BIKES 'N' LIGHTS IN NORTH AMERICA: FINDINGS FROM A STUDY TOUR

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ABSTRACT

Megan Fowler, the author of this paper, was a recipient of the 2016 IPENZ Transportation Group study award and supplementary funding from the New Zealand Transport Agency. The study focuses on ways of addressing conflict between people on bikes and motor vehicles at signalised intersections with separated cycleways on the approaches.

The author undertook a background literature review and visited seven cities in North America to investigate relevant sites with a variety of different treatments and talk to people involved in the planning, design and operation of these sites. The author also attended the NACTO Designing Cities Conference, which gave insights into the technical, political and legislative context of planning and designing for cycling in North America, plus the chance to meet a great number of North American planners and designers, some of whom became interviewees for the study tour.

The particular treatments studied include: full protection of cycling movements (i.e. via traffic signal operation); allowing filter turning of motor vehicles through cycle movements, with physical treatments to highlight the potential for conflict; addressing the conflict on the approach to the intersection by cycle facility transitions; and 'protected' intersection design (a combination of geometric and operational aspects similar to what is used in Holland).

This paper outlines the key findings from the study tour, including recommendations for aspects that could be applied in New Zealand.

1 INTRODUCTION

1.1 Rise and challenges of separated cycleways

The New Zealand Transport Agency has set a goal to increase the number of cycling trips by 30% by 2019. This will involve targeting people who do not currently choose to cycle. Koorey and Teather (2016), building on work by Geller (2009) and Dill and McNeil (2012), showed that a large proportion of the population prefer to be physically separated from high-speed and / or high-volume motor traffic when cycling. Accordingly, many Road Controlling Authorities currently have, or are considering, 'separated cycleways' with physical elements and / or buffers between people on bikes and motor traffic.

Separation devices can prevent or dissuade motorists from infringing on the cycling space and are therefore assumed to improve cyclist safety between intersections. They have also been found to increase people's perceived levels of safety and therefore attract more people to cycling (Monsere, Dill, McNeil, et al., 2014). However, the most dangerous locations for cycling are at intersections (Cycling Safety Panel, 2014), where multiple movements and modes seek to occupy the same space, and where there is limited opportunity to provide physical separation. As separated cycleways are relatively new (outside of continental Europe), there is limited guidance available for this treatment, particularly regarding the layout and operation at signalised intersections.

1.2 Study focus

This research focuses on addressing the conflict between cyclists and motorists at signalised intersections where protected bike lanes are involved. The main treatment types considered are:

- Full protection of all cycle movements - i.e. the traffic signal phasing never operates conflicting motor vehicle movements at the same time as cycle movements.
- Filter turning - i.e. turning motorists may judge when it is necessary to give way to cyclists and when it is appropriate to turn across the cycle trajectory. A number of phasing, layout and traffic control device treatments are available to mitigate this style of operation.
- Addressing the conflict on the approach to the intersection – either by crossing the two conflicting movements, or 'mixing' them together into one lane.
- 'Protected intersections' – a style of design involving layout and phasing components.

Section 2 gives a more detailed description of these available treatments.

1.3 Study approach

Many continental European countries, notably Holland, Denmark and Germany, have a long-standing experience with separated cycleways. However, these countries differ markedly to New Zealand in terms of road layout (e.g. location and density of driveways), traffic conditions, transport law, and general cultural aspects relating to cycling. Thus, it was decided to focus this study on experience from the United States and Canada, whose traffic, regulatory, and cultural environments are more similar to New Zealand's. Admittedly, separated cycleways are relatively new in North America as well, but the sheer size of the continent offers a vast quantity of useful lessons, including things to avoid as well as best practice to adopt. Where advice from Dutch practitioners might be "start 40 years ago," the forerunners in North American separated cycleways have a fresher understanding of the challenges faced.

The study method consisted of a literature review of available research and guidance, plus a study tour of seven North American cities to observe relevant sites and interrogate professionals with useful experience in the design and operation of the treatments considered. Thanks to additional financial support from the NZ Transport Agency, the author was also able to attend the NACTO Designing Cities conference in Seattle. Attending the conference was an invaluable start to the study tour, providing an overview of the current context in planning and designing for cycling in North America, some specific insights regarding the study focus, and also the opportunity to meet a number of useful interviewees.

The choice of cities visited was based on a number of factors:

- The Green Lane Project (2014) focus cities and database of separated cycleways in North American cities
- The location of the NACTO conference
- Seeking to collaborate with Claire Graham (the other recipient of the 2016 IPENZ study award), to increase complementarity and avoid overlap
- Seeking to utilise experience from colleagues
- Seeking a range of cities with useful but varied experiences and approaches

The cities visited were:

- Seattle, WA, USA.
- Vancouver, BC, Canada
- Denver, CO, USA
- Chicago, IL, USA
- Toronto, ON, Canada
- Boston, MA, USA
- New York City, NY, USA

1.4 Structure of this paper

Section 2 gives a more detailed description of the possible treatments and section 3 discusses the potential for applying them in New Zealand, with the overall conclusions given in section 4.

