AUSTRALIAN
BICYCLE COUNCIL

Traffic Signal Features for Bicycles

Traffic Signal Features for Bicycles

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Abstract

This report summarises a review of national and international literature on traffic signal features implemented across the world to provide for bicycles.

While the literature review was not exhaustive, the report documents features that can be incorporated into the design and operation of traffic signals to accommodate bicycles.

The report also aims to identify rules, regulations or equipment limitations which may need to be reviewed or resolved to implement improved bicycle features.

Keywords

bicycle, cycling, traffic signal, lantern, road rules, phasing

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About the Australian Bicycle Council

The role of the Australian Bicycle Council (ABC) is to:

- oversee and coordinate the implementation of the Australian National Cycling Strategy.
- provide a forum for the sharing of information between stakeholders involved in the implementation of the strategy.
- maintain a repository of information and resources to promote increased cycling in Australia.

The ABC reports annually to the Transport and Infrastructure Council, through Austroads and the Transport and Infrastructure Senior Officials' Committee (TISOC), on the implementation of the Australian National Cycling Strategy.

The ABC acts as a jurisdictional forum providing input to Austroads on technical matters and provides a cycling perspective on Austroads research and the development of Austroads publications. The ABC members include representation from Austroads, road agencies, the cycling industry and bicycle users on cycling issues.

The Council meets at least twice a year and meetings are chaired by a nominee of Austroads. Meetings are hosted by participating organisations and the location of meetings varies accordingly. Meeting attendance costs are borne by attendees and no sitting fees are paid to members.

The Council may convene a technical committee comprised of its jurisdictional representatives to facilitate input on technical matters; it may also convene working groups, comprising members of the Council and other stakeholders, to address specific issues. The Council may invite participation from others from time to time on specific issues.

Summary

The approach to providing cycling infrastructure in Australian cities is increasingly focusing on providing paths that are separated from motor vehicle traffic. This change is primarily occurring so that people who currently do not ride a bicycle feel safer riding and are therefore more likely to ride. Separated infrastructure also provides improved safety for existing riders.

While separated bicycle paths allow riders to safely and easily access intersections, they are still required to mix with vehicles and pedestrians or dismount and become pedestrians to cross at signalised intersections. This can introduce delays if bicycle traffic signal phases are not designed well.

This report summarises a review of national and international literature on traffic signal features implemented both in Australia and internationally to provide for bicycles. While the literature review was not exhaustive, this report documents a number of features that can be incorporated into the design and operation of traffic signals to accommodate bicycles. Furthermore, this report aims to identify any rules, regulations or equipment limitations which may need to be reviewed or resolved in order to implement the improved bicycle features.

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1. Introduction

The use of bicycles for recreation, transport and tourism offers many benefits to individuals and to society. These benefits include improved health, reduced traffic congestion, improved air quality, improved accessibility to transport and reduced transport costs.

In order to capture these benefits, the National Cycling Strategy 2011-2016 (Austroads 2010) set a goal of doubling cycling participation over the life of the strategy. Many Australian states and territories have developed integrated transport and bicycle strategies that give effect to the national strategy and also seek to double cycling participation. Many urban centres aim to increase cycling even further.

Safety improvements have been made in recent years by providing road space for bicycles in the form of on-road lanes and off-road bicycle paths. In many situations, bicycles can now safely and easily access intersections, however, in many instances they are still required to join vehicular traffic or dismount and become pedestrians to cross at signalised intersections. Providing well-designed bicycle traffic signals can improve both safety and level of service for bicycle riders and improve the competitiveness of cycling as a mode of transport. These improvements assist government in meeting the targets to increase cycling participation.

This report documents a number of features that could be considered in the design and operation of traffic signals to accommodate bicycles.

1.1 Scope

This report summarises a review of Australian and international literature on traffic signal features implemented to provide for bicycles. Whilst the literature review was not exhaustive, this report aims to identify areas for potential improvement within Australia and to identify rules, regulations or equipment limitations which may need to be reviewed or resolved to improve safety and level of service for people riding bicycles.

2. Australian Road Rules

2.1 Definitions

Although the Road Rules vary slightly between the states and territories of Australia, there is consistency in the definitions of terms such as vehicles, bicycles, driver and rider. In this regard the Australian Road Rules (Australian Legal Information Institute 2016, National Transport Commission 2012, VicRoads 2016) and the Austroads Glossary of Terms (Austroads 2015) have the following definitions:

Bicycle lane:

A bicycle lane is a marked lane or the part of a marked lane located on the carriageway, adjacent to traffic. A driver (except the rider of a bicycle) must not drive in a bicycle lane, unless the driver is driving a public bus, public minibus or taxi, and is dropping off or picking up, passengers; in which case the driver may drive for up to 50 metres in a bicycle lane.

Bicycle path:

A path or path section intended for the exclusive use of cyclists, generally referred to as an exclusive bicycle path.

Shared path:

A paved area particularly designed (with appropriate dimensions, alignment and signing) for the movement of cyclists and pedestrians.

Separated path:

A path divided into separated sections one of which is designated for the exclusive use of cyclists and an alternate section for other path users.

Road user:

A road user is a driver, rider, passenger or pedestrian.

Vehicle:

A vehicle is a conveyance that is designed to be propelled or drawn by any means, whether or not capable of being so propelled or drawn, and includes:

a. a motor vehicle, trailer and tram
b. a bicycle
c. an air-cushion vehicle
d. an animal that is being ridden or is drawing a vehicle.

Driver:

A driver is the person who is driving a vehicle (except a motor bike, bicycle, animal or animal drawn vehicle). However, a driver does not include a person pushing a motorised wheelchair.

Rider:

A "rider" is the person who is riding a motor bike, bicycle, animal or animal-drawn vehicle. A "rider" does not include a passenger; or a person walking beside and pushing a bicycle.

Unless otherwise expressly stated in the Australian Road Rules, each reference in the rules to a "driver" includes a reference to a rider, and each reference in the Rules (except in this Division) to "driving" includes a reference to riding.

Pedestrian:

A pedestrian includes

a. a person driving a motorised wheelchair that cannot travel at over 10 kilometers per hour (on level ground)

b. a person in a non-motorised wheelchair

c. a person pushing a motorised or non-motorised wheelchair

d. a person in or on a wheeled recreational device or wheeled toy.

Based on the above definitions, people driving motor vehicles and people riding bicycles must both obey the road rules for stopping at red lights, stop signs or give way signs and indicating when changing direction through indicator lights or giving hand signals. The requirement to signal a change in direction is only mandatory for right turns.

In addition to the vehicle road rules, a bicycle:

- may use bus lanes (in some jurisdictions only when signed)
- may be ridden on the footpath (except in New South Wales, Victoria and Tasmania where the rider must be a child under 12 years of age, or an adult rider who is supervising a cyclist under 12)
- may be ridden on a shared path
- must ride in a bicycle lane if practicable when it is provided (this rule indicates that there may be circumstances where it is not practicable to ride in the bicycle lane, such as when avoiding debris and potholes, or when overtaking another bicycle rider).
- must not ride across a zebra crossing or signalised crossing to cross the road from one side to the other. (bicycles must be walked across the road, unless a green bicycle lantern is provided).

The key difference is in Queensland where bicycles are permitted to ride across signalised pedestrian crossings if they proceed slowly and safely, give way to any pedestrian on the crossing and keep to the left of any oncoming bicycle rider.

Furthermore, in Queensland bicycles can be ridden across a zebra crossing or children's crossing as long as the rider comes to a complete stop first, and then proceed slowly and safely, give way to any pedestrian on the crossing and keep to the left of any oncoming bicycle riders.

Similar exceptions apply in the Australian Capital Territory.

2.1.1 Shared Paths

At signalised intersections along shared paths, the bicycle movement typically operates parallel to the pedestrian movement. In most states this requires a red and green bicycle lantern to be provided so that riders do not have to dismount to cross the road. Shared path crossings (including Puffin Crossings) are designed so that the bicycle signals are synchronised with the pedestrian lanterns, and therefore riders will observe a green bicycle phase, a flashing red clearance bicycle phase and a solid red bicycle phase.

The flashing red clearance bicycle phase is recognised in Road Rule 260 and 262 as the clearance phase of the bicycle phase (i.e. riders should not commence crossing during the flashing red portion of the phase however riders already on the crossing will be provided with sufficient time to cross).

