Conflict path analysis: Analysing & managing the cyclist-driver interface

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ABSTRACT

When a road user must change their speed and/or trajectory to avoid a collision, awareness of other road users is crucial. Bicycles take a range of positions within lanes and sometimes "share" lanes, so may not be located where drivers look. Where awareness of cyclists by drivers required to yield to them is impossible or improbable, crash risks are high. Conflict path analysis considers driver and cyclist trajectories and how path choice affects the level of awareness between road users. Conflict path analysis involves plotting an awareness diagram including: (1) road user trajectories; (2) sightlines; (3) road user "awareness" zones (based on guessing the minds of road users); and (4) constraints. A clear problem statement is articulated, the process of which may lead to an obvious solution. Questions about the alignment of trajectories and awareness zones can assist with problem articulation and solution identification. This process is illustrated with four road conflict scenarios which particularly affect cyclists: left turn side-swipe crashes; right-through and left-near crashes with cars turning through queued vehicles; and roundabout entering-circulating crashes. All analyses yield reasonable solutions. "Conflict path analysis" is a flexible and versatile analysis system which can usefully assist designers to create safer roads.

KEYWORDS: road safety; conflict points; conflict path; conflict path analysis; cyclists; looked but failed to see; LBFTS crashes; left turn side swipe; keep clear; roundabout.

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 prior to the conflict point and correctly assess their location, speed and path trajectory. This paper considers road user awareness; and factors that contribute to awareness; and how awareness may be influenced by small changes in trajectories. Trajectories are referred to as *"paths"*. Where a driver must consider a "path" in order to give way to road users following it, that path is referred to as a *"conflict path"*.

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. To ensure that road users are able to be aware of others to whom they must yield, *"sightlines"* are considered as part of the design process for new roads. These are usually considered from the middle of the driving lane (ASD, SSD, SISD, MGSD, roundabout "criterion 2 SD") (Austroads 2010a, 2010b & 2011). Sight distances for crossings (CSD) (Austroads 2010b) and stop sign warrants (Standard Australia 2009) are exceptions[1]. It is unknown the extent to which sightlines are systematically considered when bicycle lanes or shared paths are retrofitted to existing roads.

[1] These terms refer to: approach sight distance, stopping sight distance, safe intersection sight distance, minimum gap sight distance, roundabout sight distance towards approaching vehicles, and crossing sight distance.

"Looked but failed to see" (LBFTS) researchers investigate crashes in which drivers look in the general direction of a conflicting road user but fail to see them and respond appropriately. Frequently after such a crash, the cyclist will report having seen the driver look and the driver will report that "the cyclist came from nowhere". Koustanaïa et al (2007) identified that cyclists and motor-cyclists are particularly at risk from LBFTS crashes. 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. When a cyclist is located laterally away from the middle of the driving lane, they form a new conflict path and sometimes a second traffic stream which must be considered by road users required to yield to traffic in that lane.

Terminology for describing cyclist lateral positioning is adopted from UK practice. *"Primary position"* is in the centre of the left[2] 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. In this paper, these terms are used with quotation marks. The terms "taking ...", "owning ...", "claiming ..." or "occupying the lane" encompass whenever a cyclist makes a lane unavailable to drivers, but do not necessarily imply riding in primary position. (E.g. a cyclist following a straight line through a roundabout claims the lane, but effectively weaves from the left to the right to the left of the lane).

Examples of LBFTS scenarios, where car drivers look in the direction of cyclists without perceiving them, include: turning into a priority roadway; switching lanes; and entering a roundabout. In all these scenarios, crashes could be explained by yielding drivers correctly checking the "primary position" conflict path but failing to consider the possibility of a "secondary position" conflict path.

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 paths used and the likelihood of awareness between road users.

LBFTS researchers Herslund & Jorgenson (2003) suggest that experienced drivers selectively focus their attention on the parts of the road environment where conflicts are most likely and sometimes don't give adequate consideration to other aspects of the road environment. Conflict path analysis accepts this as a premise and plots the *"primary conflict path"* which a manoeuvring driver needs to consider as an indicator of probable driver awareness. Consideration of a "conflict path" as "primary" is relative to a particular road user and a particular manoeuvre. Thus a conflict path which is primary relative to one manoeuvre may be secondary relative to another.

Sometimes a driver is required to give way to multiple types of road users in quite different locations. For example, a driver turning right must wait for a gap in the oncoming traffic stream, whose path they must cross, and also give way to "secondary position" cyclists in that same lane and to pedestrians crossing the road into which they are turning. As a driver requires a gap in the oncoming traffic stream to start the turn, this can be considered the primary conflict path and the predominant (or sole) focus of driver attention; the "secondary position" cyclists and crossing pedestrians are secondary conflict paths which may or may not receive brief consideration after the driver sees a gap in the oncoming traffic.

The process of conflict path analysis includes the plotting of primary conflict paths as an indicator of probable driver awareness. Where a driver is required to yield to (secondary conflict path) road users located 180^{o} away from the direction of the primary conflict path, the likelihood of road users in the secondary conflict path being overlooked is significant. An example of this is where two-way bicycle facilities are installed alongside a two-way road and turning drivers are required to filter through

[2] This paper is written in Australia where road users travel on the left. For readers from countries which drive on the right, the terms left and right should be swapped (and figures reversed).

oncoming cars and simultaneously monitor and filter through cyclists from both in front and behind them – a burden considered by the author to be an unreasonable.

Just as plotting of sightlines can indicate situations where awareness between road users may be impossible, plotting of primary conflict paths can indicate where awareness of (secondary conflict path) road users may be low. Conflict path analysis is a deductively logical process which systematically analyses general or specific road scenarios.