1.5 Terminology

Note that, between the various literature reviewed and cities visited, there are multiple terms used for many of the aspects discussed in this paper (for example, separated cycleways are also known as protected bike lanes, cycle tracks and green lanes). To maintain consistency within this paper and with New Zealand's national guidance, the author has attempted to use the terminology of the *Cycling network guidance* (NZ Transport Agency, 2016).

1.6 Contextual differences between North America and New Zealand

While North America was chosen for its similarities with New Zealand, there are some important differences to note when considering applying learnings from this study to New Zealand.

Firstly, driving on different sides of the road affects the implications vehicles making left- or right-turns across cycle trajectories. This can be addressed simply by mirroring designs when transferring between New Zealand and North America. To aid comparisons, this paper often refers to 'short turns' (i.e. left in New Zealand or right in North America, or either direction at intersections of one-way streets) and 'long turns' (i.e. right in New Zealand and left in North America), or identifies the relevant country wherever a turning movement is mentioned.

Bicycle signals in the USA are subject to the Interim Approval for Optional Use of a Bicycle Signal Face, 'IA-16' (FHWA, 2013). Some practitioners deem IA-16 overly-restrictive (see for example: Alta, 2015; BAC, 2014) and consider that the wording of this legislation isn't in line with the spirit of what it's trying to achieve (Chang, 2016b, pers com). The main criticism seems to be IA-16's requirement that cycle movements are not operated "in conflict with any simultaneous motor vehicle movement…" (FHWA, 2013). However, after the study tour was completed, a subsequent clarification was issued (FHWA, 2017) to confirm that the wording of IA-16 is as the FHWA intended it to be and the stated restrictions do apply.

Right turn on red (RTOR) is by default allowed throughout the USA and Canada, except New York City and Montreal City (Sustainable Streets Index, 2009; Lord, 2002; Libman, 2014). This has safety implications wherever there is a kerbside cycle facility and hence right turns on red are included among a list of potential conflicting movements that are prohibited by IA-16 (FHWA, 2013). If a green bicycle signal is used in the USA, right turn on red must be specifically prohibited by installing a supplementary 'no right turn on red' sign (Alta, 2015).

The constraints of IA-16 and right turn on red apply in North America and not New Zealand, which can affect the transferability of treatments. Conversely, there are number of anomalies in the New Zealand regulations regarding cycle signals and separated cycleways (Wilke, 2014) that authorities are aware of and seeking to address; these also affect how easily treatments from North America can be applied in New Zealand.

2 TREATMENT TYPES

This section describes possible treatments that can be used to address the conflict between cyclists coming from separated cycleways and turning motor vehicles at signalised intersections.

2.1 Protected yet concurrent phasing

At signalised intersections, the traffic signal phasing can be designed so no conflicting movements are operated at the same time as cyclists. This is called 'full protection' and requires the use of specific traffic signals for cyclists, so that the general traffic and cycle movements can be distinguished and controlled independently. The main type of full protection[1] for cycle movements is termed 'protected yet concurrent' phasing, which ensures only non-conflicting vehicle movements are operated at the same time as cycle movements.

2.1.1 Phasing

It makes sense to operate as many non-conflicting movements as possible at the same time, whilst still trying to maintain an efficient system.

Specific signals for cyclists are generally required to achieve full protection for cyclists, although, at most locations, it could also be achieved simply by fully controlling opposing turning movements, so that cyclists follow the green disc for general traffic and no conflicting turning movements are operated at this time. This latter approach, however, is likely to be less efficient for all users.

A common protected yet concurrent arrangement would be to allow cyclists travelling straight through simultaneously with general through traffic, whilst prohibiting all turns across the cycle movement. At T intersections, it may be possible to allow cyclists to travel across the head of the T whilst allowing turning movements.

2.1.2 Layout

In most cases, the only cycle movements 'protected' through signalisation will be the straight ahead and short turns. Cyclists making the long turn will not have right of way over adjacent through traffic; providing for hook turns (i.e. a long turn made in two stages whilst remaining kerbside) is the most common method of doing this.

2.1.3 Safety

This temporal separation of conflicting movements may, at first glance, appear to be a perfectly safe solution. However, operating fully protected movements has significant implications on the amount of green time that can be dedicated to cyclists, delay to cyclists, and overall intersection time, which can adversely impact the actual safety of the operation.

Furth, Koonce, Yu, et al. (2014) suggest that it is possible to incorporate protected yet concurrent phasing for cycle movements in the intersection phasing in a way that bicyclists experience only a small increase in delay compared to if filter turns were allowed (in which case, the cycle movement can be operated during a greater proportion of the intersection cycle time). However, the intersections studied by Furth et al (2013) were generally unique examples (several on one-way grids, and a T intersection) and the author of this paper suggests increase in delays quoted (ranging from 3 s to 25 s per cycle) are in fact significant. In practice, many designers and authorities still consider that it can be difficult to achieve a suitable proportion of green time for cyclists. The signals engineer from New York City summed this up by saying that if a fully

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[1] The other potential form of full protection (at least, from motor vehicles) would be to operate a cycle Barnes' dance. However, the author considers that if a cycle Barnes' dance is operated, cyclists should not be permitted to proceed during other phases, to avoid confusion. Therefore, unless an intersection experiences significant volumes of cyclists undertaking right turns or diagonal movements, not just during peak periods but throughout the day, a cycle Barnes' dance would not achieve a higher level of service than a regular protected yet concurrent operation. The author is not aware of any sites in New Zealand that meet these criteria and therefore does not consider cycle Barnes' dances to be a viable option in New Zealand at present and has chosen not to discuss this treatment in this paper. Furthermore, there are associated legal aspects (see Wilke, 2014) that would need to be addressed to enable operation of a cycle Barnes' dance.

protected cycle phase is introduced to the phasing currently used at most intersections in Manhattan, it would only be possible to give cyclists the bare minimum movement time and this would lead to non-compliance (Carmona, 2016, pers com.). Dales, Jones, Black, et al. (2014) report that New York City previously explored using exclusive stages for cyclists but “found that some cyclists ignored the cycle-only red and came into serious conflict with turning traffic”.

