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Reversing priority: an investigation of cyclist and driver behaviours at cyclist priority intersections

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Abstract

Typically, when an off-road cyclist or shared path intersects with a road, the active transport users must give way to the road traffic. Reverse priority, or cyclist priority, intersections reverse that priority and are designed so the road traffic (i.e. motor vehicle drivers, motorbike riders, cyclists on the road) must give way to the cyclist travelling on the off-road path as they cross the road. Relatively new in Melbourne, the Victorian Government has plans to implement this cyclist priority in more locations and this study was conducted in two stages, first a review of the intersection design as per Austroads design and international best practice and, site inspection and two, observations of the behaviours of cyclist and drivers. Key findings indicated that existing intersections have been designed adequately according to Australian standards however could be improved to meet international best practice (e.g. London, The Netherlands). At reverse priority intersections, cyclist volumes were higher, cyclists exhibited less slowing and stopping behaviour and had fewer conflicts per cyclist compared to standard priority intersections. Specific observations and recommendations for characteristics associated with each intersection are also presented.

1.Introduction

Victoria's population is rapidly growing, creating significant and increasing congestion trends that directly impact the economy and residents' quality of life, particularly within the Melbourne transport network (Transport for Victoria, 2017). In Melbourne, over half of all vehicle trips are shorter than 6km (Transport for Victoria, 2017), yet cycling remains a small proportion of the transport mode share comprising only 6 percent of trips to, within and from the City of Melbourne (City of Melbourne, 2016), and a smaller share further from the CBD.

Studies have shown that improved cycling infrastructure has a positive impact on increasing the number of trips by bicycle and that this is more effective when introduced in integrated packages (Pucher et al., 2010). As such, Active Transport Victoria has proposed a number of projects to increase 'the role of cycling and walking as a form of transport, making it easier and safer for people to ride and walk where they need to go' (Transport for Victoria, 2018). These projects are consistent with recommendations across a range of broader policy and strategy plans including Plan Melbourne 2017-2050 (Victorian Planning Authority, 2017), Victorian Cycling Strategy 2018-28 (Transport for Victoria, 2017) and City of Melbourne's Bicycle Plan 2016- 2020 (City of Melbourne, 2016).

Throughout Melbourne, one type of infrastructure being implemented to foster growth in cycling as a form of transport is the construction of reverse or bicycle priority intersections which provide priority to cyclists over road traffic where off-road bike paths intersect with the road carriageway. A number of these upgrades have been completed across inner and middle Melbourne.

This paper presents a review of the literature related to intersection design used in reverse priority, followed by the Methods, next key Results are presented, followed by the Discussion and Conclusions.

2. Literature review

The primary purpose of implementing reverse priority intersections is to improve safety for people when they ride a bicycle and as a consequence, increase the number of people cycling. The link between increasing cycling participation and broader benefits are well established including reducing congestion, improving public health, the economy and environment (City of Melbourne, 2016; Cycling Embassy of Denmark, 2017). Specifically, to achieve this goal the Victorian Cycling Strategy 2018-2028 aims to create a safer, lower stress, better connected and more inclusive cycling network, prioritising strategic cycling corridors (Transport for Victoria, 2017). To be effective reverse priority treatments must meet these objectives in order to make cycling more attractive along these routes.

2.1. Effectiveness of cycling infrastructure

Reverse priority intersections are a relatively new type of bicycle path treatment, particularly in Australia. The literature on reverse priority intersections is limited with a focus on the effectiveness and functionality, however the effect of specific designs and new types of facilities is relatively unknown (Buehler & Dill, 2015). In Australia, reactions of cyclists and motorists to reverse priority intersections are largely unknown. However, it is known that other cycling orientated interventions have a positive impact in increasing the mode share of cycling including on-road bicycle lanes, bi-directional options for cyclists on one way streets, shared bus/bike lanes and signed bicycle routes (Pucher et al., 2010).

Increasing the prevalence and amenity of off-road bike paths can be effective in creating an attractive option for transport. A US survey of route choice by cyclists reported approximately 40 percent of cyclists preferred a longer route using a separated bike path to a shorter route with no separation (Pucher et al., 2010). An Australian study showed that this percentage could be even higher, with 80 percent of cyclists choosing routes up to a third longer than their shortest bike route if the longer route provided a bike lane or path. This preference was particularly noted by female cyclists (SGS Economics and Planning, 2015).

Subjective concerns about safety are significant deterrents to riding a bicycle, particularly in relation to crash involvement with motor vehicles (Haworth, 2012; Pooley et al. 2013). Thus, reverse priority bike paths have the potential to increase actual and perceived safety.

2.2. Intersections

Intersections, roundabouts and junctions, or nodes, of the bicycle network can be major hazards for cyclists (Dill, 2009). However, with appropriate treatment such as dedicated separate cyclist tracks these nodes can be made safer (CROW, 2007). These types of treatments have already been implemented internationally in cycling cities such as Amsterdam in The Netherlands and increasingly in London in the United Kingdom. At nodes within Melbourne, currently the most prevalent cycling intersection treatments are bicycle boxes and bicycle specific traffic signals. These treatments tend to be suitable for roads with mixed priorities (e.g. on-road bike lanes), indicating priority throughout Melbourne and the surrounding suburbs at nodes is to motor vehicle traffic.

