Final Report

TAC ATC

Traffic Signal Guidelines for Bicycles

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INTUS

B TEAM

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1.0 Introduction

Marshall Macklin Monaghan Limited (MMM), in association with Intus Road Safety Engineering Inc. and The Behavioural Team, was retained by the Transportation Association of Canada (TAC) to undertake the development of traffic signal guidelines for bicycles.

Chapter 2.0 of this report provides a review of national and international guidelines, experience and research.

Chapter 3.0 details the observations and problematic issues of bicycle signal installation in Canada, the United States and Internationally. This includes dialogue with various jurisdictions in North America and around the world, in order to properly assess the operation of various types of intersection traffic control for bicycles.

Chapter 4.0 builds upon the practices and observations in Chapters 2.0 and 3.0, focusing on the specifications for the Bicycle Signal Display. In addition, various sets of recommendations for bicycle detection as well as implementation strategies and applications for Bicycle Signals.

The guidelines set forth in this report have not been developed with the intention of giving absolute priority to cyclists over all other roadway users. Rather, they are recommended to allow for the safe and efficient shared use by all types of road users at intersections and on roadways. Further, the guidelines are not meant to provide an exhaustive list of all possible applications that will cover every situation in the field. Instead, practitioners are expected to apply good engineering judgement in the interpretation of this document.

Accordingly, this document can be viewed as providing a list of best practices that may be modified by the designer to adapt to the specific circumstances encountered in the field. One aspect of these guidelines that must be adhered to is the recommendation of bicycle signal heads. It is important to provide a uniform signal display that will be recognized by all roadway users. This consistent application will reduce confusion among cyclists, motorists and pedestrians.

Under the vast majority of circumstances, standard vehicle displays are adequate to control bicycle movements through intersections. There are a wide range of applications and solutions that may be suitable for improving cyclist priority through intersections, some of which are discussed herein, that do not even involve the application of bicycle traffic signals. The use of exclusive bicycle signals should, therefore, be limited to special circumstances and not randomly or universally applied to all signalized intersections.

It must also be understood that any of the bicycle signal evaluations that are referenced in this document are not based on a rigorous scientific process. Instead, most, if not all treatments tend to be based on anecdotal evidence or at best, the application of "engineering judgement" rather than a comprehensive human factors, safety and evidence-based analysis. Accordingly, the user is cautioned that while the "best practices" contained herein represent the current state-of-the-art in bicycle signal design and application, they are not to be construed as scientifically designed and exhaustively tested.

1.1 Background

A review of collision reports in the US, Canada and Northern Europe show that approximately 66% of all cyclist casualties in urban areas occur at intersections[i]. Furthermore, detailed studies have shown that bicycle-motor vehicle collisions accounted for 75% of these casualties. Intersections equipped with standard traffic control signals should be able to meet the requirements of cyclists. However, under certain circumstances, there may be requirements for bicycle-related features to improve safety. In addition, many jurisdictions are promoting the activity of cycling as environmentally conscious and healthy, both as an alternative to automobile commuting and as a form of recreation and exercise.

TAC's Project 209 produced the document entitled "Bikeway Traffic Control Guidelines" which developed standards for signs and pavement markings associated with bicycle operations within the road allowance. This project is intended to complement these Guidelines by providing the companion signals component.

1.2 Data Collection

MMM undertook a significant literature collection and review exercise to obtain the latest information on the accommodation of bicycles at signalized intersections. The reference material provided by TAC was reviewed, and many of the key individuals were contacted again in order to determine if new data was available, or to follow up on previous information submitted to TAC.

In addition, an extensive internet search was undertaken to identify new sources of information from various sites around the world. These sites included Federal and Provincial/ State Departments of Transportation, municipal and regional cycling departments, the Institute of Transportation Engineers and numerous cycling and pedestrian advocacy groups. A detailed list of reference sites is included in **Appendix A**.

The information assembly exercise also included a review of various cycling master plans, planning and design guidelines plus numerous reference books and manuals. A review of this material indicated that the existing North American installations were located in New York, NY, Tucson, AZ, Portland, OR, Davis, CA and Montreal, PQ. We have contacted cycling representatives from each of these municipalities in order to better understand their experience with bicycle signals.

2.0 Inventory of Safety and Operational Issues

Before considering the application of bicycle traffic signals at intersections, it is important to understand how cyclists typically operate on roads. The application of designated bicycle traffic signals should be analyzed based on the current rules for vehicular traffic, particularly in locations where cyclists have the right of way. The following should be recognized:

- Cyclists can legally ride in bicycle lanes and on all roads used by motor vehicles, with the exception of freeways;

- At intersections, bicycles and pedestrians who proceed straight through an intersection have the right of way over vehicles turning right from the curb lane;

- Cyclists are generally obliged to ride on the right side of the roadway; and

- Cyclists are expected to follow the rules of the road, especially at traffic signals just like all other motor vehicles.

2.1 SAFETY REQUIREMENTS OF CYCLISTS

The first step towards developing useful guidelines for bicycle signals is understanding the types of conflicts experienced by cyclists at signalized intersections. Based on a US study, more than 95% of bicycle-motor vehicle collisions occur as a result of turning or crossing movements[ii]. By comparison, 58% of bicycle-motor vehicle collisions are the result of turning or crossing movements in the City of Toronto[iii]. Since these movements tend to be concentrated at intersections, the proper design and operation of intersections is very important.

Crossing manoeuvres involve two parties whose travel paths intersect; one must yield to the other to avoid a collision. Turning manoeuvres complicate that situation by immediately placing the two parties on a collision course. The situation is compounded when the ability to see other road users is impaired, decisions about the right-of-way are unclear and judgements of differential speed and closing rates are imperfect. To avoid a collision, the turning party must yield to the straight through manoeuvre before commencing their turn. Therefore, mitigating turning and crossing movement conflicts should be the focus of efforts to reduce bicycle-motor vehicle collisions.

2.1.1 Straight-Through Movements

Conflicts between crossing movements for cyclists are similar to those for motor vehicles. The separation of crossing movements through the use of traffic control devices is the primary method of improving safety at intersections. Under normal circumstances, signalized intersections should provide adequate separation of conflicting movements for cyclists' needs as well. By having separate signal displays for motor vehicles and cyclists operating on different phases, this may help to clarify the right-of-way and eliminate any confusion over intersection operations.

2.1.2 Right Turns by Cyclists

One concern with right turns by cyclists is the potential conflict with pedestrians on the parallel crosswalk, since the cyclist must yield to them prior to making the turning movement.

Consideration may also be given to exempting cyclists from right turn on red prohibitions, where it is safe to do so, since these restrictions for motorists may not be applicable to cyclists. For example, cyclists making right turns on red would not typically interfere with traffic approaching from the left, especially if the cyclist is turning into a bicycle lane.

2.1.3 Right Turns by Motorists

The right-turn movement for motorists is potentially dangerous when the motorist is not aware of cyclists on the road. This is especially true when there is a shared through-right lane adjacent to a bike lane, and if the through-right lane is very wide. The motorist may tend to turn directly from the shared through-right lane even though there is room for him to approach the turn from a position closer to the curb. The conflict occurs when the motorist turns across the path of a cyclist who is proceeding straight through the intersection. This results in a side-impact collision between the cyclist and the motor vehicle. Every effort should be made to encourage right-turning motorists to merge right prior to reaching the intersection. Merging before turning is much safer than turning across the bike lane since the motorist can select the timing and location to merge in order to avoid cyclists.

2.1.4. Left Turns by Cyclists

The common left-turn method for cyclists is the standard motor vehicle left turn. This manoeuvre is relatively safe under most traffic conditions, is the quickest and most direct route, and interferes least with other traffic. The preference for this manoeuvre, however, can fluctuate depending on many factors. Some of these factors are related to geometric design such as the presence or absence of a left turn lane. Other factors vary, even moment by moment, including past experience at that location, how conspicuous the cyclist feels, traffic density and speed, the presence of other cyclists and pedestrians, cyclist speed, road gradient, and the cyclist's experience or risk tolerance.

The alternate method is for the cyclist to undertake a "pedestrian-style" left turn by crossing the intersection in the curb lane, stopping at the far corner, then yielding to cross traffic or waiting for the signal to change (if one is present) prior to proceeding in the new direction. Variations on this method include a left-turn-refuge with an advanced stop bar, a "jug-handle", "hook turn" or a "bike box" on busy cycling routes.

Figures 2.1, 2.2 and 2.3 illustrate the jug-handle, hook-turn, advanced stop bar and bike-box treatments for bicycles at intersections.

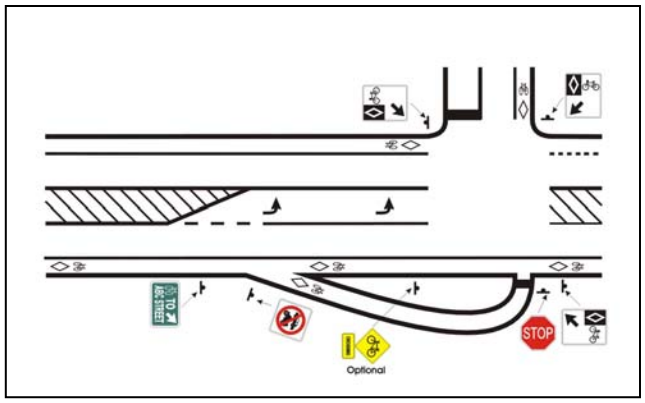

FIGURE 2.1
Bicycle "Jug-Handle"Left Turn
Source: Transportation Association of Canada (TAC), Dec. 1998

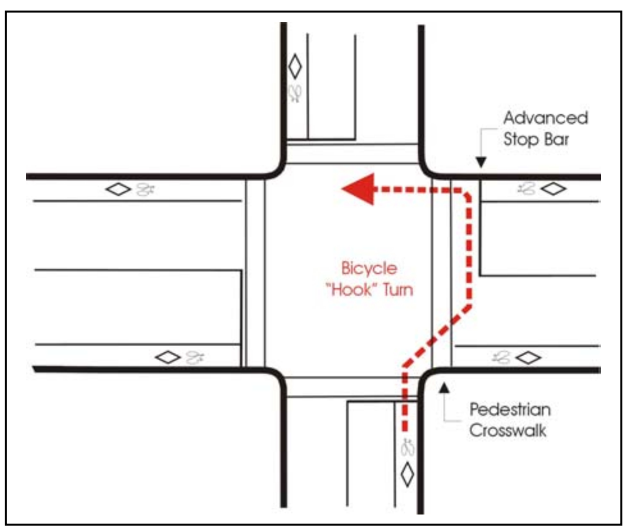

FIGURE 2.2
Bicycle "Hook Turn" with" Advanced Stop Bar"
Source: Marshall Macklin Monaghan Limited

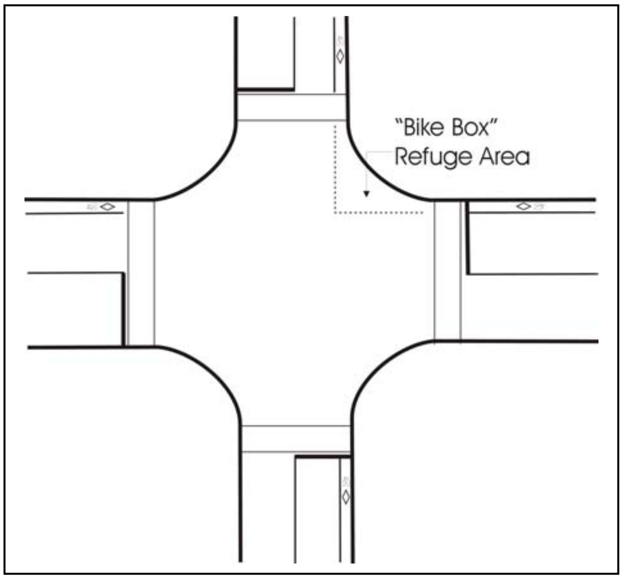

FIGURE 2.3
"Bike-Box" Cyclist Refuge Area
Source: Marshall Macklin Monaghan Limited

The vehicular-style left turn requires the cyclist to cross from the right side to the centre of the roadway. Motorists travelling straight through in the same direction would overtake the cyclist on the right without hindrance. As the number of lanes the cyclist must cross increases, so does the number of potential conflict points. This is much safer, however, than the cyclist attempting to make a "wide" left turn from the curb lane, potentially turning in front of an overtaking motor vehicle.

Since cyclists have a greater minimum gap acceptance threshold than passenger cars and light trucks, the provision of protected left-turn phases, along with exclusive left-turn lanes, can be a significant benefit to them. A protected left-turn phase, specific for cyclists, would not only clearly identify cyclist priority when travelling through an intersection, but it would also give cyclists more confidence, knowing that they would not have to be concerned about conflicting motor vehicle traffic. Exclusive left-turn lanes for cyclists would also provide a refuge area as cyclists wait for their signal display to proceed left through an intersection.

2.1.5 Left Turns by Motorists
Collisions in which a motorist makes an improper left turn by misjudging the gap in opposing traffic, of which cyclists may be a part, is a common type of bicycle-motor vehicle collision. The basic preventative countermeasure is the provision of exclusive left-turn lanes and protected left-turn signal phases. This provides a safety benefit since left-turning vehicles are able to queue separately from the flow of through traffic, reducing the need to accept unreasonably short gaps in opposing traffic.