FHWA (2015) notes this relationship between green time and compliance by saying that “signal phasing, cycle lengths, and traffic progression should all be carefully considered for bicyclists where significant delay frequently results in poor signal compliance.” Similarly, OTC (2015) notes with respect to fully protected movements: “The chief drawback is the short time interval available for bicycles, which may generate complaints and / or result in lack of compliance, as well as increased delay for motorists.”

In Chicago, a two-way separated cycleway was installed on the left side of Dearborn Street, a one-way street that did not previously have any cycle facilities. This made it necessary to also install signals for cyclists, which were part of the official trial required by the FHWA to approve cycle signals. The intersections are operated with full protection and lag long turns across the cycleway. Cyclist signal compliance in the with-flow direction increased from 31% before the installation of the cycleway to 79% afterwards (Klein, 2013). The author of this paper suggests that the marked increase is in part due to the introduction of a cycle facility, not simply the protected phases and cycle signals. Klein (2013) notes that cyclists departing during the all-red phase do so “in order to be visible to vehicles” i.e. for safety reasons in an environment where there was no protection for cyclists. The rate of non-compliance during the all-red phase reduced from 41% to 7%, whereas non-compliance during the red phase reduced from 27% to 14%, i.e. a lower initial level and lesser reduction. Monsere, et al. (2014) also conducted a study of four Chicago intersections with separated cycleways and full protection and observed that 77-93% of cyclists and 84-92% of motorists behaved compliantly.

In Seattle, a two-way separated cycleway was installed on the left side of 2nd Ave, which is a one-way street that previously had a painted cycle lane on the left side (for with-flow cycling only). Cycle signals were installed with the separated cycleway. Chang (2016a) reported that one month after the installation, cyclist compliance was observed to be 92%; and after eleven months it had increased to 93% (no data are available for the original situation). Motorist compliance for the two periods was 85% and 93%, respectively.

In Sydney, a study of two two-way cycleways on two-way streets and two two-way cycleways on intersecting one-way streets found “less than half of all cyclists who encountered a red bike light stopped and waited for the light to turn green… in the vast majority of cases cyclists are following the directions of the car traffic signals as they would when riding on a non-cycleway road” (Zeibots, Baumann, Brennan, et al., 2012). The researchers also noted that unduly long delays for cyclists leads to a high level of dissatisfaction.

The poor results from Sydney contrast with the positive results from Chicago and Seattle. Key differences between the North American examples and the Sydney sites are the likelihood of cyclists arriving on a green cycle light and the proportion of green time allocated to cyclists in relation to adjacent vehicles.

German research (Alrutz, Willhaus, Meyhöfer, et al., 1996) found that cyclist compliance with signals is proportional to the amount of green time they receive compared to parallel through traffic. As the green time for cyclists reduces compared with that of adjacent traffic, cyclists take on riskier behaviour. If they choose to ignore the red cycle light, they run the risk of conflicting with turning vehicles. Consequently, German design guidance is to give cyclists the same length of green time (minus any early cut-offs for clearance purposes) as parallel motor traffic (Alrutz, Willhaus and Sonderhüsken, 2007; Alrutz, Willhaus and Sonderhüsken, 2013, p 16).

Therefore, fully-protecting cycle movements can be counter-productive. Non-compliant behaviour by both cyclists and motorists is likely to increase, which increases the crash risk.

2.2 Filter turning of vehicles through cycle movements

The research quoted in section 2.1.3. relating to user compliance makes for a compelling reason to consider allowing filter turning of motor vehicles through straight ahead cycle movements. Whilst this no longer constitutes full protection for cyclists, it makes a higher proportion of the total intersection time available to cyclists, and therefore improves their level of service, meaning they will be less likely to undertake unsafe manoeuvres.

If conflicting movements are not separated temporally and filter turning is allowed, it is necessary to use other techniques to reduce the likelihood and consequences of conflicts occurring. This generally involves layouts that emphasise the give way requirements.

2.2.1 Phasing and signal hardware

It may be appropriate to partially separate conflicting movements through phasing, to reduce the extent of filter turning and guide motorists to filter turn correctly:

Cycle head starts

One example is providing a 'cycle head start' (Figure 1), whereby a green cycle signal is displayed a few seconds before the green signals for adjacent general traffic, which enables cyclists to start progressing through the intersection first, and makes them more visible to motorists.