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

After explaining the process of conflict path analysis, the process is illustrated with several road scenarios in which crashes involving cyclists are common. Where barriers to awareness are identified, countermeasures are proposed. To conclude, some reflections are made in relation to the use of the new process of "conflict path analysis".

Process

Figure 1 illustrates the process of conflict path analysis. This process may be used for analysing: specific crash sites; general crash types; or any road scenarios. In all cases it requires choosing specific road users for consideration.

An "awareness diagram" is constructed showing road user paths and one or more of constraints, sightlines and "awareness zones". Awareness zones are illustrated based on guessing what is on the minds of road users, largely determined by their primary conflict path.

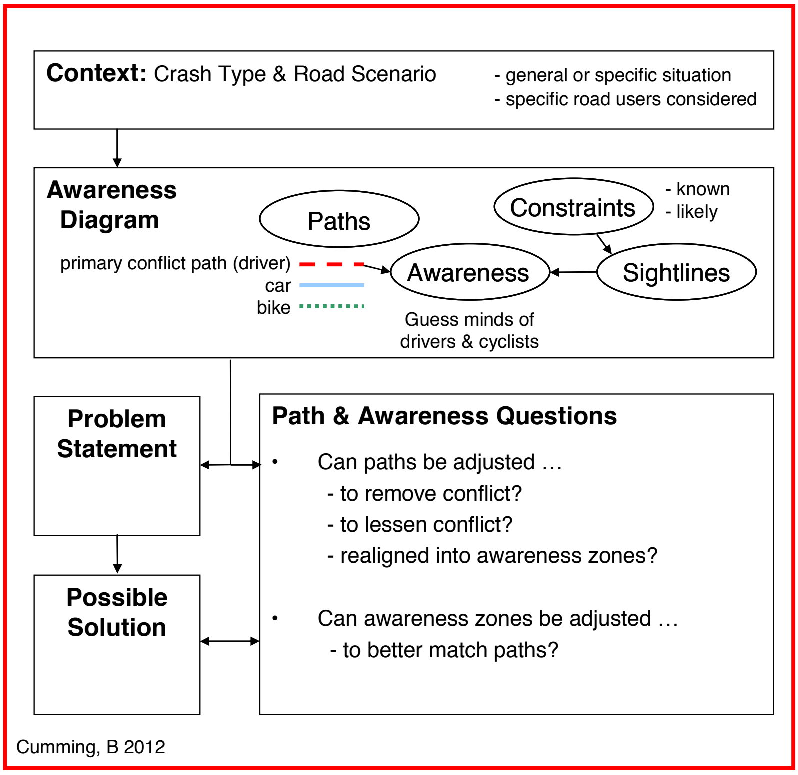

Figure 1: Conflict path analysis – the process

The process of constructing an awareness diagram leads to insights about the problem. If the precise problem statement has not become obvious, asking path & awareness questions may help to articulate the problem statement.

Clearly stating the problem may lead to an obvious solution. If not, path & awareness questions may be of assistance.

Analysis

The road scenarios below are chosen to illustrate the use of conflict path analysis. They are not necessarily the worst or the most important conflict scenarios for cyclists. However, each of these scenarios affects cyclists in particular as is illustrated by figure 3. The area of the circles represents the number of crashes and the overlaps represent overlaps between categories. Context B – "crashes involving vehicles turning through keep clear areas" is not included in figure 3 because that is not a category for which statistics are kept in Victoria. Figure 2 illustrates definitions for classifying accidents (DCAs) mentioned are in these scenario descriptions. Statistics mentioned are from Victoria's official crash statistics database, CrashStats, but only include reported injury crashes. They cover the 5-year period from 2007-2011 (VicRoads, 2012).

A. Left-turn side swipes (DCA 137) account for 6% of cyclist crashes in Victoria and 9% in Inner Metro. 69% of all left-turn side swipe crashes involve cyclists (80% in Inner Metropolitan Melbourne[3]). 29% of left turn side swipe crashes result in severe injuries.

B. 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, 2011[2]). Measures proposed address "right through" and "left near" conflicts - DCAs 121 and 116.

C. 8% of cyclist crashes in Victoria occurred at roundabouts (6% in Inner Metro). For all of Victoria, 27% of crashes at roundabouts involve cyclists, and for inner urban areas, the figure is 54%.

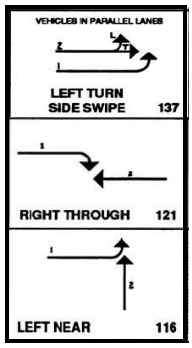

Figure 2: Some DCAs, illustrated

The analysis leads to suggestions relating to driver behaviour, cyclist behaviour, and engineering measures.

