Limitations of Using Police Crash Data to Identify the Benefits of Innovative Cycling Infrastructure

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Abstract

Innovative bicycle infrastructure treatments are gaining popularity in Australia. There is a need to identify treatments that can be beneficial for treating frequent bicycle crashes. The presented methodology is used to match treatments with frequent crash types identified through the use of police crash data. Results suggest that police crash data, analysed at an aggregated level, show promise for relating the benefits of treatments to frequent crash types through identification of crash mechanisms. Gaps within the data were identified that prevent this method from being used to fully appreciate the benefits of some treatments, particularly those used at intersections.

Background

In recent years, a significant amount of new infrastructure has been implemented in order to increase the confidence and safety of cyclists using public road networks. Places such as Denmark, Germany, The Netherlands, and several cities in the United States of America are leading the way in terms of placing the safety of cyclists at the forefront of road infrastructure design (Andersen et al. 2012; City of Copenhagen 2013; Federal Ministry of Transport 2012; National Association of City Transportation Officials 2014). More recently, cycling infrastructure is being implemented on a widespread scale on Australian road networks and these infrastructure treatments are aimed at creating a connected and coherent cycling network to increase the rate of cycling participation (Austroads 2014c). Many of the current Australian guidelines have a focus on high volume road environments and as such recommend segregation treatments. It can be argued that there is limited guidance as to what may be the best approach to improving cyclist safety on low volume residential streets and if segregation solutions are still practical in such situations (Government of South Australia 2012).

Traditionally, the implementation of bicycle lanes along arterial roads, collector roads and a relatively non-cohesive set of off-road shared tracks has been the standard for cycling infrastructure in Australia. Recently, more innovative and progressive treatments have started to be implemented in order to provide infrastructure that ensures a greater level of harm mitigation for cyclists. These treatments have started to become mainstream in Australia, with new guidelines and other publications from Australian jurisdictions highlighting the use of innovative and progressive solutions that bring safety to the forefront of design (Government of South Australia 2012; TMR 2015; Vicroads 2016a; Vicroads 2016b; Vicroads 2016c).

There is a growing appreciation in Australia that cycling infrastructure that minimises the possibility of harm (or the perception of harm) to cyclists is required to increase the rate of cycling involvement and encourage cycling as part of a mainstream alternative to the use of private motor vehicles (e.g. TMR 2015). In order to cater for cyclists of all ages and capabilities, cycling routes need to meet the standards of cyclists in terms of safety, directness, cohesiveness, comfort, and attractiveness (TMR 2015). In terms of managing interactions between cyclists and motor vehicles, conflict avoidance and conflict presentation must be properly managed. Conflict avoidance means removing the opportunity for conflicts to arise between cyclists and vehicles. This can take the form of separation, in both time and space, and the use of off-road facilities. Conflict presentation is about making sure that where conflicts can arise, safe interaction speeds are achieved and priority is made clear to all road users. The safe interaction speed threshold for pedestrians is generally considered to be between 20 and 30 km/h (Jurewicz et al. 2015) and without other forms of guidance, it is assumed that the threshold for cyclists is similar; above this threshold, the risk of serious injury or death in the event of a crash increases exponentially. It must also be recognised that certain interactions, such as between cyclists and heavy vehicles, may have a much higher risk of severe outcomes, no matter what the speed.

One of the most readily available sources of crash information for researchers, police crash data (i.e. crash data sourced from police crash records), has a number of associated limitations that reduce the ability to garner accurate information. This is particularly true for crashes involving non-motorised vehicles such as bicycles. While other sources of information have been used for detailed studies into cyclist involved conflicts and crashes (Harris et al. 2013; Mulvancy et al. 2013; Rissel et al. 2013), much of the data used, such as hospital and survey data, can be difficult to source and its use is therefore not always practical. Police crash data as it exists in South Australia today is not able to provide sufficient information to understand all of the mechanisms related to how cycling crashes occur and therefore how cycling infrastructure may help mitigate the harm caused by these crashes. While definitions for coding accidents (DCA) codes (also called road user movement, or RUM, codes in other states of Australia) that are now used to code police crash data may shed some light on these mechanisms, basic information such as where a cyclist was travelling (e.g. footpath or road) and whether bicycle infrastructure was present and being used is still missing.

Objectives

While literature exists regarding the design of bicycle infrastructure and tolerable levels of harm for cyclists and other vulnerable road users, there is little research about the ways in which design may reduce harm through better management of the interactions between cyclists and motor vehicles. Moreover, there is little guidance for the objective comparison of different bicycle infrastructure treatments and in what situations they may be effective at minimising harm or ineffective at managing for safer interactions.