Figure 1: Head-start for cyclists, Western Ave, Boston

Partial protection using turn arrows

In New Zealand, assuming some underlying legal aspects are clarified (see Wilke, 2014) it will be possible to use a red turn arrow to hold back conflicting turning vehicles for an initial period, while cyclists and general traffic progress on a green disc. When the red arrow is extinguished, turning motorists may filter turn across the cycle movement. At this point, it is likely motorists will be aware of the potential for cyclists to be present, but also that most cyclists will have already progressed through the intersection. Note that the USA traffic signal regulations include the principle of 'conservation of arrows' meaning that if an arrow signal aspect is used for a particular movement, there must be an arrow (red, yellow, or green) displayed at all times.

Flashing yellow turn arrows

A flashing yellow arrow can be used to emphasise the requirement for turning drivers to give way to cyclists travelling straight ahead (Figure 2). A flashing yellow arrow pilot programme is currently being undertaking in New York, whereby, during the time a green bike light is displayed, a red arrow is initially displayed (for a period of partial protection) followed by a flashing yellow arrow (i.e. filter turning) (NYC DOT and Vision Zero, 2016). While New Zealand regulations allow for the possibility of extinguishing a red arrow without displaying another arrow, and therefore do not have the same restrictions of 'conservation of arrows' as in the USA, it might be worth considering flashing yellow arrows simply to make drivers more aware of the need to look for and give way to cyclists.

Figure 2: Flashing yellow arrow with green bike light, 2nd Ave, New York City

Layout

Where filter turning of vehicles through cycle movements is allowed, clearly defining the intended path of cyclists through the intersection can help prevent conflict. Markings through the intersection can help to guide cyclists through the intersection, and alerts motorists to the general possibility that cyclists may be present and the specific location of where to expect them. NACTO

(2014) recommends marking styles such as dotted lines, ‘elephant’s feet’, ‘shared lane markings’ (i.e. sharrows) and coloured surfacing. In addition, the Ontario Traffic Manual (MTO, 2013) suggests dashed line markings.

Hook turn boxes (see section 2.1.2) may also be appropriate at intersections with filter turning of motor vehicles through cyclists, to provide for the long turn for cyclists.

2.2.2 Safety

The likelihood and severity of crashes between cyclists and filter turning motor vehicles across a separated cycleway depend on:

- Volume of turning vehicles
- Proportion of heavy vehicles
- Volume of cyclists
- Users’ understanding of the give way rules
- Intervisibility – especially motorists’ ability to see cyclists
- Motorists’ awareness of possible presence of cyclists (in particular concerning cyclists in the contraflow direction)

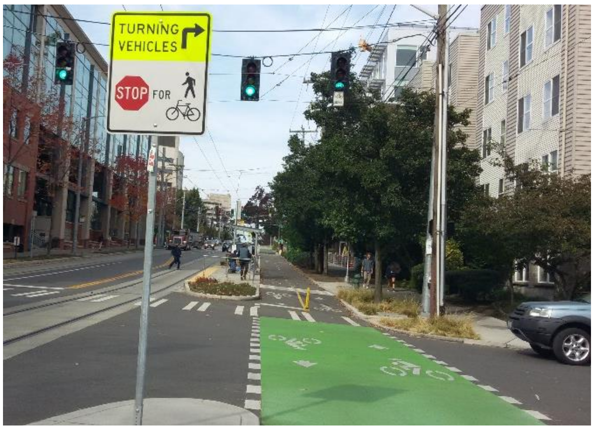

Figure 3: One variation of sign used for filter turning in USA, Broadway, Seattle

Cycle head starts, partial protection and flashing yellow turn arrows (discussed previously) are possible methods of increasing driver awareness; others include various marking treatments, flashing yellow beacons (as used at some unsignalised intersections in North America, and some signalised intersections in Germany), and informational / regulatory signage (e.g. Figure 3).

It may be possible to reduce the volume of motor vehicles turning across the cycleway by decreasing the attractiveness of the movement (in terms of efficiency and accessibility) and / or increasing the attractiveness of turning at adjacent intersections. If this approach is taken, it would be useful to have a target volume to aim for or, conversely, a threshold volume above which filter turning is no longer considered appropriate – this is discussed further in section 3.5.

The severity of conflicts that do occur is largely dependent on the impact speed and vehicle weight. Treatments to reduce the speeds of motor vehicles turning across a cycleway can improve safety not only by reducing the severity of conflicts that do occur, but also by reducing the likelihood of conflicts occurring because if a motorist is travelling more slowly, they are more likely to see a cyclist and more likely to be able to avoid the collision. These treatments could include tighter corners and speed platforms / humps.

Of the seven cities visited, examples of signalised intersections with filter turning across the cycleway were sighted in Seattle, Vancouver, Denver, Toronto, Boston, and New York. Chicago DOT prefers using full protection, or mixing zones if this cannot be achieved, but is currently looking into allowing filter turning at approaches with a shared through and turn lane (Roseberry, 2016, pers com).

2.3 Lateral shift: cycleway transitions to the inside of turn lane

The conflict between short turning vehicles and cyclists travelling straight through can be eliminated from the intersection itself by shifting the conflict location upstream, i.e. on the approach to the intersection (e.g. Figure 4). This involves a transition point where the two trajectories cross.

2.3.1 Phasing

At the intersection, it is not necessary to operate turn arrows and / or cycle signals, but there is flexibility to do so if it would be more efficient to operate these movements independently of the general through traffic.