Garder and colleagues (1998) conducted a comprehensive study on reverse bicycle priority intersections in Gothenburg, Sweden. In that study, they investigated the before-and-after effect of raising 44 (4 in detail) urban reverse priority intersections. Before treatment, cyclists rode on the roadway or on separate parallel paths and at intersections, the paths ended with a regular curb and then a marked bicycle crossing. The treatment raised the crossings by 4 to 12 cm and attracted over 50 percent more cyclists. Gains reported also included improved cyclist safety and increased cyclist flow.

Key observations and findings from Garder et al. (1998) were:

- Velocity of turning motor vehicles was reduced by 40 percent
- Velocity of cyclists tended to increase with varying results at different intersections
- Surveys indicated cyclists perceived a 20 percent improvement of safety at intersections
- Modelling indicated injury risk was reduced but collision risk was unchanged

A visual inspection of the treatments sites in Sweden using Google Street view identified similarities in treatment types to those existing and proposed by Active Transport Victoria. However, separate parallel bike paths appear to function closer to on-road bike paths and not the off-road shared paths considered in this study. Further, this study considers an urban environment with sufficiently more developed cycling infrastructure to Melbourne and a culture that provides more care and concessions by motorists to cyclists.

While treatments in Gothenburg were positive, not all reverse priority intersection treatments have been well received. In September 2017, in Eikenlaan in Groningen, The Netherlands, a two-month bicycle priority crossing trial was cut short. Providing access to the Groningen University campus, reversing the priority at this location was deemed a failure because “it wasn’t safe enough” after incidents with drivers crashing into cyclists (Bicycle Dutch, 2017). Suggestions for why the intersection was unsafe were that although the intersection is raised, there were no speed reduction measures provided leading up to it, with only a couple of warning signs and red paint on the road (Bicycle Dutch, 2017). In addition, a number of trees and road furniture, including the warning signs informing drivers to give way, visually obscured the approach of cyclists. Other issues were raised, with a primary concern being long vehicle queuing due to the number of cyclists (16,000) and cars (10,000) using the respective path and roadway (Hebel & Hollander, 2017).

At the International Transport Forum (2013), the exacerbation of crash risk at the interface of bike paths and roads by poor sight lines and confusion regarding the expectations of cyclists and motorists was raised. Highlighting the importance of design and ensuring that priority and expectations are clear for both cyclists and motorists.

2.3. Current Australian practice

Currently in Australia, the nationally agreed design standards for bicycle facilities are provided in Australian Standards, AS 1742.9:2000 – Manual of uniform traffic control devices – Part 9: Bicycle facilities. Table 3.2 of AS 1742.9:2000 outlines cases and corresponding appropriate treatment for when a bicycle or joint-use path treatment intersects at a mid-block road crossing.

Australian Standards state that at an intersection where road traffic gives way to a joint-use (shared) path “road traffic shall be controlled by a pedestrian (zebra) crossing in accordance with AS 1742.10.” Further, cyclists should be warned to dismount prior to using the crossing, or a deflection fence used to offset path alignment. At an intersection where road traffic gives way to an exclusive bicycle path “road traffic shall be controlled by give-way signs or stop signs if warranted." AS 1742.9:2000 also sets a number of wider general requirements including:

- The road shall be a minor residential type street less than 8m wide at the crossing
- Traffic speeds on the minor road shall be either consistently below the general urban speed limit or controlled in the vicinity of the crossing by Local Area Traffic Management (LATM) measures
- Crossings shall be located on a flat-top road hump
- The treatment should not be used at locations where significant numbers of primary school children may be crossing
- Adequate sight distance shall be provided for approaching traffic on all crossing approaches

The VicRoads supplement to this standard takes precedence where any difference or 'departure' occurs (VicRoads, 2015). The supplement states that a basic requirement is for cyclists to maintain speed, and harsh treatments or signage informing cyclists to dismount should not be implemented. Instead, sufficient visual and/or physical clues should inform cyclists of the approaching crossing.

2.4. International best practice

To determine best practice for the construction and design of reverse priority bike paths, examples and design guides were reviewed from The Netherlands (CROW, 2007) and London (TfL, 2014). These standards also provide the following considerations when designing bicycle priority intersections:

- Continue colour and type of pavement of cycle route across surface of the intersection
- Implement with traffic lights if vehicle speed is greater than 50km/h and vehicle volume is > 5,000 pcu/day (CROW, 2007)
- Line marking leading up to the crossing
- Narrow main carriageway prior to intersection and shorten length of bicycle crossing
- Piano-teeth arrows (Figure 1)(CROW, 2007) or Elephants footprints (Figure 2)(TfL, 2014) on cycle track facing motorists
- Good lighting
- The appropriateness of the crossing type given vehicle, cyclist and pedestrian volumes (TfL, 2014)
- It is recommended zebra crossings not be used

Figure 1. 'Piano key', The Netherlands (Bicycle Dutch, undated)

Figure 2. 'Elephant footprints', UK (Cycling Embassy of Great Britain, undated)

Each of these elements were considered in the review of the observed sites in this study for sites with priority to road traffic or reverse/bicycles.