An important objective of traffic engineering, especially in relation to cycling, is to support and encourage the safest and most effective behaviour. A compromise strategy may be required if cyclist and motorist behaviour is not consistent at a particular intersection. This may be due to unusual geometry or at "gateway" locations where visitors to a community encounter their first significant bicycle / motor vehicle interaction. A compromise system may not be optimal for motor vehicles or for cyclists, but operates more safely when bicycles are numerous. A separate bicycle phase is essentially a compromise, at least for motorists and compliant cyclists.

2.1.6. Trail-Road Crossings
Bicycle trails intersecting with local and major roads can cause concern for both motorists and cyclists. These crossings typically occur mid-block, and the concern for safety becomes more evident if the bicycle path or the roadway has a high volume of traffic. When a mid-block crossing is necessary, it should be designed to provide advance warning to both motorists and cyclists. The bikeways should be designed and signed to encourage cyclists to reduce speed and stop. Grade changes on the trails in advance of the crossing combined with adequate sight distances, signing, textural surface contrast, and bollards should be considered. Mid-block

crossings of arterial or collector roads may warrant consideration of a separate traffic signal. TAC's Pedestrian Crossing Warrants may be referenced for further guidance.

2.2 OPERATIONAL CONSIDERATIONS

The second step towards developing useful guidelines for bicycle signals is identifying the issues surrounding the accommodation of cyclists at signalized intersections. Some of these issues include:

- Cyclists' compliance with traffic signals
- Increasing delay for cyclists
- Increasing delay for transit, motorists and pedestrians
- Separation from pedestrians
- Uniformity with other intersections
- Liability and education
- Visibility and sightlines
- Signal timing design

Each of these issues are described below. Since bicycles are defined as vehicles in the various Highway Traffic Acts and The Code de Sécurité Routier du Québec, the same rights and responsibilities should be applied to them.

2.2.1 Cyclists' Compliance with Traffic Signals

One of the issues with accommodating cyclists at signalized intersections is the assumption that cyclists consistently obey the signal display. Given the current state of traffic law enforcement towards cyclists, as well as cyclist compliance with traffic control devices, this may not always be a reasonable assumption. For the purposes of traffic design, it is essential to make assumptions which are true to the expected behaviour of users. In turn, the expected behaviour of road users depends on their cognitions, which further includes their expectations for other road users. Thus, it would be unsound to assume that cyclists in Canada routinely stop for stop signs or traffic signals whatever the law might be. Further, it would be inappropriate to assume that motorists can properly "read" the intentions of cyclists (and vice versa) in an acceptably high proportion of potential conflicts.

In other words, the assumptions about normative and consistent behaviour which are reasonably applicable to a street with few cyclists, becomes impossible to hold when many cyclists are present. Because we cannot make these assumptions, designing for streets with high volumes of cyclists demands greater sophistication and sensitivity to expected behaviours.

2.2.2 Increasing Delay for Cyclists

The implementation of bicycle-only signal phases for a particular direction of traffic can cause delays on the intersecting cross street. If cyclists use the intersecting street, they too would be delayed further by the addition of a bicycle only phase on the conflicting street. One style of phasing used for intersections with bicycle-specific signals is to hold all bicycle traffic on all approach legs for most of the cycle, and then to release the bicycles during an exclusive bike-only or "scramble" phase, when all motor vehicle traffic is stopped. The bicycle phase for these signals is relatively short in order to maintain adequate green time for the other phases in the cycle. This inherently leads to an increased delay for most cyclists who arrive during the "motor vehicle" phases of the signal. In addition, there is significant potential for collisions between cyclists during a scramble phase since there is no identification of priority between conflicting movements.

2.2.3 Increasing Delay for Motorists and Pedestrians

The provision of any exclusive phasing for bicycles will reduce the amount of green or walk time available for motorists and pedestrians. This will reduce the overall capacity of a signalized intersection, and possibly reduce the overall level of service.

Reduced green or walk times may also impede the ability of slower pedestrians to cross wide intersections. If consideration is given to reducing the signal time allotted to pedestrians, this should only be implemented if the pedestrian phase is actuated. If there are no pedestrians crossing an intersection during a particular phase, this time may be reallocated to a bicycle phase if required. However, minimum green or "walk times" should never be reduced to less than the minimum green time allotted for pedestrians to cross the intersection.

2.2.4 Uniformity with Other Intersections

The application of special bicycle signalization can promote non-uniformity of traffic control for cyclists. They may be expected to operate in a significantly different manner at the intersections controlled by these signals.

For example, at signalized multi-use trail crossings of a roadway, cyclists must currently dismount and make a pedestrian style crossing since they are governed only by the walk/don't walk signals. The provision of separate bicycle signals will afford cyclists the opportunity to legally ride across the intersection on their own green indication. This may lead to some confusion for cyclists and pedestrians as their two modes diverge as they approach the roadway crossing, and then merge as they complete the crossing where the trail continues. Clear pavement markings and signage are essential at these locations so that the expectations of pedestrians and cyclists are clear.

Further, in similar situations where boulevard bicycle trails are constructed, cyclists, pedestrians and motorists may encounter the same confusion over the assignment of the right-of-way depending on the signalization, signing and pavement marking treatments that are applied. This is especially true at locations where bicycle signals are used, compared to those adjacent signalized intersections that have similar features, but for some reason bicycle signals are not applied.

2.2.5 Liability and Education

Many of the potential solutions for increasing bicycle safety at signalized intersections require behaviour that may differ significantly from existing roadway behaviour. In some instances, the concept directly contradicts existing legislation governing all vehicles, including bicycles. Careful consideration should be given to understanding the implications on liability, both for the governing body and for cyclists, and the education of all road users towards the potential changes in cyclist behaviour. Future recommendations for improving bicycle safety at signalized intersections should be consistent with and incorporated into general roadway and driver behaviour, wherever applicable. Furthermore, provinces will need to amend their respective Highway Traffic Acts to recognize the new symbol for a bicycle traffic signal.

2.2.6 Visibility and Sightlines

Bicycles are typically obstructed by much larger motor vehicles on the road. Although the eye level of cyclists tends to be at a higher elevation than many motorists, they are usually not readily visible to motorists. Quite simply, drivers frequently only pay attention to other motorists. This increases the potential for cyclist/motor vehicle collisions. Consideration should also be given to "recumbent" bicycles, which have seats that are lower than those of a standard bicycle. Visibility and sight lines for users of this vehicle would be more constrained than those for a cyclist riding a bicycle with more typical geometry.

2.2.7 Signal Timing Design

The signal timing that is applied to bicycle signals must be "bicycle appropriate". In other words, the green, amber and all red periods must respect the acceleration and deceleration characteristics of bicycles, as well as typical cruising speeds. In addition, many traffic signal controllers are limited to eight phases, so whenever possible, separate bicycle phases should be designed to operate as an overlap. Otherwise, if all eight phases are in use, then the vehicle pre-emption feature may need to be employed.

3.0 Review of Existing Signal Installations

3.1 REVIEW OF EXISTING GUIDELINES

Since bicycle traffic signals are relatively new in North America, the few existing installations have been established without much guidance from regulatory agencies. A few design handbooks include minor sections on bicycle signals, but no detailed guidelines were found during our literature review. This section outlines the various technical documents reviewed during the study.

Canada

Transportation Association of Canada: The *Manual of Uniform Traffic Control Devices for Canada* does not have any references to bicycle signals.

Ontario: The *Ontario Traffic Manual, Book 12: Traffic Signals*, has made provisions for the future addition of "bicycle control signals". There is also provision for the potential addition of a bicycle signal justification methodology.

Quebec: The *Traffic Control Devices Book 2*, published by the Ministère des Transports du Québec (MTQ), contains a section in Chapter 8: Traffic Control Signals, on bicycle signals. The following in an excerpt relating to the standard use of the signals:

> *Bicycle signals are devices installed at the intersection of a bicycle path and a public highway to indicate to cyclists when they may cross. They are used to control bicycle movements to avoid any conflicts with vehicular traffic.*[iv]

The MTQ also includes a standardized drawing for the shapes and minimum dimensions of bicycle signals.

Vélo Québec has published a document entitled *Technical Handbook of Bikeway Design*, which also mentions traffic control signals for cyclists in a limited context.

United States

Federal Highway Administration: The recently released MUTCD 2000 includes a chapter outlining traffic control for bicycle facilities. The signals section is minimal, and only outlines the use of visibility-limited signal faces. The standard is as follows:

> *At installations where visibility-limited signal faces are used, signal faces shall be adjusted so bicyclists for whom the indications are intended can see the signal indications. If the visibility-limited signal faces cannot be aimed to serve the bicyclist, then separate signal faces shall be provided for the bicyclist.*[v]

No standard is given for the use of signals with bicycle symbols.

Institute of Transportation Engineers: The Institute of Transportation Engineers (ITE) and the ITE Pedestrian/Bicycle Task Force prepared an information report on *Innovative Bicycle Treatments* in 2001. One of the many treatments documented in this paper was Bicycle Signals. The objective identified for bicycle signals was to "separate conflicting movements and facilitate the flow of all types of traffic"[vi]. This informational paper identified existing applications, advantages/disadvantages, evaluation studies and sample sites.

International
Bicycle signal locations have been identified in numerous countries outside of North America, including Australia, Great Britain, Finland, Germany, the Netherlands, France and China. This information will be discussed in the following subsections in this chapter.

3.2 General Overview

When designing for bicycles, perhaps more than in other aspects of traffic engineering, the behavioural imperatives of cyclists need to be accommodated. A significant degree of compromise is needed between the best principles of traffic engineering and recognition of the way cyclists behave. Until it is modified, such behaviour may not be in the best interests of cyclist safety, of other road users, or otherwise consistent with good engineering judgement.

For example, cyclists do not like to stop. They will try to maintain their forward momentum at all times wherever the cyclist perceives that it is reasonably safe to do so. Such a desire is a matter of fact, and to design without due recognition of this imperative would lead to well intentioned but unsound recommendations.

Another example relates to time frames. Pedestrians, cyclists and motorists have different scales of time relative to their daily activities. There are few manoeuvres that a pedestrian performs which substantially impede forward progress, except sometimes at intersections. For example, the length of a signal phase, which would seem comfortable for a motorist seems intolerably long for both a cyclist and a pedestrian. Therefore, either or both of them may be inclined to disobey their signals under these circumstances if they perceive that their safety is not significantly compromised, especially during inclement weather.

3.3 NORTH AMERICA

3.3.1 Canada

Quebec
According to the standard in Quebec, bicycle signals should be installed at intersections where bicycle paths and bicycle lanes meet public highways, and to control cyclist movements for the sole purpose of avoiding conflict with any other vehicular traffic. The Quebec standard specifies that bicycle signal indications be mounted vertically, and consist of three circular lenses 200 mm in diameter containing the outlines of a bicycle. The outlines are shown in red, amber or green colours as per **Figure 3.1** from the Quebec manual.

FIGURE 3.1
Quebec Bicycle Signal Head
Source: Gouvernement du Quebéc; Ministère des Transports

Bicycle outlines are all shown on a black background. A minimum of one signal head must be installed within the field of vision of cyclists so it can be easily located and identified. Bicycle signals are placed in locations that are high enough above the roadway so that they do not interfere with pedestrians or cyclists. The typical height of a bicycle signal head measured from the sidewalk grade or the adjacent pavement grade (if no sidewalk is available) is 2.5 m to 3.5 m.

Plans showing the general aspects of intersections with bicycle signals in place were received for eight locations in Montreal. The data collected showed examples where bicycle trails meet intersections, detailing pavement markings and general intersection layouts. All of the intersections collected were identified as "problem" intersections where numerous conflicts between motor vehicles and bicycles were a concern. This included intersections in heavily built-up areas of downtown Montreal, as well as for suburban areas.

Rachel Street in Montreal has 22 intersections with bicycle signals in use. It is reported that the signals are easy to understand and do not result in confusing traffic operations at these intersections. However, cyclists do not always respect the bicycle traffic signals due to the long red and amber intervals dedicated to cyclists. These clearance periods are a function of the design of the two-way bikeway on one side of the street, which is unique to Quebec. As a result, cyclists tend to cross intersections when an appropriate gap in traffic is available, rather than when the traffic signal permits the movement.

Ottawa

The City of Ottawa provided electronic copies of traffic signal drawings, phasing diagrams and traffic counts for three intersections with "bicycle signals" currently in use. Two intersections are located in downtown Ottawa, while the third is located in a rural area outside of the Ottawa City limits. The downtown intersections with "bicycle signals" are located at Isabella and O'Connor Streets and at Nicholas / Water Streets at the Mackenzie King Bridge. The third intersection is located at Acres/Nanaimo Road (Regional Road 16) and Richmond Road (Regional Road 36).