2.3.2 Layout

It is important to convey to users that there is potential for conflict and who is required to give way to whom. It is preferable that the cycle lane has a straight alignment, to emphasise that it is the motorist who crosses the cycle lane, and the need to turn will reduce the motor vehicle speed. Coloured surfacing, dashed cycle lane edge lines and sharrows are suitable marking treatments. It may be possible to use flexible delineator posts to separate the storage section of the cycleway after the transition.

Figure 4: Separated cycleway transitions to cycle lane between through and right turn lanes, Lawrence St, Denver

2.3.3 Safety

There is conflicting evidence and opinions about the safety of these layouts.

When considering intersections with cycle lanes (not separated cycleways) in New Zealand and Australia, Hughes, Turner, Singh, et al. (2011) found that sites with exclusive left turn lanes are much safer for cyclists than those with a shared through and left turning lane. The project manager of this Austroads research report later went on to analyse the data further and concluded that addressing the conflict between left turners and cyclists on the approach to the intersection is four times safer than addressing it at the intersection (Hughes, 2014, as cited in NZ Transport Agency, 2016). The theory is that the cognitive demand on road users is lower at the midblock than at the intersection, and therefore drivers are more likely to look for, notice and give way to cyclists.

However, Wagenbuur (2011) maintains that the Dutch previously used this approach but found that it was unsafe. This was due to the angle at which motorists cross the cycle lane to access an auxiliary right (NZ: left) turn lane which means motorists have to look over their right shoulder (NZ: left) and through their vehicle to see a cyclist. As a result, the Dutch converted back to retaining cycle facilities in a kerbside position at intersections, and attempted to make these safer through the design of 'Dutch' or protected intersections.

Roseberry (2015), during a webinar on intersections and protected bike lanes, identified that the MUTCD design based on this principle does address the conflict on the approach to the intersection and implies that it works well for cycle lanes. However, Roseberry considers that "forcing" this design on a protected bike lane can create an undesirable situation – what he calls a "double weave" whereby through bicyclists and right (NZ: left) turning motorists must cross. This is uncomfortable for bicyclists as they have to look over their shoulders and merge. Roseberry considers that this is just "moving the conflict up" rather than addressing it. Thus, Roseberry identifies "keep bicycle kerbside if possible" and "mitigate turn conflicts at or near intersection" among design goals for signalised intersections.

2.4 Mixing zones

A mixing zone is a lane shared by vehicles making the short turn and cyclists who may be turning or travelling straight through.

Figure 5: Mixing zone, Smithe St, Vancouver

2.4.1 Phasing

Mixing zones should not be used where the turn movement is operated independently of the adjacent through movement, i.e. a lead or lag turn, as cyclists waiting to travel straight ahead will be in conflict with turning vehicles in the same lane.

2.4.2 Layout

A number of different mixing zone layouts have been identified in the guidance and at study tour sites; the author has identified two key components: the entry into the mixing zone (for both vehicles and cyclists); and the section of mixing on the approach to the intersection.

The entry point, where vehicles and cycles enter the mixing zone, should be designed to communicate to users the change in environment and hierarchy (e.g. ‘first-come, first served’, or ‘motorists give way to cyclists’). Entry designs range from drivers simply crossing into the mixing zone as they would change into a turn lane (e.g. Figure 5) to a more detailed treatment with give way markings and defined channelisation (e.g. Figure 6).

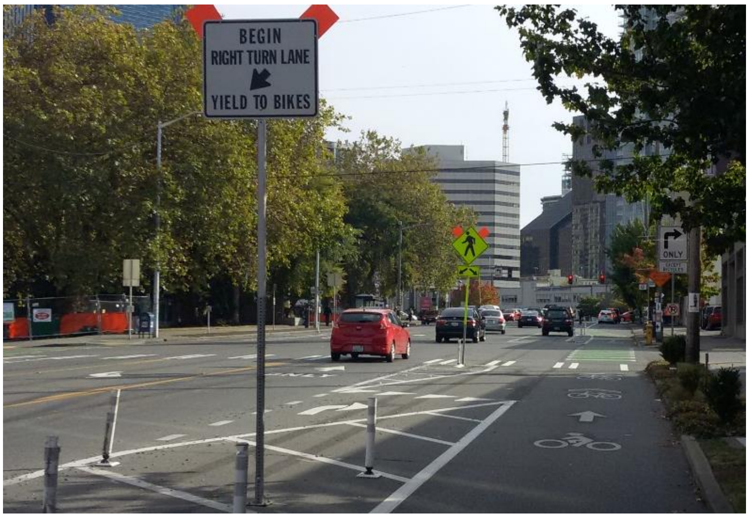

Figure 6: Mixing zone, Dexter Ave, Seattle

Within the mixing zone, sharrows are generally used to indicate the preferred cycling position. Many mixing zone designs reviewed (especially in New York) retain the cycling position on the kerbside. Others position cyclists to the non-kerbside side of the lane (e.g. Figure 7). Finally, a few designs, including those presented in MassDOT (2015), involve a central cycling position, thus encouraging single-file lane use (e.g. Figure 5); it is the author’s opinion that this is generally the most appropriate configuration. The width of the lane also influences whether cars and bikes can travel side-by-side, or whether single-file use is necessary.