2.5. Aim

The aim of this study was to compare behaviours of cyclists and road traffic at intersections where an off-road path intersected with the road across the standard priority (road traffic) and reverse priority (cyclists on off-road path). This study is an initial, exploratory study that targeted a range of intersection designs to determine how the reverse priority sites are currently operating and to generate before data to be used to compare behaviour at those sites scheduled for reverse priority to be implemented.

3. Method

This study used a mixed method approach that included: 1) a desk-based review of design standards including current Australian practice and international best practice; 2) a review of the crash data at the targeted intersection sites and; 3) an observational study of cyclist and driver behaviour at the intersection of off-road paths and roads. The Monash University Human Research Ethics Committee approved the research protocols for this study.

3.1. Infrastructure review

Review criteria was based on the Australian Design Standard outlined in AS 1742.9 and VicRoads Supplement, and international ‘best practice’ from the London Cycling Design Standards (TfL, 2014) and the Dutch Bicycle Design Manual (CROW) (2007).

3.2. Cyclist crash data analysis

Publicly available crash statistics for the last five years from January 2012 through December 2017 (VicRoads, 2018) was analysed at each intersection location to provide context to the safety of each intersection for cyclists. It was anticipated that crashes would be a function of exposure and more likely to occur at those locations with high volumes of cyclists and road traffic.

3.3. Observational study

Covert video cameras were used to capture the behaviour of cyclists and road traffic at the intersection points. Undetected by passers-by, the video cameras eliminated behavioural bias (Hawthorne effect) that may occur when people are aware they are being observed. Site inspections and data collection was conducted during April 2018.

Observations were recorded using a GoPro Session video camera fitted inside custom built housing fixed to a standard galvanized pole near the site. Where possible, the camera was positioned to face the same direction as the primary flow of cyclist traffic. Figure 3 shows a typical camera position related to the intersection and Figure 4 shows a typical view of the recording.

Figure 3. Typical camera position (Atkinson Street)

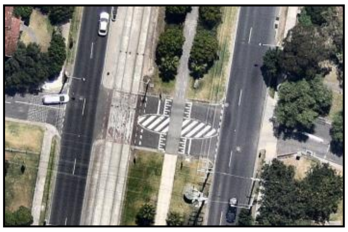
Figure 4. Typical camera view (Amess Street)

3.3.1. Site selection

Sites were identified in consultation with Active Transport Victoria with the aim of observing a variety of road designs and conditions. Suitable sites required a suitably positioned pole to attach the video camera with clear sightlines to the intersection unobstructed by path-side furniture, vegetation or path curvature.

In total, eight sites were selected along major cycling routes into the Melbourne central business district (CBD), of which, three were reverse priority intersections and five were road traffic priority (Table 1, Figure 5). Each location was observed for two-hour period.

Table 1. Observations: intersection locations and priority road user

Bicycle priority sites		
St Georges Road / Sumner Avenue	St Georges Road / Beaconsfield Parade	Capital City Trail / Amess Street
		
Motor vehicle priority sites		
Scotchmer Street / Mark Street Reserve	Napier Street / Cecil Street	Napier Street / Freeman Street
		
Scotchman's Creek Trail / Atkinson Street	Scotchman's Creek Trail / Drummond Street	
		