The bicycle signals are actually 3M programmable traffic heads directed at the bicycle lanes, with supplementary signing to indicate "bicycle signals". Simple red, amber and green ball displays similar to those in typical traffic signal installations are used. The purpose of the "bicycle signals" at these intersections is to separate cyclists from other conflicting vehicular traffic, but there is still some confusion that arises between cyclists and motorists. Because these signals use the standard green, amber and red displays, motorists occasionally proceed through the intersection on a green "bicycle" signal instead of their own display, despite the fact that the bicycle signals are optically programmed. Because there is still some "trespass" or "spillover" of the bicycle display into the adjacent motor vehicle lanes, this increases the potential for cyclist / motor vehicle collisions.

There are a number of intersections in the Ottawa area that demonstrate the potential benefits that could be achieved by the addition of bicycle signals.

Nicholas/Waller Streets at Mackenzie King Bridge

In downtown Ottawa, the intersection of Mackenzie King Bridge / Nicholas and Waller Streets is an excellent application for the new bicycle signal heads. Currently, an eastbound left-turn from Mackenzie King Bridge onto Waller Street is permitted for cyclists from the centre median lane. This movement is provided through an exclusive bicycle-only phase to avoid conflicts with other vehicle movements.

The location of the present "bicycle signal" is directly across the intersection in clear view of the approaching cyclists. Due to the orientation of the intersection, the "bicycle signal", which uses standard red, amber, and green displays, is partially in the "cone-of-vision" of eastbound motorists who are turning left. With the existing bicycle signal heads, which are the same as motor-vehicle signal heads, motorists occasionally proceed through the intersection during the bicycle phase. Although cyclists and motorists are both turning left, cyclists must cross two lanes of traffic and turn right at the next block onto Stewart Street in order to continue along the cycling route, as illustrated in **Figure 3.2**.

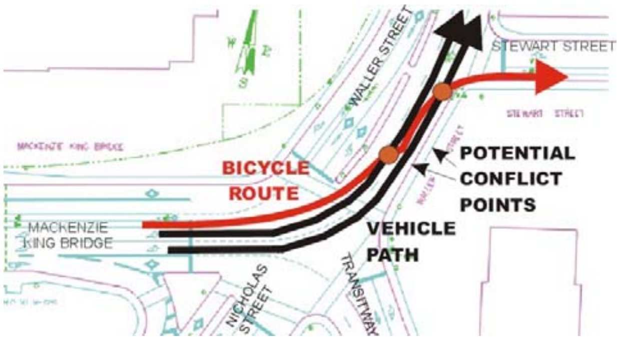

FIGURE 3.2
Potential Conflicts at Mackenzie King Bridge and Nicholas Street/Waller Street
Source: Regional Municipality of Ottawa-Carelton, Environment & Transportation Department; Mobility Services Division, Traffic Operations Branch

Since cyclists must cross these lanes of traffic, the potential for cyclist/motorist collisions increases when motorists proceed through the intersection during the bicycle phase. With the installation of the new signal heads, confusion would be reduced over right-of-way since motorist and cyclist phases would be clearly identified.

Nanaimo Drive / Acres Road
In suburban Ottawa, the intersection of Nanaimo Drive/Acres Road (R.R.16) and Richmond Road (R.R. 36) would also benefit from the installation of the new bicycle signal heads. Dual left turn lanes, a through lane and a right turn lane currently exist on the Acres Road (R.R. 16) eastbound approach to the intersection. During certain time periods, the eastbound through movement is restricted along Acres Road through to Nanaimo Drive. Traffic and "bicycle signals" are located in clear view of the eastbound cyclists and motorists approaching the intersection as illustrated in **Figure 3.3**.

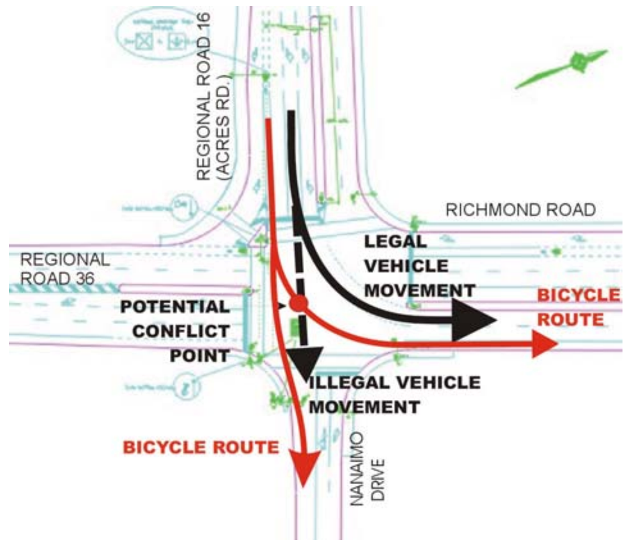

FIGURE 3.3
Potential Conflicts at Nanaimo Rd and Richmond Road
Source: Regional Municipality of Ottawa-Carelton, Environment & Transportation Department; Mobility Services Division, Traffic Operations Branch

Since the "bicycle signals" are within the cone of vision of approaching motorists, on occasion motor vehicles proceed though the intersection during the bicycle signal display when the through movement is restricted.

With the installation of the new signal heads, motorists would be able to clearly identify which movements are permitted through the intersection, and confusion over the right-of-way would be minimized.

O'Connor Street & Isabella Street
The installation of the new bicycle signal heads at the intersection of O'Connor Street and Isabella Street in downtown Ottawa would help to reduce the number of illegal turning movements, which presently occur at the intersection. Presently, all motorists travelling south on O'Connor Street must turn left onto Isabella Street, a one-way eastbound street as illustrated in **Figure 3.4**.

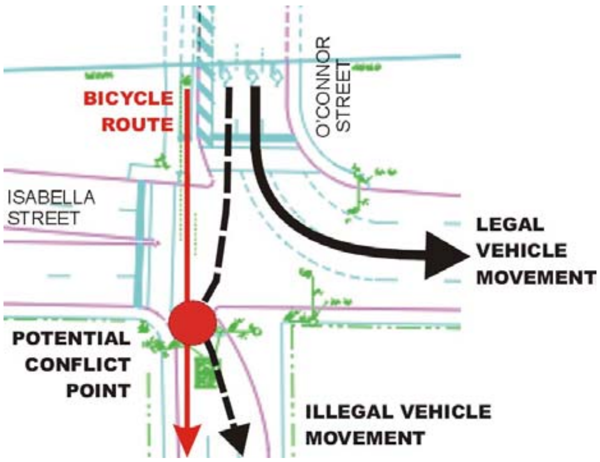

FIGURE 3.4
Potential Conflicts at O'Connor Street and Isabella Street
Source: Regional Municipality of Ottawa-Carelton, Environment & Transportation Department; Mobility Services Division, Traffic Operations Branch

O'Connor Street does proceed south of Isabella Street, but no through movements are allowed, with the exception of bicycles, "Bicycle signals" that are currently in place are clearly visible to approaching cyclists and motorists. Motorists frequently proceed illegally though the intersection onto southbound O'Connor Street by following the bicycle signal. By installing the new bicycle signal heads, it would become evident to motorists that through movements on O'Connor Street are restricted to cyclists only. This would help to reduce the number of illegal movements that occur at the intersection, thus improving the safety for both cyclists and motorists in the area.

Toronto
The City of Toronto also provided electronic copies of traffic signal drawings for six intersections with "bicycle signals" currently in use. These intersections are located through various urban areas around the City. These include: Lakeshore Boulevard East at Carlaw Avenue, Don Roadway; Lake Shore Boulevard West at Windermere Avenue and Colborne Lodge Drive; Oriole Parkway at Kilbarry Road; and Bloor Street at Montrose Avenue.

The bicycle signals heads presently in use in Toronto are identical to the standard heads used for traffic signals with only two exceptions. A black housing is used for bicycle signal heads as opposed to the yellow colour that is typically used for vehicular and pedestrian traffic signals in Toronto, and the signal heads are mounted in pairs with a sign in between identifying them as "bicycle signals". Bicycle signals are also placed at a lower elevation than motor vehicle signal heads. The photograph below illustrates a typical bicycle signal installation in use in the City of Toronto.

Bicycle Signal Head: Lake Shore Blvd and Carlaw Avenue in the City of Toronto

There are a number of intersections in the Toronto area that demonstrate the potential benefits from the installation of the new bicycle signal heads.

"Bicycle signals" are presently located along a bicycle trail paralleling Lake Shore Boulevard East at the crossings of Carlaw Avenue and Don Roadway. **Figures 3.5 and 3.6** detail the layouts for these two intersections.

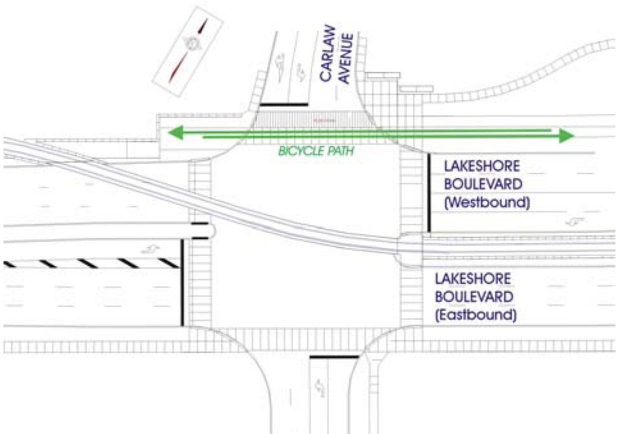

FIGURE 3.5
Lake Shore Blvd. and Carlaw Avenue

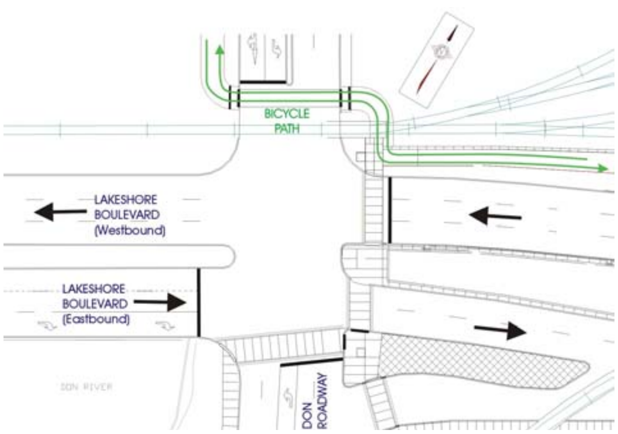

FIGURE 3.6
Lake Shore Blvd. and Don Roadway Intersection Layout

Replacement of the regular signal heads used at present with the new bicycle signal heads would provide a clearer indication to cyclists of their right of way, eliminate the need for the "bicycle signal" signs which would reduce the clutter at the intersection, and finally indicate to pedestrians that bicycles "belong" on this trail crossing, *(Refer to photograph on Page 13).*

Lake Shore Blvd at Windermere Avenue
Bicycle signals are also located at the intersection of Lake Shore Boulevard West and Windermere Avenue in Toronto's west end. This is a Tee intersection with a bicycle crossing located on the western edge of the intersection, crossing Lake Shore Boulevard parallel to Windermere Avenue, detailed in **Figure 3.7**.

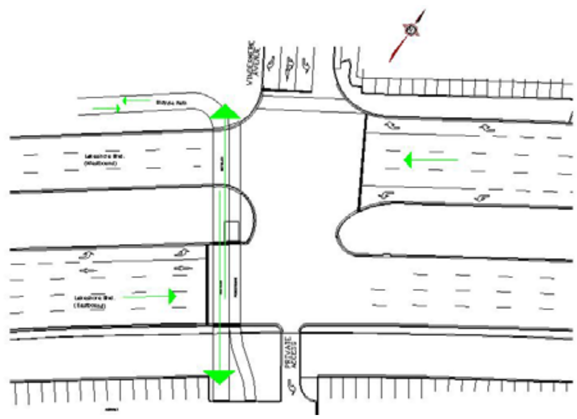

FIGURE 3.7
Windermere Avenue and Lake Shore Blvd Intersection Layout

Bloor Street West & Montrose Avenue
Bloor Street West and Montrose Avenue is another Tee intersection with a contra-flow bicycle lane located along Montrose Avenue as illustrated in **Figure 3.8**.

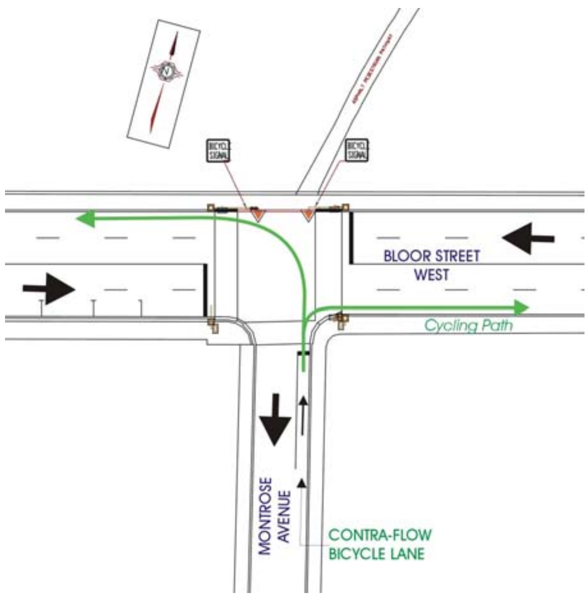

FIGURE 3.8
Bloor Street and Montrose Avenue Intersection Layout

"Bicycle signals" are currently installed at this intersection to control northbound cycling movements in the contra-flow bicycle lane along Montrose Avenue turning east or west onto Bloor Street. The new bicycle signal heads should be installed at both of these intersections, replacing the signal heads currently in use.