The purpose of this study was to highlight some of the design concepts that are becoming more widely considered in Australia, and test whether police crash data in its current form can be used to evaluate the benefits of these designs for the safe management of interactions between cyclists and motor vehicles. It should be noted that in this study it was not aimed to reproduce the details of previous conflict analysis literature, such as Cross and Fisher (1977). Instead, conflict points were merely used as a tool for locating the possible interaction points between bicycles and motor vehicles when interactions occur. The objectives of this study were:

- To identify the benefits of innovative bicycle infrastructure treatments in terms of eliminating interactions and reduction of crash likelihood and severity when interaction elimination is not possible
- To determine whether police crash data is suitable for identifying the above benefits and what limitations exist with the use of this data.

Method

This study was undertaken in three phases: 1) the identification and theoretical analysis of selected bicycle infrastructure treatments; 2) analysing aggregated police crash data (i.e. where individual crashes were aggregated by crash type) to identify frequent crash types; 3) mapping frequent crash types to vehicle (bicycle and motor vehicle) movements to identify were infrastructure treatments may allow crashes to be eliminated or reduced in likelihood or severity.

Selection of treatments

Both traditional and innovative bicycle infrastructure treatments were considered in this study. Innovative treatments that address the principles of conflict avoidance and conflict presentation have been identified through jurisdictional guidelines and other resources (Government of South Australia 2012; TMR 2015; Vicroads 2016a; Vicroads 2016b; Vicroads 2016c). The selected treatments were physically protected bicycle lanes, kerbside (left side of on-road parking) bicycle lanes, buffered bicycle lanes and offset/raised bicycle crossings. More traditional delineation based treatments were used for comparison and were identified through Austroads publications (Austroads 2014a; Austroads 2014b). The selected treatments were delineated/painted (coloured pavement) bicycle lanes and delineated/painted bicycle lanes through intersections. It should be noted that supporting infrastructure treatments, such as pavement colourings, bicycle boxes and advanced control lines, hook-turn boxes, and traffic management treatments (e.g. bicycle signals and bicycle only phases), were not selected for evaluation but are recognised as important features of bicycle friendly design (Austroads 2014b; Austroads 2014d).

Mapping of infrastructure treatments

Locations of interaction, and hence locations where crashes can occur, between cyclists and motor vehicles were identified by mapping their respective travel paths onto movement diagrams and identifying points where it was possible for their respective travel paths to intersect. Both midblock and intersection environments were considered in this study.

Two types of interaction were considered; cross-path and parallel (same direction) movement interactions. Cross-path interaction points were considered at specific locations where bicycle and vehicle movement paths cross one another. These could include right angle interactions or those involving a turning bicycle or vehicle. Parallel movement interactions were those where bicycle and vehicle movement paths run side-by-side to one another. These could include manoeuvring type interactions, such as rear-end, sideswipe or lane changing interactions.

For midblock locations, a two-lane/two-way cross-section with and without roadside parallel parking was considered. While other forms of midblock environments exist, this scenario was considered feasible for investigating the key types of interactions that can occur between cyclists and motor vehicles: between through cyclists and motor vehicles travelling in the same direction; between through cyclists and parking or unparking motor vehicles; between cyclists and opened doors of parked motor vehicles; and between cyclists and motor vehicles entering or exiting side roads and access points.

For intersection locations, only cross road type intersections were considered. While the number of interaction points will differ for other intersection configurations (e.g. T-junctions), the benefit to like interaction points is unlikely to change. Each cross road intersection was considered as having four two-lane/two-way legs with standard motor vehicle movement paths for through, left turn and right turn movements.

Movement paths of bicycles are not as strictly controlled as those of motor vehicles. Previous cycling conflict analysis literature has considered a large number of movements from which conflict points were identified (Cross and Fisher 1977). Movement diagrams, which were used for mapping intersecting vehicle movements (Rodegerdts et al. 2004), provide an idealised representation of motor vehicle traffic interactions. The movement diagrams were created to represent points of interaction between bicycle and motor vehicle streams. The use of movement diagrams was chosen as they can be used to provide a simplistic representation of more complex interactions. While this simplicity reduces the ability to identify detailed differences between different interactions, it allows categorised police crash data to be more easily matched to individual interaction points.

For this study, two types of bicycle movements were considered that may be affected by on-road cycling infrastructure – through and (at intersections) right turn movements. Left turn movements at intersections were not considered. For through movements, bicycles were considered to follow a path close to the left kerb, or a bicycle lane where one was provided. For right turn movements at intersections, the bicycle movement path was considered to be dependent on the type of infrastructure that was provided. Where no protected bicycle path was provided, right turns were considered to be made by merging across the parallel traffic lane and performing a right turn from the traffic lane (i.e. a traditional right turn movement). Where a protected bicycle path was provided, two-stage right turns (also referred to as hook turns) were considered to be used. This consideration was made on the basis that the protected bicycle path will restrict cyclists from merging across the parallel traffic lane.