2.1.2 Road Rule Changes

A number of the Australian Road Rules relate to managing conflict between vehicles and pedestrians, however, these rules have no regard for the potential for conflict between vehicles and bicycles. This is particularly relevant with Road Rule 62(1a) which states:

> *"A driver turning at an intersection with traffic lights must …[sic] give way to any pedestrian at or near the intersection who is crossing the road the driver is entering; …[sic] and any pedestrian at or near the intersection who is on the road the driver is leaving."*

The omission of cycling from this rule is a significant concern, as the road rules imply that vehicles do not need to give way to a person on a bicycle who is crossing the road that the driver is entering. In the case of shared paths, or kerbside bi-directional bicycle lanes this rule places riders at risk and designers need to be aware of this issue to ensure that left turn arrow protection is provided for the duration of the shared path and/or bicycle phase.

It is understood that numerous bicycle groups are seeking to have this road rule changed to remove the ambiguity regarding right of way and to remove the need to separate bicycle and vehicle movements at traffic signals. Recent changes in Queensland and ACT have addressed this issue.

3. Traffic Signal Hardware

3.1 General

The Austroads Guide to Traffic Management Part 9: Traffic Operations (Austroads 2016a) states that traffic signals are used within our road network as a tool to:

- maximise operational safety and efficiency of the road network
- minimise negative impacts caused by recurring congestion or non-recurring incidents within the road network
- provide all road users with information necessary to help support their judgement on travel and reduce stress.
- providing the desired level of service to priority road users.

Most signalised intersections around Australia are designed to adapt to the vehicular or pedestrian demands across the day in order to optimise the use of the road network capacity. Bicycles also represent a demand on the road network and therefore should be included in the design. The identification of demands and the intersection capacity are discussed at a high level within the following sections, noting that the detailed operation of traffic signals is included in the Austroads Guide to Traffic Management Part 9 Traffic Operations (Austroads 2016a) and relevant state based supplements to Austroads Guide to Traffic Management Part 9 Traffic Operations (Department of Transport and Main Roads 2015, VicRoads 2015).

3.2 The Traffic Signal Controller

A traffic signal system is made up of a series of components such as detectors, the traffic signal controller and lanterns. The traffic signal controller is the electric circuit board that operates the lanterns which advise drivers and pedestrians whether or not it is safe to proceed through an intersection. The controller receives data from inputs (detectors) to identify the demands at an intersection. This data is then either sent through to a regional computer for analysis and processing or analysed within the controller against a series of logic tests to identify which outputs (traffic signal lanterns) to activate. (Refer to Figure 3.1).

3.2.1 Existing Traffic Signal Controllers

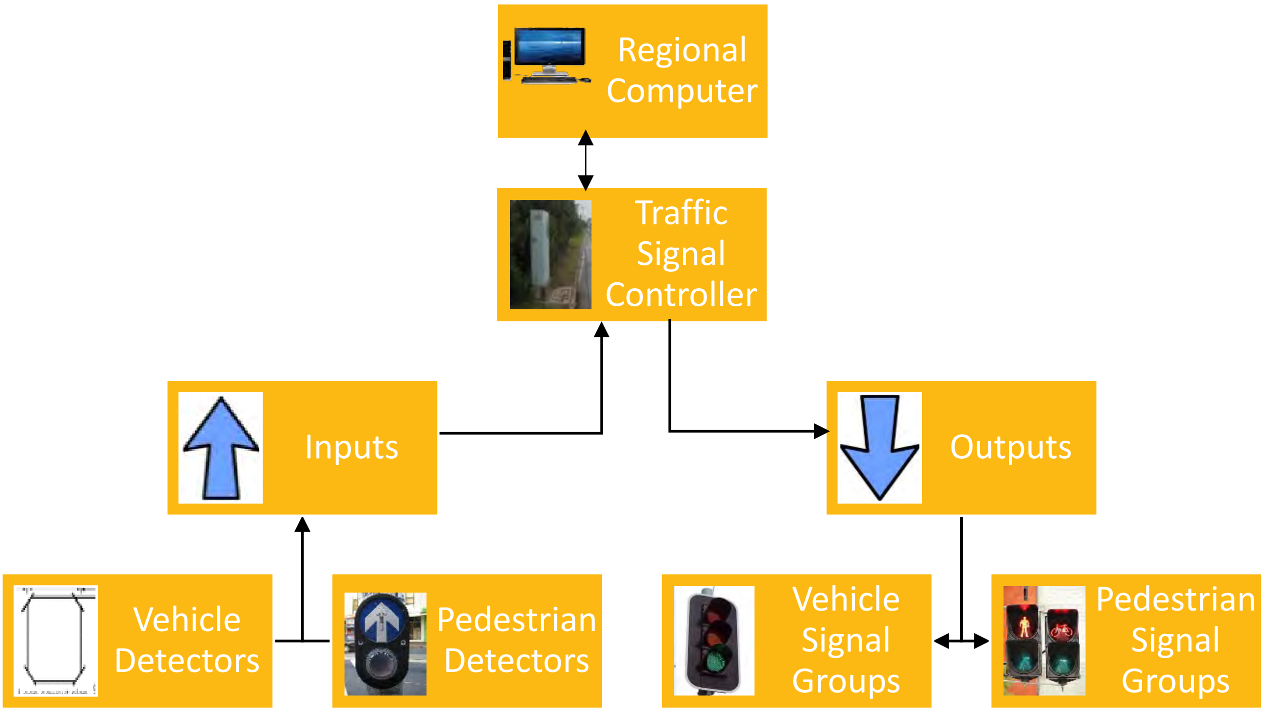
In order to provide dedicated bicycle facilities at an intersection, consideration needs to be made to the type of traffic signal controller being used. Traffic signal controllers have a long design life and therefore when retrofitting an existing intersection, it is possible that an older style traffic signal controller is used. Some older traffic signal controllers (VC4 software) are limited to the following:

- 24 inputs consisting of eight inputs for pedestrian and bicycle push buttons and 16 inputs for vehicles, emergency vehicles, buses, bicycle detectors
- 24 outputs consisting of eight signal groups for pedestrians and bicycles and 16 signal groups for vehicles
- seven traffic signal phases.

Large or complex signalised intersections regularly approach or exceed these limitations, particularly with regards to the pedestrian inputs and signal groups. A cross road intersection with signalised slip lanes or staggered pedestrian crossings would often meet or exceed the capacities of the traffic signal controller. Therefore, the ability to incorporate bicycle facilities using existing hardware may sometimes be limited.

Fortunately, the capabilities of traffic signal controllers have improved over time and newer traffic signal controllers operating the VC6 software are capable of receiving up to 64 detector inputs and can operate up to 32 outputs (Aldridge Traffic Controllers 2016). It is anticipated that the use of larger controllers will become standard practise for road authorities in the future to ensure that the hardware is capable of accommodating any future requirements.

Figure 3.1: Traffic Signal Controller



Source: GTA Consultants

3.2.2 Traffic Signal Wiring

Detector inputs and signal group outputs are generally connected to the traffic signal controller by electrical cables. To provide protection from accidental damage and to maintain a sense of order within the ground, cables are run through PVC conduit pipes around the intersection. Two 100mm conduits are generally provided, with one conduit dedicated for traffic signal cables and one dedicated for street lighting.

Providing dedicated bicycle facilities to an existing site requires additional detector inputs and outputs and therefore electrical cables. Planning for traffic signal upgrades for bicycle facilities should consider the available space within the electrical conduits. If there is insufficient room within the existing electrical conduits the intersection may need to be re-wired more efficiently or additional conduits may need to be provided around the intersection. This may become an important aspect in the future when designing signalised intersections with newer style controllers as it may be necessary to install three 100mm conduits around the intersections with two conduits dedicated to traffic signal cables.

4. Bicycle Detection

Detection of bicycles at traffic signals represents one of the greatest challenges for traffic signal designers and operators. In order for a traffic signal to respond to the demands of the intersection, detectors must identify if road users are waiting at a red signal, whether a phase should be extended or if there are any movement classes with special requirements.

4.1 Detector Uses

Detectors can be used at signalised intersections to provide information to the controller such as whether a road user is waiting at a red light for a particular traffic signal phase or if a phase should continue. Detectors can distinguish the difference between moving and stationary vehicles and therefore enable the designer to develop different reactions to address the needs of road users.