Lake Shore Blvd. at Colborne Lodge Drive
The intersection of Lake Shore Boulevard West and Colborne Lodge Drive is another Tee intersection with "bicycle signals" currently in operation. Bicycle lanes are located on both sides of Colborne Lodge Drive connecting to the Martin Goodman trail as shown in **Figure 3.9.**

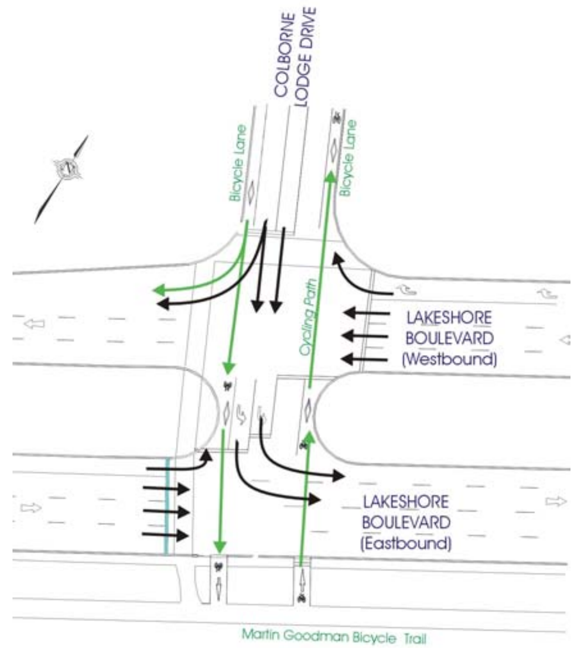

FIGURE 3.9
Lake Shore Blvd and Colborne Lodge Drive Intersection Layout

"Bicycle signals" are currently installed on the far side of the intersection, directing northbound cyclists to cross Lakeshore Boulevard onto Colborne Lodge drive. The new bicycle signal heads could be installed at this location since the use of bicycle signals here has already been established.

On the south west corner of the intersection, another "bicycle signal" is currently in operation permitting southbound cyclists travelling along Colborne Lodge drive to turn right or left onto Lake Shore Boulevard or to proceed straight across the intersection and onto the Martin Goodman trail. Since southbound cyclists are the only vehicular movements permitted to travel straight through the intersection, the installation of the new bicycle signal head would be useful at this location.

Kilbarry Road at Oriole Parkway

The intersection of Kilbarry Road and Oriole Parkway located in midtown Toronto is a 4-legged intersection with bicycle lanes on the east and west approaches. Numerous traffic restrictions are presently in place at this intersection for motor vehicles. **Figure 3.10** details the turning movements permitted for both motorists and cyclists.

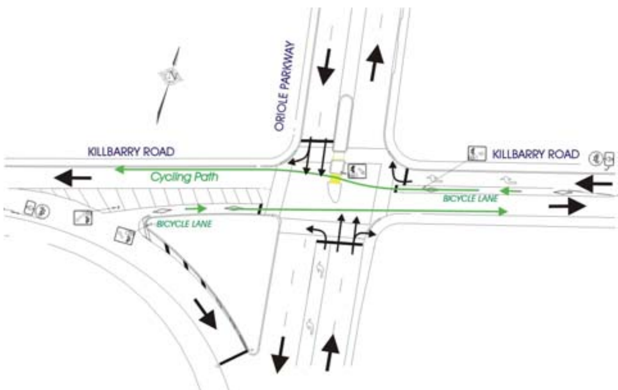

FIGURE 3.10
Kilbarry Road and Oriole Parkway

Through and right turning movements only are permitted for northbound and southbound motor vehicles approaching the intersection. Eastbound and westbound motor vehicles must turn right onto Oriole Parkway. However, eastbound and westbound cyclists are permitted to travel through the intersection, continuing along Kilbarry Road, as well as proceeding north or south along Oriole Parkway. Although no bicycle signals are presently located at this intersection, the installation of bicycle signal displays for eastbound and westbound through movements, which are prohibited for motor-vehicles would prove to be very useful. However, bicycle signals are not required to reduce conflicting movements.

3.3.2 United States

Davis, California

The City of Davis, California installed new bicycle signal heads in 1990 that contain the outline of a bicycle symbol in the lens. The amount of signal time that was allotted to cyclists was determined based on field experience and the activity of bicycle riders. A six-year study was conducted to assess their usefulness and effects on collisions. With the installation of the new signal heads, motor vehicle/bicycle collisions were reduced by 40%, while motor vehicle/pedestrian collisions remained the same.

Tuscon, Arizona

The City of Tuscon, Arizona installed bicycle traffic signals at the intersection of 3rd Street, a minor residential roadway and Country Club Road, a major arterial. As a “traffic calming” measure to discourage through motor vehicle traffic on 3rd Street while encouraging bicycle use, all motor vehicle traffic on 3rd Street must turn right at Country Club Road, while bicycle traffic is permitted to travel straight through the intersection. This was done by installing channellizing islands and pavement markings that require motorists to turn right, combined with bicycle channellization and a bicycle traffic signal to give a clear indication that only cyclists may proceed straight across Country Club Road. The installation of bicycle traffic signals has not resulted in confusion for drivers or cyclists, and establishes no inherent conflicts between bicycle and motor vehicle travel.

New York City (Herald Square), New York

Bicycle traffic signals have been installed at the Avenue of the Americas (6th Avenue)/ Broadway Avenue / 33rd Street intersection, also known as Herald Square in Midtown Manhattan. 6th Avenue is a one-way major arterial road running from south to north through Herald Square. 33rd Street is a one-way minor road running from east to west out of the Square. Broadway Avenue is another major arterial road running in a diagonal direction from northwest to southeast. A single contra-flow lane for motor vehicles exists on 6th Avenue running between Broadway Avenue south to 33rd Street. Motor vehicles travelling in this lane must turn right onto 33rd Street. The bicycle lane runs northbound along 6th Avenue through Herald Square and is physically separated from motor vehicle traffic by a median. **Figure 3.11** illustrates the layout of the Herald Square intersection showing the location of the bicycle signal.

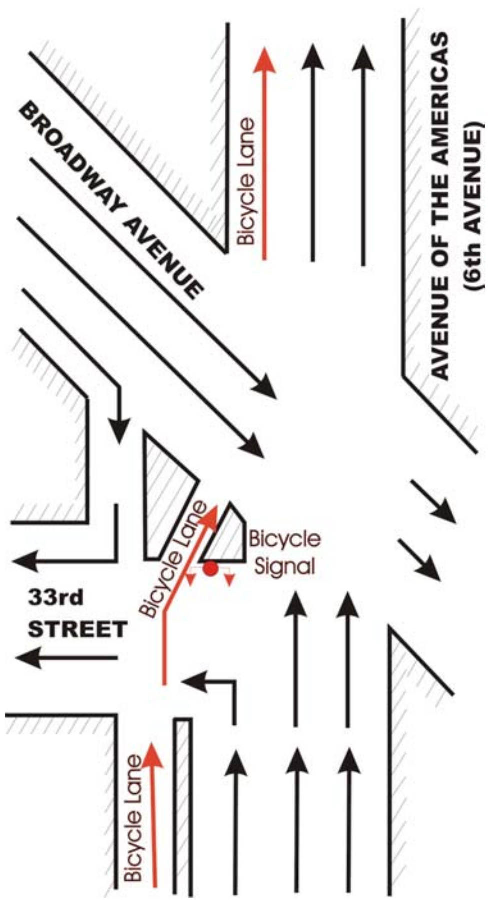

FIGURE 3.11
Herald Square Permitted Movements
(Not lane configurations)

Source: Allen, John S. The Herald Square, Manhattan bike lane, "Getting Across" or just getting by? www.bikexprt.com, *March 1986*

Although the bicycle traffic signal helps to clarify cyclist priority through the intersection without causing confusion among motorists, there are other inherent problems with the placement of the bicycle lane itself that encourage cyclists to make illegal or unsafe manoeuvres. This intersection has high volumes of motor vehicle traffic and, as a result, slower moving or less experienced cyclists tend to use the bicycle lane. However, the introduction of a separate bicycle phase increases the delay to all road users, especially to those law-abiding cyclists who use the bike lane. Although the introduction of the bicycle phase allows for the safe movement of cyclists through the intersection, if they "miss" their bicycle only phase, they have to wait through two full signal cycles before they are permitted to proceed. This is one of the reasons why experienced or impatient cyclists tend to ride alongside motor vehicles, proceeding through the intersection on the northbound phase.

The fact that the bicycle lane is physically separate from the motor vehicle lane, and outside of the left turn lane on 6th Avenue, the bicycle lane almost acts like a sidewalk. This suggests that cyclists operate at slower, pedestrian-style speeds. Observations at the intersection confirm this.

This case study shows that even when facilities which encourage safe cycling are installed at intersections, it can actually lead to potentially unsafe operations when this is done at the expense of time and convenience. Cyclists' behaviour and tendencies must be recognized when providing treatments for them at signalized intersections, as well as the impacts these treatments may have on all movements through the intersection.

3.4 INTERNATIONAL

3.4.1 United Kingdom

Cycling is a major mode of transportation in the United Kingdom with many individuals choosing to cycle for utilitarian purposes. In response to this, numerous bicycle signals have been installed in many cities across the United Kingdom.

London, UK

The safety of cyclists was a major concern at the intersection of Strand and the Waterloo Bridge in London, England. As many as 40 cyclists per hour were making an illegal crossing of Strand from Wellington Street to access Lancaster Place in order to avoid a long, legal detour around Aldwych. A new signalling plan was developed to allow direct access to Lancaster Place from Wellington by adjusting the signal phases to allow for pedestrians and cyclists as illustrated in **Figure 3.12.**

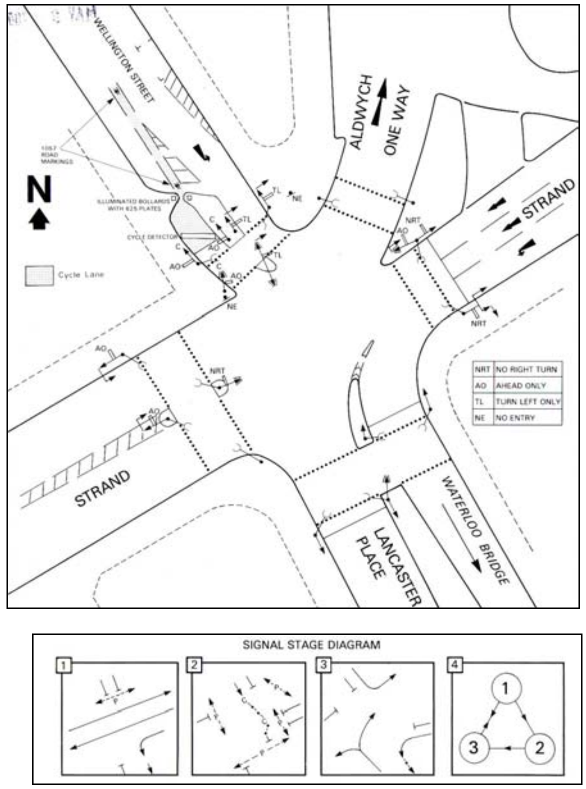

FIGURE 3.12 Strand/Lancaster Place Signal Staging Diagrams

Source: Department of Transportation, Traffic Advisory Unit (TAU); London, UK, 1986

During the cyclist/pedestrian phase identified as stage 2, all motor vehicle traffic is stopped on all approaches to the intersection. Cyclists can then proceed directly through to Lancaster Place from Wellington Street. Pedestrians are signalled safely over the remaining arms during this stage and, because of this, cyclists arrive at a red signal at the pedestrian crossing over Lancaster Place. At this point, they must wait until the pedestrian phase is complete before being given a green signal to continue. This is called by either a push button or loop detector in the bicycle lane.

A bicycle/pedestrian traffic signal was installed at a bicycle path crossing Uxbridge Road in West London. The bicycle path parallels the heavily trafficked Highway A312 to provide a route for residents to access the Hayes Town Centre. Before the bicycle path was installed, cyclists used to travel along Highway A312. Results show that cycling traffic along the new route is lighter than expected. This has been attributed to a lack of publicity of the new route.

The Albert Gate / Albion Gate signalized bicycle crossings were also installed in London's west end to provide a north-south link through a heavily congested area along the Ambassador Cycle Route. The Albert Gate and Albion Gate crossings allow cyclists to safely cross Knightsbridge and Bayswater Road respectively. With the two signalized crossings, cyclists can safely travel along the Ambassador Bicycle Route between Paddington Station and Victoria Station via Hyde Park, a popular cycling destination in Central London.