Each treatment was subjectively judged on its ability to affect each point of interaction, such that each potential interaction was:

- Virtually eliminated – the interaction was no longer possible, either by adequate physical or spatial separation, or a change in geometry that means cyclist and vehicle paths would not intersect.
- Reduced in terms of severity – vehicles involved in this interaction were unlikely to be travelling at speeds above safe interaction speeds for cyclists (i.e. where fatal or severe injury outcomes are unlikely), should a crash occur. While research into safe interaction speeds is ongoing, Jurewicz et al. (2015) has determined this speed to be at or below 20 km/h for interactions between pedestrians and passenger vehicles. A similar safe interaction speed was inferred for cyclists.
- Reduced in terms of likelihood – the likelihood of a crash subsequently occurring at a point of interaction was reduced by an increase in cyclist conspicuity, reduction in cognitive load on the driver or complexity of the manoeuvre that they were undertaking, or non-physical delineation between cyclist and vehicle paths. The scale of the reduction in likelihood was not considered and the effectiveness of treatments to reduce likelihood of a crash may not be known.
- Not changed – the treatment does not affect the likelihood of a crash occurring or the severity of a crash if one occurs.

The number of eliminated conflict points at intersections was considered to be the total number of conflict points for the same intersection with no treatment minus the number of conflict points remaining for the treated intersection. The remaining conflict points were then judged on whether the treatment was able to reduce the severity or likelihood of a crash.

Analysis of crash data and matching infrastructure treatments to crashes

In order to identify the types of cycling related crashes that occur in the metropolitan area, police generated crash records, collected through the South Australian Traffic Accident Reporting System (TARS) were analysed at an aggregated level (i.e. without the detailed analysis of individual cases). This police crash data was extracted for the period 2006 to 2016, inclusive.

All recorded crashes involving cyclists were analysed to assess their frequency. Frequent crash types (i.e. those involving 10% or more of all crashes for each location type and case study area) were further analysed to identify the crash location on the movement diagrams (discussed above). This was undertaken with movement diagrams for each infrastructure treatment type to identify whether crash types were aligned with points of interaction that were either eliminated, reduced in likelihood or reduced in severity. Interactions and hence crashes between two or more cyclists and between cyclists and pedestrians were not considered.

Police crash data was analysed by identifying information of each crash (e.g. date, time, weather, crash type, crash severity), its location (e.g. midblock or intersection, control type) and the units involved in the crash (e.g. unit type, directions, movements, recorded errors). These features were then used to define the crash type based on the crash mechanisms. For most crash types, a combination of the above information was needed to identify the crash mechanisms. For example, crashes involving a motor vehicle turning right from the major road at a non-signalised intersection were identified as a right turn crash (crash type) involving a right turning vehicle (movement) that failed to give way. Some crashes were defined differently to how they were defined in the police crash data. For example, "dooring" crashes were identified as those where a motor vehicle made an error of opening or closing a door; the crash type for dooring crashes was often coded differently for different crashes (e.g. could be coded as a hit parked vehicle or sideswipe type crash). Crash descriptions for a sample of crashes were checked to verify that the crash mechanisms were correctly identified.

There were several limitations in relation to investigating cycling crashes when using police crash data. These include the recording of attributes associated with cycling infrastructure and the under-reporting of some crash types, such as when no injuries occur.

Alignment to the Safe System objective of harm reduction (i.e. elimination of fatal and serious injury crashes) is considered to be an important feature of bicycle infrastructure treatments. It is necessary to identify the harm reduction benefits associated with these treatments, rather than their ability to influences crashes in general. As such, it was decided to focus the crash analysis on injury crashes only. While Safe System objectives are generally aligned to the prevention of severe injuries, such crash outcomes were comparatively rare and analysis of just severe injury crashes would be difficult due to their low numbers. To circumvent the issue of not having enough data, all crashes where an injury was reported were included in the analysis of police crash data.

Police crash data case study

Two case study areas were chosen for the analysis of the aggregated police crash data. The two case study areas represent South Australian postcode areas with the highest number of reported bicycle involved crashes. Both case study areas are inner-urban central business district (CBD) and suburban environments with high numbers of cyclists.

The first case study area ("Adelaide") was undertaken for the 5000 postcode area in South Australia. This area encompasses the Adelaide CBD and the surrounding parklands. This area comprises approximately eleven square kilometres of medium and high density residential, commercial and light industrial premises and extensive parklands surrounding the built-up area. 577 injury crashes involving cyclists were recorded in this area between 2006 and 2016.

The second case study area ("Norwood") was undertaken for the 5067 postcode area in South Australia. This area comprises approximately four square kilometres of mainly low and medium density residential, commercial and light industrial premises. 227 injury crashes involving cyclists were recorded in this area between 2006 and 2016.

