysis considers the micro-geography within the road environment of: (1) the paths of road users, particularly 2-wheeled vehicles; and (2) the relationship between path choice and the likelihood of awareness between road users.

Being a defensive driver (or cyclist or pedestrian) includes being aware of situations where other drivers' awareness may be low and proceeding with great caution even where another road user should yield. Common examples include: (1) pedestrian at zebra crossing waits for vehicles to slow or stop before proceeding; (2) pedestrian at signalised crossing or slip lane checks for turning vehicles before proceeding; (3) footpath cyclist approaches blind driveway very slowly; or (4) left lane driver or cyclist proceeds past a queued right lane slowly, especially if there are gaps in the queue.

The goal of conflict path analysis is to identify road situations where yielding driver awareness is impossible or improbable (i.e. high crash risk situations) and to suggest counter-measures to improve likely awareness. Countermeasures could relate to any of: (1) road design; (2) vehicle design; or (3) road users – training, public education, or road rules.

Vulnerable road users – including pedestrians, cyclists and motor cyclists - tend to suffer more severe injuries when involved in a crash due to the lack of physical protection that being within a metal vehicle provides. Thus they have a stake in adopting defensive behaviours.

This paper uses conflict path analysis in relation to cyclists, with a focus on several road scenarios in which crashes involving cyclists are common. Where barriers to awareness are identified, counter measures are proposed, with a primary focus on infrastructure design.

These four road conflict scenarios are not necessarily the worst or the most important conflict scenarios for cyclists. However, in each of the conflict scenarios outlined below, cyclists in particular are affected. The definitions for classifying accidents (DCAs) mentioned are illustrated in Figure 1.

1. Left-turn side swipes (DCA 137) account for 6% of cyclist crashes in Victoria (2007-2011). 69% of all left-turn side swipe crashes involve cyclists; 29% result in severe injuries (2007-2011) (VicRoads, 2012).
2. “Car door opened into the path of a vehicle” (“car dooring”) (DCA 163) accounts for 10% of cyclist crashes in Victoria (2007-2011) (VicRoads 2012). In inner Melbourne¹, 92% of these crashes involve cyclists (2006-2010) (Munro, 2012).
3. Crashes involving vehicles turning through Keep Clear areas: The Melbourne CBD location with the highest number of cyclist severe injury crashes (2005-2009) has a Keep Clear area, a down-hill bicycle lane, and a history of crashes involving vehicles turning through a keep clear area and striking cyclists (Cumming, 2011²). Measures proposed address “right through” and “left near” conflicts - DCAs 121 and 116.

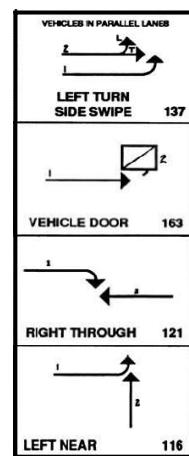


Figure 1:
 Some DCAs,
 illustrated.

¹ Melbourne, Yarra, Port Phillip, Stonnington, Glen Eira, Moreland, Boroondara, Bayside, Kingston & Darebin local government areas.

4. Roundabouts account for 8% of cyclist crashes in Victoria (2007-2011) (VicRoads 2012). For all of Victoria, 25% of crashes at roundabouts involve cyclists, and for inner urban areas², the figure is 49% (Cumming, 2011¹).

Suggestions are made relating to driver behaviour, cyclist behaviour, and engineering measures. Following this analysis is a reflection on the process of conflict path analysis.

Terminology

The term *path* is used to refer to the precise travel path followed within the road. *Primary position* is in the centre of the left lane. *Secondary position* is to the left of moving traffic, effectively creating a second traffic stream within one lane. These terms are widely used in UK cycling instruction and manuals and are endorsed by the UK Department for Transport.

Cyclist lateral position within the lane

For cyclists, primary position offers safety advantages on narrow lanes when there isn't enough room for drivers to comfortably overtake (even though they might feel tempted); in busy, slow-moving traffic; and near some types of intersections. Advantages include: space to react, high visibility to other road users, and the smoothest road surface. Primary position is sometimes referred to as “taking”, “owning”, “claiming” or “occupying” the lane. Safe use of secondary position requires kerbside lanes wide enough for drivers to overtake safely within the one lane. Austroads (2010) suggests minimum widths of 3.7m in 60 km/h zones, 4.2m with high truck volumes, and 4.3m in 80 km/h zones.