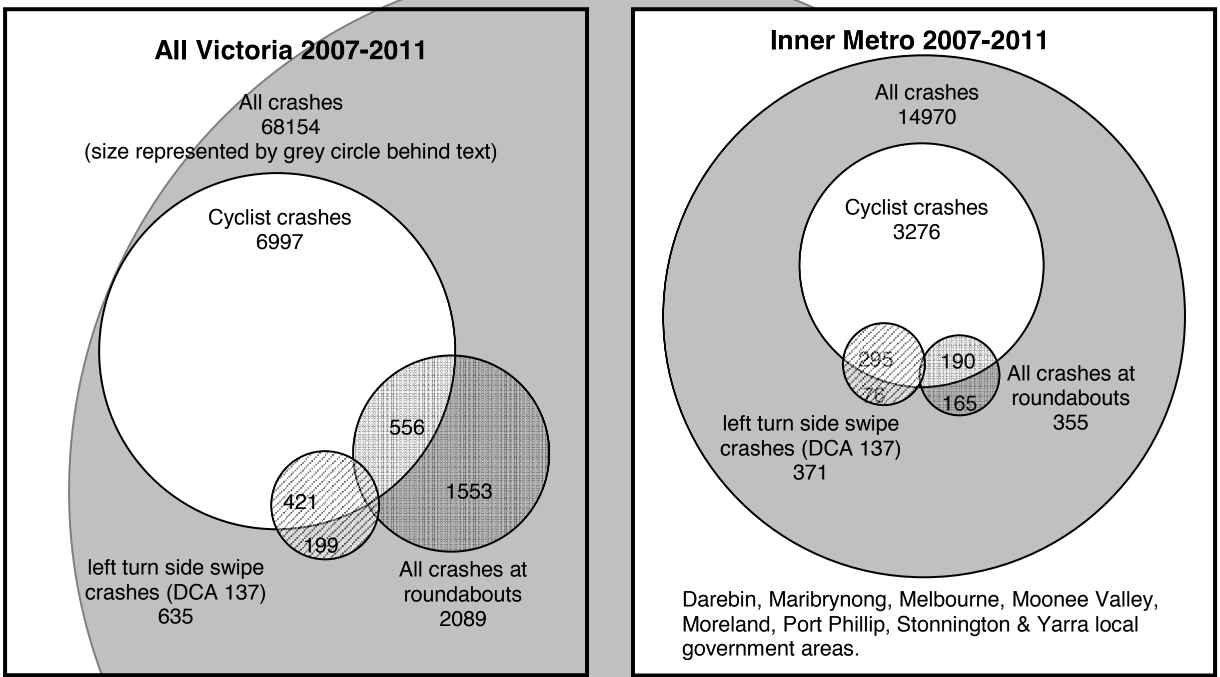

Figure 3: These diagrams represent the significance of these particular crashes compared to all crashes in Victoria (large grey circle behind text on page). The area of each circle represents the number of reported injury crashes during the 5 years 2007-2011. Inner metropolitan area circle sizes represent significance on the same scale.

Context A: Left-turn side swipe

Left-turn side swipe crashes account for 6% of recorded cyclist injury crashes in Victoria (VicRoads 2012). Whenever a vehicle turns left starting from a point to the right of a cyclist "path", the turning vehicle could potentially side swipe the cyclist. This can occur on minor and major roads; with sign

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

control, traffic signals or at roundabouts. Although 69% of these crashes involve cyclists they are dispersed across many locations. Of the 404 reported injury crashes of this type in metropolitan Melbourne during 2007-2011 (VicRoads 2012), only six intersections experienced as many as three. Thus this crash type is worth considering in general. Of the six intersections experiencing three such crashes, three are signalised and three non-signalised.

These crashes may be caused by one or a combination of: a driver passes a cyclist then turns in front of them, underestimating cyclist speed; a cyclist passes to the left of a left-indicating vehicle (or a driver fails to indicate); or a stationary driver moves forward and turns, unaware of a cyclist to their left due to focusing their attention in front.

Figure 4 illustrates this crash scenario at a Melbourne CBD location which is a high volume cyclist commuter route. Three crashes occurred here involving cyclists travelling in the downhill direction. Southbound driver and cyclist paths are shown. As the drivers "cut off" the cyclists, driver awareness should be considered. In this CBD location, crossing pedestrians may well be the primary conflict path for turning drivers. Thus driver awareness (indicated by the blue splay) is directed towards crossing pedestrians.

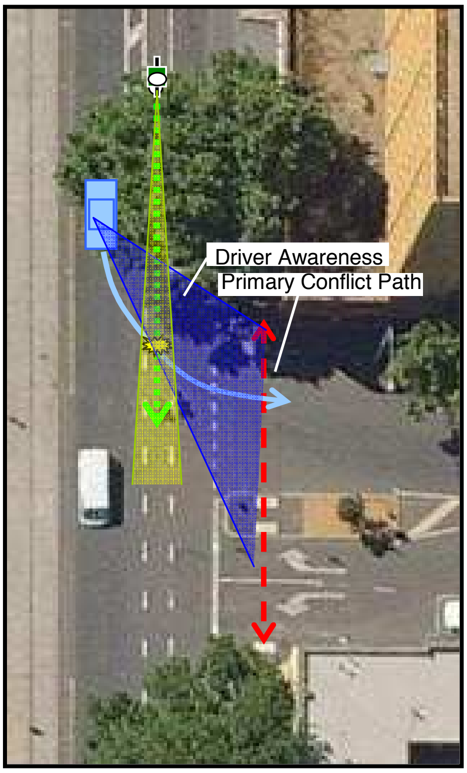

Figure 4: Left-turn side swipe crash showing road user paths. Can paths be adjusted …
- to remove conflict?
- to lessen conflict?
- realigned into awareness zones?

Assuming the driver is stopped (either waiting for pedestrians or in a queue for the traffic signals a block further down), the cyclist sees a straight clear bicycle lane. Meanwhile the driver, pleased to be able to move again, starts to turn without considering the secondary conflict path created by "secondary position" cyclists (in this case in a bicycle lane). The driver moves forward and a crash occurs. The problem occurred because of the high driver burden of simultaneously monitoring and giving way to road users in quite different directions. This may be exacerbated by a wide buffer between the car and the bicycle lane, meaning the approaching cyclist is more likely to be obscured by shade or blend in with parked cars.

