Accommodating Cyclists at Signalised Intersections

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Glossary of Terms

ASB	**A**dvanced **S**top **B**ox. This is an area, located between the limit line of a traffic lane and the pedestrian crosswalk lines, designated for cycle storage at traffic signals, i.e. cyclists can queue in front of a traffic lane.
ASL	**A**dvanced **S**top **L**ine. Cycle lane projecting past the limit line of an adjacent traffic lane, creating an advanced stopping position for cyclists.
Cycle Facilities	A general term denoting provisions made to accommodate cyclists. This can include both on and off road and end of journey facilities.
Cycle Lane	A portion of the carriageway that has been designated by road markings, signs or pavement surfacing for use by cyclists. By definition always on-street.
Cycle Path	Pathway segregated from the roadway, e.g. by a kerb, or completely away from the road corridor.
Signal Phase	A certain arrangement of the traffic lights at an intersection so that some movements can go and some are stopped. When the lights change (i.e. different movements can now go/stop), a new phase starts.

Abstract

This paper explores how cyclists can be accommodated at signalised intersections using specific cycle facilities and creating a more cycle-friendly environment by speed control.

Guidance is given where cycle lanes should be placed and the exceptions to the rules are explored. Advanced Stop Lines should be the standard treatment for cycle storage at the limit line, but Advanced Stop Boxes can sometimes be more appropriate. Slip lanes and bypasses for cyclists can overcome some safety problems and increase the level of service. Experienced cyclists can most effectively be assisted with turning right by design measures on the intersection approach, whilst hook turns and special signal phases are available to support less competent cyclists.

Cycle paths are complex to integrate into the operation of signalised cross intersections. Current New Zealand practice does not appear to be supported in law and a review is suggested

1 Introduction

Most cycle crashes happen at intersections. Land Transport NZ injury crash data for 2000-2004[1] show that 59% of reported urban cycle crashes are intersection crashes. Emphasis should thus be put on retrofitting intersections with some priority and this paper discusses how to accommodate cyclists at signalised intersections. It should be read in conjunction with the paper *Designing Signalised Intersections for Cyclists* (Wilke, 2002). The 2002 paper covers some more basic concepts.

This 2005 paper discusses some of the underlying principles of how cycle lanes can support cyclists at signalised intersections. Special features like hook turns, advanced stop lines and advanced stop boxes are examined. Signal phases for cyclists are looked into. It is explored how cycle paths leading up to a signalised intersection should be incorporated into the operation of the signals. Efforts have been made to keep the terminology relatively straightforward where possible, even to the layperson.

[1] Data from the Crash Analysis System (CAS) database, 2000-04.

2 Cycle Lanes at Signalised Intersections

2.1 Cycle Lanes – for which Movement?

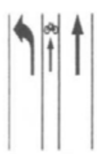
Cyclists may turn left or right, or proceed straight ahead at traffic signals. A common question is: which of these three movements should be assisted by a cycle lane? As space is at a premium at intersections, often only one cycle lane can be fitted per approach, so a choice has to be made.

A common design principle is that lane sharing is not recommended when the speed differential between cyclists and motorists becomes too large. The Dutch design manual recommends separation (or at least a spacious lane profile) rather than lane sharing for 85th percentile speeds of motorised traffic over 30 km/h (*CROW*, 1993, Figure 4.3). Equivalent advice in NZ manuals is that lane sharing is possible at speeds up to 50-60 km/h at low volumes (LTSA, 2004, Figure 6.1).

Through-lanes at urban signalised intersections generally have speeds at which lane sharing is not recommended, whilst speeds in the turning lanes are relatively lower as motorists prepare to turn. Hence, the most common choice for the location of a cycle lane at intersections is for the through movement.

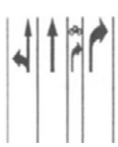
In some cases, the number of right turning cyclists is far higher than the number of through cyclists. In that case, it could be considered to assist that movement instead, or maybe there is enough room to provide a second cycle lane.

2.2 Where to Place Cycle Lanes



The most desirable layout is achieved when it is possible to separate the left turn and through car lanes. In that case, the cycle lane is to be placed between the two car lanes. A through cycle lane should never be placed to the left of an exclusive left turning lane.