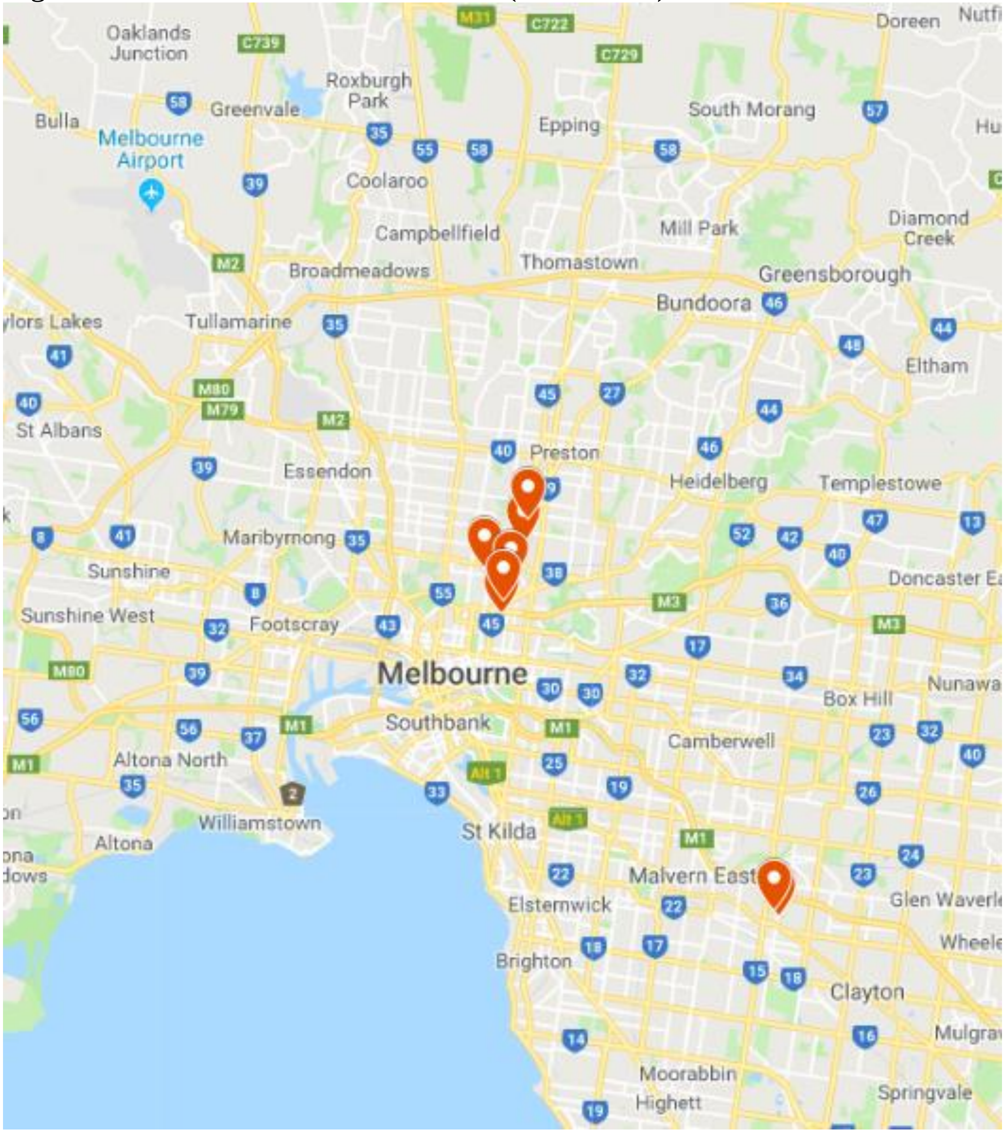


Figure 5. Location of observation sites (Melbourne)

As several sites were along the same route, for clarity, sites are referred to by their unique street name (e.g. Beaconsfield Parade). Most observations were during the morning peak travel time (7:15-9:15am) and two observations during afternoon peak travel time (4:00-6:00pm; Cecil Street and Freeman Street). All observations were on a weekday, with either sunny or cloudy conditions. Two observations were during school holidays (Beaconsfield Parade and Sumner Street).

3.4. Data analysis

All video footage was reviewed and observed characteristics, behaviours and interactions (with infrastructure, other road users) was analysed. Variables coded included: cyclist direction of travel (north/south/east/west); cyclist description (male/female/child); cyclist speed behaviour on approach to intersection (maintain speed/slow/stop); presence of a motor vehicle (yes/no); motor vehicle speed behaviour on approach to intersection (maintain speed/slow/stop); conflict between cyclist and motor vehicle (yes/no), and; conflict description.

Speed refers to observed behaviour, rather than a measurement of actual speed. Early in the analysis, it was apparent that cyclists changed speed in response to different situations. To capture this variation, when a cyclist slowed on approach it was classified as:

1. Due to infrastructure or path alignment. On paths with no cause for slowing, cyclists who appeared to slow for no reason were also included in this category
2. To wait for a gap in traffic (when drivers have right of way)
3. To be cautious (when cyclists have right of way or no car is present)
4. To ensure oncoming traffic is stopping
5. Due to surrounding bicycle traffic
6. Due to surrounding pedestrian traffic
7. Due to a conflict with vehicles

The distinction was made between the above behaviour (related to courteous, confusion or caution) and a conflict (cyclist reaction to avoid a crash). A conflict represents an increased level of danger for a cyclist and such events were classified as:

1. Cyclist forced to slow
2. Cyclist forced to stop
3. Vehicle forced to slow/stop
4. Collision

The intention in this study was to gain a broad understanding of a range of locations and an indication of cyclist and driver behaviour. As a result, data analysis was limited to descriptive statistics, generated using Microsoft Excel. More detailed statistical analysis will be used to analysis the before-and-after data once the treatments have been installed to compare the behaviour of cyclists and drivers at the same sites. The timing for the next phase is dependent on the implementation of the reverse priority infrastructure (ongoing).

4. Results

4.1. Infrastructure review

Table 2 presents the review of each observed site against the review criteria. All intersections where the road traffic gives way to cyclists assessed in this study failed the Australian Standards for treatment requirements at mid-block crossings outlined in Section 2.3 due to the road width at each intersection being greater than 8m. At the Scotchmer Street intersection, cyclists were prompted to ‘dismount’ which does not meet the standard in the VicRoads supplement (AS 1742.9:2000).

The existing reverse priority intersections failed to meet a number of general requirements outlined within AS 1742.9:2000 including road width and sight distance.

In regards to international best practice, observed reverse priority intersections are in low traffic speed environments, across medians or nearby an intersection. However, a number of criteria were not met including lack of coloured pavement and poor lighting. Some lighting was at intersections, but only lighting at Amess Street increased visibility at the intersection.

Both the Cecil Street and Freeman Street intersections had an off-road bike path transitioning into an on-road bike path. For this review, these sites were compared as a mid-block intersection between a road and shared path.