Problem statement: (1) Driver turns left from a place to the right of through traffic; and (2) turning driver is unaware of cyclists.

Possible solution: Change the complex turning manoeuvre with multiple conflict paths in different directions to a two-stage left turn, (shown in Figure 5) where the driver first checks for cyclists (now the driver's primary conflict path) and moves to the left edge of the road, then waits for pedestrians before completing the turn. The burden of simultaneously monitoring and giving way to road users in quite different directions is removed.

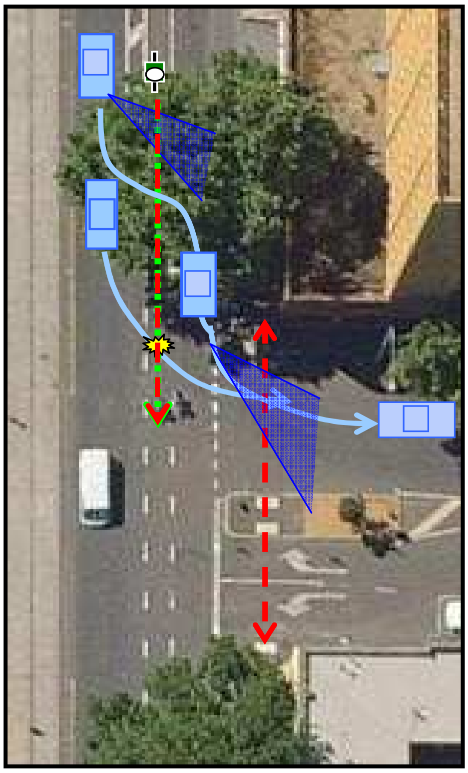

Figure 5: Left-turn side swipe crash avoided with 2-stage left turn.

This driver behaviour solution to the problem 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.

This driver behaviour 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 to the right of the left turning vehicle for through vehicles including cyclists, thus increasing road capacity as well as safety.

Figure 6 shows possible changes to encourage this driver behaviour: A left turn arrow indicates the place for drivers to turn from. Green colouring of the bicycle lane encourages driver awareness and dashed bicycle lane lines show where drivers can merge left and cross it. Switching the bicycle lane and the painted buffer makes cyclists more visible to moving cars (and provides cyclists with protection from opening doors of parked cars) as well as providing more width for the left-turn "lane".

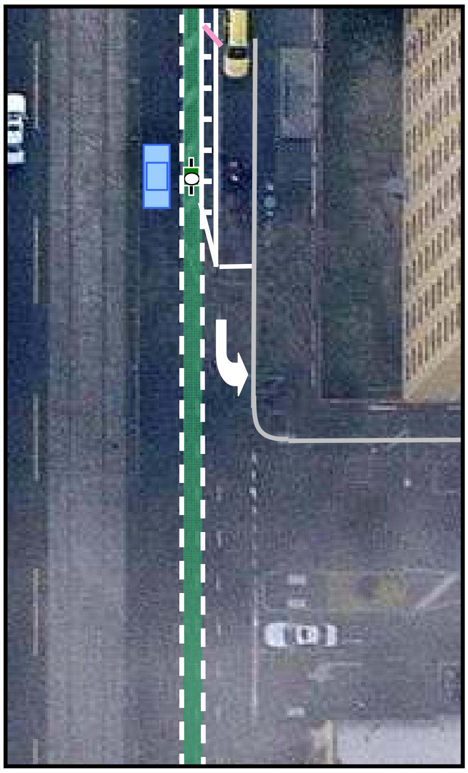

Figure 6: Intersection changes to encourage two-stage left turn:
- left turn arrow
- green dashed bicycle lane
- bicycle lane and buffer switched

Implications - Bicycle lane layouts at intersections

Road users seeking to turn left should do so from the left-most part of the road. 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 across to the leftmost part of the road as the first stage of making a left turn.

Context B: "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 cyclists riding in secondary position), as can be seen in relation to the cyclist in figure 7.

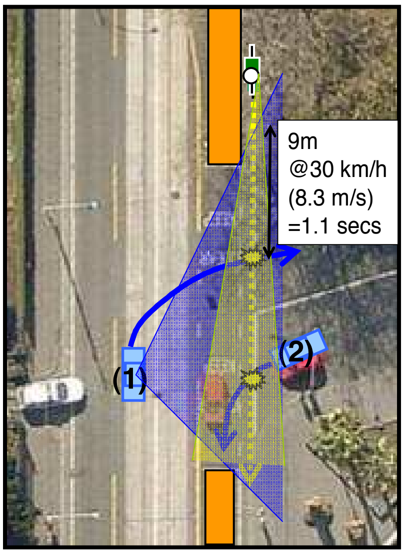

Figure 7:
(1) Right-through crash due to obscured sightlines between turning vehicle and cyclist.
(2) Left-near crash due to left-turning driver propping across bicycle lane.

Figure 7 shows an intersection which has more cyclist serious injury crashes than any other in Melbourne CBD record of (2006-2010) (VicRoads 2012). It has a downhill high volume cycle lane, a Keep Clear area and a history of crashes involving southbound cyclists and turning vehicles – both right-through crashes and left-near crashes. These two crash types need to be considered separately

(1) Right-through crashes

Paths of the road users are shown for both crash types and sightline constraints (queued vehicles) are represented by orange rectangles blocking the main through lane north and south of Keep

Clear markings. The coloured splays show that the driver and cyclist cannot see each other until about 9m prior to the conflict point. At speeds of 20-30 km/h, visibility between a cyclist and driver (1) would be available for a period of only 1 – 2 seconds. Typically, sightline calculations are made to allow 2.0 – 2.5 seconds reaction time followed by the required braking distance. Sightlines are inadequate. Once plotted, it is unsurprising that crashes occur here.