Results and Discussion

Mapping of infrastructure treatments

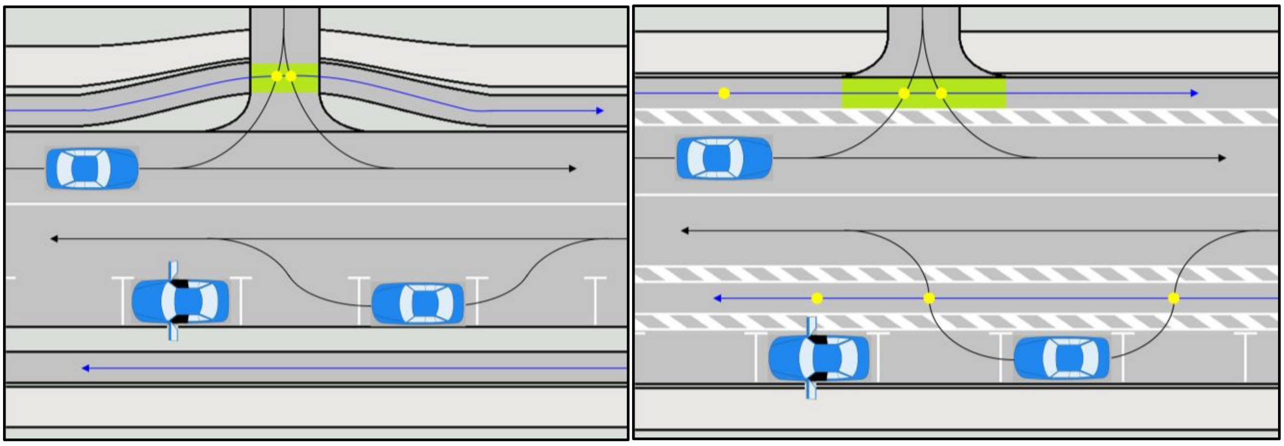
In this section, the identification of interaction points along midblock sections and at intersections, along with the justification of the likely effects of bicycle infrastructure treatments to eliminate these points of interaction or reduce the severity or likelihood of subsequent crashes, will be discussed.

In Australia, cyclists generally ride on the left side of a traffic lane close to the left kerb (Austroads 2014b). Where a road does not provide any form of bicycle treatment and in some circumstances where treatments have been provided, cyclists are exposed to interactions with through motor vehicles passing on their right side; motor vehicles entering and exiting parking spaces; opened doors of parked vehicles; and motor vehicles entering and exiting access points such as driveways. Most midblock treatments can reduce the likelihood of crashes associated with these six types of interaction, though to what extent is likely to be site specific where visual cues (e.g. delineation) are relied upon (Table 1). Protected bicycle lanes can virtually eliminate most interactions by removing the cyclist from the locations where interactions are permissible (e.g. Figure 1); the exception here is with vehicles crossing the protected bicycle lane for roadside access. When on-street parking is presented to the right, buffered bicycle lanes may also eliminate these interactions (e.g. Figure 1).

Table 1. Points of interaction associated with midblock treatments. Identification of changes to likelihood, severity of crashes or elimination of interactions was undertaken using movement diagrams.

	Conflict points				
	Total	**Virtually eliminated**	**Reduced severity**	**Reduced likelihood**	**No change**
Bicycle lane[1]	6	0	0	6	0
Buffered bicycle lane[1]	6	0	0	6	0
Buffered bicycle lane[2]	6	4*	0	2	0
Physically protected bicycle lane[2]	6	4	0	2	0
Mixed traffic (20 km/h design speed)	6	0	1	3	2

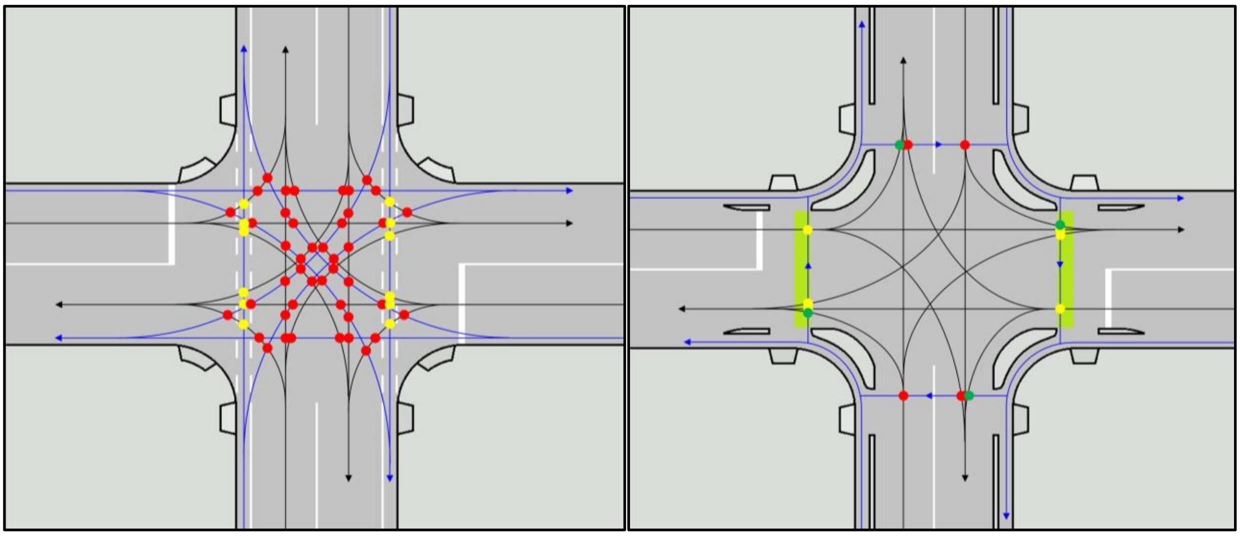
[1]On-road parking to the left (kerb-side) of bicycle lane
[2]Bicycle lane between kerb and on-road parking
***Where on-road parking can be used to physically separate cyclists from moving traffic**