A less desirable layout is achieved when the left and through movements have to share a lane, as the kerbside cycle lane places through cyclists to the left of left turners. This situation is often unavoidable when it is considered not possible to find the required width to give left turners their exclusive lane. In this case it is essential to provide some form of advance cycle storage at the limit line so that left-turning vehicles can see non-turning cyclists.



If right turning cyclists are to be accommodated with their own lane, then the cycle lane would generally be placed to the left of the right turning lane for the cars. Similarly, if left turning cyclists are to be accommodated with a cycle lane (e.g. in a left turn slip lane), then the cycle lane would generally be to the left of the car lane.

That said, the behaviour of cyclists needs to be observed, as the cycle facility should support the manoeuvres that cyclists wish to undertake. For example, at one T-intersection, it was found that most cyclists turning left from the stem of the T would do so from the right hand side of the left turning lane. Their reason for doing so was that they intended to turn right at the next downstream intersection. Hence, the cycle lane for left turning cyclists was placed to the right of the left turning lane. Another example of unusual cycle lane placement is where right turning lanes are adjacent to a solid median. Here, cyclists on the approach to those lanes place themselves close to the median island. This behaviour can be supported by an approach cycle lane placed against the median.

3 Treatments at the Limit Line

There are two common facilities available for cyclists' storage at the limit line – an Advanced Stop Line (ASL – Figure 1) or an Advanced Stop Box (ASB – Figure 2).

3.1 Advanced Stop Line

At an ASL, the limit line is 2m ahead of the adjacent limit line for motorists. An ASL allows cyclists to be seen by left-turning vehicles, especially trucks. An ASL is desirable even at mid-block pedestrian signals, because there is a risk that a driver will turn left into a private entrance just after the signal. An ASL should also be used next to a slip lane island, as the driver in the through lane might have a change of mind and wish to turn left instead.

Hence, an Advanced Stop Line is strongly recommended as the default layout for all cases where a limit line is placed in a cycle lane, unless an Advanced Stop Box (ASB) is provided instead.

Figure 1: Advanced Stop Line

3.2 Advanced Stop Box

An ASB is an area provided for cycles ahead of the stop line for motor vehicles and spans across the full width of one or more traffic lanes. The distance between the motor vehicle and cycle stop lines is between 3 and 5 metres. An approach cycle lane usually leads into an ASB, but ASBs are also used as standalone elements.

ASBs provide high cycle capacity and allow a faster cyclist to overtake a slower one. These facilities highlight the presence of cyclists and encourage drivers to be more aware of cyclists. ASBs can be used for cyclists to reach their turning position from a through cycle lane. The question is then how many lanes should ASBs go across so that cyclists can reach that turn position?

Austroads (1999) makes reference in section 5.4.2.3 to Sustrans (1997), from which designers have been known to conclude that an ASB can go across three traffic lanes. The advice given in Sustrans (1997) reads "*Advanced Stop [Boxes] have proved successful for vehicle flows up to 1,000 per hour in one direction and with up to three lane approaches. However, on the National Cycle Network, they will normally be appropriate for right-turning cyclists on approaches with one or two lanes.*" So the Sustrans recommendation is for providing Advanced Stop Boxes across two lanes only.

Figure 2: Advanced Stop Box

Much of the guidance in the British Sustrans manual is based on experience in continental Europe. It would be fair to say that many of the countries where such experience was obtained (e.g. Holland, Germany, Denmark) have a culture where drivers are much more accepting of cyclists than in Britain. Hence the statement that whilst ASBs have been successfully operated at intersections with three approach lanes, this is not appropriate for the National (i.e. British) Cycle Network.

The culture of New Zealand drivers with respect to interacting with cyclists is at best only as good as in Britain, so there is at least the same 'cultural gap' to continental European countries. From this the authors conclude that the advice in Sustrans of providing ASBs in front of no more than two lanes should equally apply in New Zealand.

The authors regard ASBs as useful in some circumstances, but don't see them as solving all problems that cyclists may experience at signalised intersections. Designers should exercise caution and obtain advice either from Road Controlling Authorities that have installed ASBs or from experienced peers.

One useful application for an ASB is shown in Figure 3. The signals operate an exclusive left turning phase, and straight through cyclists have nowhere safe and legal to wait. Assuming that a through cycle lane cannot be retrofitted due to insufficient carriageway width and the exclusive left turning phase needs to be operated, then installing an ASB in front of the through lane would be the next best option.