In Australia, the author's observations suggest that the majority of cyclists use secondary position most of the time, regardless of lane width. The author is primarily a commuter cyclist, but has cycled with and observed commuter cyclists, recreational cyclists and sport cyclists. While each of these groups exhibit vastly differing behaviours, when observed cycling alone, many members of each of these three groups tend to ride in secondary position.

Using a bicycle lane is similar to riding in secondary position in terms of conflict paths and level of visibility to other road users. Bicycle lanes clarify that there is sufficient space for a secondary traffic stream next to the primary traffic stream. However, cyclists in the vicinity of bicycle lanes may be less likely to choose primary position at times when it is safer due to its higher visibility to other road users.

Analysis

Left-turn side swipe

Whenever a left turning vehicle is on a cyclist's right, the turning vehicle could potentially side swipe the cyclist. This can occur on minor or major roads; with sign control, traffic signals or roundabouts. 69% of these crashes involve cyclists. These crashes may be caused by one or a combination of: a driver passing a cyclist then turning underestimates cyclist speed; a cyclist passes to the left of a left-indicating vehicle; or driver unawareness of a cyclist to their left due to focusing their attention in front.

² Darebin, Maribyrnong, Moonee Valley, Moreland, Port Phillip, Stonnington & Yarra local government areas.

Defensive cycling – passing side roads in light traffic

British Cycling (2012) advises major road cyclists to move out to primary position in the vicinity of side roads. This (1) avoids a left turn side swipe conflict (DCA 137) by effectively forcing a following left turning driver to slow sooner and turn left behind the cyclist; and (2) reduces the chances of a left-near crash (DCA 116) due to a major road cyclist being overlooked by a side road vehicle scanning to the right for vehicles prior to turning left (as drivers tend to scan primarily where other cars would be) (Herslund & Jorgenson, 2003). This suggestion makes sense when traffic conditions are light.

Defensive cycling – arriving at a left-signalling driver

At the hold line at traffic signals, a driver wishing to turn left waits for the signal. At a sign controlled minor road a driver scans the major road hoping to see a gap in traffic in order to continue. If, during either of these, a cyclist approaches the hold line in secondary position beside the waiting driver, the cyclist is located approximately 180° from the probable direction of the adjacent driver’s gaze, so is likely to remain unseen. When the driver proceeds, the adjacent cyclist may well be side-swiped by the turning vehicle.

Road Rule 141(2) states that a cyclist “must not ride to the left of a vehicle that is turning left and is giving a left change of direction signal”. However, the starting point of when “a vehicle is turning left” is neither clearly defined in the road rules nor clearly understood by all cyclists. Furthermore, the degree to which this rule is known and enforced is unknown.

A cyclist wishing to avoid potential conflicts with a waiting, left-signalling vehicle can safely wait behind the vehicle; or if space is available, they can pass to the right of the vehicle by either sharing the lane on the vehicle’s right or changing into the next lane to the right.

Driver two-stage left turns

A driver wishing to be free from the burden of having to look to their left and behind for secondary position cyclists at the same time as monitoring other traffic conflicts (largely to their right) can avoid the possibility of being surprised by a cyclist on their left by undertaking left turns in two stages: first checking for cyclists and moving as close as possible to the left side of the road (so that a cyclist has no space in which to “sneak up”), then monitoring other possible conflicts and turning. This two-stage left turn is consistent with Road Rule 27 which requires drivers turning left to do so from as near as practicable to the left side of the road and Road Rule 158 which clarifies that driving in bicycle or bus lanes is permitted for 50m prior to turning. It follows the traffic safety principle that a sequence of simple manoeuvres is safer than one complex manoeuvre. Two examples of the two-stage left turn are shown by the blue solid arrows in figure 2, as contrasted to the red dashed arrows.