Table 2. Observation site infrastructure review

Intersection location	Speed (kph)	Crossing width (m)	Reverse priority	Warning signage: Bike path	Warning signage: Road	Clear sight triangle	Raised crossing	Coloured pavement	Traffic island/road narrowing	Line marking	Lighting
Sumner Avenue	Low	11	✓	✓	✓	X	✓	X	✓	✓	X
Beaconsfield Parade	Low	10	✓	✓	✓	✓	✓	✓	X	✓	X
Amess Street	50	11	✓	✓	✓	✓	✓	✓	✓	✓	✓
Scotchmer Street	50	11	X	✓	✓	X	✓	X	✓	X	✓
Cecil Street	40	8	X	X	X	✓	X	X	X	X	X
Freeman Street	40	12	X	✓	X	✓	X	X	X	X	✓
Atkinson Street	60	14	X	✓	X	✓	X	X	✓	X	X
Drummond Street	50	11	X	✓	✓	X	X	X	X	X	X

4.2. Cyclist crash data

Over the last 5 years, there were a total of 13 crashes involving cyclists at the 8 sites observed: 6 at Beaconsfield Parade (1 serious, 5 other injury), 5 at Sumner Avenue (1 serious; 4 other injury) and, 2 at Amess Street (2 other injury).

Notably, crashes involving cyclists only occurred at the sites that are now reverse priority. As noted above, this could be a function of a higher number of cyclist and drivers at these sites or cyclists may take more care at standard intersections. During the five-year period analysed, the Beaconsfield Parade intersection was upgraded (October 2016). Since the upgrade, there have been no reported incidents.

4.3. Observations

Table 3 presents the observed characteristics of cyclists. At locations where priority is provided to cyclists, Sumner Avenue, Beaconsfield Parade and Amess Street, there were considerably higher number of cyclists compared to other sites. The lowest number of cyclists were observed at two sites (Atkinson Street and Drummond Street), both located in Oakleigh, approximately 15km south-east of Melbourne's CBD. In addition, there were higher proportions of males cycling at these sites and the primary direction was split more evenly reflecting commuters travelling towards either the CBD or Monash University and the surrounding suburbs industrial, commercial and education precincts.

Considerably higher volumes of vehicles were counted on Atkinson Street, Scotchmer Street and Amess Street compared to other sites, which is correlated to the high proportion of vehicles present when a cyclist was approaching the crossing. This provided the opportunity to assess the vehicles behaviour towards the infrastructure without cyclists.

High proportions of conflicts per cyclist occurred on Freeman Street, followed by Scotchmer Street, Amess Street and Sumner Avenue. Across all interactions observed, in 3.5 percent a cyclist or road traffic were forced to slow or stop.

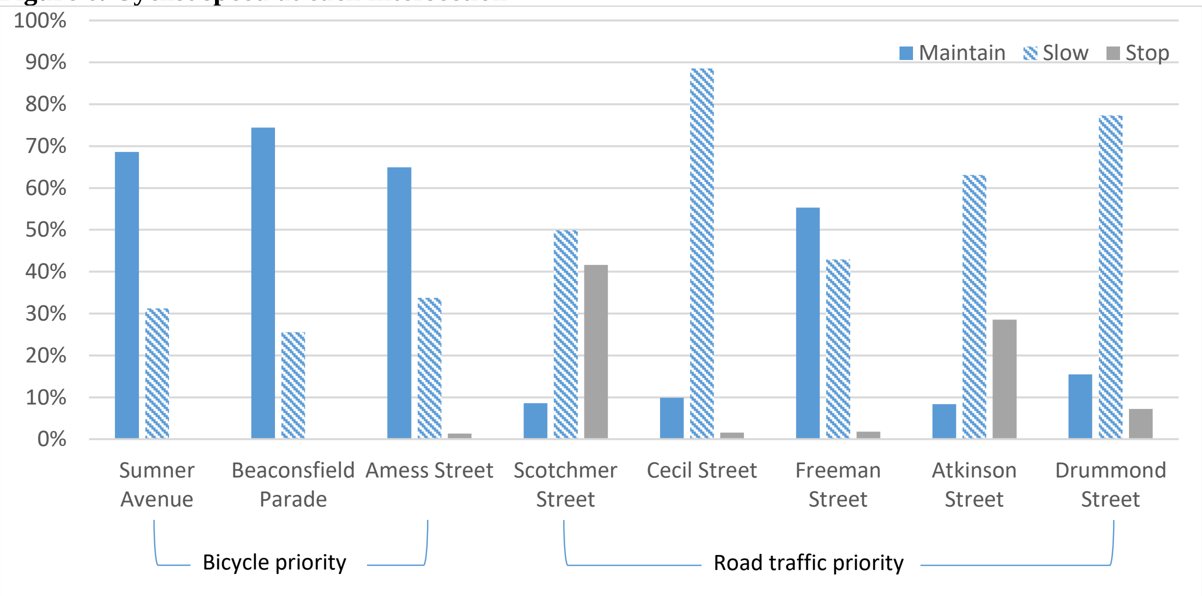
Table 3. Cyclist characteristics by observation sites

Intersection location	Total cyclists	Cyclist characteristics				Primary direction		% cyclists vehicle present	Total conflicts	
		Male	Female	Gender Unknown	Children		%		Count	% by number of cyclists
Sumner Avenue	576	374	169	32	1	South	93%	16%	17	3%
Beaconsfield Parade	512	365	122	24	1	South	92%	20%	12	2%
Amess Street	924	570	286	34	34	West	70%	57%	34	4%
Scotchmer Street	303	175	104	15	9	South	87%	56%	20	7%
Cecil Street	253	133	86	28	6	North	87%	6%	6	2%
Freeman Street	331	191	93	43	4	North	83%	15%	19	6%
Atkinson Street	84	65	8	9	2	East	62%	58%	0	0%
Drummond Street	97	80	3	12	2	West	51%	11%	1	1%

4.3.1. Behaviour assessment

Figure 6 presents the speed behaviour of cyclists at each intersection. At reverse priority sites, the majority of cyclists (68%) maintained speed, a third slowed (31%) and the remainder stopped (1%). At intersections with road traffic priority, most cyclists slowed (60%), a quarter maintained speed (24%) and the remainder stopped (16%).