Another useful application is where there are traffic lanes with combined turning movements (e.g. straight-through and right-turning) and a turning cyclist to the left of this lane is in danger of being cut off by straight-through traffic. Although the ideal solution is to eliminate combined traffic lanes where possible, alternatively an ASB in front allows cyclists to take their position in the traffic queue.

4 Supporting Cyclists with Turning Left

4.1 Speed Control

Turning left at a signalised intersection is one of the easier manoeuvres for cyclists, but designers can nevertheless aim for an improved cycling environment by controlling motor vehicle speeds.

The most effective tool available for speed control is to reduce the length of the left turning lane, so that drivers have to decelerate on the approach to the lane in preparation for their turn. However, the required length of the lane is also a function of the expected queue length, and a turning queue over-spilling into a through lane can create all sorts of problems, including for cyclists.

Figure 3: Potential application for ASB in front of through lane

Another speed control measure is to minimise the corner radii. This also helps when installing tactile paving at a pedestrian crosswalk that is in compliance with New Zealand guidelines (LTSA, 2003). Turning truck movements do need to be accommodated, though, but this can often be assisted by setting back the limit line of the right turning lane in the side street, allowing a truck to swing wide.

Yet another tool is to minimise the width of the turning lane, i.e. maximising the side friction. Some turning lanes at signalised intersections in Christchurch are only 2.75m wide (measured from the kerb face) (Figure 4).

Figure 4: Narrow and short turn lane for speed control

4.2 Slip Lanes for Motorists

Where left turning motorists are given a lane separated from the rest of the intersection by an island, speed control is once again key on how cycle-friendly the facility will be. High entry angle layouts in accordance with Austroads Part 5 (Austroads, 1988, Figure 5.29) are generally safe layouts, but the cycle lanes across both the slip lane entry and departure should be highlighted by colour. Pedestrian crossings in the slip lane placed on a raised platform provide vertical deflection and are an excellent tool to further reduce speeds (Figure 5). Apart from the considerations for cyclists, the authors suggest that the vertical deflection of these crossings give motorists a constant reminder of their presence, thus increasing the willingness of motorists to give way to pedestrians.

At the other end of the scale, a free turn lane (i.e. where motorists turn into their own lane, with the geometry generally allowing a quick turning manoeuvre) encourages high speeds and

Figure 5: Pedestrian crossing on raised platform in slip lane

cyclists on the side street can be caught between lanes of fast flowing traffic at the slip lane merge. Some treatments have attempted to provide a crossing point for cyclists to get to the left hand kerb, but they usually violate the principle that the straight-through cyclist should have priority over the turning motorist. Well-designed high entry angle slip lanes are recommended for good intersection design. The most important consideration from a cyclist's perspective is that with a slip lane, the conflict between left turning motorists and cyclists can often be shifted from the central intersection area to an area on the approach. There, decision-making processes are far less demanding for motorists, reducing the likelihood of motorists making mistakes. Another benefit with slip lanes is that the central area of an intersection is more confined, making the intersection less daunting.

4.3 Off-road Treatments for Left Turning Cyclists

Sometimes, it may be beneficial to provide left turning cyclists with an off-road facility. This could be in form of a pathway and may be useful where this pathway forms part of a longer facility. In other cases, a slip lane for cyclists could be considered, for example if there is a squeeze point at the intersection itself. In either case, interaction with pedestrians must be considered.

Figure 6 shows a proposed cycle slip lane. Cyclists will be able to avoid turning left within the intersection, but use the left turn slip lane instead. This addresses the previous problem of getting squeezed at the corner kerb and provides a higher level of service, as they can turn regardless of whether the traffic lights are displaying green.