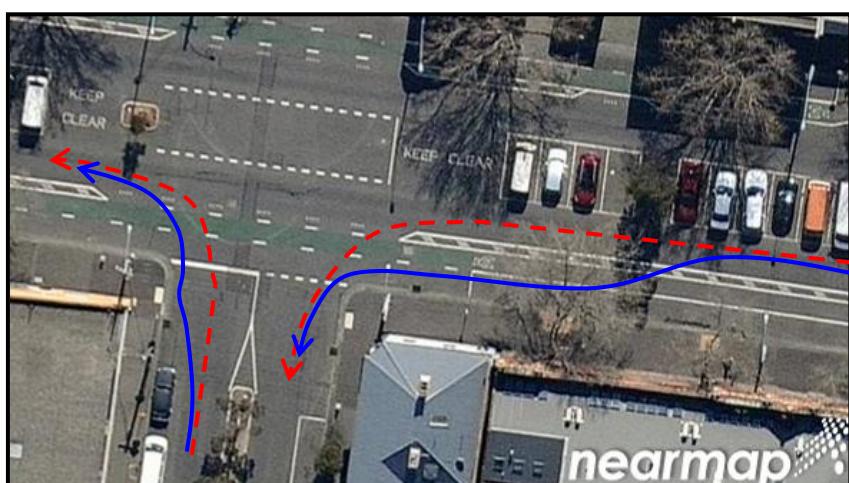


Figure 2: Red Arrows show a “normal” left turns. Blue arrows show 2-stage left turns. (Queensberry St, North Melbourne, Vic)

This process protects cyclists from potential left turn conflicts, reduces driver burden and is consistent with Australian Road Rules. Other advantages include: removing the cyclist's uncertainty of exactly when the driver will move left across the cyclist's path; and freeing space within the lane on the right of the left turning vehicle for a through cyclist to safely pass without changing lanes. In the example pictured above, it provides enough space for through cars to pass, so increases road capacity as well as safety.

This two-stage left turn is appropriate when turning left from a major road or a minor road, but is not appropriate in locations where all traffic (including cyclists) must turn left.

Bicycle lane layouts at intersection approaches

Road users seeking to turn left should do so from the left-most part of the road. This is accommodated with the northbound bicycle lane arrangement in figure 3. The bicycle lane is coloured green where drivers need to cross it as an extra indicator to drivers that they may be crossing the path of bicycles so should look back to the left.

In contrast, the westbound arrangement at the same intersection directs drivers to turn left across the path of through cyclists – thus encouraging behaviour likely to lead to left turn side-swipe crashes.

Consistency with Road Rule 27 and safety require that wherever left-turn lanes are provided, they should be located at the left-most part of the road, which may be to the left of a bicycle lane (as in figure 4). If the road-width is insufficient for a bicycle lane between the left turn and through lanes, a shared “left-turn / cyclist through” lane can be provided, as in figure 5.



Figure 3: Northbound, left turners turn from the left side of the road.
 Not so, westbound.

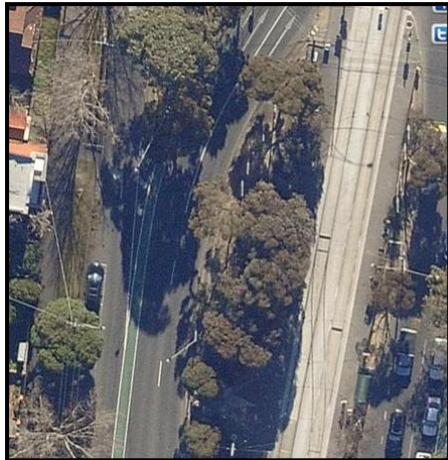


Figure 4: Bicycle lane between left turn lane and through lanes.
 (Royal Pde, Parkville, Vic)



Figure 5: Left turn lane is split, requiring left-turning drivers to follow behind through cyclists
 (Princes Hwy, Werribee, Vic)

In order to support the driver two-stage left turn, where bicycle lanes continue past side roads without left-turn lanes, the bicycle lane line should have a dashed continuity line for the 50m prior to the turn to indicate that drivers are permitted to merge left to the leftmost part of the road as the first stage of making a left turn.

Conclusion

Adopting the cyclist behaviours, driver behaviour and cycle lane layouts suggested above would decrease left-turn side swipe crashes.