Detect Methods:

- Locking Call: a passing vehicle (or bicycle) or presence of a vehicle on a detector for a nominated time period creates registration of a demand which places a locking call for the nominated phase. The demand for the phase is only cancelled once the signal group has run in a nominated phase (or phases). Once a locking call has been placed, subsequent vehicle detections can extend the phase if required.
- Non Locking Call: A non-locking demand for a phase is registered once a vehicle (or bicycle) is located within the detection zone. A non-locking call is cancelled once the vehicle or bicycle moves out of the detection zone.

Due to the challenges associated with bicycle detection and the ease in which a bicycle can venture outside of the detection zone, locking calls are best-suited for the detection of bicycles. The use of non-locking calls could result in failure to detect the demand for a dedicated bicycle phase. This increases rider frustration and may encourage riders to proceed through the intersection illegally.

The four main methods used of bicycle traffic signal detection available for designers are as follows:

- induction loop
- video
- push button
- microwave.

The advantages and disadvantages of the methods are detailed in Table 4.1.

Table 4.1: Bicycle Detection Methods

Method	Description	Advantage	Disadvantage
Induction loop detectors	Inductive loops embedded in the pavement to detect the presence or passage of a bicycle. Induction loops are the most common detector used.	• Induction loops can be positioned anywhere which enables options for advance and stop line detection. • Induction loops can be used to detect once a bicycle has travelled through an intersection. • Sensitivity can be adjusted to enable detection of bicycles rather than vehicles when used in shared lanes. • Performs well in all weather.	• Different layout arrangements have different areas of detection sensitivity which could be missed if not highlighted to riders. • Must be recut when carriageway resurfaced. • Alternative materials such as carbon fibre rims can reduce detection reliability. • Rider is not informed that their demand has been recorded.

Method	Description	Advantage	Disadvantage
Video detectors	Processes images from camera.		• Sensitive to light. • Have been expensive, but costs are dropping. • Rider is not informed that their demand has been recorded.
Push button	User activated button mounted onto a pole facing the street.	• Unquestionable demand. • Rider is aware that their demand has been recorded. • An LED light on the push button can be displayed to show demand placed.	• No option for advanced detection. Requires riders to wait for bicycle phase. • Requires grab rails or bicycle boxes.
Microwave detection	Mounted on a structure above the roadway.	• Performs well in all weather. • Sensitivity can be adjusted to enable detection of bicycles rather than vehicles.	• Only registers a moving bicycle. • Has a limited range of view for detection • Rider is not informed that their demand has been recorded.

Source: Austroads 2016a.

4.2 Induction loops

Induction loop detectors are the most common type used around the world for vehicle detection. The induction loops are cut into the pavement at a distance from the stop line and the presence of a motor vehicle or bicycle is set to trigger a chain of actions. Because of their narrow width, bicycles can easily bypass a detector or proceed over the detection zone which reduces the likelihood of a presence being detected. Furthermore, the use of non-magnetic materials such as carbon fibre rims can reduce the ease in which pavement detectors can identify a bicycle.

The Urban Bikeway Design Guide (National Association of City Transportation Officials 2011) identifies that the configuration of the induction loops influences the signal detection areas. The guide states that square and/or rectangular induction loops are most sensitive at their edges whereas diagonal and quadruple loop detectors are most sensitive in the centre. An example of this is shown in Figure 4.1.

Figure 4.1: Signal Detection Areas by Loop Type

Source: Adopted from National Association of City Transportation Officials 2011

Sensitivity Settings of Detector Loops

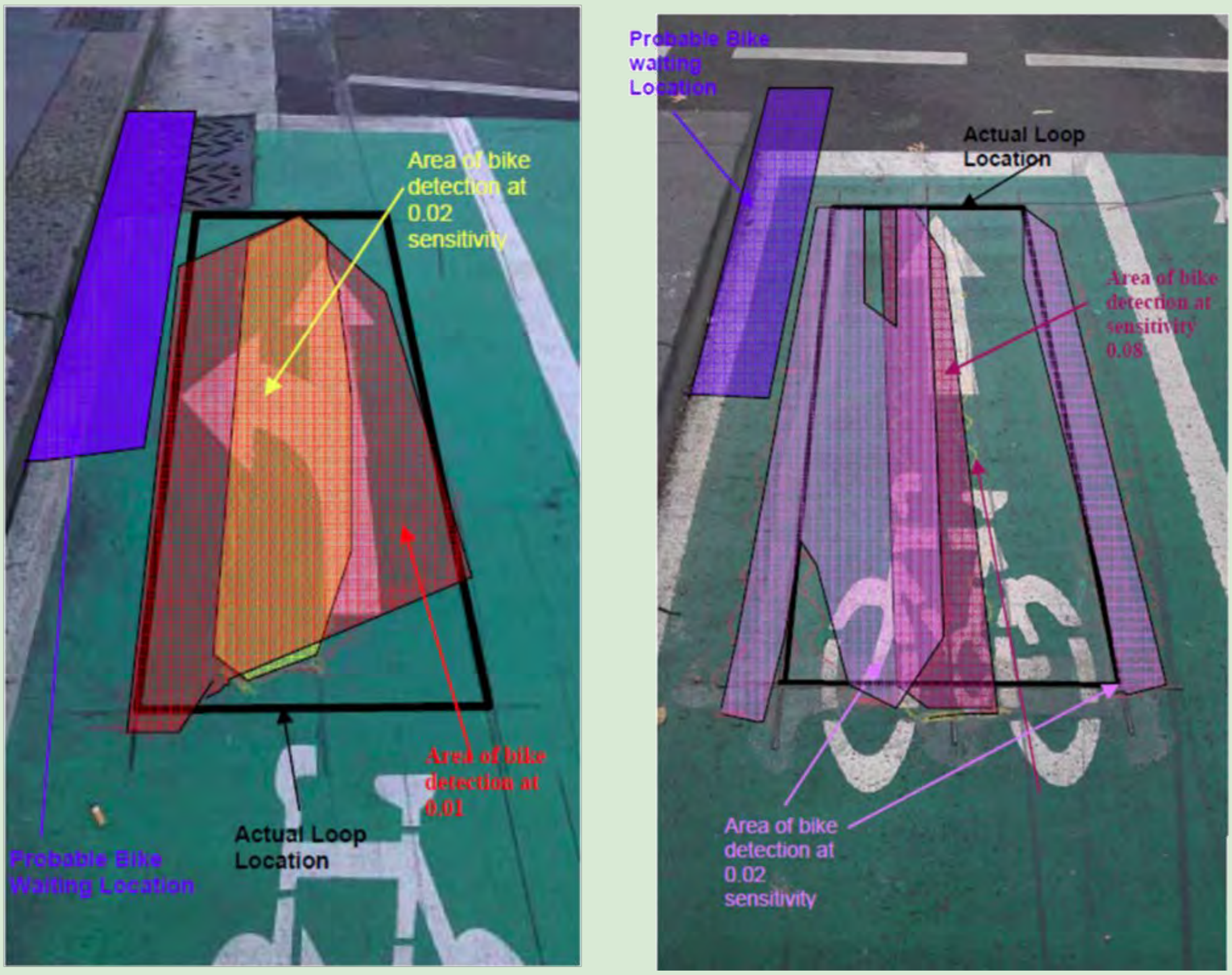
Research conducted by the City of Sydney and the Roads and Traffic Authority New South Wales in 2011 (City of Sydney 2011), assessed the detection areas for quadruple loop detectors with specific settings of sensitivity. The tests were conducted along Bourke Street and Kent Street cycle ways in Sydney and tested two types of controllers with the following sensitivity settings:

- Controller A: Default Sensitivity = 0.08%, Maximum Sensitivity = 0.02%
- Controller B: Default Sensitivity = 0.02%, Maximum Sensitivity = 0.01%

The research concluded that the controller sensitivity significantly affected the detection areas as a percentage of the total area bounded by the loops. The default sensitivity settings resulted in between 45 – 89% of the loop area resulting in detection for type A controllers and 22 – 37% of the loop area resulting in detection for type B controllers. Increasing the sensitivity to the maximum settings improved the percentage of detection area by 150 – 500% with between 89 – 120% of the loop area resulting in detection for type A controllers and 48 - 125% of the loop area resulting in detection for type B controllers.