Problem statement: Queued vehicles obscure sightlines.

Possible solution: Adjust “Keep Clear” markings to extend sightlines. Adjusted “Keep Clear” markings were installed in early 2012 (figure 8), allowing visibility between turning vehicles and cyclists for about 20m prior to the conflict point. With 20m of visibility, the time available to respond and brake increases to 2.4 – 4.0 seconds – a major improvement. While still on the low side for taking evasive action, increased visibility is likely to have a major benefit in terms of increasing the probability of mutual awareness, so the driver is less likely to turn into a conflict.

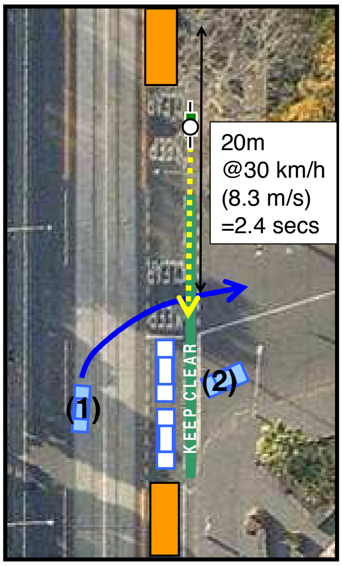

Figure 8:
(1) Right-through crash risk reduced by extending Keep Clear area to north, to improve sightlines between turning vehicle and cyclist.
(2) Left-near crash risk reduced by: removing Keep Clear area in front of left-turning driver; colouring cycle lane green; and new Keep Clear area in bicycle lane.

(2) Left-near crashes

Figure 9 shows awareness splays. It is assumed that these crashes are caused by the common driver behaviour of propping (illegally) in the “Keep Clear” area in order to cut into the queue when it starts to move again. The driver needs to: (1) check for no pedestrians crossing; (2) check that the queue to their right is stopped; and (3) monitor the queue on their left for how far to drive. Meanwhile, the cyclist sees a clear bicycle lane ahead and is pleased to be passing the queue of cars on her right. She might even see driver (2) looking to their right (to be sure the queue is stopped. They both proceed and crash. While sightlines are clear, cyclist approach path is not within the awareness of the driver.

Problem statement: Turning driver unaware of cyclists; and driver props (illegally) within Keep Clear area (across bike lane).

Possible solution: Education and enforcement could be part of a solution. Green colour on the bicycle path might help to increase driver awareness of the possibility of cyclists. Once again, the greatest benefit appears to be obtainable by adjusting constraints. Figure 8 shows how the temptation for driver (2) to prop across the bicycle lane in the Keep Clear area has been removed by removing the Keep Clear area from in front of the side road. In addition, the bicycle lane has been coloured green and an additional “Keep Clear” marking added – painted on the bicycle lane facing side road traffic.

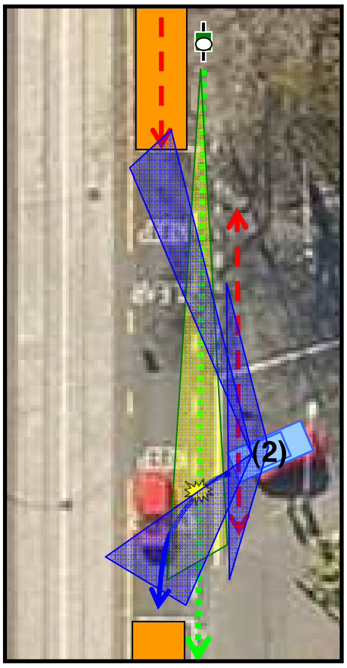

Figure 9:
Left-near crash scenario: showing driver & cyclist awareness splays.

Implications – Keep Clear Areas in general

While the pictured intersection has a history of crashes due to a downhill high volume bicycle lane, these “Keep Clear” area design changes are equally appropriate for all “Keep Clear” areas with two or more lanes of traffic or where a cyclist might approach in secondary position or along a bicycle lane.

Context C: Roundabout entering-circulating

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 2011[1]).

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.

In order to test this assumption, Cumming (2012) observed lane positioning of over 200 commuter cyclists during a morning commuter peak period at three inner suburban Melbourne roundabouts including the one shown in figure 10, which has a history of crashes involving southbound cyclists. Lateral positioning (left / middle / right) was observed at entry, circulating and exiting. Appendix B provides additional information about this unusual roundabout.

Cyclists who arrived and travelled through the roundabouts in groups were not analysed. Observations of the 70 cyclists analysed at this roundabout are summarized in Table 1. That research informs the plotting of conflict paths in figure 10. At this roundabout, 0% of cyclists observed followed path A; 76% path B, and 19% path C. Although none of the observed cyclists entered and travelled through in primary position (path A), all the path B cyclists can be said to have "taken the lane". Anecdotally, cyclists following path B appeared to travel at higher speeds than those following path C. Some appeared to hardly slow for the roundabout. As path B is almost a straight line, path B cyclists do not need to slow to physically negotiate the roundabout.

The corner buildings constrain sightlines as shown in figure 10. Anecdotally, it is understood that many road users think of give way rules at roundabouts as giving way to the right. Thus sightlines to the right are significant to the speed of road users entering roundabouts, with clearer sightlines (to the right) leading to lower speeds. In this case, as southbound road users have clearer sightlines than westbound road users, southbound road users could be expected to enter the roundabout at higher speeds than westbound road users. Higher southbound approach speeds necessitate clearer westbound sightlines, which in this case cannot be provided due to nearby buildings.