Conflict points: red = no change in the conflict point, yellow = reduction in likelihood, green = reduction in severity

Figure 1. Examples of movement diagrams for a physically protected bicycle lane (left) and a buffered bicycle lane implemented between on-road parking and the kerb (right). Note that only two types of interaction (entering/exiting vehicles) were present when bicycle lanes were physically protected.

Without any form of treatment, non-signalised cross road intersections have 56 potential points of interaction between cyclists and motor vehicles. This was derived from the consideration that cyclists will chose to perform a right turn from the traffic lane, with a substantial number of conflicts coming from this manoeuvre. Visual cues alone are unlikely to effect the majority of interactions, as they occur away from where the bicycle lane/painted bicycle lane is implemented (Table 2); these interactions are associated with right turns and cyclists crossing the major road without any form of delineation to follow (e.g. Figure 2). The most significant effect is likely to come from infrastructure that enables two-stage (or "hook") right turns. Protected bicycle lanes along the major road can physically prevent cyclists along the major road from accessing the through traffic lane, thereby forcing them to make a two-stage right turn. Physical medians (or "islands") used to create an offset crossing (e.g. Figure 2) could further eliminate interactions if they were implemented in such a way that cyclists approaching the intersection from any direction were forced into a two-stage right turn manoeuvre. This type of infrastructure can also reduce corner radii for left turning motor vehicles, thereby reducing vehicle speeds and the severity of associated conflicts. Vertical deflection at key locations (e.g. at cyclist crossings) can also reduce the severity of the remaining interactions by reducing vehicle speeds as they enter/exit the minor road.



Conflict points: red = no change in the conflict point, yellow = reduction in likelihood, green = reduction in severity

Figure 2. Examples of movement diagrams for a non-signalised intersection with bicycle lanes (left) and physically protected bicycle lanes with offset crossings (right). Note: cyclist experience a high level of freedom of movement – in real life, interactions may occur in different locations.

Table 2. Points of interaction associated with non-signalised treatments (treatments implemented along major road only). Identification of changes to likelihood, severity of crashes or elimination of interactions was undertaken using movement diagrams

	Conflict points				
	Total	**Virtually eliminated**	**Reduced severity**	**Reduced likelihood**	**No change**
Bicycle lane	56	0	0	12	44
Painted bicycle lane	56	0	0	12	44
Physically protected bicycle lane	56	16	0	12	28
Physically protected bicycle lane with offset crossing	56	40	4	6	6
Physically protected bicycle lane with raised and offset crossing	56	40	10	0	6

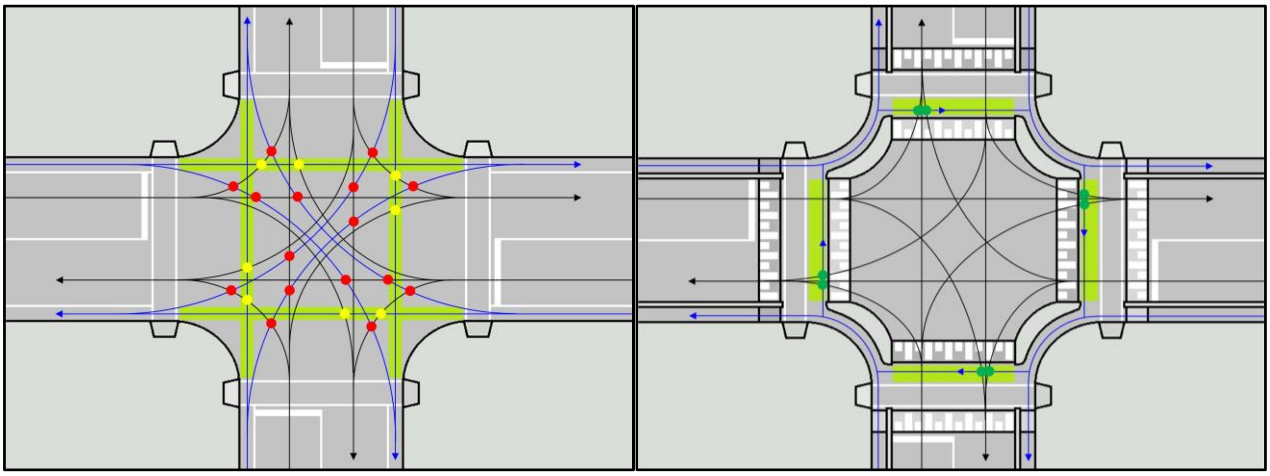
When time separation is considered (i.e. not considering conflicts due to red light running), signalised intersections have 24 potential conflicts. In Australia, bicycle lane delineation generally does not extend through a signalised intersection and will therefore have little effect on interactions occurring in the intersection (Table 3). Extending painted bicycle lanes through the intersection could reduce the likelihood of some crashes; as with non-signalised intersections, most interactions were unaffected due to their location away from the through travel path where delineation and painted lanes are implemented (e.g. Figure 3). Again, the most substantial effect comes from the prevention of cyclist right turns from the traffic lane. Protected bicycle lanes and offset crossings on all approaches can eliminate most interactions, which were associated with cyclist right turns.