An example of the detection areas can be seen in Figure 4.2

Figure 4.2: Detection Areas by Sensitivity Level



Source: City of Sydney 2011, Page 8　　*Source: City of Sydney 2011, Page 12*

The ability for a bicycle to be detected by an induction loop was also found to be improved by:

- installing the loop at surface level rather than at sub surface level
- ensuring that the loop was long enough such that both the front and rear rims fall onto the loop area
- installing double loops as per RMS TDT 2012/09 (RMS NSW, 2012).

An evaluation of traffic signal detector loops (Wachtel) identified that the Santa Clara County in California adopted a policy that all future signal installations must:

- be bicycle sensitive
- have identifiable marking on the surface of the carriageway to identify where bicycles should be to activate the signals
- provide bicycle sensitive hardware when signal hardware is being replaced or upgrades.

This approach should be considered for adoption in Australia.

4.3 Improving Detection

In addition to increasing the sensitivity of the detector loops, the likelihood of detection of bicycles can be improved by clearly identifying where riders should wait to place a demand for the traffic signal phase. A study conducted in the City of Sydney (Zeibots, M., Baumann, C., Brennan, T., and Besh, N. 2012) identified that there appears to be a very low level of knowledge of the correct usage of detection zones as only 30–40% of riders observed to stop in the correct location to trigger the bicycle signal phase, and it is reasonable to assume that some stopped in the correct location by accident. This was also identified in a study into traffic signal optimisation of existing Sydney CBD cycle ways (Bitzios Consulting 2012).

In the City of Portland, (Oregon, USA) a study tested the comprehension of riders for seven types of pavement markings of which all were intended to indicate the detection zone (Boudart, J., Foster, N., Koonce, P., Maus, J., Okimoto, L. 2015). The markings included a combination of symbols, colours and text to “Wait here for green” or “Wait on lines for green”. The study surveyed 213 survey participants to identify which of the seven pavement markings had the highest comprehension levels and found that the two symbols with text (Refer to Figure 4.3) provided the clearest message with approximately 93% comprehension levels for the survey participants.

Figure 4.3: City of Portland, Identifiable Pavement Markings

Source: Boudart, J., Foster, N., Koonce, P., Maus, J., Okimoto, L., 2015.

The significance of the study should be considered when assessing the types of line marking used within Australia. There appears to be no consistent approach with regards to the identification of detector zones, with Victorian designers typically relying upon the saw cuts to indicate a detector loop, whilst in the City of Sydney an arrangement of six small diamonds with or without a bicycle symbol (Refer to Figure 4.4) is used. However, it is unclear whether this message is truly understood by riders.

Figure 4.4: Sydney Detection Pavement Markings

Source: GTA Consultants

4.4 Advanced Detection

In Australia it is typical for the bicycle phase to be demanded either by a rider using a push button at the stop line, or through the use of a stop line detector. This introduces delays as users have to wait for the traffic signal sequence to reach the bicycle phase.

However, in many European and American cities, induction loop detectors are used in dedicated bicycle facilities in advance of the intersection to place a demand for a bicycle phase. Two examples were found of advanced detectors with the spacing provided as follows:

- Netherlands: 25 metres in advance of the stop line (Bicycle Dutch 2016), which provides approximately 5-6 seconds head start when cycling at 20km/h.

- Massachusetts, USA: 100 feet (approximately 30m) in advance of the stop line (Massachusetts Department of Transport 2015, p. 115), which provides which provides approximately 5-6 seconds head start when cycling at 20km/h.

Advanced detection is commonly used around Australia to register a demand for tram, train and bus phases and therefore this approach is not unknown to traffic signal operators. The purpose of an advance detector is to call priority before the desired vehicle reaches the stop line and therefore there are many situations within a segregated bicycle path or shared path where providing advanced detectors for bicycles may be advantageous. These include, but are not limited to, the following:

- shared path or bicycle paths crossings of major roads
- shared path or bicycle paths with steep uphill or downhill gradients
- heavily used shared path or bicycle paths where there is insufficient room to store bicycles.

The location of advanced detectors will vary on a site by site basis depending on the intersection geometry, grades, signal operation and complexity of the intersection. In general, advanced detectors should be positioned to allow the same travel time in seconds for bicycles as the vehicle intergreen, based on the 85th percentile speed of the bicycles of 20km/h. For example;

> *If a rail trail had an 85th percentile speed of 20km/h for bicycles (5.55 meters / second) and the vehicle signal phase had an intergreen period of 6 seconds (4 seconds yellow and 2 seconds red), the advanced detector should be located 33 metres from the intersection (i.e. 5.55m/s multiplied by 6 seconds intergreen).*

At a two-phase site, this approach would allow an operating phase to shut down before arrival of the bicycle, provided that the minimum green requirement for the phase has already operated.

5. Signal Lanterns

In Australia, bicycles are controlled at signalised intersections through the use of either a two-aspect bicycle symbol lantern (red and green) or a three-aspect bicycle symbol lantern (red, yellow and green). The bicycle lanterns apply for all bicycle movements (through, left and right) and currently there is no ability to differentiate between straight through movements and turning movements.

The following sections discuss the limitations of the approved bicycle lanterns and identify practices from around the world.

5.1 Combined Pedestrian and Bicycle Lanterns

The Australian Road Rules (National Transport Commission 2012) state that a rider must not ride across a pedestrian crossing to cross the road from one side to the other unless a green bicycle lantern is provided, noting recently introduced exceptions in Queensland and the Australian Capital Territory. In this regard two-aspect bicycle lanterns must be provided at shared paths in addition to pedestrian lanterns in order for a rider to legally ride across the carriageway (Refer to Figure 5.1).

Providing separate bicycle lanterns increases the cost of shared path projects. Current practice by road authorities is for LED lantern technology to be used at signalised intersections due to lower operating costs and ability for the message to be understood by road users even if some of the LED globes fail. If a bicycle project required a considerable change to an old signalised intersection, it is possible that the road authority may seek to have the intersection upgraded to LED technology as part of the project.

In 2009, the City of Sydney sought approval from RMS to replace the existing pedestrian signal lanterns with a combined pedestrian and bicycle lantern at signalised crossings along 57km of new shared paths. The lanterns, similar to those used in Europe and as seen in Figure 5.2, were proposed as a low cost means to upgrading signal hardware whilst meeting the legal requirements for the shared paths. The use of the lanterns was approved on October 2010 on a trial basis by the RMS traffic management team subject to the City of Sydney providing a report on the behaviour of pedestrians and riders as a result of the new lanterns. However, it is noted that the City of Sydney did not proceed with the trial and the author is unaware of any successful implementations within Australia.

Figure 5.1: Current Shared Path Signal Lanterns

Source: GTA Consultants

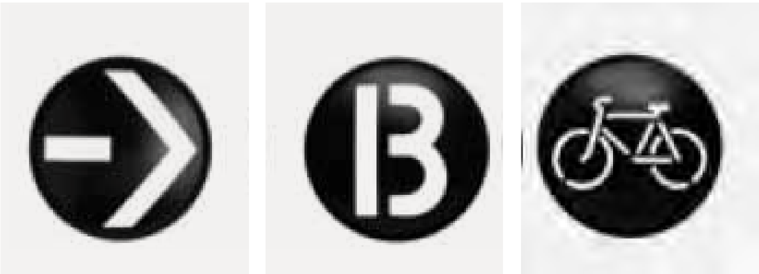
Figure 5.2: Proposed Trial Shared Path Signal Lanterns

Source: City of Sydney

5.1.1 Combined Lantern Trial

It is noted that the older quartz halogen lanterns (200mm and 300mm diameter) and some LED lanterns use masks to display arrows, bicycle, bus and tram symbols. It is considered that the use of masks may provide a low cost opportunity to trial the use of combined lanterns.

Figure 5.3: Quartz Halogen Lantern Masks



Source: Aldridge Traffic Controllers 2016.

Although the use of a combined pedestrian and bicycle lantern is practical for shared paths, it should not necessarily be used for situations where parallel pedestrian and bicycle crossing facilities are provided. This is discussed further in Section 8.3.

5.2 Bicycle Turning Lanterns

The approved bicycle lanterns in Australia do not currently provide an ability to differentiate between straight through movements and turning movements. No Right Turn and No Left Turn signs in combination with pavement line marking such as dedicated bicycle turn lanes are used to direct the movement of bicycles.