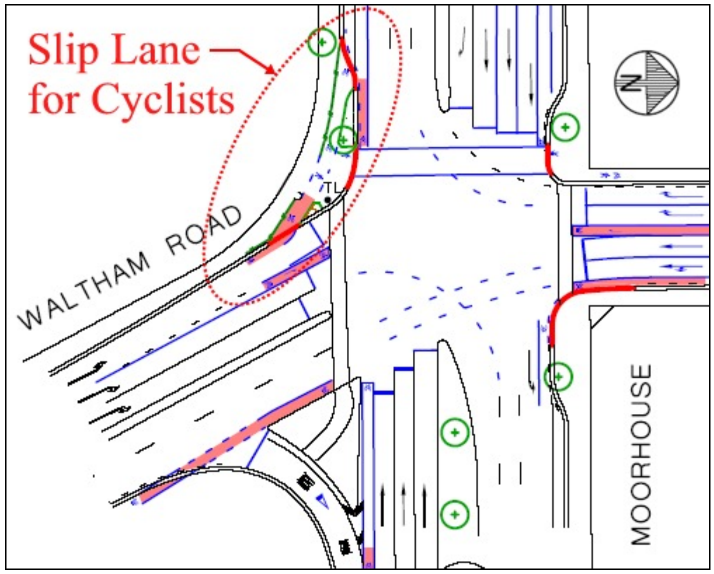


Figure 6: Slip lane for cyclists

4.4 Cycle Bypass at T Intersections

At T intersections, cyclists are sometimes not inclined to stop for a red light when they are travelling on the side opposite to the stem of the T, as they don't perceive to have a conflict with other traffic. Figure 7 shows the example of a bypass for cyclists. This increases the level of service for cyclists and avoids motorists becoming disrespectful of cyclists when they otherwise see them flouting the road rules (i.e. not stopping for a red light). Again, interaction with pedestrians must be considered.

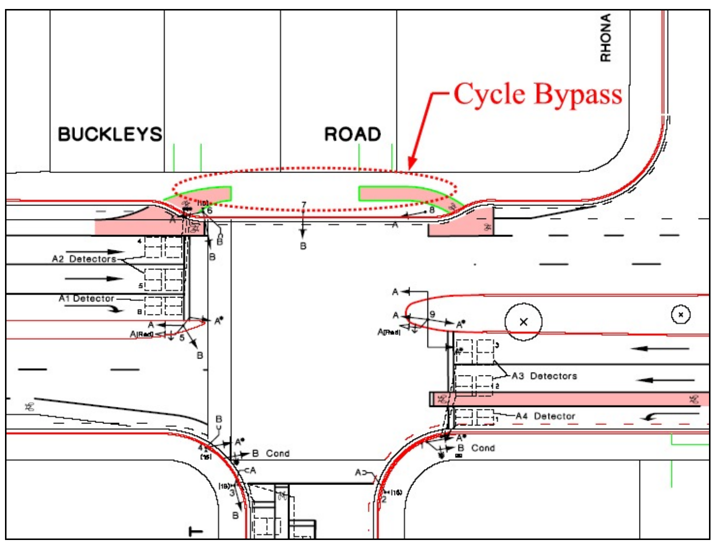


Figure 7: Cycle bypass at T intersection

5 Supporting Cyclists with Turning Right

5.1 Intersection Approach

Cyclists turning right generally face the task of having to reach the right turning lane by finding a suitable gap in the through traffic for changing lanes. Designers can assist with this by lengthening the area where cyclists change lanes and give them room when approaching the intersection. Typical design tools are flush (painted) medians or hatching that cyclists can cycle over. The busier the approach, the longer these facilities should be, as it might take a while to find a suitable gap.

In some cases, it may be possible to narrow a solid median by the width of a cycle lane prior to the right turning lane starting, creating room for right turning cyclists. Figure 8 shows an example of back-to-back right turning lanes, where room for cyclists have been created on both approaches.

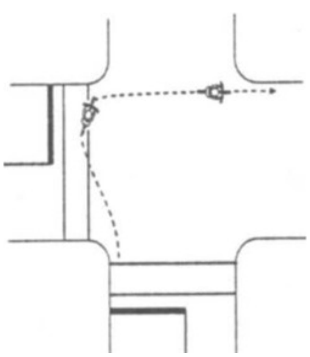
Where a flush median or hatched area is marked against a solid median island, a gap could be left for cyclists along the median, indicating the area that they should be using. Figure 9 shows an example of such a facility. Use of coloured surfacing would also help to highlight the area to cyclists and motorists alike.

Figure 8: Solid median set back

Figure 9: Gap for cyclists in chevron markings

An Advanced Stop Box (ASB) is an alternative tool for assisting with a right turn. See section 3.2 above.