Table 1: 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

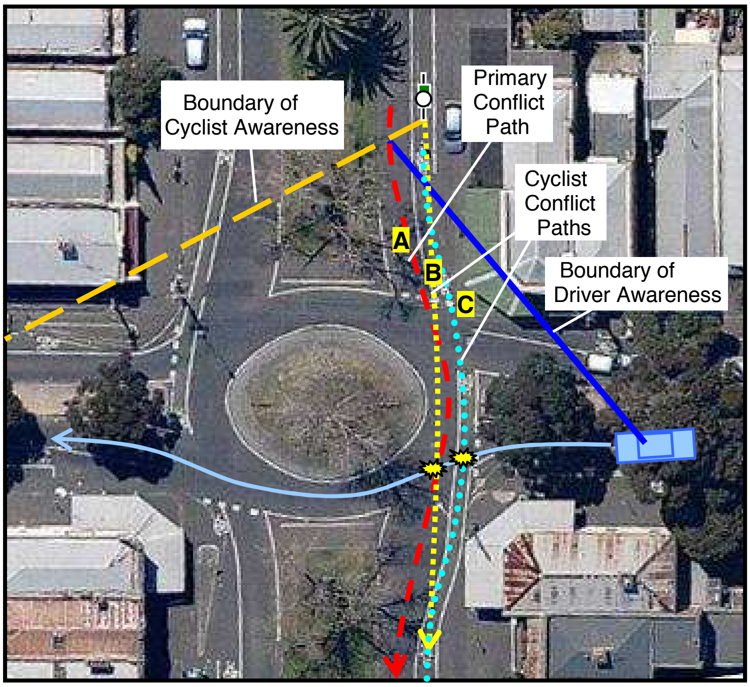

Figure 10: Roundabout with conflict paths related to entering-circulating crashes:

A. Typical path for cars
B. "Straight-lining" cyclists – 76%
C. "Edge-riding" cyclists – 19%

Awareness for the driver is indicated by the typical path for cars (A) and limited by the solid blue line– limited due to the property boundary. From 10m before the hold line, drivers can see the car lane to their right about 10m prior to its hold line, but a substantially smaller distance along the bicycle lane to their right. For southbound cyclists, their awareness is likely to be focused towards vehicles entering from their right to whom they must give way. Due to being on a wider road, their sightlines to the right are somewhat better than for drivers from the east, leading to the possibility of yielding as required while maintaining higher speeds – unaware of the limits to sightlines of the drivers from the east who must give way to them. Note that 94% of those observed entered from the left edge of the lane – where their approach would be least visible to drivers from the east. In addition to being obscured for longer on the approach, cyclist entry points are in the peripheral vision of the entering driver looking towards path A entry point.

At the locations pictured neither the cyclist nor the driver can see the other. From these locations, if a cyclist continues along path B for 30m at 30 km/h, they will arrive at the conflict point together with the driver travelling 15m at 15 km/h after 3.6 seconds. *If the driver or cyclist is looking towards the other*, they will have been visible to the driver for a period of only about 3 seconds. Roundabout design criterion 2 sightlines requires visibility foe 4-5 seconds (Austroads 2011). (These hypothetical speeds are realistic given: the downhill southbound grade, relatively clearer sightlines for southbound cyclists and the ability of cyclists to follow path B with negligible deflection).

With three conflict paths in figure 10, cyclist choice of lateral positioning has created a more complex conflict path environment for drivers to monitor than if all cyclists followed path A when entering and circulating.

If a driver approaching the roundabout assumes there is just one conflict path to attend to (A), there are locations along cyclist paths (B & C) they may overlook. If a driver looks to the right and sees an empty space along the car path A, they may enter the roundabout - with ignorance of the possibility of other cyclist conflict paths.

Problem statements: Cyclists do not approach from where drivers look. Sightlines between driver and "fast" cyclist may be obscured, especially if the cyclist is riding near the kerb.

Can paths be realigned into awareness zones? Can sightlines between road users be improved?

If a cyclist enters and travels through the roundabout in primary position following path A, they are aligned with the expected minimum awareness zone of entering drivers. This improves cyclist chances of being seen by drivers and reduces the likelihood of crashes.

If cyclists could be made to follow the typical path for cars, this would: (1) place them where they are more likely to be seen by approaching drivers; (2) improve sightlines between the driver and the cyclist; and (3) lead to greater cyclist deflection, so slow cyclists. This cyclist behaviour is also consistent with researcher findings cited above.

Possible solution: Adjust the road environment to encourage cyclists to merge right into primary position prior to entering the roundabout and to travel through in primary position. Figure 11 shows the roundabout, with 2012 modifications designed to encourage central lane positioning by cyclists. Circulating bicycle lanes have been removed. Kerb extensions force greater deflection, (although they are mountable to accommodate large vehicle swept paths). Approach bicycle lanes terminate with bicycle symbols combined with 45° arrows directing cyclists to merge right. Bicycle symbols in the middle of lanes at roundabout entries (circled) direct cyclists where to ride and warn drivers to expect cyclists there. The dotted path shows that straight-lining cyclists will follow a path much closer to path A than in figure 9, particularly near the entry, where being seen is most important.