However, internationally, there are approaches to bicycle lantern layout that allow for an ability to differentiate between movements. Examples include the use of a dedicated set of circular or turn arrow lanterns for bicycles which are clearly identifiable; or by incorporating a bicycle logo and arrow within the standard diameter lantern (refer to Figure 5.4 and Figure 5.5). The use of such lanterns may need to be considered by practitioners in the future as the complexity of intersections and bicycle treatments increases and should be considered for inclusion in the appropriate Australian Standard.

Figure 5.4: Dedicated Bicycle Turn Signals

Figure 5.5: Combined Bicycle and Arrow Lanterns

Source: ViaStrada 2014

5.3 Bicycle Detection Indicator

Pedestrian push buttons often provide a visual or audio indicator that a request for demand has been made such as those seen in Figure 5.6.

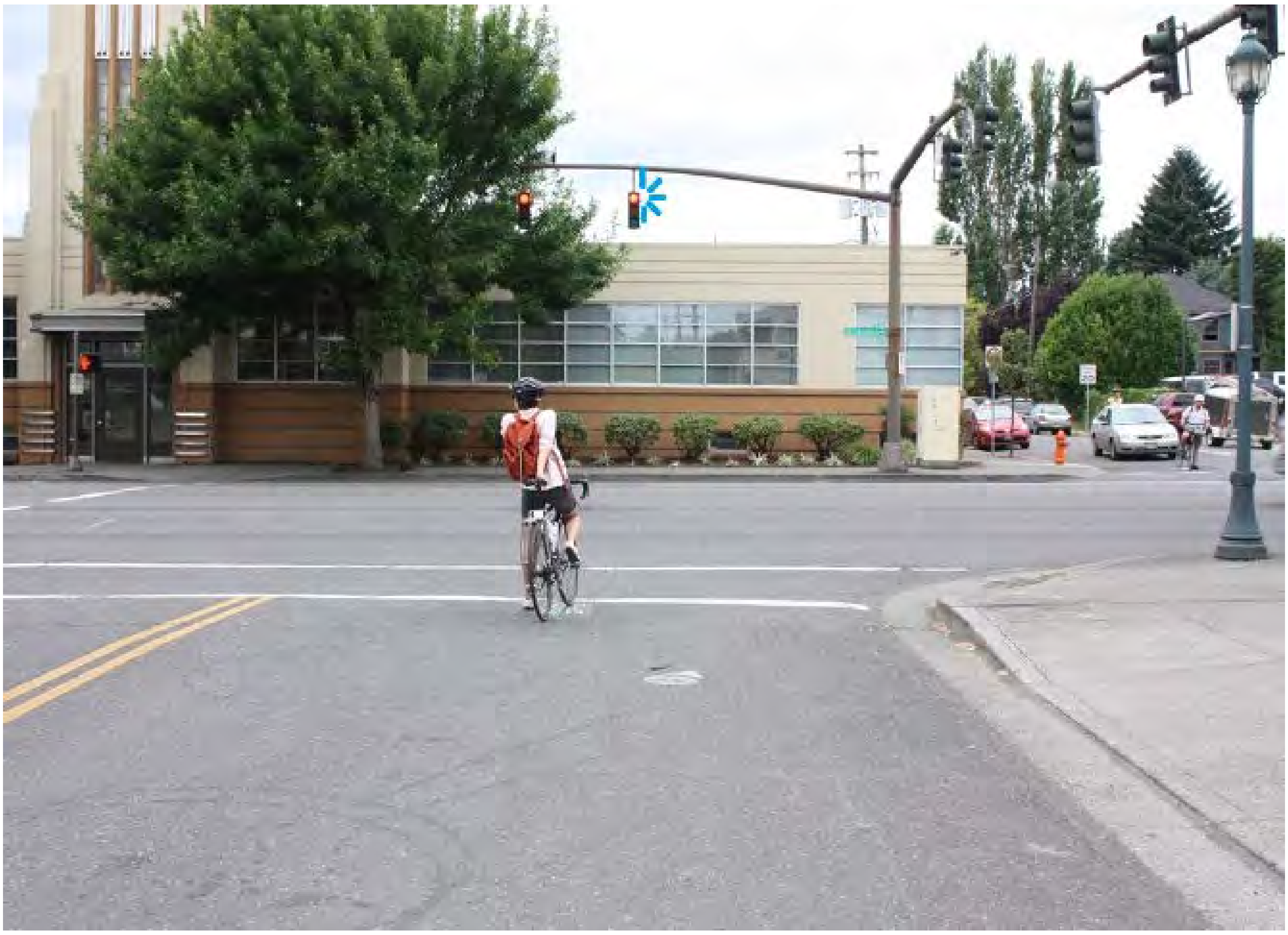
Figure 5.6: Pedestrian Push Buttons with Demand Indicators

Source: Google Images

Bicycle detection indicators are not commonly provided in Australia and it is possible that the unknown nature of whether a bicycle phase will operate may encourage riders to undertake risky behaviour.

In some American cities, this issue is being mitigated by providing a small blue light on the departure side of the signalised intersection (as shown in Figure 5.7) which provides feedback to riders by illuminating when a bicycle has been detected and a demand placed for the bicycle traffic signal phase.

Figure 5.7: Bicycle Detection Feedback Lantern



Source: Boudart, J., Foster, N., Koonce, P., Maus, J., Okimoto, L., 2015.

The City of Sydney has recently investigated using LEDs within the pavement near the bicycle detector loops to display when a demand has been registered and to reinforce the message to riders that they need to wait on the detector for the demand to remain. It is understood that preliminary discussions have been held with RMS but this treatment is yet to be trialled.

5.4 Bicycle Lantern Placement

The location of bicycle lanterns relates more to the design rather than operation of traffic signals, however, it can influence the behaviour of riders. In Australia, the lanterns are typically placed on the departure side of the intersection using standard 200mm or 300mm diameter lanterns and are mounted above rider head heights (typically 2.3m height clearance). This places bicycle lanterns outside of the natural field of view of a rider on a road bicycle or hybrid bicycle (where the body angle results in the head facing downwards). In many European cities, bicycle lanterns are also placed on the approach side of the intersection and can use smaller pedestal mounted lanterns. Trials within Australia could be beneficial to assess if stop line and red light compliance are increased by providing lanterns at the desirable stop location. Furthermore, the introduction of countdown timers for either the crossing time, or time until green could be considered such as seen in Figure 5.8

Figure 5.8: Alternative Bicycle Lantern Displays

Source: Bicycle Dutch 2016.

6. Phase Times

6.1 Bicycle Design Speed

The design speed for bicycles varies depending on the type of facility provided and typically range between 20 – 30km/h. Design speeds are typically included within design manuals to dictate the quality of the ride for bicycles and to define the design of horizontal and vertical geometry. However, there appears to be little information with respect to the design speed to be used for calculating traffic signal phase times and intergreen periods for cycling.

The Austroads Guide to Traffic Management Part 9: Traffic Operations (Austroads 2016a) identifies that dedicated bicycle phases (with separate bicycle lanterns) should be designed to reflect a bicycle speed of 20 km/h. Austroads remains silent on the design speed for on-road bicycle facilities which operate parallel to the vehicle movements and are controlled by the vehicle lanterns. In this regard, the VicRoads Supplement to Austroads Part 9: Traffic Operations (VicRoads 2015), states that: *'when bicycles operate in the same phase as the vehicle movement (i.e. the majority of sites where specific bicycle lanterns are not provided), the adopted speed limit for vehicles shall be used (i.e. posted speed limit for through movements and 45km/h for turning movements).'*

The implications of adopting vehicle design speeds when a bicycle operates parallel to the vehicle phase is discussed in Section 8.5.

6.2 Minimum Green

The Austroads Guide to Traffic Management Part 9: Traffic Operations (Austroads 2016a) identifies that the minimum green time for vehicles should be between 5 – 10 seconds for through and left turn movements and between 5-6 seconds for right turn vehicles. The minimum green typically adopted around Australia for all vehicle movements is 6 seconds.

Bicycle groups have questioned whether the minimum green is appropriate for bicycles to start from a stop. In this regard, the CROW Recommendations for Traffic Provisions in Built-up Areas recommend that a guaranteed green of more than 5 seconds is provided for trams, bicycles and pedestrians and 6 seconds for vehicles (CROW 1998).

The CROW Design Manual for Bicycle Traffic advises that the acceleration rate for bicycles is between 0.8 – 1.2m/s^2 (CROW 2016). In this regard, it is noted that bicycles would take between 3.7 – 6.9 seconds to reach the design speed of 20km/h. On this basis, a minimum green of 6 seconds, as typically adopted within Australia is appropriate for most bicycles.