5.2 Hook Turns



There are four potential problems for cyclists to overcome when turning right at traffic signals (Hughes, 2002):

- Merging across to the right lane.
- Is there somewhere safe to wait?
- Picking a gap in opposing traffic.
- Having turned, merging back to left.

A hook turn allows cyclists to turn right at an intersection in two stages avoiding all four problems. Stage 1 is to proceed straight through the intersection to the far side. Stage 2 is to then turn right at the same time as the side street traffic starts.

Hook turning is a common practice in many Asian countries. It is also used by motorists in Melbourne, Australia where trams occupy the central roadway. Whilst some cyclists execute hook turns by default, this can be assisted by providing some markings in the area where right turners can await their second stage movement. Markings are useful, as some intersection phasings are unsuitable for hook turns (e.g. an exclusive left turning phase of the side street, without the through traffic moving at the same time).

Figure 10 shows the official Land Transport NZ trial that Christchurch City Council is currently undertaking. It can be expected that the results of the trial will be reported in a ‘Traffic Note’ by Land Transport NZ in due course.

Figure 10: Christchurch Hook Turn trial

5.3 Special Signal Phase

A special signal phase can be used to allow cyclists to turn right from a position on the left kerbside. Cyclists request a signal phase during which all other traffic is stopped, allowing them to turn right from their kerbside position. There is one such facility operating in NZ (Figure 11). This treatment is suitable even for young cyclists, but some education of cyclists (e.g. at nearby schools) is desirable. Because it introduces an additional signal phase into the intersection, some spare intersection capacity is needed to provide the extra time for this.

Figure 11: Protected Right Turn for Cyclists and Sign Detail

5.4 Off-road Treatments for Right Turning Cyclists

Some T intersections require right turning road users to merge with through traffic. This can be challenging for motorists and almost impossible to do for cyclists. Figure 12 shows a short off-road facility that presents an alternative to the merge from the right for cyclists.

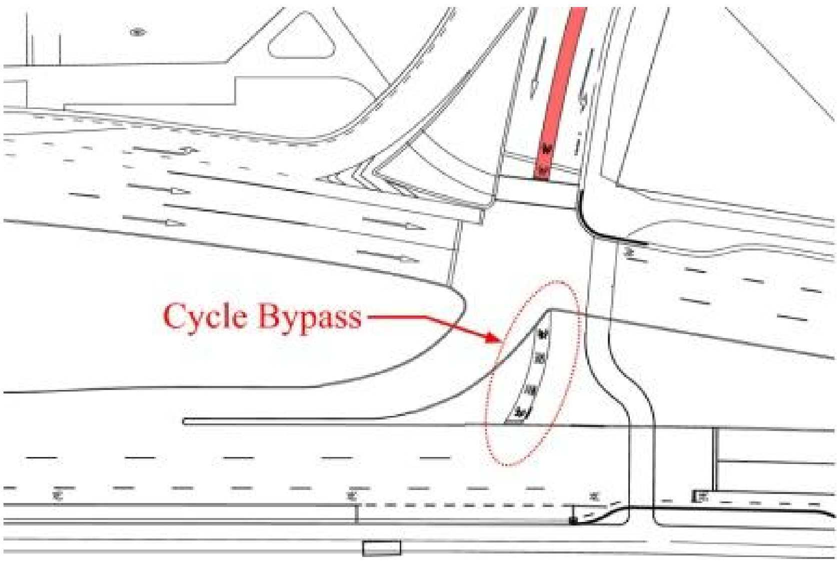


Figure 12: Cycle bypass to avoid merge from the right

6 Marking of Detector Loops

At most intersections, some signal phases are called only when a demand is detected by a wire “loop” placed under the road. As these loops detect ferrous (metallic) objects, the vast majority of cyclists can be detected if the loops are tuned to detect the relatively small amount of metal that a bicycle contains. However, detection will usually not occur if for example cyclists ride along lane lines, away from the loops. Generally the best locations for detecting bicycles are over the parts of the loop that are parallel or slanted to the direction of travel. More information about the theory and practice behind detector loops and cyclists can found in Koorey (2005).