Figure 6. Cyclist speed at each intersection



As noted above, changing in cyclist speed may be attributable to a range of factors. Figure 7 presents the factors that were observed that might influence cyclist speed behaviour on approach to each site. Conflicts are plotted against the secondary axis for each site, calculated as the proportion of the total number of cyclists observed.

There was a distinct difference in the speed behaviour of cyclists on approach to those sites with bicycle priority compared to road traffic priority. Across all the bicycle priority sites, cyclists were most likely to slow due to other bicycle traffic (33.6%) and less likely due to infrastructure (17.9%), caution (16.0%) or to ensure a car was stopped (15.6%).

Whereas at the road traffic priority sites, almost half the cyclists (44.9%) slowed due to infrastructure. At Cecil Street, the site with the highest occurrence, this was mainly due to misalignment of the intersection and crossover treatments. At Drummond Street, the second highest site, slowing due to infrastructure was related to cyclists needing to turn onto the bike path. It became apparent that this was to avoid slowing down at a T-intersection to the west of the crossing location on Drummond Street on the bike path. Other locations where slowing occurrences due to infrastructure were high were at Freeman Street, as southbound cyclists navigated a cobblestone crossover and several posts before continuing on the on-road bike path on Napier Street.

Cyclist at the road traffic priority sites were also much more likely stop due to apparent caution (31.2%) compared to the bicycle priority sites and more likely to slow to find a gap in road traffic (17.1%).

While the highest number of conflict events occurred at Amess Street (n=34), these events only involved 4 percent of cyclists. Proportional to the number of cyclists, the most events occurred at Scotchmer Street (20/303; 7%). At both sites, the most frequent reaction to an event was for the cyclist to take rapid and evasive action to slow to avoid a collision. Rapid braking was the most common behaviour observed at the sites where conflict occurred, with two exceptions. At both Scotchmer Street (100%), and Freeman Street (21.1%) the vehicle was observed to slow//stop to avoid a collision. One collision event was observed at Amess Street, a cyclist took rapid and evasive action to avoid a crash with a motor vehicle resulting a ‘cyclist-only’ crash. The cyclist was observed leaving the site without support or medical treatment.

Figure 7. Slowing behaviour and conflict by site

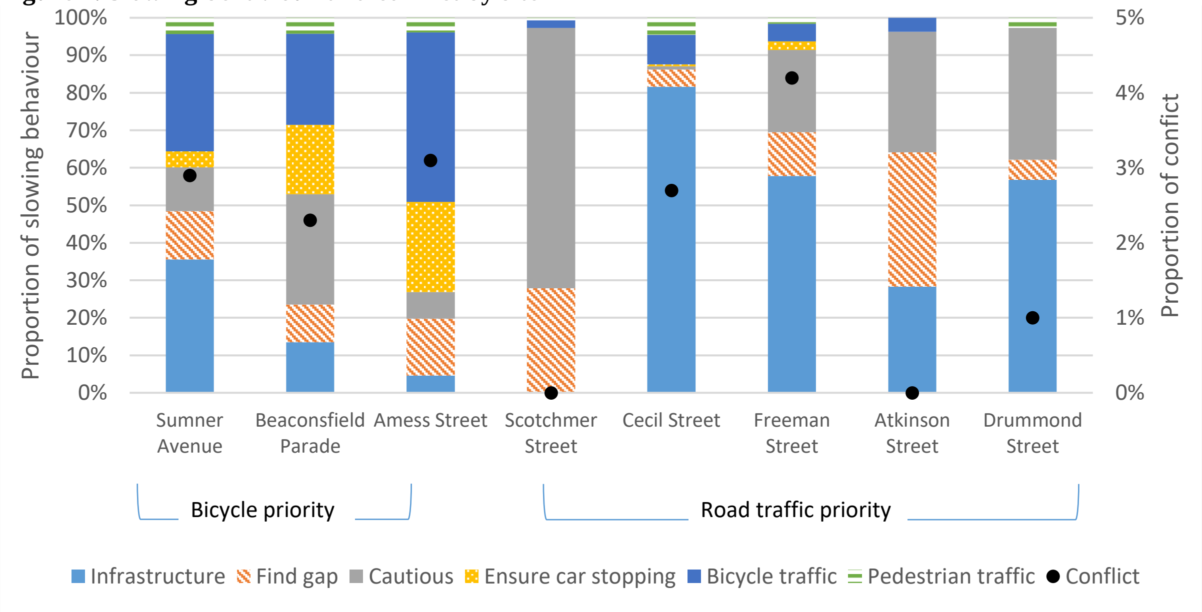


Table 4 presents the speed behaviour of cyclists and drivers in relation to the absence or presence of each other at the different priority sites. Not surprisingly, a higher proportion of cyclists were able to maintain speed on bicycle priority intersections when no motor vehicles were present (76.5%) compared to when motor vehicles were present (50.2%). In contrast, higher proportions of slowing and stopping were observed at intersections where vehicles had priority with cyclists slowing or stopping approximately 68.2% when no vehicles were present and 95.2% when vehicles were.