Car door opens into path of cyclist

Whenever a vehicle door is opened into a driving lane, it could partially or fully block the path of a moving vehicle. This is sometimes referred to as a “dooring” crash and the portion of the road adjacent to parked cars is sometimes referred to as the “door zone”. Cyclists are particularly vulnerable to dooring whenever they ride within door zones. In inner Melbourne, 92% of these crashes involve cyclists. These crashes are caused by drivers or passengers (illegally) opening car doors without noticing oncoming traffic. 25% of these crashes occur on the passenger side (Munro 2012) – probably mostly relating to passengers alighting from vehicles stopped in queues in driving lanes.

Driver behaviour

Drivers (and passengers) should ensure they are aware of oncoming traffic before opening a car door. This requirement is not necessarily simple. Should drivers check with the central mirror or outside mirror or with a head check or all three, and in which order? What about frail people with limited neck movement? If a cyclist is riding at 30 km/h, they will move 8 metres every second. Thus if two or three checks are made one second apart and the door is opened one second later, a cyclist will have moved 25-35m or 5-6 car lengths since the first check.

Some cyclist organisations advocate that drivers be taught to always open the door using the hand away from the door as that process causes the body to twist towards the outside of the vehicle.

Figure 6 shows two possible cyclist paths past a parked car. With a cyclist following the black (solid line) path at 30 km/h, the cyclist would not be visible to a side mirror or head check until about one second prior to striking the car door. Thus a thorough head check needs to include looking back while opening the door.

Defensive cycling

A cyclist can avoid all risk of dooring by never cycling in door zones. This would mean never passing a vehicle within 1m – on the left or right (however this would negate the cycling advantage of filtering past queues of motor vehicles).

A cyclist can reduce risk by slow cautious cycling when within door zones, or by sounding a loud warning when approaching a vehicle that has recently stopped, or with a head showing above the seat, or with any lights on.

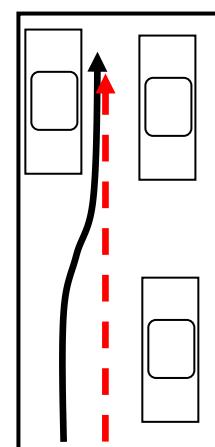
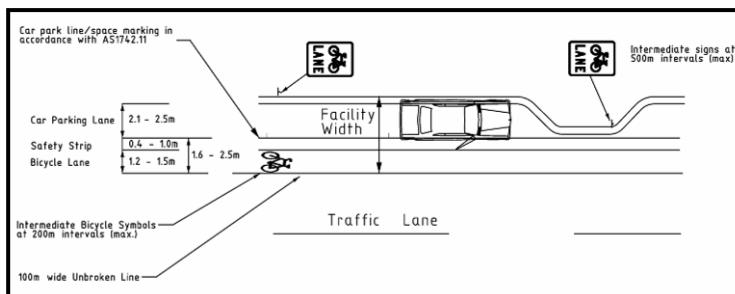


Figure 6:
Possible
cyclist path
around a
parked car.

Choosing the red (dashed arrow) path means a cyclist will be visible to a driver checking on the right for much longer, so reduce the risk of being overlooked. Note that the straighter path improves visibility from the queued vehicles on the right as well as the parked vehicle on the left.

Bicycle lane layouts near parallel parking

Austroads (2010) states that a safety strip 0.4 - 1.0m wide should be provided between parking and bicycle lanes - as shown in the figure 7.



Historically, Victorian design practice has not included this “safety strip” design feature. Some bicycle / parking lanes as narrow as 2.8m have been installed as in figure 8, effectively directing cyclists into the door zone. Two sites with safety strips are illustrated in figure 9.



Figure 8: Cyclists forced into “door zone”. (Dundas St, Preston, Vic)



Figure 9: Safety strip between parked cars and bicycle lanes. (Raglan St, Preston & Piggott St, Princes Hill, Vic)

Adding a safety strip is inexpensive. By reducing currently marked 2.3 – 2.5m parking bays to 1.9m, painted safety strips 0.4 – 0.6m wide could be added with no sacrifice of lane width.

Vehicle turns through “Keep Clear” area

“Keep Clear” markings are designed to allow major road vehicles to turn through queued traffic in order to maintain major road traffic flows (VicRoads 2011). Consisting of the words “Keep Clear” usually bounded by lines, they restrict vehicles from stopping in front of a side road. The typical design sometimes leads to crashes due to vehicles queued in the right lane obscuring sightlines between right turning vehicles and vehicles in the left lane (or bicycle lane or riding in secondary position), as pictured in figure 10.