In order to cater for cyclists during periods of low traffic demand, cyclists will need to know how they can call a green light. It is therefore required to tune all detector loops on non-arterial intersection approaches (i.e. approaches that get a green light only when a vehicle is present) to detect bicycles. Furthermore, the loops need to be marked according to *AUSTROADS* part 14 (1999, figure 5-9), with Figure 13 showing an example. This indicates to cyclists where the most sensitive location to be detected from is, so that they can position themselves there. It is necessary that an engineer who is used to biking in an urban environment specifies the position to be marked. If cycle-tuned detector loops are not possible, then provision of a push-button at the side of the road is an alternative solution. In both cases, some education of cyclists may be necessary to explain how to use the intersections.

Figure 13: Loop Marking

7 Cycle Path Treatments at Signalised Intersections

Integrating cycle paths that run alongside a road into a signalised intersection is rather challenging, as this case is not well accommodated in the transport legislation[2]. The treatments could be grouped as follows:

- The solution is legal, offers a reduced level of service for cyclists and a reduced level of service for motorists (the 'legal solution'), or
- the solution has no impact on the level of service for motorists, but requires cyclists to either dismount, or cross the side street without having the right of way over traffic turning into the side street (the 'common solution').

7.1 The Legal Solution

Where a cycle path forms part of a signalised intersection, it is necessary to incorporate the pathway into the signal programme to achieve a 'legal' solution. Whilst the Road User Rule appears to imply that filter turners have to give way to "cycles lawfully proceeding straight ahead" [3] (e.g. when those cycles are on a pathway parallel to the road), it was not the intention to give priority to cycles that are not on the roadway and this may well be modified during the legal review process currently undertaken by Land Transport NZ (B. Gibson, pers. comm.). Under the Traffic Regulations 1976, which were in force until February 2005, it was clear that cyclists did not have the right of way over turning traffic when entering an intersection from a parallel pathway.

It is necessary to provide separate signal lanterns for pedestrians and cyclists, rather than just have pedestrian signals, as pedestrian signals don't apply to cyclists. Furthermore, as discussed above, it is necessary to hold back turning motor vehicles with red arrow aspects for the full duration of the green period for cyclists, as cyclists not on the roadway do not have the right of way over turning motorists (unlike pedestrians).

Figure 14 shows a phasing diagram for a proposed signalised intersection with a two-way pathway along the south side. Left turning traffic into the side street can proceed in the A phase and may have to give way to pedestrians on the crosswalk when those are present. When cyclists want to get across the side street, this can happen during the A1 phase, during which the left turning traffic is held back. This means that cyclists have to be present at the beginning of the A1 phase. If they arrive during the A phase, when the left turners have already started, they will have to wait through the D and E phases for their signal (there is the option that the cycle phase is re-introduced once the left turning traffic has cleared the intersection and there is still sufficient through traffic remaining).

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[2] Note that this is different to the situation where a perpendicular cycle path crosses a road mid-block by means of traffic signals; this is a reasonably straightforward arrangement to implement.

[3] Extract from the Land Transport (Road User) Rule 2004, Section 3.2, (1) While a green signal in the form of a disc is displayed,—
(b) a driver facing the signal, including a driver turning left or right, must—
(ii) give way to pedestrians lawfully crossing or about to cross the roadway; and
(iii) give way to motor vehicles and cycles lawfully proceeding straight ahead:

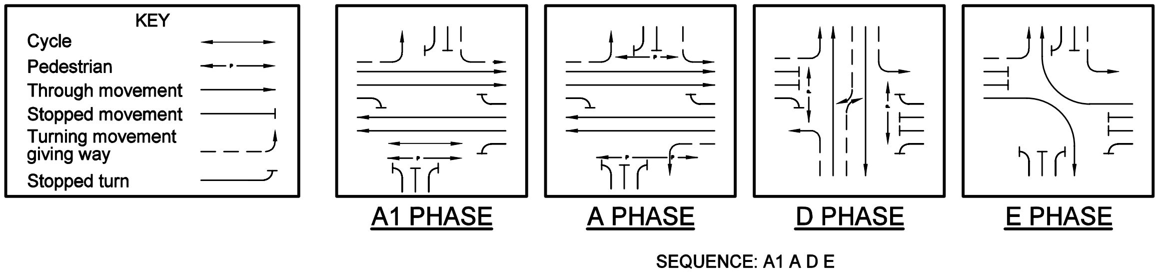

Figure 14: Proposed phasing incorporating pathway on south side of intersection

In comparison, Figure 15 shows the situation if cyclists are catered for on the carriageway. They can proceed straight ahead in an eastbound or westbound direction if they arrive at the intersection anytime during the A phase.