Raised crossings can potentially help to reduce the severity of crashes associated with the remaining interactions (e.g. Figure 3).

Assuming cyclists will stay as far left as possible when negotiating the circulating area of a roundabout, eight points of interaction were identified [note that recent research suggest this assumption may not always be valid (Austroads 2014a)]. None of the identified treatments were able to eliminate any of these points of interaction, though the use of offset crossings can shift interaction locations away from the circulating area and onto the approach/departure roads (Table 4); prioritising bicycle crossings may further benefit the safety of cyclists, however this is currently contrary to Australian practice. Reducing the left turn radius to reduce vehicle speeds can potentially reduce the severity of crashes associated with departing vehicles. Raised crossings are another way to reduce crash severity and can affect conflicts with both approaching and departing vehicles.

Table 3. Points of interaction associated with signalised treatments (treatments implemented along both intersecting roads). Identification of changes to likelihood, severity of crashes or elimination of interactions was undertaken using movement diagrams.

	Conflict points				
	Total	**Virtually eliminated**	**Reduced severity**	**Reduced likelihood**	**No change**
Bicycle lane	24	0	0	0	24
Painted bicycle lane	24	0	0	8	16
Physically protected bicycle lane	24	16	0	8	0
Physically protected bicycle lane with offset crossing	24	16	4	4	0
Physically protected bicycle lane with raised and offset crossing	24	16	8	0	0

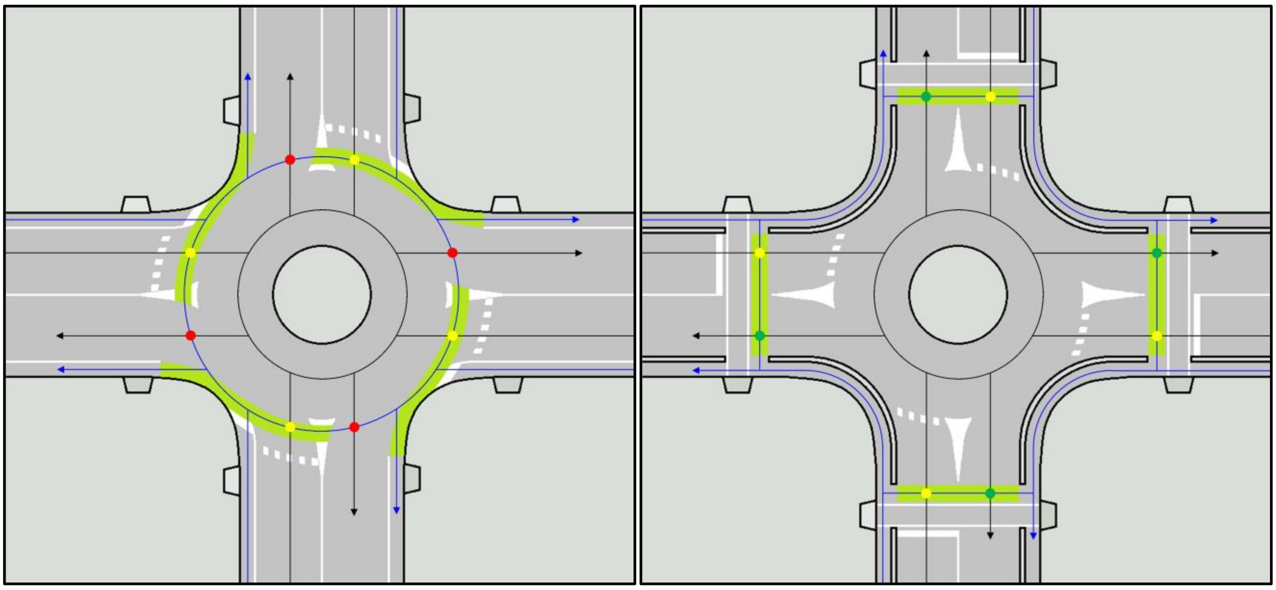


Conflict points: red = no change in the conflict point, yellow = reduction in likelihood, green = reduction in severity

Figure 3. Examples of movement diagrams for a signalised intersection with painted bicycle lanes (left) and physically protected bicycle lanes with raised and offset crossings (right). Note: cyclist experience a high level of freedom of movement – in real life, interactions may occur in different locations.