The intersection in Melbourne CBD with the worst cyclist serious injury crash record (2006-2010) (VicRoads 2012) has a downhill cycle lane, a Keep Clear area and a history of crashes involving southbound cyclists and turning vehicles.

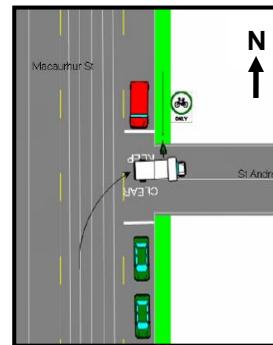


Figure 10:
 Right-through
 crash due to
 obscured sightlines
 between turning
 vehicle and cyclist.

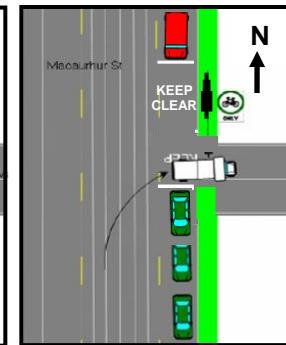


Figure 11:
 Right-through
 crash avoided by shifting
 “Keep Clear” area
 upstream to provide
 clear sightlines.

Recently, in order to reduce “right-through” crashes, the Keep Clear area has been extended to the north to allow right turners and approaching cyclists to see each other without being obscured by queued vehicles (figure 11).

Another common issue in Keep Clear areas is left-turning side road vehicles propping across the bicycle lane and obstructing cyclists on the major road, leading to “left-near” crashes. This issue has been addressed by painting KEEP CLEAR on the bicycle lane facing left-turners from the side street and relocating the south end of the keep clear area in such a way that space to turn into is not left vacant.

These “Keep Clear” design changes are equally appropriate at all areas.

Roundabout: entering car vs. circulating cyclist

Crashes at roundabouts disproportionately involve cyclists, particularly in inner urban areas where approximately half of reported injury crashes involve cyclists. The type of crash experienced by cyclists is predominantly entering - circulating (Cumming 2011¹).

This section draws heavily from Cumming (2012). Cumming’s literature review suggests relevance of LBFTS research - roundabout crashes appear to be largely caused by lack of driver awareness of cyclists.

Many researchers share the conclusion that prior to entering roundabouts drivers tend to look mainly for cars and thus miss circulating cyclists (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 (with cyclists circulating 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.

Researcher advice is generally that cyclists are safest if cycle lanes end prior to approaches and cyclists merge with motorists prior to entering roundabouts. However, the advice tends to stop there, assuming that if cyclists do not have a separate lane they will ride where drivers drive, and so be seen by other entering drivers.

Cumming’s primary research observed lane positioning of over 200 commuter cyclists during a morning commuter peak period at the three inner suburban Melbourne roundabouts in figure 12 - at entry, circulating and exiting.

The 70+ cyclists who arrived and travelled through the roundabouts in groups were not analysed. Observations of the other 130 cyclists are summarized in Table 1. Cyclist lane positioning behaviour 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, and none of these remained in primary position while circulating and exiting. Common cyclist paths observed are shown in figure 13. 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 (path A), presumably to minimise

deflection and maintain speed. Approximately one third entered from the left and travelled in “secondary position” through the roundabout, some travelling parallel with cars (path B).



Figure 12: Roundabouts where cyclists were observed. Arrows indicate dominant cyclist direction.

Table 1: Summary of observations of individual (and small group) cyclists.

	Roundabout						Total
	Canning & Pigdon	Canning/Faraday/Barkly		Faraday/Cardigan			
Approach characteristics	bike lane	bike lane	bike lanes				
Roundabout characteristics	small, poor vis to left	large, marked circ bike lane	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

Most cyclists entered from secondary position beside the kerb. From the perspective of an entering driver, in addition to the car conflict path D, there are three new conflict paths they must be aware of and monitor: path A with “straight-lining” (potentially fast-moving) cyclists; path B with “edge-riding” (generally slower) cyclists; and location C where a cyclist may arrive from behind.

Cyclists’ range of behaviours when approaching and negotiating a roundabout create a much more complex conflict path environment than if all cyclists followed primary position, path D, when entering and circulating.