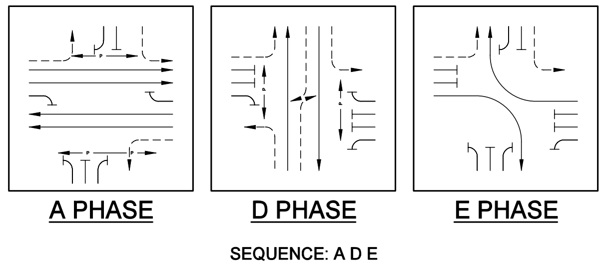

Figure 15: Proposed phasing with cyclists provided for on carriageway

The pathway may offer a more pleasant environment to travel on than the road, but the level of service is reduced at the intersection, as cyclists will have to wait longer on average compared to an on-street solution. This (and the safety ramifications) is why some overseas jurisdictions are recommending that off-road paths be returned on-road prior to intersections (SWOV 2004).

7.2 The Common Solution

The common solution of catering for cyclists on a pathway coming up to a signalised intersection is no specific provision in the signal phasing, with cyclists proceeding straight ahead on the pedestrian crosswalk at the same time as motorists turning across the cyclists' paths. As pointed out above, cyclists do not have the right of way over motorists in this situation and it can be assumed that this is not generally known by road users.

One of the bigger problems at signalised intersections is turning motorists failing to give way to pedestrians on a crosswalk. If motorists are unable to safely filter through pedestrians, what will happen when those motorists are expected to also give way to much faster moving cyclists?

Figure 16 shows a pathway crossing where left turning motorists are held back during the "green man" period for pedestrians, but they are allowed to turn when the crossing is clear (i.e. filter turning) during the pedestrian clearance phase (i.e. when the pedestrian signals are flashing red). Pedestrian signals legally do not apply to cyclists and cyclists may well choose to proceed into the intersection during the pedestrian clearance phase (i.e. on a full green, as those signals apply to them). This may well catch motorists by surprise, especially when cyclists are travelling with the flow of traffic as in this example, since motorists may not check behind before commencing their turn.

Figure 16: Pathway crossing at traffic signals

Figure 17: Pathway crossing at traffic signals

Figure 17 shows another example where filtering is allowed for both left and right turning traffic. This situation is potentially even more dangerous, as turning motorists might be more preoccupied with giving way to each other to observe people on the crossing.

The authors conclude that it is not a safe practice to allow motorists to filter turn through straight through cyclists, but the movements need to be separated by appropriate signal phasing. The authors do not know of a single signalised cross intersection in NZ where the 'legal solution' has been implemented, but motorists are allowed to filter turn in all cases (i.e. the 'common solution'). Road Controlling Authorities might be vulnerable to litigation if a coroner's court investigated such a 'common solution' and our advice is to review existing installations and to consider the full context before implementing further pathway solutions at traffic signals.

8 Conclusions

- Cycle lanes are most commonly provided for the through movement. Sometimes, a cycle lane for right turning cyclists is made available instead of or in addition.
- Whilst there are certain rules for the placement of cycle lanes at signalised intersections, the facility should support the manoeuvres that cyclists wish to undertake, which sometimes requires a departure from common solutions.
- Advanced Stop Lines are the most common storage facilities at signalised intersections. Sometimes, Advanced Stop Boxes could be more appropriate, but these should be used with caution and guidance should be sought from experienced designers. One of these stop line treatments should always be used.
- Speed control of motorists is an important design concept for creating cycle-friendly intersections.
- Slip lanes and bypasses for cyclists can improve their safety and level of service.
- Several design tools can be used on the approach to signals to accommodate right turning cyclists. In addition, hook turns and exclusive signal phases can cater for less experienced cyclists.
- Provisions need to be made to detect cyclists during low traffic periods, so that relevant signal phases can be demanded.
- Cycle paths at signalised cross intersections are a matter of concern, as their current operation does not appear to be supported in transport law. A review of current practice is suggested.

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