It was not feasible to provide a bicycle-only phase at the Knightsbridge crossing since this would cause major delays to motor vehicles travelling along Knightsbridge. As a result, cycling phases were incorporated into appropriate left-turn and pedestrian phases already in operation. After the "bicycle signals" were installed at Albert Gate, the number of cyclists at the crossing increased by 60%. The majority of cyclists used the crossing correctly and adhered to the bicycle signals. Collisions at the Albert Gate crossing decreased by 30%, but remained consistent elsewhere.

Cambridge, UK

Cycling in the City of Cambridge is a popular mode of travel, particularly for students. Statistics show that more than one third of all road collisions involve cyclists. A pedestrian/bicycle signal was installed along Fen Causeway in Cambridge at a highly travelled paved footpath. In order to minimize confusion at the crossing, low demand movements were banned, and small display boards installed explaining to cyclists and pedestrians how to use the crossing. With the installation of the bicycle signals, cycling movements at the crossing increased while the collision rate at the site or in the surrounding area saw no significant change.

A bicycle signal was installed at the Hills Road and Brooklands Avenue intersection, also in Cambridge, which is heavily travelled by cyclists and motorists. The bicycle signals were installed to separate through and left-turning cycling movements from through and left-turn movements by motorists. With the installation of the signal, there were no reported collisions at the intersection. However there were concerns about the non-compliance of cyclists travelling through the intersection. Some cyclists disobeyed the red and amber displays of the bicycle signal, and some proceeded through the intersection during the phases allotted for motorists.

Preston, UK

The safety of cyclists was noted as a concern at an intersection in Preston, located in Lancashire County. This is a complex intersection at which four streets meet each other. A scheme was devised by connecting existing traffic islands around the intersection with bicycle paths allowing cyclists to "skip" across the intersection from island to island during appropriate phases of the traffic signals. The bicycle signal phases were incorporated into the existing traffic signal system allowing cyclists to cross the intersection at times that do not conflict with other vehicular traffic as illustrated in **Figure 3.13.**

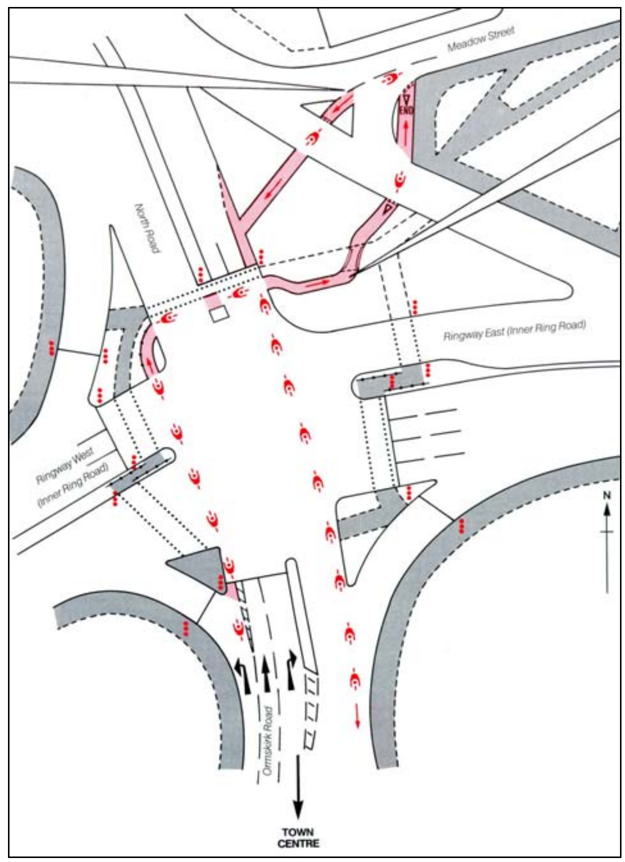

FIGURE 3.13
Ring Road Intersection Layout (Preston, UK)
Source: Department of Transportation, Traffic Advisory Unit (TAU); London, UK, 1986

Approximately 47% of the cyclists crossing the junction use the bicycle crossing scheme, however many cyclists still cross during the pedestrian crossing time. Since the installation of the signalization scheme, the junction has operated relatively safely without impeding other vehicular traffic movements.

Manchester, UK

A concept similar to that used in Preston was developed for a bicycle/pedestrian crossing in Manchester England. Bicycle signal timings were incorporated into appropriate left-turn and pedestrian phases of the traffic signals. As in the case with the Knightsbridge crossing, a bicycle-only phase could not be added to the existing traffic signal phases, since the additional phase would cause significant delays to motor vehicle traffic approaching the intersection.

3.4.2 Europe

Helsinki, Finland

Developers of the bicycle network in Helsinki have considered the installation of bicycle-only traffic signals. A new bicycle control technique called BEPOLITE (Bicycle Early Pass Over Stop Line Technique) was implemented to decrease conflicts between pedestrian and cyclist movements. The first phase of the signal allows vehicles and bicycles only to proceed through an intersection. A standard green display is used for vehicles while a green display beneath a bicycle symbol is used to control cyclist movements. After an amber and green display, only pedestrians may proceed through the intersection. Approximately 4 to 6 seconds later, a flashing amber display under the bicycle symbol permits cyclists to proceed through the intersection again, but with caution yielding to all pedestrians. After an amber then red display for pedestrians, the flashing amber signal for bicycles returns to green and the first phase sequence begins again as illustrated in **Figure 3.14.**

Some cyclists had some safety concerns over the BEPOLITE system. The amber flashing signal caused some confusion to users who were not familiar with BEPOLITE. Riders stated that they did not know what to do during the flashing amber display and would behave against the traffic code, therefore causing unsafe conditions. High speed and careless behaviour among cyclists was also a major safety concern at controlled intersections. Some cyclists approached controlled intersections on red displays and continued through during the pedestrian phase. Cyclists would only stop if there were pedestrians in the way. Only 1% of all cyclists approaching signalized intersections on red displays stopped when there were no pedestrians blocking their path. Despite this, The BEPOLITE system has worked effectively in Helsinki with no reported collisions during its 2 1/2 years of operation. The system has generally been well understood by cyclists, with only 2% viewing the BEPOLITE system as "risky". Approximately 90% of the cyclists prefer the BEPOLITE signals compared to conventional displays.

3.4.3 Australia

Canberra, Australia

The City of Canberra installed bicycle signals at 16 intersections within the urban area. These indicate precisely when and where cyclists are permitted to enter the intersection. The locations chosen were selected on the basis of safety and the amount of ridership along the cycling route. Bicycle signal heads used in Canberra are similar to the pedestrian signals used throughout Australia, but instead of depicting a "green man" symbol to walk and a "red man" to stop, they show a "green bicycle" to proceed and a "red bicycle" to stop. As is the case in most jurisdictions, cyclists are prohibited from riding their bicycles within a pedestrian crosswalk at traffic signals. Technically, they must dismount and walk their bicycle across the road. Installation of the bicycle traffic signals at

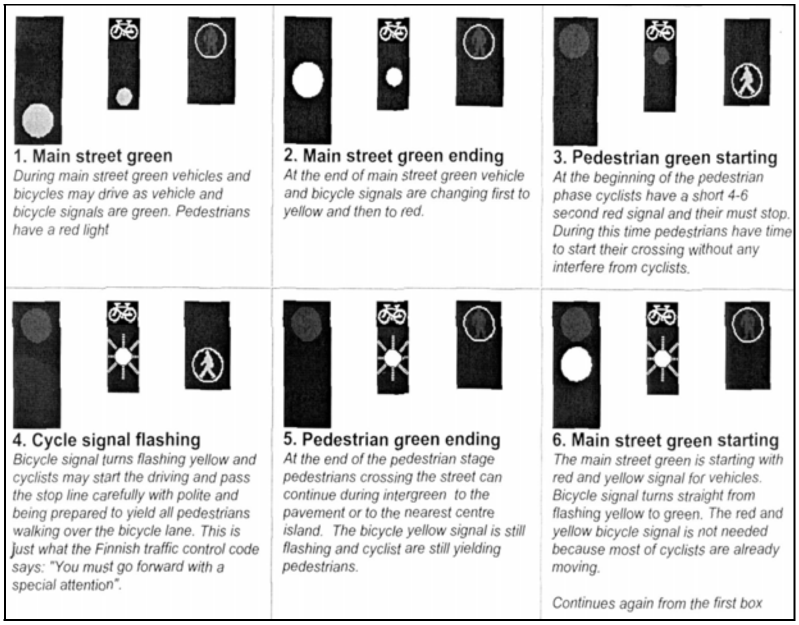

FIGURE 3.14
Helsinki Phasing Sequences
Source: City of Helsinki, Traffic Planning Division, 1999

these 16 intersections has helped to clarify priority and the right-of-way for cyclists, especially in locations where they cross adjacent to pedestrians in the parallel crosswalk.

3.5 SUMMARY OF FINDINGS

3.5.1 General Concerns

Based on the background information collected and observations from other cities with operational bicycle signals, the following concerns were identified with regard to cyclist collisions and movements at intersections.
One common problem that was identified in cities all over the world was cyclists' non-compliance with traffic signals. Cyclists frequently choose to ignore traffic signal restrictions, and simply proceed through intersections whenever the way is clear. Cyclists complain that the time allotted to motorists at traffic signals is too long and therefore, too short for cyclists. This increases their frustration levels, thus encouraging them to make illegal movements.

There is a general perception that cyclists can safely proceed on the green indication for motorists at the vast majority of intersections. This leads to the principle that a separate phase for cyclists should only be used in special cases, and not as a general rule. Cyclists should be accommodated within the regular signal phases as much as possible. The tendency for cyclists to make unsafe or illegal movements due to frustration and impatience was evident in many jurisdictions, but was specifically noted in Montreal, PQ, New York, NY, Cambridge, UK and Helsinki, Finland.

Confusion over the right-of-way at intersections was another concern identified through the research. This can be attributed to complicated signal phasing patterns and signal head arrangements. Users at a particular intersection who were not familiar with the traffic operations in place were not clear on how to proceed. This can cause cyclists and motorists to perform movements that are dangerous or illegal as identified in Ottawa and Helsinki.

3.5.2 Bicycle-Related Problems with Traffic Signal Installations

A national study conducted in the United States identified semi or fully actuated traffic signals as a major bicycle-related problem with regard to traffic signals. Actuated signals typically utilize loop detectors that are designed to call or extend a phase when motor vehicle traffic is present. However, many of these installations are not designed to detect bicycles, making it difficult for cyclists to effectively use an intersection. As a result, law-abiding cyclists must wait for motor vehicles or pedestrians to arrive to trigger a signal change permitting them to advance through an intersection. Many cyclists simply disobey the red signal indication and proceed through the intersection when the way is clear. This leads to a general disrespect for traffic signals which may result in hazardous manoeuvres and an increase in collisions.

The following comparative chart shown in **Table 3.1** outlines the most frequent types of Cyclist/Motor Vehicle and Cyclist/Pedestrian collisions that occur, and their cause. Countermeasures to minimize the potential for these conflicts are recommended, with the advantages and disadvantages to each countermeasure listed.

Tables 3.2 and **3.3** highlight various types of intersection treatments and bicycle-detection methods that could be applied at these intersections, with the advantages and disadvantages listed for each.

TABLE 3.1

Cyclist / Motor Vehicle / Pedestrian Conflicts and Possible Counter Measures

CONFLICT	CAUSE	COUNTER MEASURE	ADVANTAGES	DISADVANTAGES
CYCLIST / MOTOR VEHICLE				
Right-Angle collisions at Intersections.	Cyclists or motorists running red light.	Installation of bicycle signals with an exclusive phase for cyclists' [1] following the motor-vehicle phase of the parallel movement.	Reduces risk of right-angle collisions between cyclists and motor vehicles.	Can significantly increase delay for cyclists, and thereby increase their likelihood of disobeying the signals.
			Helps to clarify right-of-way.	May increase cycle length or reduce timing allotted to motor vehicle or pedestrian movements.
Right-Turns by Motorists at Intersections.	Motorists turning right colliding with cyclists proceeding straight through.	Encourage motorists to merge right before reaching the intersection.	Allows motorist to determine the proper time and location to merge and avoid a cyclist rather than crossing the bike lane at the intersection.	There must be sufficient pavement width on the approach to the intersection to ensure that a motorist has enough time and space to merge before reaching the intersection.
Left-Turns by Motorists at Intersections.	Motorists turning left colliding with cyclists going straight through the intersection.	Providing separate left-turn phases for motorists.	Separates left-turning traffic from through traffic if most left turns can be accommodated during this phase. Otherwise a restrictive or fully protected left turn phase would be required.	Cyclists would be delayed by a lengthy opposing left turn phase, and significant bicycle queues may develop on heavily travelled cycling routes.
				Reduces time allotted to the opposing through vehicular, pedestrian and cycling movements.
Left-Turns by Cyclists at Intersections.	Cyclists colliding with motorists while making left-turns or crossing from the right side of the roadway to the left before making a left turn.	Installing facilities for "jug-handle" or "hook" turns.	Eliminates the need for cyclist to cross over to the left side of the roadway to turn.	Cyclists need to travel through two signal phases to make a single turn.
Mid-Block Crossings.	Motor vehicles colliding with crossing cyclists.	Provide advanced warning to motorists and cyclists of the approaching crossing, prompting both users to be more cautious.	Minimizes the potential for conflicting movements.	Delays to cyclists at crossing while waiting for a safe gap.
			The safest means to cross a roadway at a midblock location is to wait for a safe gap in traffic.	
		Install traffic signals at crossing if motor vehicle and/or cycling traffic is high.	Reinforces priority at crossing, eliminating confusion over right-of-way.	Delays to cyclists and motorists at crossing.
CYCLIST / PEDESTRIAN				
Right-Turns by Cyclists.	Cyclists turning right colliding with pedestrians in the parallel crosswalk.	Exemption of cyclists from right turn on red restrictions.	Reduces the number of cyclists turning right during green and WALK indication that conflict with pedestrians crossing adjacent to the cycling movements.	Consideration must be given to pedestrians crossing perpendicular to the cyclists movements. This countermeasure is only applicable where right turns on red are already prohibited.
Cyclists riding on sidewalk.	Insufficient room or unsafe conditions on roadway.	Providing bike lanes or parking restrictions along streets.	Helps to define user right-of-way on roadways.	May not be suitable on narrow streets.
		Prohibit cyclists from riding on sidewalks.	Provides pedestrians with an exclusive space within the R.O.W.	May not be justified in areas with little cycling traffic.