6.3 Intergreen Phases

The VicRoads *Supplement to Austroads Guide to Traffic Management Part 9: Traffic Operations* (VicRoads 2015) details that the intergreen times for bicycles should be applied as follows:

Table 6.1: Intergreen Phases for Bicycles (Source: VicRoads 2015)

Signal Control	Yellow Time	All Red Time
Bicycles operate with an exclusive bicycle phase	3.0 seconds	Calculated based on the intersection geometry and a design speed of 20km/h.
Bicycles operate parallel to the vehicle phase	Calculated as the Yellow Time for the parallel vehicle movements.	Calculated as the All Red Time for the parallel vehicle movements.

7. Signal Demand and Introduction

7.1 Background

The design and operation of traffic signals has changed significantly over the past 90 years. Traffic signals no longer control priorities for only vehicle traffic, with the inclusion of facilities for pedestrians, buses, trams or trains now commonplace around the world.

Cycling is widely recognised as a mode of transport and engineering practitioners around the world design a range of treatments for bicycles. The treatment of bicycles at traffic signals is influenced by a number of factors including the intersection geometry, type of bicycle facility provided, user classes, segregation requirements and the road hierarchy (Department of Transport and Main Roads 2015, Sinclair Knight Merz 2010, Roads and Traffic Authority 2005, ViaStrada 2001).

7.2 Demanding Bicycle Phases

7.2.1 Permanent Demand Phases

Traffic signals within Australia are typically operated with active traffic signal priority, or basically to respond to the demands of the road users through the use of detectors. This means that if a detector is not activated by a vehicle, pedestrian or bicycle, then the corresponding traffic signal phase will not operate.

The SCATS operating system allows for a permanent demand request to be made for a particular traffic signal phase. This technique is always applied to the pivot (main) traffic signal phase; however, it may also be appropriate in situations to provide a permanent demand for bicycle phases.

Permanent demand requests for bicycle phases are best suited to peak hour operation along heavily used bicycle routes where a number of bicycles will use the phase each cycle and advanced detection is not provided. This will reduce delays for bicycles as they no longer have to activate a call for the bicycle phase.

7.2.2 Auto-Introduction

The automatic introduction of pedestrian facilities at the start of a traffic signal phase is used in many capital cities where pedestrian numbers are high and cycle times are long. This technique can reduce the delays for pedestrians, particularly for those arriving near the end of a phase and would have to wait another traffic signal cycle in order to be provided with a green phase.

Automatic introduction of bicycle signal phases should be considered for use on heavily used segregated bicycle routes where the bicycle movement operates parallel to the vehicle movement. However, implementation of this technique requires special consideration of the bicycle facility provided as well as the road rules relating to the give-way conditions for left turning vehicles.

It is noted that if automatic introduction is applied to pedestrians at a toucan crossing, then the bicycle signal groups should also have automatic introduction and vice versa.

7.2.3 Stretch Walks

Adaptive traffic signal phasing requires nomination of a main phase which can gain unused time from the proceeding phases if the vehicle and pedestrian demands do not require the full phase time allocation (known as gapping out). In this instance, it is possible for the “stretch phase” to operate for longer than originally programmed.

When a pedestrian movement operates parallel to the stretch phase, it may be possible to nominate these movements as a “Stretch Walk” in SCATS. This allows the green pedestrian lantern to display once the vehicle green display commences and to operate for longer than the typical programmed walk period.

“Stretch Bicycle” signal phases should be considered for use on heavily used segregated bicycle routes where the bicycle movement operates parallel to the vehicle movement. Implementation of this technique requires special consideration of the bicycle facility provided and the road rules relating to the give way conditions for left turning vehicles.

It is noted that if a stretch walk is applied to pedestrians at a shared path or toucan crossing then the bicycle signal group should also be a stretch bicycle and vice versa.

7.2.4 Early Starts (late starts for vehicles)

Early starts are commonly used to provide protection for pedestrians from left and/or right turn vehicles or to provide buses and trams an opportunity to clear an intersection before other vehicle traffic. This provides the targeted road user with a green lantern for a nominated period of time before other road users receive the green light.

In situations where a uni-directional on-road bicycle lane or advance stop line is provided, it may be possible to provide an early start for bicycles (UK Department of Transport 2016). Riders are particularly vulnerable where on-road bicycle lanes are provided adjacent to traffic lanes with high left turn traffic volumes, as the visibility for motorists to observe a rider travelling within the bicycle lane at speed may be limited.

When an early start is provided, the traffic signal operation is as follows:

- during the early start, bicycles are controlled by a green bicycle lantern
- at the end of the early start period the green bicycle lantern goes blank
- the adjacent normal three-aspect circular display turns green to control vehicle and bicycle traffic
- the termination of the phase is controlled by the normal three-aspect circular displays.

The length of the early start time period is dictated by the purpose of providing the early start. Considerations may include the distance to be travelled by bicycles to a point of conflict such as lane merges and right turn filter storage areas and/or the number of bicycles. Early starts for bicycles can also be used in situations where the pedestrian crossing times control the length of a traffic signal phase rather than the vehicle demands.

The provision of early start bicycle signals requires installation of a dedicated green bicycle lantern. If an early start for parallel pedestrian movements is provided, then it may be possible for the bicycle lantern to be wired to operate with the pedestrian lantern which may reduce hardware requirements. This is also the case if bus jump lanes are provided and bicycles are permitted to cycle in the bus lane. However, if the early start for bicycles is to be provided as a standalone feature, then the bicycle lantern will need to be set up as a separate signal group. This requires consideration for the capacity of the traffic signal controller and electrical ducting.

7.2.5 Advanced Detection

In some instance, such as at dead-end streets, bicycle-only paths and shared paths, a bicycle movement may travel perpendicular to the main road and require a dedicated bicycle phase to be incorporated within the traffic signal design. At these locations, a three-aspect bicycle lantern is used to control bicycles.

In Australia, it is typical for the bicycle phase to be demanded either by a rider using a push button at the stop line, or through the use of a stop line detector. This introduces delays for bicycles as they have to wait for the traffic signal sequence to reach the bicycle phase.

However, in many European countries, induction loop detectors are used in advance of the intersection to place a demand for a bicycle phase. In the Netherlands, advanced detector loops are installed 25m in advance of the stop line (Bicycle Dutch 2016), which provides approximately 5-6 seconds advanced detection when cycling at 20km/h. Traffic signal phases within Australia typically have a minimum green requirement of 4 - 10 seconds and an intergreen period of 6 seconds. Therefore, at a simple two phase site, providing advance detection may halve the delay for bicycles.

Advanced detection is commonly used around Australia to register a demand for tram and bus phases and therefore this approach is not unknown for traffic signal operators. Providing for advanced detection requires additional detector loops and wiring and reprogramming of the traffic signal controller.

7.2.6 Co-Introduction

In some instances, bicycle movements and their traffic signals are located adjacent to walk movements. In these cases, it may be possible for a demand from either the pedestrian or bicycle movement to generate demand for both movements.

This may reduce the average wait time for both pedestrians and bicycles, thereby improving their level of service, while incurring no loss in the level of service offered for other road users.

8. Signal Sequencing Options

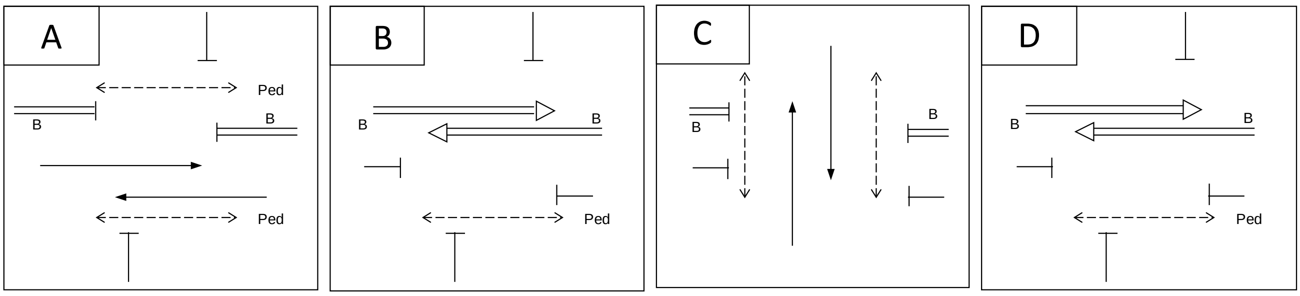
8.1 Separated Cycle Ways

8.1.1 Priority Movement Repetition

Priority movement repetition is a technique commonly used for trams within Victoria and at at-grade railway crossing intersections around Australia. This technique provides multiple phases for trams or trains to introduce within the traffic signal cycle which reduces the maximum delay experienced.