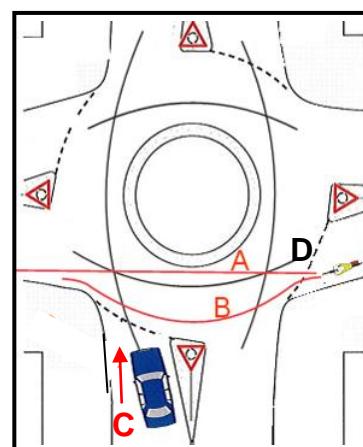


Figure 13: Common cyclist paths through a roundabout.

If a driver approaching a 1-lane roundabout assumes there is just one conflict path to attend to (D), there are many locations along cyclist paths that they may overlook. In any of these locations there may be a cyclist. 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 other cyclist conflict paths.

A secondary position entry point lies in the peripheral vision of the entering driver looking towards primary position. Secondary position cyclists may also be obscured by vehicle pillars or by roadside posts or vegetation. On approach, secondary position cyclists may be obscured by property fencing.

Defensive cycling

If a cyclist enters and travels through the roundabout in primary position following path D, the simpler conflict path environment can be expected to match the assumptions of entering drivers. This improves cyclist chances of being seen by drivers and reduces the likelihood of crashes.

Bicycle lanes near roundabouts

Bicycle lanes provide lateral separation from cars, which “feels safe” to cyclists. However, as bicycle lanes remove cyclists from the path that most drivers check before entering roundabouts, “feeling safe” is at the cost of real safety. Roundabouts are a place where cyclist safety is better served cyclists following the paths that cars follow (i.e. no bicycle lanes in or near roundabouts).

As drivers can be expected to check path D, but not necessarily other cyclist paths, *bicycle circulating lanes and/or bicycle lanes on approaches ensure cyclist entries from kerbside which reduces the chances of them being seen by entering drivers compared to them following path D.*

Recommendations

The following recommendations (detailed in Cumming, 2011¹ & 2012) could be expected to reduce cyclist crashes at roundabouts by relocating cyclists to where entering drivers scan before entering: (1)terminating bicycle lanes prior to roundabout entries; (2) adopting strategies to encourage safe merging of cyclists to primary position (e.g. cycling training; “Look, Signal, Merge” signs; bicycle logos with 45° arrows along approaches, and bicycle logos in the middle of lanes at roundabout entries); and (3) adopting strategies to encourage cyclists to maintain primary position through roundabouts (such as bicycle logos in the middle of circulating lanes).

Some examples (installed during 2011 and 2012) are shown in figures 9, 14 and 15.

Figure 14: Bicycle symbols indicate safe lateral position & bicycle route.
(Prince St, Waratah, NSW & Merewether St, Newcastle, NSW)