1 This countermeasure can be applied to all of the conflicts noted on this table. The same or similar advantages and disadvantages exist for each case.

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TABLE 3.2
Bicycle Treatments at Intersections

INTERSECTION TREATMENTS	ADVANTAGES	DISADVANTAGES
Incorporating bicycle displays into existing signal phasing and timing plans.	Does not change cycle length or signal timing since bicycle phases operate as an overlap.	May lead to a proliferation of bicycle signals where they may be unwarranted.
		Adds to visual "clutter" as well as installation and maintenance costs of the intersection.
Separate bicycle phasing.	Allows cyclists to proceed through an intersection without conflicting with other modes of traffic.	Would increase signal cycle lengths and increase delays for motorists and pedestrians.
		May require the installation of a new or upgraded signal controller.
		Many traffic controllers are limited to eight phases. If all of them are currently in use, then an unused signal pre-emption feature may need to be employed.
Bicycle pavement markings.	Clearly defines cyclist operating space.	Only applicable on streets with a sufficient pavement width.
	Helps to direct cyclist to proper operating area.	

TABLE 3.3
Bicycle Detection Methods

BICYCLE-DETECTION METHODS	ADVANTAGES	DISADVANTAGES
Infrared Detectors.	Greater viewing distance in fog than with visible wavelength sensors. Provide direct measurements of speed, vehicle counting, length assessment and queue measurement. Can be mounted between heights of 15 and 30 feet.	Performance degraded by heavy rains, snow and other obscurants in the atmosphere.
Video Image Processors.	Can analyze a location of interest and extract pre-set information. Can be mounted overhead and be concealed so they do not interfere with driver behavior. They can measure a large area and can replace multiple detector loops.	May be affected by strong winds.
		Expensive, but costs are decreasing. May be cost effective if used for intersection control and data collection.
Microwave Detectors.	Good performance in inclement weather. Direct measurement of speed.	Cannot detect stopped or slow-moving vehicles.
Inductive Loop Detectors.	Very reliable below ground detectors that respond to ferrous metal mass within the zone of influence.	Cyclists have difficulty in knowing exactly where to place their bicycle in the best location to ensure they are detected.
		Loops are prone to physical damage from frost heave, pavement deterioration or utility cuts.
	Most older bikes have enough ferrous metal components to be detected.	Newer bicycles have less ferrous metal components, and detecting them can be problematic. If the sensitivity of the loops are increased to detect bicycles with less ferrous metal, there is an increased probability of detecting vehicles in adjacent lanes. This is problematic if an exclusive bicycle phase is called separate from the phase controlling an adjacent lane.
Ultrasonic Detectors	Can detect an approaching cyclist and measure its speed.	Cannot detect a stationary bicycle
		Not appropriate for use at a semi-actuated intersection or to call a separate bicycle phase.
Call Buttons.	Demand responsive and reliable.	Requires the cyclists to stop and push the button to prompt a signal change.
	Provides visual and tactile response to the cyclist, depending on the type of pushbutton.	May require the installation of a separate pole to mount the push button which adds to the cost of an installation.

4.0 Implementation and Application

When implementing bicycle traffic signals, they should function in such a way as to:

- Avoid unnecessary or frequent stops which typically encourage vehicles, especially cyclists, to disrespect the traffic signal; and

- Take into account the characteristics of a bicycle, particularly a cyclist's ability to manoeuvre more freely than other motor vehicles, and their inability to steer properly at low speeds, thus requiring additional space for another vehicle to pass safely.

It is also important to ensure the uniformity of bicycle traffic signals at intersections so that they provide a clear message to cyclists and motorists alike. Furthermore, excessive signing should be avoided.

4.1 Exclusive Bicycle Signal Display

4.1.1 Application

Bicycle signals should be installed only when the standard vehicle displays are not adequate to control bicycle movements without introducing confusion over who has the right-of-way. For example, bicycle signals may be installed at intersections where bicycle paths meet public highways and wherever a dedicated signal display used to control bicycle movements from a bike lane or bicycle refuge area is considered beneficial. They must be used to control cyclist movements only, wherever warranted, as defined in **Section 4.1.5.**

The provision of an exclusive signal display for bicycles may help to reduce or eliminate the practice of cyclists riding on sidewalks, since bicycle signals would be located over the travelled portion of a roadway or bicycle path. The placement of a bicycle signal in these locations would help to define a cyclist's operating area and would encourage cyclist's to ride there.

Furthermore, the application of bicycle signals would further define a bicycle as a "vehicle" with the legal right to share all classes of roadways including arterials, collectors and local streets, with the exception of controlled access highways. Exclusive bicycle signals would also help to reduce a cyclist's reliance on walk / don't walk signal displays at intersections.

4.1.2 Signal Heads

Despite the application of supplementary signing, visors, straight rays or optically programmed heads, experience indicates that confusion still exists between motorists and cyclists when standard but separate signal heads are used to control bicycle movements.

This confusion has largely been eliminated in Quebec, where provincial standards dictate that bicycle signals contain the green, amber or red outline of a bicycle in a black circular lens. These bicycle signal displays are reportedly easy to understand, and do not result in confusing traffic operations at intersections where they are applied.

Nonetheless, on the strength of its relative success in Quebec, it is recommended, therefore, that a national standard for bicycle traffic signals be adopted by the Transportation Association of Canada (TAC) based on the existing Quebec standard. As a result of studies on bicycle signals that have been conducted in various cities around the world, this standard would prove to be the most effective and applicable for Canada. **Figure 4.1** details the shapes and dimensions for the bicycle signals using the Quebec standard.

FIGURE 4.1
Quebec Standard Signal Head
Source: Gouvernement du Quebéc; Ministère des Transports

Specifically, the Quebec standard dictates that bicycle signals be mounted vertically and consist of three 200 mm circular lenses containing the outlines of bicycles.

Cyclists should treat bicycle signal displays in the same manner that a motorist would treat a standard traffic signal display. A green indication on a bicycle signal head would indicate a “permissive” movement and all cyclist movements on that approach would be permitted, including through movements and right and left turns, provided the right of way is clear.

Any cyclist turning restrictions or prohibitions would be indicated through the application of the appropriate signing.

Amber and red displays on bicycle signal heads would also be treated by cyclists in the same manner that amber and red displays would be treated by motorists at typical traffic signal installations.

The MUTCDC affords the option, however, of mounting standard signal heads horizontally. Given the need to provide a more “distinctive” display, there may be some benefit if the bicycle signal heads are mounted opposite to the signal heads used by motorized traffic. Thus, mounting the bicycle signal horizontally would further distinguish it from the vehicle heads. Of course, the opposite would be true in Alberta or any jurisdiction that currently uses a horizontal signal.

The outlines are typical red, amber and green colours. The background of the signal head is black, to further differentiate it from signal heads applicable to motorists. By using a bicycle symbol in the signal lens rather than a traditional red, amber or green display, confusion over the right-of-way at intersections, similar to the case in Ottawa, would be minimized.

The outline of the bicycle is 95 mm high by 161 mm wide and is considered to be small by ergonomic standards. There is some residual concern over the legibility of the bicycle signal, and whether road users (particularly the elderly) would be able to distinguish the bicycle outline from the standard circular indication.

Thus, the use of 300 mm bicycle lenses may be an appropriate treatment for physically large, complex or visually cluttered intersections. The dimensions of the bicycle display outlined in Figure 4.1 would be increased proportionally to suit the 300 mm lens.

4.1.3 Signal Timing Considerations for Cyclists in Mixed Traffic

Green Intervals

At intersections where there is no separate bicycle phase, signal timing for cyclists that operate in mixed traffic or in an exclusive bicycle lane, should be no different than that provided for motor vehicle traffic in the majority of cases. When no special phasing for cyclists is provided, the pedestrian and motor vehicle timing usually governs.

In the case of pedestrian timing, the minimum walk time will usually provide more than sufficient time for cyclists to cross the intersection in parallel with pedestrians since the latter will operate at a much slower speed than cyclists. If the pedestrian crossing is actuated and no call is placed by the pedestrian, then the minimum vehicle time should be reviewed to ensure that it is sufficient for cyclists to safely traverse the intersection in parallel with motor vehicles. The typical cruising speed for cyclists is in the range of 15 to 25 km/h, with an average of approximately 20 km/h. Acceleration rates for cyclists are approximately half that of motor vehicles. Given these parameters, and recognizing that cyclists may need to have additional time to engage a lower gear or to lock into toe clips or clipless pedals, an absolute minimum of 5 seconds should be allocated for even the shortest crossing situations. Depending on the length of the crossing and the topography, especially if uphill gradients exist through the intersection, then additional time should be allocated for cyclists within the minimum vehicular green indication.

Clearance Period

Clearance intervals at intersections are typically governed by the deceleration rates of motor vehicles, perception and reaction time, stopping sight distance, and the physical size of an intersection. These intergreen periods should be sufficient for most cyclists operating in mixed traffic. At intersections with very wide cross sections, consideration may be given to extending the all-red display to allow for a slower cyclist to complete their crossing should they enter an intersection towards the end of the amber display.

4.1.4 Separate Bicycle Phasing at Intersections

Green Intervals

At intersections were an exclusive cycling facility, such as an off-road trail, intersects with a roadway, a minimum green interval of 10 seconds should be adequate to allow cyclists to cross the intersection. This 10 second interval is sufficient even for extremely wide intersections up to 45 m (150 feet) across if cyclists are cruising at an average speed of 20 km/h. Obviously, this does not cover the entire spectrum of cycling conditions, however. In the case where cyclists must accelerate from a stop, a minimum of 5 seconds should be allocated for cyclists to accelerate to a moderate cruising speed. This brings the minimum time for these wider intersections to approximately 15 seconds. The individual timing parameters should be tailored to the specific intersection, but the 10 and 15 second thresholds provide a reasonable guideline as a basis for more detailed analysis.

Clearance Period

The clearance interval or intergreen period for an exclusive bicycle phase should be adjusted to account for a cyclist's approach speed to an intersection since it is lower than that of a motor vehicle. Cyclist's can stop more readily than motor vehicles, hence a reduction in the amber signal time is appropriate. However, since a cyclist's speed across an intersection is lower than that of a motor vehicle, cyclists entering an intersection at the onset of the amber display would require more time than a standard motor vehicle to clear. Therefore, a longer all-red time is recommended.

The following factors should be considered when determining signal timing calculations for cyclists:

- Cyclists Speed;
- Bicycle Acceleration;
- Bicycle Deceleration;
- Perception / Reaction Time; and
- Bicycle Length.

Signal timing requirements for bicycles should take into account both left-turning and through traffic movements at an intersection. The "Traffic Signal Green Time and Clearance Interval Requirements for Bicycle-Motor Vehicles in Mixed Traffic" report prepared by the City of Toronto's Bicycle Signal Timing Task Force, specify formulae for calculating the minimum green, amber and all-red times to accommodate cyclists. These formulae are attached in **Appendix B** and may be referenced when determining suitable timings at signalized intersections.

It should be noted, however, that any adjustments to signal timing to accommodate cyclists will effect other road users. Therefore, adjusting signal times for cyclists should not substantially increase the delay or degrade the level of service for other motor vehicles and pedestrians.

4.1.5 Installation

The following procedures should be followed or considered for bicycle signal head installation:

- One bicycle signal head should be installed within the field of vision of cyclists where they are at or, as a minimum, within 30 m upstream of the stop bar so the display can be easily perceived and identified.

- Larger (300 mm) signal lenses may be considered for bicycle signals located beyond the minimum 30 m field of vision for cyclists, such as along roads with wide medians. A bicycle signal may be placed within the median with another signal placed on the far side of the roadway.

- The use of LED's for these signal heads is recommended. Regular maintenance and replacement procedures currently used by municipalities for pedestrian signal heads should also be used for bicycle traffic signal heads.

- Alternatively, similar to that of the "shape coded" signal displays used in Quebec, or for the fully protected left turn signal displays used in Calgary, a double red indication may be utilized.