Similar techniques could be considered for bicycles at simple intersections with dedicated bicycle phases , particularly when the bicycle movement is on the minor road movement and crosses a major road (see Figure 8.1). . It is noted that priority movement repetition for bicycles has been trialled for use at some intersections in the Netherlands (Hendriks, R 2010).

Figure 8.1: Segregated Bicycle Path with Priority Movement Repetition Example



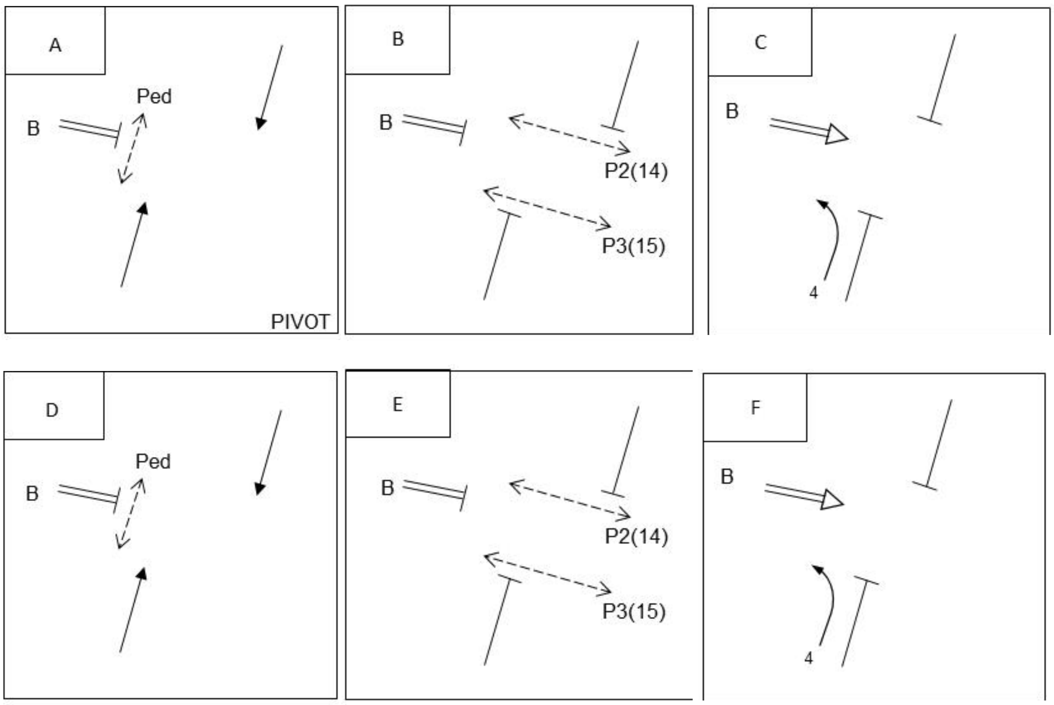
Source: GTA Consultants

8.1.2 Double Cycling

In some instances, linking multiple signalised intersections requires minor intersections to operate with a longer cycle length than the intersection would operate with in isolation. To reduce the delays for side road traffic it is sometimes possible for the traffic signal phases to operate twice in a traffic signal cycle, known as “double cycling” (Fitts T 2014). The ability to double cycle an intersection is determined by the time required to meet minimum green, intergreen and pedestrian walk and clearance timings for all phases twice within the operational cycle length. Traffic signal controllers are typically limited to seven phases and therefore double cycling is best suited to two or three phase intersections or when the bicycle phase can operate parallel to a vehicle phase without conflict.

An example of double phasing is shown in Figure 8.2

Figure 8.2: Double Cycling Example



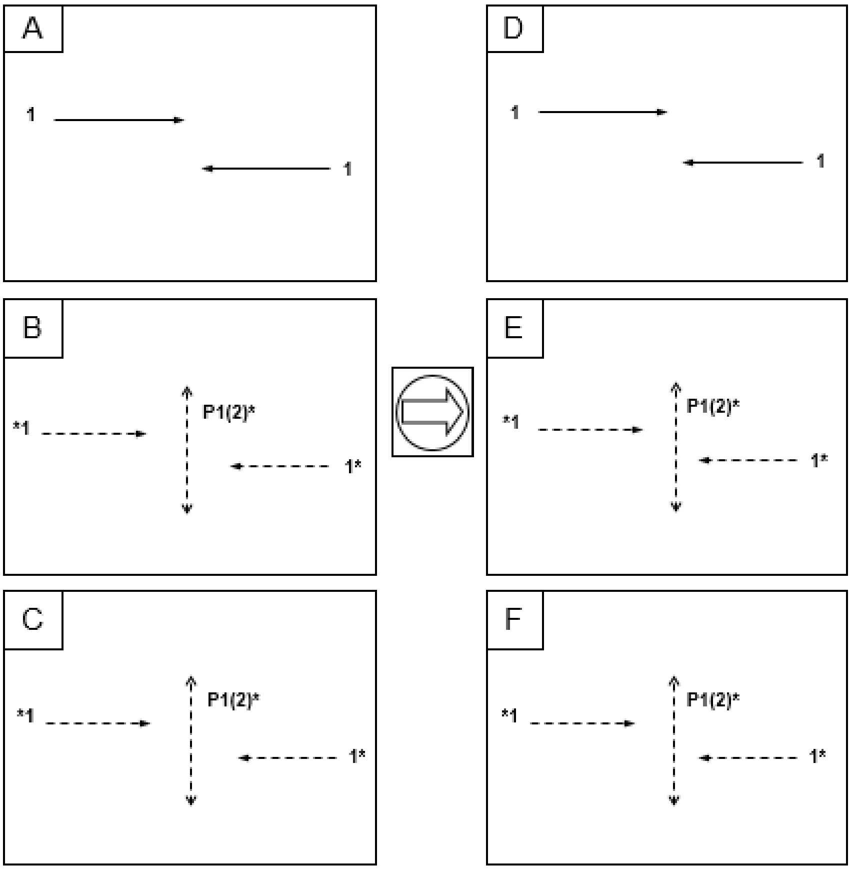
Source: GTA Consultants

8.2 Shared Paths

8.2.1 Push Button Operated Signals

In Victoria, push button operated signals (i.e. signalised pedestrian crossings or shared path crossings) are designed to provide maximum flexibility by allowing the pedestrian walk phase to operate at almost any time during the traffic signal cycle. Although pedestrian operated signals only require two phases (vehicle phase A and pedestrian phase C), pedestrian operated signals are set up with six phases as shown in Figure 8.3.

Figure 8.3: Pedestrian Operated Signal Phasing



Source: GTA Consultants

The operation of the signals is as follows:

Phase A: Phase A represents the minimum green time required for the vehicle phase. During this time period, pedestrians cannot introduce, however, a demand for pedestrians can be made.

Phase B: Phase B represents the extension green time which operates after the Phase A minimum green period. The vehicle movement will continue until a demand for a pedestrian is identified or the phase time expires. If a pedestrian phase is demanded, and the vehicle demands are low enough so that no vehicles are detected on both signal groups for a nominated time period (i.e. the signal group's gap out and wastes), the vehicle movements can shut down. Once the vehicle movements shut down, the pedestrian phase will commence and overlap into Phase C.

Phase C: Phase C is the dedicated pedestrian phase. If a pedestrian phase was registered in Phase A or Phase B, then the pedestrian movement will introduce. If no demands for pedestrians were placed, then vehicles will continue to operate in Phase C until the phase time expires and the phase progresses to Phase A or Phase D if double cycling.

The above phasing technique is suitable for use where shared paths or dedicated bicycle paths cross a main road. This technique is best suited to isolated pedestrian or bicycle activated signals although it can be used where the pedestrian operated signal is linked to another site along a linked corridor. This technique is also suitable for use with advanced detection for bicycles as discussed in Section 4.4.