For the road traffic, infrastructure at bicycle priority intersection appears to provide a clear indication that drivers need to proceed with caution and give-way. Only 5.0% of the observed motor vehicles maintained their speed through the intersection when bicycles were not present, this tended to occur more frequently at locations where clear sight triangles were provided (i.e. Amess Street, Beaconsfield Parade).

Table 4. Speed behaviour by road user priority

	No vehicles present			Vehicle present		
	Maintain speed	Slow	Stop	Maintain speed	Slow	Stop
Cyclist speed						
Bicycle priority	76.5%	23.4%	0.2%	50.2%	48.1%	1.6%
Motor vehicle priority	31.8%	66.8%	1.4%	4.8%	43.0%	52.2%
Motor vehicle speed						
Bicycle priority	5.0%	57.1%	37.9%	0.7%	30.2%	69.1%
Motor vehicle priority	82.4%	17.0%	0.6%	42.1%	48.2%	9.7%

4.3.2. Influence of upstream activity

Upstream activity was observed to affect cyclist behaviour. At Amess Street, cyclists arrived in waves due to previous crossings on the Capital City Trail, which caused more slowing behaviour due to bicycle traffic as arriving cyclists were densely packed, forcing following cyclists to slow. This was compounded by the narrow crossing width that did not allow sufficient space to pass, ride two abreast if there was an oncoming cyclist, pedestrian or vehicle obstructing the pathway. Furthermore, cyclists' behaviour at the front of the wave influenced behaviour of following cyclists, for example, once a cyclist entered the intersection there was less slowing by following cyclists.

4.3.3. Impact of long vehicles

At all bicycle priority intersections, due to the short provision provided to motor vehicles to turn into or enter the road following the intersection, often the back of long vehicles would obstruct all or part of the bike path. This was particularly prevalent at Amess Street, which was positioned on a bus route and the bus stop did not allow the rear of the bus to clear the bike path to allow boarding and disembarking passengers. Further, when this occurred the long motor vehicle would obstruct the sightline for oncoming cyclists and drivers resulting in several dangerous conflicts.

4.3.4. Influence of infrastructure on illegal cycling behaviour

At some locations, the position of the cycling infrastructure appeared to influence illegal cycling behaviour. Almost a third (30.4%) of cyclists travelling north along Napier Street approached Freeman Street on the wrong side of the road, presumably to avoid having to cross the road on the corner intersection. While it is illegal to cycle in this direction, this behaviour allowed cyclists to maintain their speed and reduce the risk of conflict by crossing onto the cycle path at the corner.

5. Discussion

In this study of reverse priority intersections, the observed behaviours showed a direct improvement in terms of the movement of cyclists and the provision of a connected network. This is a positive outcome in terms of meeting the policy objectives of the Victorian Government to make it easier for people to cycle (Transport for Victoria, 2018). At the three sites with cyclist priority, cyclists were observed to be more likely to maintain their speed on approach compared to sites with road traffic priority with few cyclists having to stop prior to crossing the intersection. Findings in this study also concur with observations from Garder et al (1998) including that drivers are more likely to slow on approach to a bicycle priority intersection.

5.1. Road design

In terms of design, it is arguable that few of the sites failed at the first requirement in the Australian Standards, that bicycle priority intersections be implemented on minor residential type streets. While the crossroad may be a minor road, it often was the connection between major roads with high road traffic (e.g. St George's Road). For the sites where bicycle priority has been implemented, the infrastructure review determined that the sites were largely compliant with the Australian standards. However, there were also limitations in terms of the requirements from both the Australian standards and international best practice.

5.1.1 Speed

There is some discrepancy in the definition of 'low speed' between Australia and best practice. In Australia, the urban default speed limit of 50kph, which is considered acceptable for residential streets may be considered 'low'. However, in The Netherlands, on roads with a posted speed limit of 50kph or higher, there must be separate provision for cyclists (CROW, 2007).

Using the Australian definition of low speed (≤50kph), all three locations with bicycle priority met the Australian requirement. Four of the five road traffic priority locations also meet this criterion, however, one site, Atkinson Street, has a speed limit of 60kph. To meet the Australian Standards, the posted speed limit on this road will need to be reduced to or below 50kph. However, in accordance with international best practice, the site could retain the 60kph limits but then the crossing would require traffic lights.

5.1.2 Crossing width

The Australian Standards clearly state a maximum crossing width of 8m, yet only one observed site, Cecil Street that has road traffic priority, met this criteria. All three of the bicycle priority sites exceeded the maximum road width (10m Beaconsfield Parade; 11m Sumner Avenue, Amess Street). The remaining road traffic priority sites all exceeded the 8m maximum width, up to 14m at the Atkinson Street site. To meet the requirements of the Victorian Government cycling policy, it would be expected that the reverse priority treatment at these sites would include road narrowing to reduce the width of the crossing for the cyclists. Narrowing will also have a traffic calming effect on the road traffic on the approach to the crossing.