2.4.3 Safety

The main principle behind mixing zones is that turning vehicles travel at speeds that are slower and therefore more equitable with cycling speeds, thus enabling the two users to mix safely. However, there is debate over their appropriateness. Mixing zones are specified in the ‘treatment toolbox’ in the recent study of left[2] turning crashes with pedestrians and bicyclists in New York City (NYC DOT, et al., 2016) but, unlike other treatments, the report doesn’t specify the crash rates for mixing zones; representatives have indicated that the crash histories for mixing zones aren’t as good as for other treatments and that this treatment is still a work in progress (Carmona, 2016, pers com).


Figure 7: Mixing zone, Simcoe St, Toronto

Monsere, et al. (2014) studied two different mixing zones from Portland and San Francisco; when a car was present, 63% and 30% of cyclists rode in the intended alignment (down the centre of the mixing lane) at each of the respective locations. The Portland mixing zone had ‘give way entry markings’ (similar to the vehicle entry point in Figure 6, but note the sharrows were central) whereas the San Francisco mixing zone involved a direct lane change (similar to Figure 5).

The City of Chicago designs mixing zones so that the speed of vehicles is 20 mph (32 km/h) at the point where they start mixing with cyclists (Roseberry, 2015); the MassDOT (2015) guidance

[2] Note that New York City has an extensive one-way network, which means the left turn is often a short turn, but with the driver on the kerb side of the vehicle, making it different to the short turn in New Zealand.

concurs with this. FHWA (2015) recommends that mixing zones may be most effective at intersections with 50-150 turning vehicles in the peak hour. Roseberry (2016 pers com) considers it would be useful to establish a threshold based on the cross-product of vehicle and cycle volumes.

2.5 Protected intersections

Figure 8: Protected intersection, Washington St & Franklin St, Chicago

Protected intersection is a term for a package of phasing and layout aspects that seeks to minimise delay to all users whilst also minimising potential for and consequences of conflict. This is often known as a 'Dutch intersection' treatment, given its use in Holland. While protected intersections are generally considered to be 'new' to North America, Alta (2015) notes that a report on *Bikeway Planning Criteria and Guidelines* from 1972 "included a variant of protected intersection design", described as the "recommended intersection design for intersecting arterial roads with bikeways on each road".

2.5.1 Phasing and layout

Falbo (2014), one of the initial proponents of introducing protected intersections to the USA specified four main elements to protected intersection design: corner refuge island, advanced stop line for cyclists, setback bike and pedestrian crossing, and cycle-friendly signal phasing. MassDOT (2015) adds: pedestrian crossing of separated cycleway, and pedestrian kerb ramp; and Roseberry (2016 pers com) further emphasises the importance of designing the cycleway approach to enhance cyclist awareness. Exact configurations depend on the directional provisions at the intersections for general traffic as well as cycling: Figure 8 gives an example where the two intersecting streets involve one-way cycleways on one-way streets, thus only one of the four intersection corners have received the full 'protected intersection' treatment.

Falbo (2015) emphasised that the spatial requirement of accommodating a protected intersection comes down to being able set the cycleway back from the intersection by about one car length. He considers this is generally achievable if a particular intersection approach has a parking lane, a separated cycleway of standard width, and an ample footpath.

2.5.2 Safety

While many theories and some anecdotal evidence on the safety benefits of protected intersections have been identified, the author has not identified any scientific studies of protected intersections with empirical evidence of crashes or conflicts. America's first protected intersection, in Davis, California, was only installed in August 2015 (Andersen, 2015); sufficient time has not yet elapsed to conduct a thorough safety analysis.

Roseberry (2016 pers com) explained that Chicago is moving towards using protected intersections and considers the combination of phasing and layout aspects makes them inherently safer; even though drivers may still run a red light, they'll be doing so at a slow speed and with better visibility of cyclists that the chances and severities of crashes are much lower.

3 POSSIBLE APPLICATIONS

This section discusses some of the challenges and opportunities to applying the treatments previously presented in New Zealand.

3.1 Is there a place for protected intersections in New Zealand?

At present, it seems the biggest question regarding introducing protected intersections to New Zealand is whether or not we'll have the space to fit them into the existing street network. Falbo

(2015) suggests that space can be found to accommodate the corner islands by removing parking or general traffic lanes, but in New Zealand, parking lanes generally already terminate before the intersection and it's often not a feasible option to remove a general traffic lane.

The problem of finding space occurs in North America too, and is perhaps one of the reasons that there aren't more examples of this treatment. Of the six protected intersections that existed in North America at the end of 2015 (Alta, 2015), only two involved protection at all four corners of the intersection; the others (including the Franklin / Washington example from Chicago cited in section 2.5.1) involve one main corner where two cycleways intersect, possibly with some treatments on the adjacent corners for approach or departure. Engineers from Vancouver have indicated they are not sure it would be possible to fit a protected intersection at the intersection of two streets with a standard Vancouver road reserve width of 20 m (Rawsthorne, 2016, pers com).

Even so, the author is aware of some scheme designs currently being developed for New Zealand locations where it appears that it will be possible to accommodate a form of protected intersection, showing this treatment shouldn't be dismissed altogether. Also, while it may be difficult to accommodate protected intersections into existing streets, this treatment should be considered when planning greenfield development sites.