8.3 Separated Bicycle Lanterns

Traffic signals on shared paths are typically designed so that the bicycle movement operates in parallel to the pedestrian movement. To maintain a consistent approach between pedestrian and bicycle signals, the bicycle traffic signals are set up such that riders will observe a green bicycle phase, a flashing red clearance bicycle phase and a solid red bicycle phase.

The flashing red clearance bicycle phase is generally recognised by engineering practitioners as the clearance phase of the bicycle phase (i.e. riders should not commence crossing during the flashing red portion of the phase however riders already on the crossing will be provided with sufficient time to cross). However, because bicycles travel faster than pedestrians (approximately 6m/s instead of 1.2m/s) additional bicycles could easily clear the crossing during the flashing red clearance phase.

If space permits, it is possible to increase the time available for bicycles by providing slightly separated pedestrian and bicycle crossing locations and the installation of separate three-aspect bicycle lanterns (R/Y/G). This allows bicycles to receive a longer green period and an intergreen period calculated based on the travel time required to cross the intersection at a 20km/h design speed.

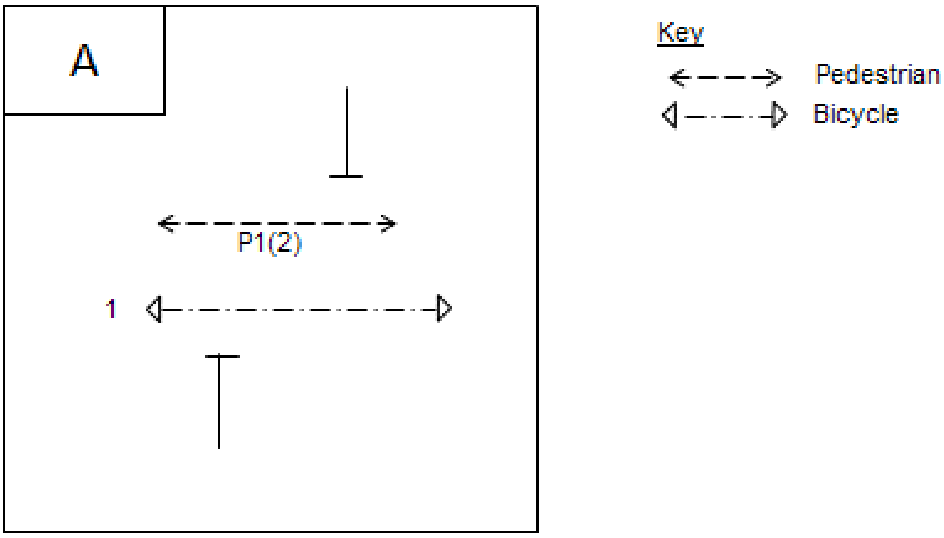
An example of separate pedestrian and bicycle lanterns from the Netherlands is shown in Figure 8.4.

Figure 8.4: Separated Vehicle and Bicycle Lanterns

Source: Bicycle Dutch 2016.

Implementation of this treatment requires additional signal groups for bicycles. A schematic example of the separate phasing operation is shown in Figure 8.5.

Figure 8.5: Separated Vehicle and Bicycle Lanterns



User Class	Signal Group	Signal Display		
Bicycles	1	G	Y	R
Pedestrians	P1	Walk	Clearance	R

Source: GTA Consultants

8.4 Bicycle Lanes

One of the simplest forms of bicycle facilities is to provide uni-directional on-road bicycle lanes, adjacent to the vehicular traffic lane. The on-road bicycle lane typically observes a stop line which is a continuation of the vehicular stop line. Alternatively, advanced bicycle boxes may be provided which permits bicycles to be positioned at the front of the queue, in clear line of sight of motorist.

With this type of facility, bicycles operate at the same time as the vehicle movements occurring in a traffic signal phase. Bicycles are controlled by the vehicle green, amber and red circle or arrow lanterns and subsequently receive the same amount of green time as other vehicles. This type of facility is best suited to cycle routes where right turn movements are limited because of the potential for vehicle to bicycle conflict.

If the bicycle lane operates parallel to the main "pivot" phase, and there is a permanent demand for the pivot phase, then bicycle detection may not be required in these lanes. However, bicycle detection is required on all other approaches in order to ensure that a bicycle demand for a phase is detected without the presence of vehicles.

8.5 Wide Intersections

Although bicycles should be able to stop within the vehicle intergreen period, unfortunately many drivers and riders often do not treat the yellow time period as a time to stop and consider this period as an extension to the green period.

An issue commonly raised with respect to on-road cycling (either in dedicated bicycle lanes or shared bicycle / traffic lanes) is that a rider who commences crossing a wide intersection late in the green period or during the yellow time can still be travelling through the intersection when vehicles in the next phase receive a green lantern because the intergreen period has been determined based on the design speed for motor vehicles (which is greater than the speed of most people on bicycles).

Capacity constraints may dictate that it is not practical to extend the all red time every cycle to avoid possible conflicts. On this basis, possible treatments to mitigate this issue are discussed below.

8.5.1 Separated Bicycle Lanterns

The potential conflict between on-road riders and the next vehicle phase could be mitigated by providing an all red period for bicycles, calculated based on the travel time required to cross the intersection at a 20km/h design speed.

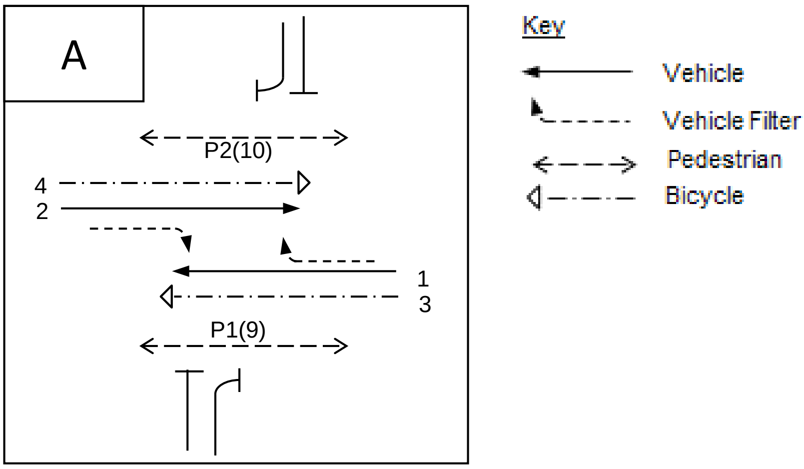
This would require installation of separate bicycle lanterns to enable the all red period to commence prior to the main vehicle phase. Depending on the intersection geometry, the yellow time period may commence before, or at the same time as, the vehicle yellow time.

Implementation of this treatment would require the following:

- Dedicated cycle lanes provided up to the intersection stop line to enable bicycles to come to a stop out of the way of vehicles.
- An education campaign to ensure riders understand why separate lanterns are provided
- Compliance from riders so that they don’t leave the cycle lane and enter the vehicle lane to continue travelling through the intersection
- Additional signal groups for bicycles.

A schematic example of separate intergreen phasing is shown in Figure 8.6.

Figure 8.6: Separated Vehicle and Bicycle Lanterns



User Class	Signal Group	Signal Display		
Vehicles	1	G	Y	R
	2	G	Y	R
Bicycles	3	G	Y	R
	4	G	Y	R
Pedestrians	P1	Walk	Clearance	R
	P2	Walk	Clearance	R

Source: GTA Consultants

8.5.2 Special All Red

An alternative to separated bicycle lanterns at wide intersections has been used in New Zealand which extends the all-red period between phases to increase the chance of a bicycle clearing the intersection.

The treatment requires a special detector loop to be provided along the bicycle desire line, within the intersection (ViaStrada 2001). The detector is programmed such that a bicycle demand in the last few seconds of the green phase or within the yellow period activates a special all red time which delays commencement of the next vehicle phase.

Application at test sites has identified that the treatment requires special consideration of the detector location to ensure that vehicles cannot accidently activate the detector. Furthermore, it is noted that the time for the special all red time period would need to be taken from the next vehicle phase. Therefore, a decision may need to be made by traffic engineers/signal operators to:

- Operate the next phase with a reduced green time after activation of the special all red, possibly increasing queues and delays; or
- Increase the phase split for the next phase so that vehicles still receive the green time required to satisfy vehicle demands after activation of the special all red.

The approach taken would need to be considered on a case by case basis depending on the road hierarchy, user hierarchy and volume of bicycles.

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