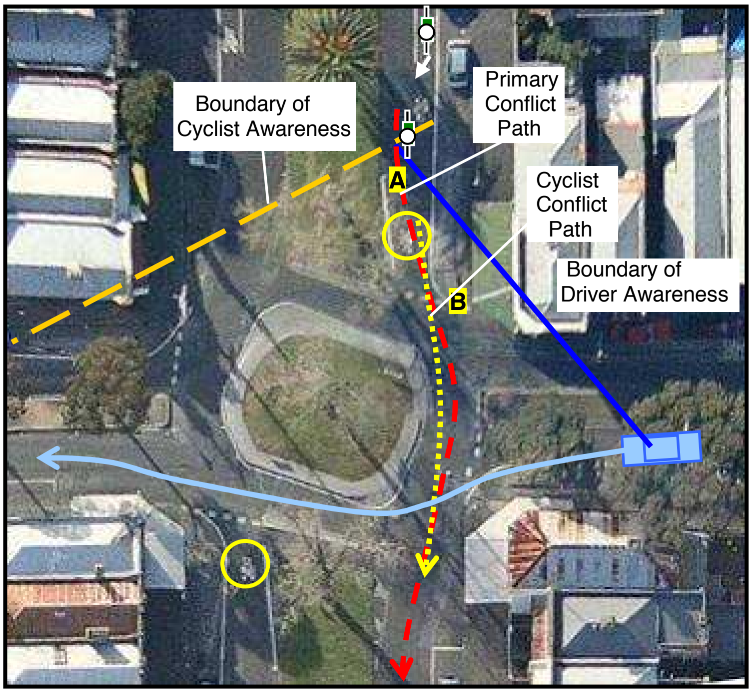

Figure 11: Changed roundabout with features to encourage cyclists to merge with cars and follow path A:
- 45º bicycle lane arrow to encourage merging to the centre
- Centrally positioned bike logos at entries - circled
- Kerb extensions to force greater deflection by cyclists

Additional bicycle symbols within the circulating area might help to encourage cyclists to follow the expected path while circulating.

Implications – Keep Clear Areas in general

The features of the solution proposed above are similar to those recommended by Cumming (2011 & 2012). Appendix A shows other examples of roundabouts with similar design features installed during 2011 and 2012. These design features could be expected to assist visibility of cyclists at all single lane roundabouts, although those on high speed roads would require additional features to slow drivers for safe merging with cyclists.

Discussion

Conflict path analysis

For illustration, four scenarios were considered at three specific sites. The solutions suggested by each of these four analyses may be generalisable to many instances of each of the four scenarios.

The four scenarios did not all require all four components of awareness diagrams. Awareness was the key component for the left turn side swipe and left-near scenarios, while sightline obstructions were the key component for the right-through scenario. Only the roundabout scenario required consideration of all four components. Proposed solutions included adjusting constraints for Keep Clear areas; changed driver paths to reduce left turn side swipe conflicts; and changed cyclist paths to reduce conflicts at roundabouts.

Path and awareness questions received only minor consideration in the scenarios as written. However, these questions certainly could assist with the process of articulating the problem statement or formulating a viable solution. Other questions may usefully be added to the list.

As an analysis process, conflict path analysis is versatile for a range of scenarios while remaining flexible for application in different ways depending of the scenario. The process could be useful when considering new or innovative designs – repeating analyses for all possible movements by all road users could be effective at anticipating possible problems before they occur, as opposed to waiting for crashes to occur as an indication of problem scenarios.

Implications from these analyses

The roundabout analysis leads to a desire to encourage cyclists to adopt specific paths. Bicycle symbols have been used as visual cues to cyclists. The strategy of providing visual cues to follow about safer paths within the road environment is consistent with the use of "bicycle awareness zones" (BAZs) in Queensland and the use of sharrows in USA, Canada and Europe to designate the safest path for cyclists within a shared lane, as illustrated in figure 12. Both have been found to be somewhat effective at changing cyclist behaviour (Hunter et. al. 2012; Munro, 2011).

Figure 12: Markings to indicate the desired safe path for cycling within a lane shared with motorists. "Bicycle awareness zone" (BAZ) in Queensland, Australia above; and "sharrows" in Toronto, Canada below.

At roundabouts, strategies to direct cyclists to use primary position to increase their visibility to approaching drivers are consistent with the advice of 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.

The roundabout sightlines analysis clearly shows how proximity of cyclists to the kerb significantly influences sightlines at intersections. This has two implications: (1) If bicycles are to be accommodated in secondary position or kerbside bicycle lanes, design guidelines should be adjusted to check sightlines to the kerb edge rather than the middle of lanes. (2) When bicycle routes are proposed and bicycle infrastructure designed, sightlines should be analysed between other road users and the edges of wide kerbside lanes, bicycle lanes or shared use paths.

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. This paper has described and illustrated a systematic process for examining the concept of road user "awareness".

The process described was effective at yielding solutions (at least in theory) to all four sample scenarios. Although specific locations were considered, all the solutions may be generalisable to a range of different instances of the scenarios considered.

Plotting road user "awareness" enables consideration of how subtle differences in the paths of cyclists and drivers could lead to significant differences in the level of awareness of road users, which in turn can inform measures likely to lead to reductions in crashes.

The four sample analyses did not all require all components of the awareness diagrams in order to generate solutions likely to be effective at reducing the scenario problems. The proposed solutions involve quite different mechanisms. Thus the process appears to be both flexible and versatile.

"Conflict path analysis", which considers the microgeography of the paths road users follow and how path choice may influence 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.