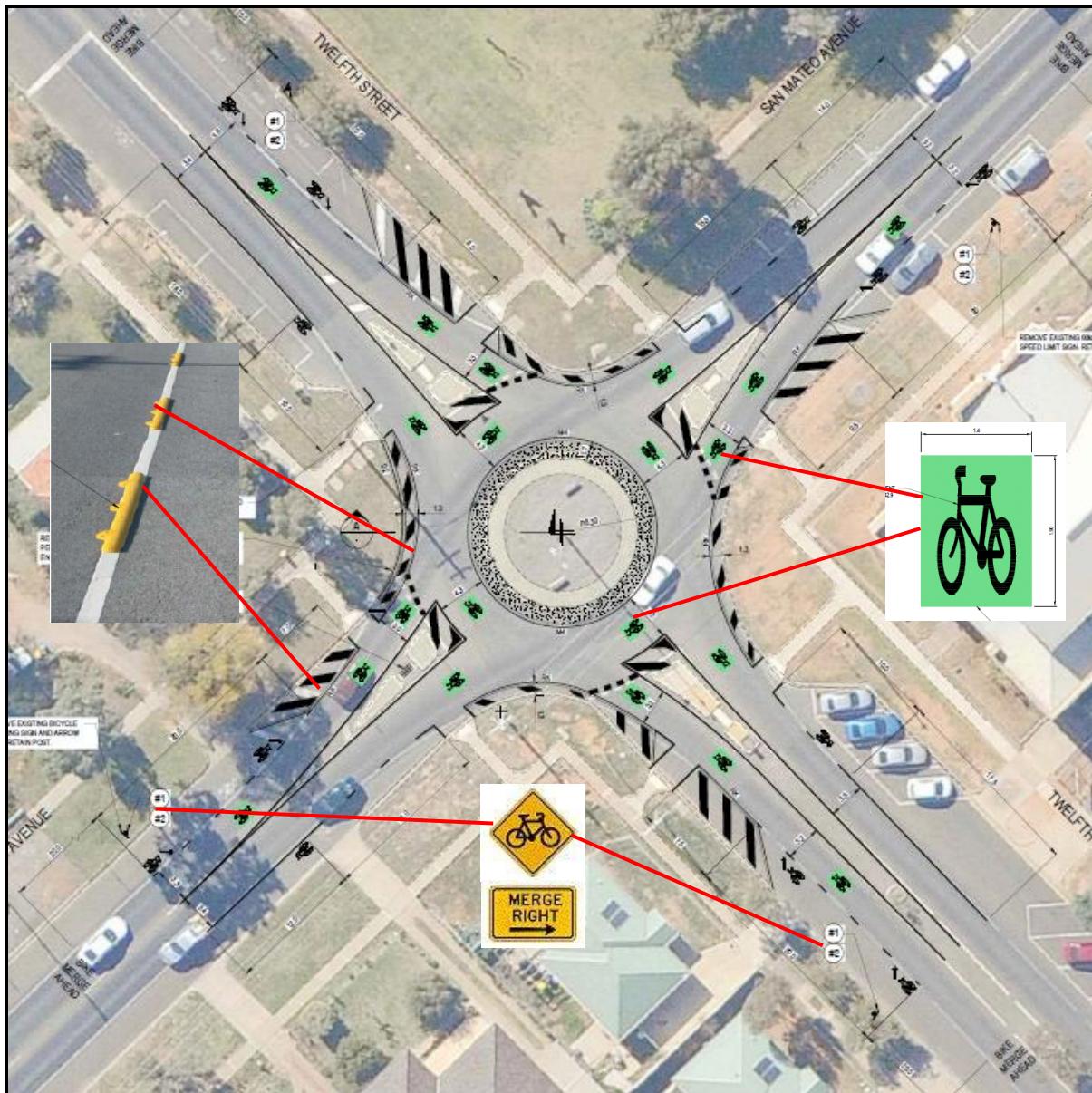


Figure 15: Roundabout design illustrating recommended design features – narrowed entries, central bicycle symbols, merge warning signs & pavement markings.
 (San Mateo Ave & 12th St, Mildura, Vic)

Conclusions

Conflict path analysis has grown from conflict point analysis. To avoid crashes between potentially conflicting road users at a conflict point, at least one of them must be aware of the other and correctly assess their locations, speeds and path trajectory. As bicycles are small and narrow, they can choose a wider range of paths compared to cars. This paper has considered some of the subtle differences in cyclist path choice which could lead to significant differences in the level of awareness of other road users and reductions in crashes. It has made some defensive cycling suggestions and associated road design suggestions - largely by providing cues to road users about the safer paths to follow.

The strategy of providing cues to follow about safer paths within the road environment is consistent with the use of sharrows in USA and Europe to designate the safest path for cyclists within a shared lane.

At roundabouts, strategies have been suggested to direct cyclists to use primary position in to increase their visibility to approaching drivers. These are consistent with the advice of other roundabout 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 entering and through roundabouts.

“Conflict path analysis”, which considers the microgeography of the paths road users follow and how path choice may influence mutual awareness between road users, appears to be a useful tool to assist designers to create safer road designs, especially for bicycles and other two-wheeled vehicles which have been shown to be particularly vulnerable to LBFTS crashes.

Acknowledgements

Early thinking about bicycles and roundabout safety occurred at City of Darebin – together with Ben Grounds & Che Sutherland when Austroads suggestions of circulating bicycle lanes just didn’t gel with us as cyclists. Ben & Che knew about “Sharrows” to indicate safer cyclist paths within shared lanes in other countries. Reviewers from the Australian Cycling Conference were significant in inspiring the empirical research about cyclist behaviour at roundabouts, first published as an appendix in Cumming (2012).

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