3.2 Hierarchy of provision

Vancouver's hierarchy of preference (Rawsthorne, 2016, pers com) choosing between 1-way and 2-way separated cycleways along the midblock, is:

1. 2 x 1-way separated cycleways (i.e. one on either side of the street)
2. 2-way separated cycleway on a 1-way street, to the right [Vancouver: left] of general traffic
3. 2-way separated cycleway on a 1-way street, to the left [Vancouver: right] of general traffic
4. 2-way separated cycleway on a 2-way street

Note that this hierarchy must be considered in conjunction with various site-specific factors, which may affect the chosen outcome. Also, one-way streets are more common in North America than New Zealand, which effectively limits the opportunities available on the hierarchy. Ward, Nicholson and Koorey (2013) note that one-way streets have a number of benefits for cyclists compared with two-way streets.

While it involves midblock facilities, the above hierarchy has been established because of the implications each combination has on the intersection design and safety of operation. Two-way cycleways involve cyclists travelling in the contraflow direction (i.e. relative to adjacent motor traffic), which involves greater risk than with-flow cycling (Foran, 2003). Furthermore, it is particularly difficult to design an intersection of two two-way cycleways in a way that all possible turning movements for people on bikes are safe, legible and intuitive (Rawsthorne, Anderson and Davidson, 2016, pers com).

In terms of the intersection treatments discussed, there is no set hierarchy, rather the preferred treatment should depend on traffic volumes and the types of conflict possible. As the level of conflict increases, so too should the level of protection. Section 3.5 proposes thresholds that may be applied to choose between the various categories.

3.3 Mixing zone configurations

A form of mixing zone is currently in use in New Zealand and has been for some time. Newman (2002) included two layouts involving mixing zones in a study of advanced stop facilities for cyclists. The existing examples involve cycle lanes (i.e. not separated cycleways) feeding into kerbside lanes which are intended for left turning vehicles and cyclists travelling straight ahead.

Having observed (albeit not thoroughly studied) the operation of several mixing zones in several cities, the author has reservations regarding mixing zones that guide cyclists to continue in a kerbside position. Such treatments may be preferable to simple kerbside cycle lanes if they involve more delineation and measures to slow vehicles down, but they do not sufficiently address the conflict between kerbside cyclists and turning vehicles. The author suggests that mixing zones should be sufficiently narrow to oblige cyclists and motorists to travel at single file, with centrally-located sharrows to emphasise this. The author is also in favour of marking a left turn arrow to formally restrict the vehicles that use the lane[3].

3.4 What type of approach treatment – transition or mixing zone?

Mixing zones and transitions both require vehicles to be travelling at equitable speeds compared with cycling speed; the further a transition point is from the intersection the harder this is to achieve. Transitions require more width at the limit lines, as there must be a full-width cycle lane as well as a turning lane, whereas a mixing zone designed for single-file sharing must be suitably narrow (although, this will only be for a short length, prior to which it may be necessary to have a deceleration lane for vehicles adjacent to a kerbside cycleway).

Monsere, et al. (2014) interviewed cyclists at three transitions and two mixing lanes and asked them to agree or disagree with the statement "I generally feel safe when bicycling through the intersection." At the sites with transitions 64-74% agreed whereas at the mixing zones 79-84% agreed with the statement. Note that at the site with full signal protection, 92% of cyclists agreed.

Overall, either treatment, if designed appropriately, could be appropriate in a location where traffic speeds can be sufficiently reduced and turning volumes remain reasonably low. Transitions are commonly used for cycle lanes in New Zealand, but some adaptations would be necessary to transfer this to a layout with separated cycleways. The author recommends also trialling mixing zones (designed according to the principles outlined in section 3.3) in New Zealand.

3.5 Thresholds

Having identified a toolbox of treatments, it is necessary to identify the appropriate situations in which to apply each of them. Figure 9 involves an indicative treatment framework developed by the author to facilitate further discussion. Effectively, two key thresholds are required:

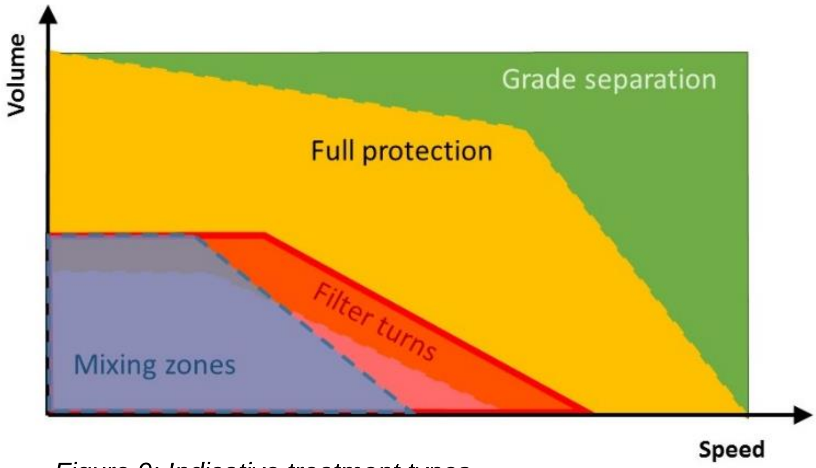

Figure 9: Indicative treatment types

3.5.1 Mixing zone / transition vs filter turning

Both of these treatment groups have a recommended upper limit of 150 veh/h, albeit from different guidance sources; FHWA (2015) for mixing zones, whereas MassDOT (2015), Vancouver (Rawsthorne, 2016, pers com) and CROW (2007) concur on the threshold for filter turning. Oddly, none of these sources gives guidance for both types of treatments. More research and trialling is required to determine the appropriateness of this treatment type and a suitable threshold volume for New Zealand.