Table 4. Points of interaction associated with roundabout treatments (treatments implemented along major road only). Identification of changes to likelihood, severity of crashes or elimination of interactions was undertaken using movement diagrams

	Conflict points				
	Total	**Virtually eliminated**	**Reduced severity**	**Reduced likelihood**	**No change**
Bicycle lane	8	0	0	0	8
Painted bicycle lane	8	0	0	4	4
Physically protected bicycle lane	8	0	4	4	0
Physically protected bicycle lane with offset crossing	8	0	4	4	0
Physically protected bicycle lane with raised and offset crossing	8	0	8	0	0
Mixed traffic (20 km/h design speed)	8	0	4	4	0



Conflict points: red = no change in the conflict point, yellow = reduction in likelihood, green = reduction in severity

Figure 4. Examples of movement diagrams for a roundabout controlled intersection with painted bicycle lanes (left) and physically protected bicycle lanes with offset crossings (right). Note: cyclist experience a high level of freedom of movement – in real life, interactions may occur in different locations.

Analysis of police crash data

A summary of frequent crash types for the two case study areas are shown in Table 5, and represent crash types that were attributed to 10% or more of all crashes (for the location type – midblock or non-signalised, signalised or roundabout intersection) in at least one of the two case study areas.

For most crashes, the mechanisms leading to the crash could be identified from the police crash data through identifying a combination of crash type, unit movements, error type and unit in error (at fault). This was generally enough information to link the crash to a specific point of interaction.

For some crashes, the mechanisms were easily identified but other important information required to link the crashes to a specific point of interaction was not. For example, right turn crashes at non-signalised intersections were identified by the crash type (right turn), unit in error (bicycle or non-bicycle) and error type (fail to stand). However, whether the involved units were travelling along the major or minor road was not clear; bicycle lanes and other bicycle infrastructure are usually only continued through a non-signalised intersection on the major road and so the whether or not the crash occurred on the major road dictates the potential impact of the infrastructure.

There were a number of gaps within the data that led the matching of frequent crash types to points of interaction to remain somewhat ambiguous. This was most apparent with intersections, where a much greater number of interactions and directional options confounded the issues:

- There was no straightforward way to determine unit directions with respect to intersection orientation. At non-signalised intersections and other intersections where treatments are unlikely to be applied to all approaches, understanding crash orientation is important for understanding the crash mechanisms.
- There was no function for coding the bicycle position prior to the crash; whether the bicycle was using a bicycle lane, traffic lane, or footpath was undeterminable. It was also difficult to determine whether cycling infrastructure was at the location of the crash and whether it was being used as intended.

Frequent crash types where these two issues were of concern for aligning treatments to crash types are labelled accordingly in Table 5.

Table 5. Frequent crashes in the case study areas for different locations. Proportions are relevant to the location type (e.g. midblock, non-signalised intersection, signalised intersection, roundabout)

	Number (proportion) of crash for "Adelaide"/"Norwood" case studies			
	Midblock	**Non-signalised intersection**	**Signalised intersection**	**Roundabout intersection**
Bicycle disobey control			19/1 (11%/5%)	
Bicycle loss of control	36/8 (12%/16%)		21/3 (12%/14%)	
Dooring	104/16[2] (34%/31%)			
Manoeuvring (read end, overtaking, lane change)	111/9[2] (22%/18%)	11/9[1,2] (11%/10%)	31/7[2] (18%/32%)	
Vehicle disobey control/fail to give way		9/4[1,2] (10%/4%)		0/54[2] (NA*/89%)
Vehicle entering/exiting parking	47/4[2] (14%/8%)			
Vehicle entering/exiting access point	22/7[2] (6%/14%)			
Vehicle left turn		25/21[1,2] (26%/23%)	19/0[2] (11%/0%)	
Vehicle right turn		17/41[1,2] (18%/44%)	34/3[2] (20%/14%)	

[1]Orientation of crash respective to intersection layout was not determined and may influence whether bicycle infrastructure could eliminate the crash or reduce likelihood or severity.
[2]Bicycle location (e.g. in bicycle lane or traffic lane) and presence of bicycle infrastructure was not determined and may influence whether bicycle infrastructure could eliminate the interaction or reduce the likelihood or severity of an associated crash.
***There were no roundabout controlled intersections located in the "Adelaide" case study area.**

Matching infrastructure treatments to crashes

In this section, the ability to identify alignments between bicycle infrastructure treatments and frequent crash types through the derivation of points of interaction from movement diagrams (discussed above). The alignments that were identified between the considered treatments and the frequent crash types identified in the case study areas are shown in Tables 6 to 9.