- The procedures used for the installation of transit signals and other vehicle-specific signal heads should be utilized where appropriate.

The placement of bicycle signals would be dependent on the geometric conditions of the intersection. The following are recommended guidelines that should be considered for the placement of bicycle signal heads:

- Bicycle signals should be mounted in locations that are far enough from the roadway so as not to interfere with pedestrians or cyclists, while remaining in the direct field of vision of the approaching cyclists.

- Pre-existing "bicycle signals" should be replaced with the modified signal heads. Signage identifying the "bicycle signals" may be removed.

- Typically, bicycle signal heads would be placed at the same height as walk / don't walk displays on the far side of the intersection.

- To supplement this display, a near side installation could be considered under some circumstances given the relatively small size of the bicycle signals. This could help to mitigate any legibility issues where bicycle signals are installed at intersections which are very large or that have complex geometry.

- In situations where existing bicycle signal heads overhang the travelled portion of a roadway, these signals would have to be placed at the standard height of 4.5 m (15 feet) above the roadway.

- At locations where bicycle signal heads do not overhang the travelled portion of a roadway, side-mounting of bicycle signal heads within the field of vision of approaching cyclists is recommended at a height lower than 4.5 m, similar to the installation guidelines for pedestrian signals.

Typical mounting heights that should be considered for the placement of bicycle signal heads are illustrated in **Figure 4.2**.

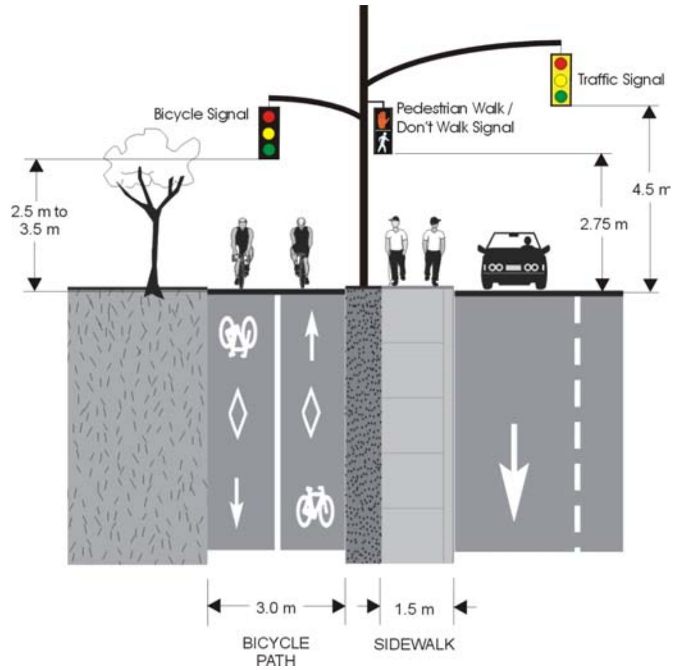


FIGURE 4.2
Typical Mounting Heights for Bicycle Traffic Signals
Source: Marshall Macklin Monaghan Limited

4.1.6 Justification for the Installation of Bicycle Traffic Signals

For the installation of bicycle traffic signal heads, it is recommended that good engineering judgement be used as a means by which a decision is reached on installing these devices, since the installation is dependent on the geometrics of an intersection and numerous other variables.

One of the most important reasons for the use of good engineering judgement is the potential proliferation of bike signals if a warrant or threshold is set too low. By contrast, if an ideal location for the installation bike signals is identified, but cannot satisfy a minimum guideline, then it may go unsignalized to the detriment of the cycling community.

A governing system is, therefore, appropriate whereby the modification of existing signals may simply be driven by an obvious need that is triggered by a serious conflict. Another application is when a contraflow bike lane has no signal display other than a pedestrian walk / don't walk indication. Thus a bicycle signal is easily justified.

Both of these applications require no "minimum" number of cyclists to justify the installation, and they do not necessarily require special timing if they operate as an overlap with the existing signal timing plan.

Another more complex example is a boulevard bike path that is parallel to an existing pedestrian crossing. Cyclists simply cross at the same time as pedestrians and the parallel vehicular movement. In locations where two-way "on-road" bicycle paths on one side of an arterial road are common, separate phasing is required. However, experience has shown that there is a very high violation rate by cyclists when their signals are red and the parallel vehicle and pedestrian signals are green and Walk. In some cases, these two-way "on-road" bicycle paths are a retrofit to an existing street, consuming an entire vehicle lane. Given the experience to date and the high violation rate, this form of bicycle facility is not recommended for widespread application across the country.

Similarly, in urban areas where new boulevard bikeways are being constructed, the application of bicycle signals along the bikeway may be justified with no consideration given to a specific warrant or threshold since the demand for cycling along the bikeway would exist once following the completion of the trail.

A different example is a new "midblock" crossing of a roadway. In this case, a warrant or threshold is totally appropriate, and many of these guidelines already exist in the form of midblock pedestrian signal warrants, Intersection Pedestrian Signal (IPS) warrants or similar "engineering thresholds" as illustrated in **Appendix C**.

There are numerous other examples of bicycle signals that are in operation today whereby a warrant was never considered or applied.

The following key factors, however, should be considered to justify the implementation of bicycle traffic signals. They include:

a) Safety:
When considering the implementation of bicycle traffic signals at intersections, good engineering judgement should be used to ensure that cyclists can be accommodated safely through an intersection. Furthermore, the installation of bicycle traffic signals must be a feasible intersection enhancement that will not detract from motor vehicle or pedestrian safety.

b) Traffic / Cycling Volumes:
Traffic volumes for both cyclists and motorists through an intersection should be observed prior to considering the installation of bicycle traffic signals. This will assist in the determination of whether the application of bicycle signals is practical since very high motor-vehicle volumes may deter some cyclists from using the bicycle signals, even if they are installed.

c) Conflicting Movements:
The installation of bicycle traffic signals may be considered as a means of reducing the number of conflicting movements through an intersection and clarify the right-of-way for motorists and cyclists.

d) Public Input:
If possible, public input should be sought to identify areas of concern among cyclists and motorists where manoeuvres between the two vehicle types at intersections is difficult. This process may assist in identifying locations where bicycle traffic signals may be installed.

It should be noted that there are no definitive numbers or values that can be used as a threshold when establishing criteria for the consideration of bicycle traffic signals at intersections. The installation of a bicycle signal is dependent on many factors that vary from location to location. For example, the justification for a bicycle traffic signal at one intersection with a certain geometry may be appropriate, but may not be appropriate at another intersection with similar geometry due to other factors, such as motor-vehicle volumes, pedestrian conflicts, sight-lines, etc.

Therefore, it is recommended that a reliance on the good engineering judgement of the transportation professional is the best means to determine the need and justification for bicycle signals.

4.1.7 Incorporating Bicycle Displays into Existing Signal Phasing and Timing Plans

In order to minimize delay for all intersection users, the installation of bicycle signals should be incorporated into existing traffic signal phases as an "overlap" whenever possible. This would involve introducing the new bicycle signal phase into an existing signal timing plan such that the new phase would operate at the same time as an existing vehicle or pedestrian phase. Therefore, the cycle length for the entire signal timing plan would not change. The determination of signal timings at intersections with bicycle signals should be based on field investigations and cycling activity in the area, as is the practice in Davis, California. By determining signal timing patterns for an intersection based on motor vehicle, pedestrian and cycling activity, this will ensure that the optimal signal timing pattern can be developed, thereby minimizing the total delay for all users.

When an "overlap" is considered and a bicycle phase is concurrent with the parallel pedestrian crossing phase, the use of standard traffic signal heads is recommended. If standard traffic signal heads are not clearly visible to an approaching cyclist, then the implementation of exclusive bicycle signal heads may be considered.

4.1.8 Warrants for a Protected Bicycle Phase

In situations where a fully protected bicycle-phase is planned for incorporation into an existing signal timing scheme, consideration could be given to the application of the warrant currently used by the City of Montreal. This warrant presently identified as **Warrants 6 and 7** in the Traffic Control Signal Standard for the province of Quebec, should be used with appropriate assumptions made for cyclists speed. The criteria as well as a numerical example for Warrants 6 and 7 are attached in **Appendix C.** This "fully actuated" bicycle phase should only be considered in extreme circumstances where it would be impossible to overlap the bicycle display with an existing phase within the signal timing plan.

4.1.9 Promotion of New Bicycle Signals

In order to make full use of new bicycle signal installations, they must be advertised and promoted to the general public. The goal is to develop an understanding of what they are, and how to react to them if encountered. Therefore, the general public must be made aware of the new signal displays and the appropriate behaviour associated with their operation. This can be accomplished through advertisements on the radio, television, in local newspapers, cycling magazines, bicycle web sites, on transit buses, and other places in the local community where residents gather frequently. In addition, Cycling Clubs and Bicycle User Groups (BUG's) can be an effective way to disseminate information on bicycle signals.

4.2 BICYCLE DETECTION

Recent years have seen an emerging choice in detection technologies. Infrared, microwave and video technologies are now available in addition to standard detector loops.

4.2.1 Infrared Detectors
Infrared detectors consist of active and passive models. These detectors are overhead mounted and view from a side-looking configuration. Active models, in addition to detecting vehicles and bicycles, can also provide vehicle counting, speed measurement and queue measurement. Passive models are similar to active models except in their ability to measure speed.

4.2.2 Video Image Processors
Video technologies for transportation systems were first introduced to provide roadway surveillance. Technical advances now allow for video image processors to analyze a location of interest and extract pre-set information. These detectors are overhead mounted and are best placed upstream of the intersection so that tall trucks do not block the field of view. Advantages of video image processors are that they can monitor a relatively large area and thus replace multiple detector loops. However, this is an advantage more suited to motor vehicle detection.

4.2.3 Microwave Detectors
Microwave detectors operate on the same premise as radar, where transmitted energy from the detector is reflected from a moving object back to the source, and the speed of the vehicle is calculated. This technology is not readily applicable to stationary or very slow moving vehicles. Thus, it is of little use for bicycle detection.

4.2.4 Ultrasonic Detectors
Ultrasonic vehicle detectors can be designed to receive range and Doppler speed data, the same information used by or microwave radar detectors. As noted above, microwave has no application for stationary objects. Ultrasonic detectors transmit sound waves, at a selected frequency between 20 and 65 kHz, from overhead transducers into an area defined by the transmitter's beamwidth pattern. A portion of the energy is back-scattered or reflected from the road surface or a vehicle in the field of view. The preferred viewing configurations for range-measuring (presence) ultrasonic detectors are downward (at a nadir incidence angle) and side viewing. The speed-measuring ultrasonic detector is forward-looking, facing approaching traffic. The transducers in both the presence and speed-measuring ultrasonic devices convert the received sonic energy into electrical energy that is fed to signal processing electronics, either collocated with the transducer or located in a roadside controller.

4.2.5 Inductive Loop Detectors
Inductive loop detectors are imbedded below the pavement surface. They sense the presence of ferrous metal within the “zone of influence” or “field of detection” that is established by the configuration of the loop. Loop detectors are a mature technology and the most widely used in vehicle detection. As a result of this, they are very reliable.

While sensing ferrous metals is extremely effective in the detection of motor vehicles which have significant amounts of metal mass, the detection of bicycles can be problematic. Many older bicycles contain a sufficient amount of ferrous metal to be detected, however, newer bicycles are frequently composed of lightweight metals or non-ferrous materials such as chrome, titanium, graphite or plastics. Ferrous metals may only be found in the gears and chain.

This lack of ferrous metal in some bicycles may make detection difficult, and will require adjustments in sensitivity for the loops.

Pavement markings should be applied to a roadway indicating where cyclists should place their bicycle at a semi-actuated intersection so that they can be detected. The application of three white dots has been used in Ontario, and other cities around the world.

Pavement Markings Indicating Bicycle Actuation Location

Reviews of this application indicate that in some circumstances, cyclists are not aware of the purpose of the three dots, or even that they must be present within the zone of detection to initiate a signal change. The success of a bicycle actuating a signal is dependent on the cyclist not only knowing that there is a detection system, but also knowing how to use it. Even though the sensitivity of the detectors may be adjusted, the effectiveness of the detectors is limited if the cyclist is not properly located in the "actuation zone".

More distinct pavement markings such as a small bicycle symbol with a directional arrow, additional signing, or better promotion of the three "dots" should be investigated to improve the effectiveness of this form of bicycle detection.

Figure 4.3 illustrates an example of more distinct pavement markings that may be applied to better direct cyclists to a signal actuation zone along a roadway.