While the recommended volumes may be the same, the distinction between the two groups occurs at higher speeds where it is not possible to slow vehicles down on the approach (often due to the lack of cross-sectional width to provide some sort of deceleration lane). In such locations, it may still be possible to control the speeds of vehicles filter turning across a kerbside separated cycleway; drivers have to slow down at the intersection to make a short turn and this can be

[3] To comply with the current Road User Rule, such lanes are currently left unmarked, but it a rule change to allow cyclists to travel straight ahead from a marked left turn lane is currently being considered (NZTA, 2016).

augmented by various treatments such as the prolongation of the separator, markings etc.

3.5.2 Filter turning vs full protection

As mentioned in above, examples of filter turning were found in most, but not all, cities visited.

In Vancouver, filter turning is considered an option at locations with up to 150 veh/h turning across the cycleway. This threshold was derived empirically when the city was first considering protected bike lanes; decision-makers looked at a number of comparable sites where engineers had chosen to ban turns across a cycle lane based on professional judgement and it was observed that filter turning was generally allowed up to 150 veh/h (Rawsthorne, et al., 2016, pers com). Subsequently, Seattle has adopted the same value (Chang, 2016b, pers com). But representatives from both cities acknowledge that they haven't yet gone back to assess their protected bike lanes and determine whether this is really the 'right' value for the North American context. Both locations apply the same threshold to two-way cycleways as well as one-way cycleways.

The MassDOT (2015) separated bike lane guide has been recognised by practitioners throughout North America and abroad as a leading manual for planning and designing separated cycleways. The guide sets out very clearly some rules about where turns across cycleways should be protected, based on the directions of the cycleway, roadway, and turning volumes. The highest turning volume allowed is 150 veh/h, for a short turn across a one-way cycleway, with lower limits for combinations that are considered riskier (MassDOT, 2015, 106-107).

The project manager for the MassDOT guide explained that the 150 veh/h threshold is based on CROW (2007), the renowned Dutch design manual (Rabito, 2016, pers com). Engineers and planners from Vancouver also pointed to the connection with CROW (Rawsthorne, et al., 2016, pers com). However, it seems this interpretation of CROW (2007) is incomplete, as CROW specifically recommends against allowing filter turning across a two-way cycleway, reasoning that "some cyclists would appear from an unexpected direction". By this reasoning, there may be some one-way cycleways which would also be unacceptable if they involve cyclists coming from the 'unexpected' direction.

At lower volumes especially, allowing filter turning can be safer than protected phasing (see section 2.1.3), due to the risky, non-compliant manoeuvres that some users may undertake if they have the impression of being held at a red light for no reason. Filter turning also has efficiency benefits when opposing movements are unsaturated. Thus, the author considers that there will be locations in New Zealand where it would be beneficial to allow filter turning across separated cycleways. However, there is not yet enough substantial evidence to automatically adopt the upper threshold of 150 veh/h as is used in many other locations. The author suggests starting at locations with lower turning volumes, with subsequent monitoring and evaluation to eventually determine an appropriate threshold. The ultimate goal should be to establish a variable threshold based not solely on motor vehicle volumes, but also including cycle volumes and speed.

New Zealand's *Cycling network guidance* (NZ Transport Agency, 2016) treats cycleways involving cycling in the contraflow direction (i.e. the opposite direction to adjacent traffic) with caution. Foran (2003) showed that the crash multipliers used in various countries are 2.5-3.5 times greater for contraflow cycling compared to with-flow cycling. Therefore, the author does not recommend allowing filter turning across contraflow cycleways in New Zealand, at least until a significant culture shift in favour of cycling has occurred.

4 CONCLUSIONS

Some North American cities have made impressive advances in installing separated cycleways with specific treatments at signalised intersections. The lessons learned from the study tour (both in terms of positive experiences and also less-successful attempts) can be applied to New Zealand. That said, the experience also affirmed that New Zealand is ahead in some ways (for example a longer history of using cycle signals and greater use of advanced stop facilities for cyclists).

While it will often not be possible to install 'protected intersections' in New Zealand, other treatments could be considered to offer some protection to cyclists at signalised intersections.

Consideration should be given to allowing filter turning in some locations, although not across two-way or contraflow cycleways, as was witnessed in some locations. Flashing yellow arrows should be trialled as a way of improving motorist awareness and compliance with the requirements for filter turning, and some sort of advisory signage would be preferable.

Mixing zones are a valuable option in the toolbox, for locations where vehicle speeds can be slowed to 30 km/h or lower. However, the author strongly recommends a departure from the classic North American mixing zone design which keeps cyclists on the 'wrong' side of turning vehicles. Transitions may also be appropriate, although particular care should be taken to ensure that these designs retain the degree of actual and perceived safety required for the intended cycling target audience.

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