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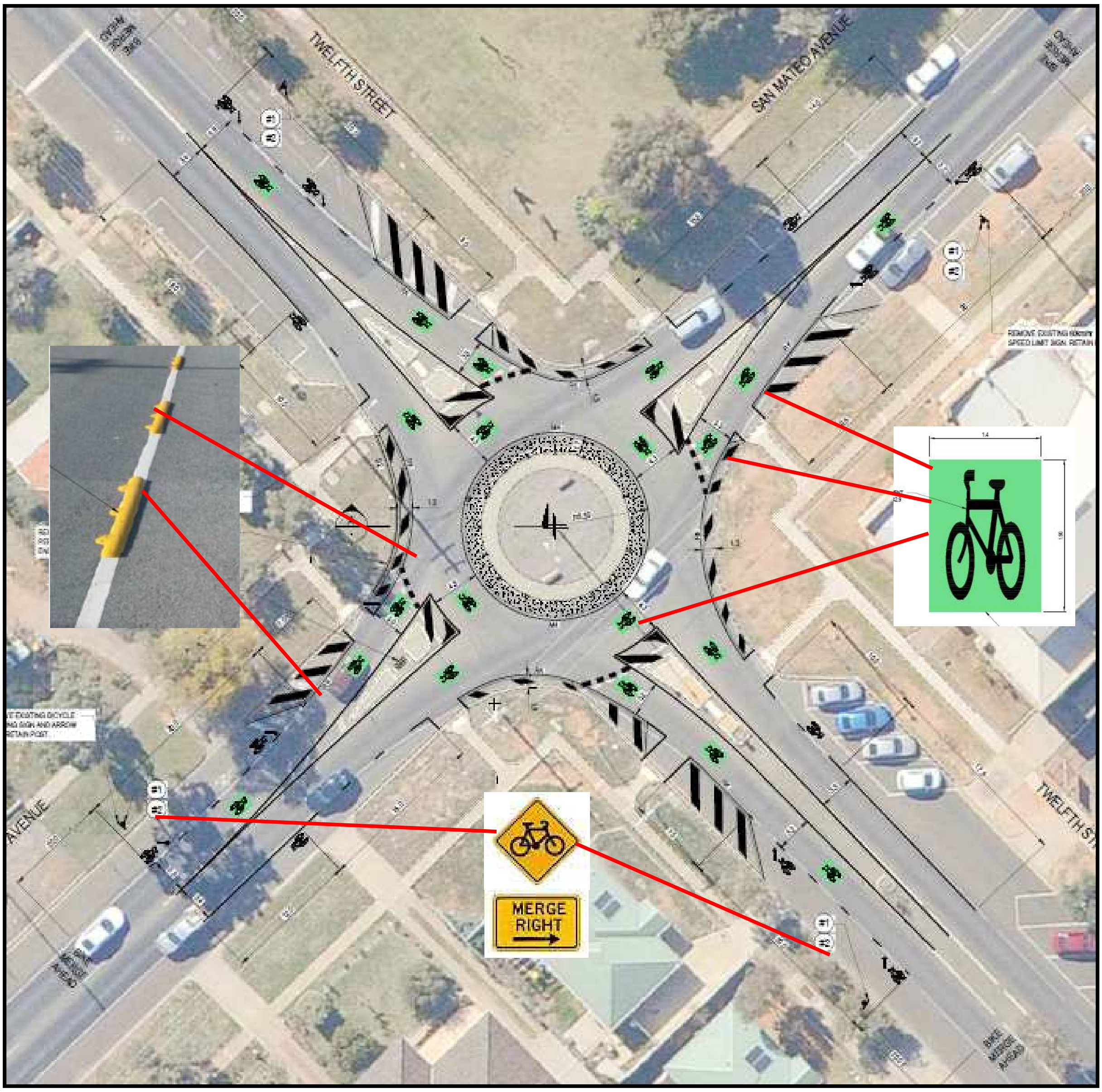
Appendix A – Roundabouts with design features to encourage central lane positioning by cyclists



Rural City of Mildura (Vic) – intersection of 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.

City of Newcastle (NSW, Australia)
Prince St & Platt St, Waratah   Honeysuckle Dr & Merewether St, Newcastle. Designs includes bicycle logos in middle of lanes (entry and circulating). Installed May 2011

City of Darebin (Vic, Australia) – intersection of Raglan St & Hotham St, Preston. Design includes sharrows in the middle of lanes on Raglan St entries. Other examples on Raglan St. Installed July 2011.

City of Yarra (Vic, Australia) – intersection of Pigdon St & Garton St, Carlton. Design includes: sharrows in middle of lanes on all entries; bicycle symbols with merge arrows on all approaches; safety strips between parking, bicycle lanes and car lanes on Pigdon Street; and narrow driving lanes – for lower speeds. Other examples exist on Pigdon St. Installed Feb 2012.

Appendix B - Roundabout at Canning & Pigdon Streets, North Fitzroy

Canning Street is an important "cyclist arterial" route between the north eastern suburbs and the Melbourne CBD. The street has wide bicycle lanes, and while bicycles may travel its whole length, it is discontinuous for other vehicles at several locations, meaning that motorists are limited to local traffic.

The intersection has a history of crashes involving cyclists, so has been reconfigured several times, as illustrated below.

The 2010 changes aimed to assist Canning St priority, but were problematic because the look and feel of a roundabout did not match the design intent.

2009: roundabout with circulating bicycle lanes.

2010: No longer functioning as a roundabout. Stop signs on Pigdon St and within median, and storage in median.

2011: A roundabout again, but a squarish one.

2012: Changed roundabout with features to encourage cyclists to merge with cars and use primary position:
- **45º bicycle lane arrow to encourage merging to the centre**
- **Centrally positioned bike logos at entries - circled**
- **Kerb extensions to force greater deflection by cyclists**