Once the crash mechanisms were identified and a link was established between the frequent crash type and point of interaction (previously discussed), the ability of the bicycle infrastructure treatment to affect the interaction, and therefore the crash, could be identified. The ability of a treatment to affect the crash type was dependent on whether the respective point of interaction was eliminated or whether severity or likelihood of an associated crash could be reduced, as determined with the use of the movement diagrams.

Table 6. Effect of infrastructure treatments on frequent crashes (midblock)

	Treatment				
	Bicycle lane	Buffered bicycle lane[1]	Buffered bicycle lane[2]	Protected bicycle lane	Mixed traffic
Dooring	L	L	E	E	L
Manoeuvring	L	L	E	E	S
Bicycle loss of control	N*	N*	N*	N*	N*
Vehicle entering/exiting parking	L	L	E	E	L
Vehicle entering/exiting access point	L	L	L	L	N

N = No change, L = Reduced likelihood, S = Reduced severity, E = Virtually eliminated
[1]On-road parking to the left (kerb-side) of bicycle lane
[2]Bicycle lane between kerb and on-road parking
***Direct effect unlikely; indirect effect through new pavement, reduced/increased obstacles, etc. possible**

Table 7. Effect of infrastructure treatments on frequent crashes (non-signalised intersection)

	Treatment				
	Bicycle lane	Painted bicycle lane	Protected bicycle lane	Offset crossing	Raised offset crossing
Vehicle right turn	L	L	L	L	S
Vehicle left turn	L	L	L	S	S
Manoeuvring	L	L	E/L	E	E
Vehicle disobey control	L	L	L	L	S

N = No change, L = Reduced likelihood, S = Reduced severity, E = Virtually eliminated

For those frequent crash types identified through the case studies, treatments that relied on delineation or visual cues (e.g. painted bicycle lanes) were at best identified as being able to reduce the likelihood of crashes. The exception to this was buffered bicycle lanes where on-street parking could be used as a physical or substantial spatial barrier between through vehicles and bicyclists. The treatments that were identified as being most successful at eliminating intersection crashes were those that provided substantial separation of through cyclist movements from the intersection and forced cyclists to make two-stage right turns (e.g. offset crossings). Treatments identified as being able to reduce crash severities were those that could reduce through vehicle speeds (either through mixing, vertical deflection or reduced corner radii and intersections).

Table 8. Effect of infrastructure treatments on frequent crashes (signalised intersection)

	Treatment				
	Bicycle lane	Painted bicycle lane	Protected bicycle lane	Offset crossing	Raised offset crossing
Manoeuvring	N	L	E/L	E	E
Vehicle right turn	N	L	L	L	S
Bicycle loss of control	N*	N*	N*	N*	N*
Bicycle disobey control	N	N	N	N	S
Vehicle left turn	N	L	L	S	S

N = No change, L = Reduced likelihood, S = Reduced severity, E = Virtually eliminated
***Direct effect unlikely; indirect effect through new pavement, reduced/increased obstacles, etc. possible**

A major drawback of the applied method was the inability to determine the magnitude of effectiveness of each treatment and this is likely to be highly dependent on how the treatments are implemented. For example, the ability to reduce crash severity was dependent on how much vehicle speeds (and potentially bicycle speeds) can be reduced. The ability to reduce crash likelihood may be the most difficult effect to measure, as most treatments that may reduce crash likelihood do so through improved delineation and visual cues. The ability to reduce likelihood is dependent on many factors, such as width of separation, clarity of delineation and visual cues and the ability of road users to perceive and abide by these.

Table 9. Effect of infrastructure treatments on frequent crashes (roundabout intersection)

	Treatment					
	Bicycle lane	**Painted bicycle lane**	**Protected bicycle lane**	**Offset crossing**	**Raised offset crossing**	**Mixed traffic**
Vehicle fail to give way	N	L	L	L	S	S

N = No change, L = Reduced likelihood, S = Reduced severity, E = Virtually eliminated

Conclusions

While the use of police crash data can provide useful insights into the effects of cycling infrastructure on crashes, there exists scope to extend this process' usefulness by improving the collection of certain crash attributes in the police crash data. Two additional attributes not routinely collected as part of police crash data are required if the benefits of cycling infrastructure are to be more accurately identified using this data. These attributes are the identification of bicycle/vehicle directions at the time of the crash with respect to intersection orientation and the more accurate identification of cyclist position (e.g. footpath, bicycle lane, motor vehicle lane).

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