5.1.3 Crossing treatment

All observed bicycle priority sites did have a raised crossing and met the Australian Standard of a flat-top road hump. This treatment was also already in place at the Scotchmer Street site. While not yet in place at the road traffic priority sites, it is assumed this will be implemented as part of the reverse priority treatment.

Although not specific in the Australian Standards, international best practice requires continuation of the colour and type of pavement across the intersection. This treatment was in place at two of the three bicycle priority sites. While the Sumner Avenue site did not have continued crossing coloured treatment, it did have piano teeth markings, so too did the Amess Street crossing. However, colored pavement treatments are not consistent across Melbourne, including at the observation sites. At Amess Street the pavement treatment is yellow, Beaconsfield Parade is a light grey concrete pavement, and throughout Melbourne bicycle lanes are being coloured green. The distinction between each colouring and their meaning, if any, is not clear.

Further study is required to determine if the lack of the pavement marking has a significant impact on road users' understanding of priority at the site or influences behaviour. This study highlights the inconsistency across the network. It is possible that there is a greater need for consistency in the implementation, particularly of new infrastructure types to maximise the likelihood of cyclist and drivers understanding the purpose and priority at the sites.

5.1.4 Lighting

A considerable concern in terms of safety at the observed sites is the lack of lighting. Only three of the eight sites (one bicycle priority, two road traffic priority) had lighting where the bike path intersected with the road. Given the relative recency of this infrastructure type to Melbourne, it would be advisable for these sites to meet this international best practice criterion and ensure good lighting at these and other cyclist crossing sites.

5.1.5 Integration with surrounding activities

This study also identified the lack of integration with some activities adjacent and surrounding the crossing site. At Amess Street, the primary cause of issues at the intersection was the proximity of the crossing to the intersection of Amess Street and Park Street. Long vehicles, particularly trailers and buses would obstruct the path. Also, the location of the bus stop often resulted in the bus, legally stopped to pick up and drop off passengers, obstructed cyclists' access to the bicycle priority crossing.

It is recommended that future bicycle crossing intersections, whether bicycle or road traffic priority, be clearly marked as a Keep Clear space for road traffic and be situated a suitable distance from any parallel roadway to eliminate obstruction. Further, bus stops need to be repositioned a suitable distance from the intersection to avoid obstructing cyclists. Consideration of the surrounding area also extends to sight distances and ensuring sufficient visibility of oncoming bicycle or road traffic so everyone has adequate time to adjust their speed to reduce potential conflict.

5.2. Cyclist and road user behaviour

Overall, reverse priority intersections performed to an expected level. Observations suggest that there are both similarity in behaviour of vehicles and cyclists between Melbourne and Gothenburg (Garder et al, 1998). That is the velocity of cyclists tended to increase and velocity of motor vehicles tended to decrease at reverse priority intersections.

Generally, by reversing priority, cyclists were able to maintain speed more, slow and stop less compared to road traffic priority intersections. One drawback that became evident is that by increasing cyclists' speed, volume and reducing caution the number of conflicts occurring tended to rise. Slowing behaviour of vehicles was suitably influenced by the infrastructure present at each intersection. Low cyclist volume, standard priority intersections tended to have high proportion of vehicles travelling at high speeds, whilst high cyclist volume reverse priority intersections tended to result in vehicles exhibiting a high level of caution by slowing or stopping the majority of the time.

Higher volumes of cyclists appear to increase users' perception of safety. Even on the same route, there was notable difference in the behaviour of cyclists along the St Georges Road Bike Path with cyclists at Sumner Street, which consists poor sight triangles and an uncoloured pavement, exhibiting significantly more caution than cyclists at Beaconsfield Parade. Crash data, remembering that no reported crashes have occurred at Beaconsfield Parade since the upgrade and analysis of conflicts at this intersection indicates that

Beaconsfield Parade provides a safer and easier intersection to negotiate for both cyclists.

However, this study also highlights the discrepancies between the design guidance given in the Australian Standard, the Vicroads supplement and international best practice. It may not be appropriate to simple cut and paste the international approach to the Australian context; however, it would be beneficial to test some of the pavement treatments to determine the most effective. This would enable a better investment by local and state governments to ensure that these treatments are well understood by all road users and greater consistency will help to reinforce the language of cycling infrastructure to both cyclists and drivers.

6. Conclusion

This study was an exploratory study of intersections between off-road bicycle paths and roads at sites that prioritise bicycles or road traffic. Overall, the cyclist priority intersections provided an opportunity for cyclists to travel without having to slow down or stop before crossing. It seems viable that implementing bicycle priority intersections will increase the number of people choosing to travel by bicycle over other travel modes, thereby achieving various objectives within Melbourne's and Victoria's transport framework. However, reversing priority requires a package of change that includes reduced speeds, pavement treatments, adequate lighting and integration with the surround area. Further insights that could inform best practice would be gained by a comparative study of the design guidelines in Australia, Victoria and international best practice and, identifying the most intuitive road treatments to maximise understanding by all road users. Future research that included interviews with road users (both cyclists and drivers) would also help to understand the intuitiveness of these site and the perceived safety gains.

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