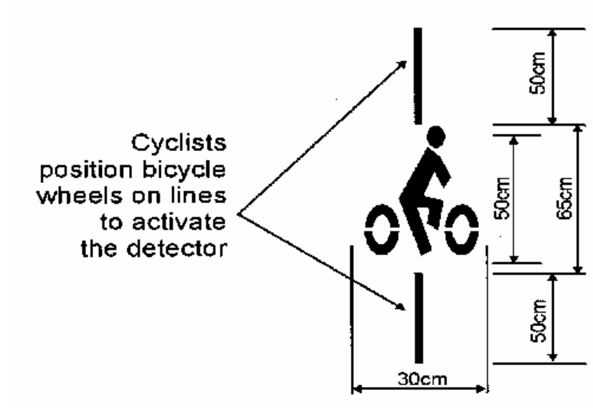


FIGURE 4.3:
Recommended Pavement Markings for a Bicycle Actuation Location.
Source: City of Nanaimo Bicycle Facilities Design Guidelines – Appendix I; Urban Systems, Fall 2001, *www.city.nanaimo.bc.ca/a_parks/pdf/appendix.pdf*

These pavement markings may be used in conjunction with additional signing such as those used in Quebec, identifying to cyclists the purpose of the pavement markings.

[Photograph of the "Radioactive" Bicycle actuation sign used in Quebec will be inserted as soon as it is reviewed]

4.2.6 Call Buttons

Call buttons represent a different form of "detection", as they require an action by the cyclist, while all previously discussed methods "sense" the presence of a bicycle. Call buttons require a user to push a button located beside the lane to call for a signal change in a fashion similar to that of pedestrian push buttons. It is incumbent upon the cyclist to be "detected" by activating the call button. It should be noted that unless the cyclist does not notice the push button, this active method of detection would not fail the cyclist like the other previously discussed passive methods could.

4.2.7 Recommendations

Since above ground passive detectors represent relatively new technologies that are still being improved, it is recommended that induction loops be used for the detection of bicycles at intersections where motorized vehicles and traffic utilize the same facilities.

The advantage of using detector loops is that most signalized intersection already use them for motor vehicles, and so controllers and wiring is pre-existing and will reduce the cost of incorporating bicycle detection.

To ensure that bicycles are detected by semi or fully actuated signals, it is recommended that quadrupole or diagonal quadrupole loop detectors be used. Quadrupole and diagonal-quadrupole loops are effective because they are bicycle-sensitive over their entire area, thus making them useful in both shared and exclusive roadway use situations. Typically, four turns of #16 gauge copper wire are required to achieve the necessary field strength. **Figure 4.4** illustrates both quadrupole and diagonal quadrupole loop detectors.

Furthermore, the sensitivity of the loops should be increased from that for motor vehicles to account for the significantly lower amount of detectable ferrous metal in bicycles. However, care should be taken so as not to make loops used in exclusive bicycle lanes overly sensitive to motor vehicles in lanes adjacent to the loops.

At all signalized mid block trail crossings of public roadways, it is recommended that call buttons be used for bicycle detection.

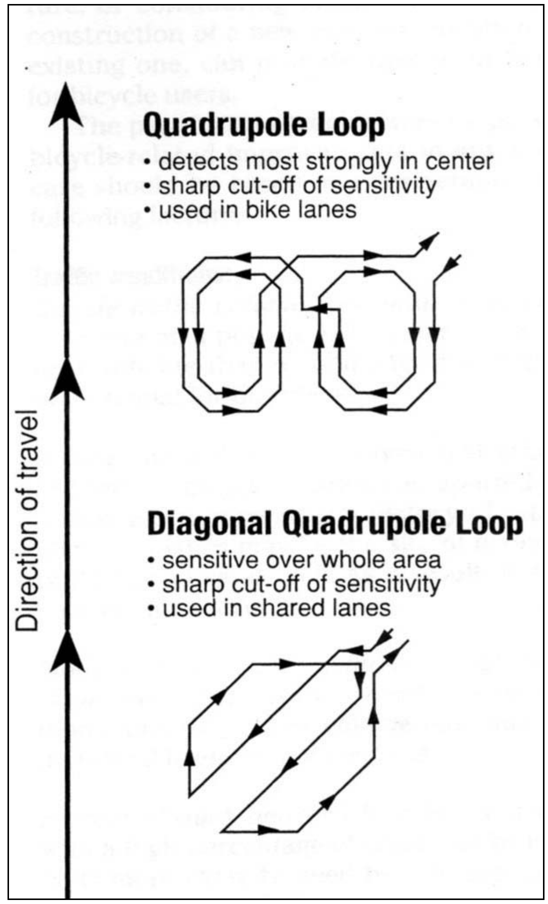


FIGURE 4.4
Quadrupole and Diagonal Quadrupole Detectors.
Source: Traffic Signal Bicycle Detection Study; City of San Diego, 1985

Having the cyclist use the call button will allow them to confirm that a call has been placed as a result of the visual and tactile response from the push button. This will reduce the chances of non-compliance with the bicycle signals, and provide a more positive form of detection.

Therefore, the call button used should be of the type that illuminates to indicate that it has been activated. To further maximize the efficiency of bicycle detectors, pavement markings should be added to roadways indicating where cyclists should position themselves when approaching or stopped at an intersection to ensure that they are detected.

4.3 IMPLEMENTATION STRATEGIES AND APPLICATIONS

There are many different types of applications for which bicycle signals may be considered. Some are under consideration for use in various jurisdictions, while others have been in place for years. The implementation strategies presented in this chapter are not meant to be rigidly applied. Nor are these strategies exhaustive. Indeed, if bicycle signals are being contemplated for incorporation into an existing intersection, it is likely that the intersection is of a non-standard nature. Otherwise, regular traffic control signals should prove sufficient.

Therefore, the intent of this document is to provide the reader with examples of "best practices". This will provide guidance in the design of signalized intersections. This section will outline many of the different types of potential applications for Canadian jurisdictions.

4.3.1 Confluence of an Off-Street Bicycle Path with an Intersection

Bicycle-specific signals could be considered at locations where an off-street bicycle path or multi-use trail meets a signalized intersection. This could typically be accommodated through a dedicated bicycle phase to allow for safe, exclusive use of the intersection by cyclists, or simply by allowing cyclists to cross the intersection with the parallel pedestrian and motor vehicle phase. A typical installation is provided in **Figure 4.5**.

Where a bicycle signal phase overlaps with a pedestrian phase, additional signage and / or pavement markings may be required that clearly identify who has the right-of-way to minimize the risk for potential collisions between right-turning motorists and cyclists travelling straight across an intersection. Right-turn-on-red restrictions may be necessary at locations where there is a high volume of right-turning motorists.

The following measures may be taken where appropriate, to mitigate the potential for conflicts between right or left-turning motorists and cyclists crossing a street during a bicycle phase.

If Street "A" as illustrated in Figure 4.5 is a one-way westbound road, and similarly Street "B" a one-way southbound road, this would eliminate conflicting turning movements between motorists travelling on either Streets "A" or "B" and cyclists crossing these two roadways.

If Streets "A" and "B" are not one-way streets, then appropriate signage should be placed along the bicycle path near the approach to the intersection, warning cyclists to watch for turning motorists turning motorists. Such signage is currently used in Toronto, and is illustrated in the photograph below.

Similarly, appropriate signage should be placed along the road approaching the intersection to warn turning motorists of cyclists on the parallel crossing. The City of Montreal currently utilizes this type of signage, as illustrated in **Figure 4.6**.

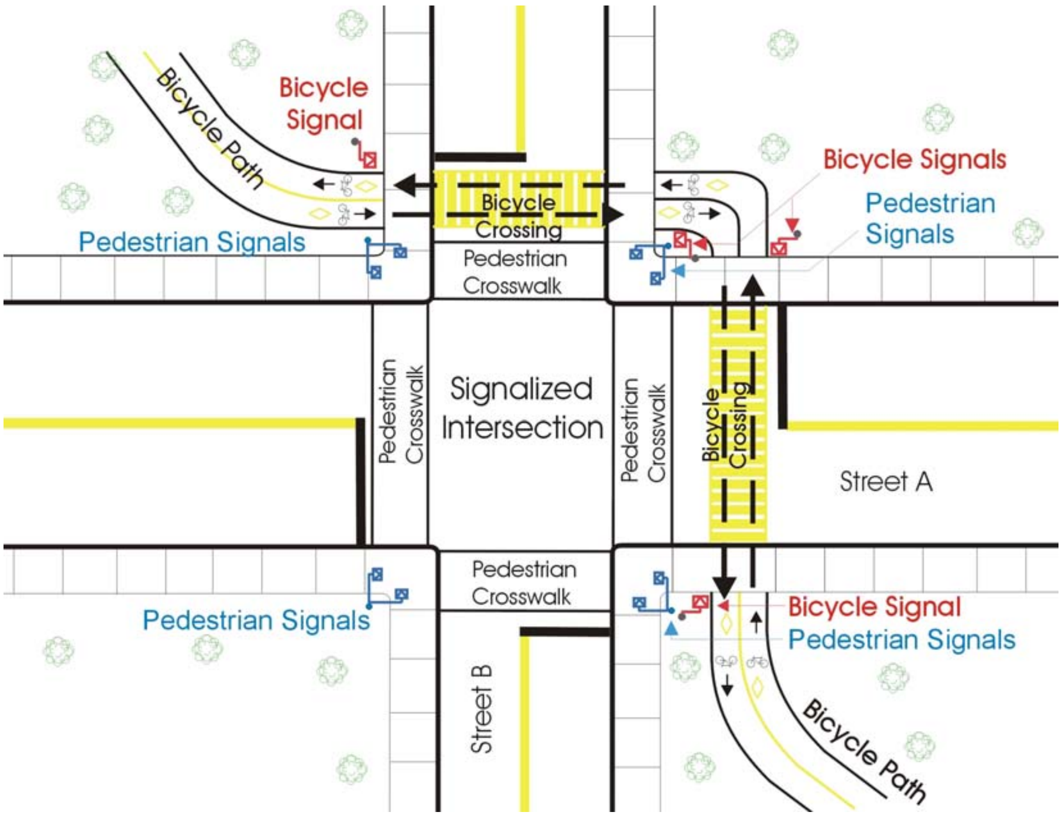


FIGURE 4.5:
Off-Street Bicycle Path Meeting a Signalized Intersection.
Source: Marshall Macklin Monaghan Limited

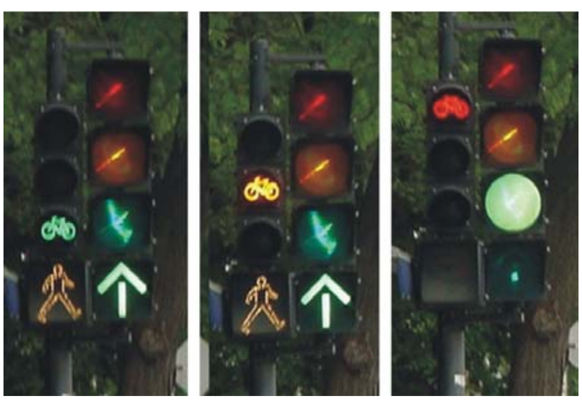
FIGURE 4.6
Warning sign for turning motorist to be aware of crossing cyclists.
Source: City of Montreal

Signing warning cyclists of turning motorists
City of *Toronto*

Another method of minimizing the potential for conflicts between cyclists and turning motorists would be to utilize the bicycle signal phasing patterns currently used in the City of Montreal.

In the Montreal system, (again using Figure 4.5 as the sample) at locations where bicycle paths cross an intersection, the bicycle signal phase for cyclists crossing Street "A" operates at the same time as the phase for motorists travelling along Street "B". The traffic signal heads show a "green bicycle" display, permitting cyclists to travel straight across Street "A" and a straight through green arrow for motorists travelling on Street "B". During this phase, there would be no conflicting movements between cyclists and motorists.

Following this phase, the bicycle display would change to amber and then red, preventing cyclists from crossing Street "A", while the straight through arrow for motorists would change to a solid "green" display, permitting motorists to travel straight through and also to turn at the intersection. The following photograph illustrates the sequence of the signal displays.



Bicycle and traffic signal display phasing sequences, City of Montreal

However, this phasing scheme suffers from a very high violation rate and, therefore, is not recommended.

Finally, another treatment that can be utilized is to combine the bicycle path with the pedestrian crossing and treat it as a multi-use path at the intersection. This treatment is currently in use in the City of Toronto.

The same criteria are appropriate for separate bicycle paths that run parallel to arterial streets as illustrated in **Figure 4.7**.

In locations where an off-road bicycle path or boulevard trail runs parallel to a major roadway, cyclists crossing side streets may be accommodated through the use of bicycle signals rather than pedestrian crosswalks and walk / don't walk signals. Under virtually all provincial Highway Traffic Acts, cyclists must dismount and walk their bicycle along a pedestrian crosswalk. The installation of bicycle traffic signals would identify cyclist priority through the crossing, allowing them to proceed without having to disembark from their bicycle. This would allow cyclists to ride across the intersecting roadway on the same phase as the parallel crosswalk and vehicular traffic flow. No separate phase would be required unless the pedestrian and motorist phases are already separated.

Bicycle signals should be placed in clear vision of cyclists approaching from each direction, typically at the same height as pedestrian signals. Bicycle crossings should be parallel and separate from the pedestrian crossing to ensure that cyclists do not conflict with crossing pedestrians.

As mentioned in the scenario of a confluence of an off-road bicycle path with an intersection, additional signage, or the addition of a separate bicycle phase may be required to minimize the potential for cyclists being struck by motor vehicles turning from the street paralleling the bicycle path. This would be another suitable application for a bicycle signal warrant.

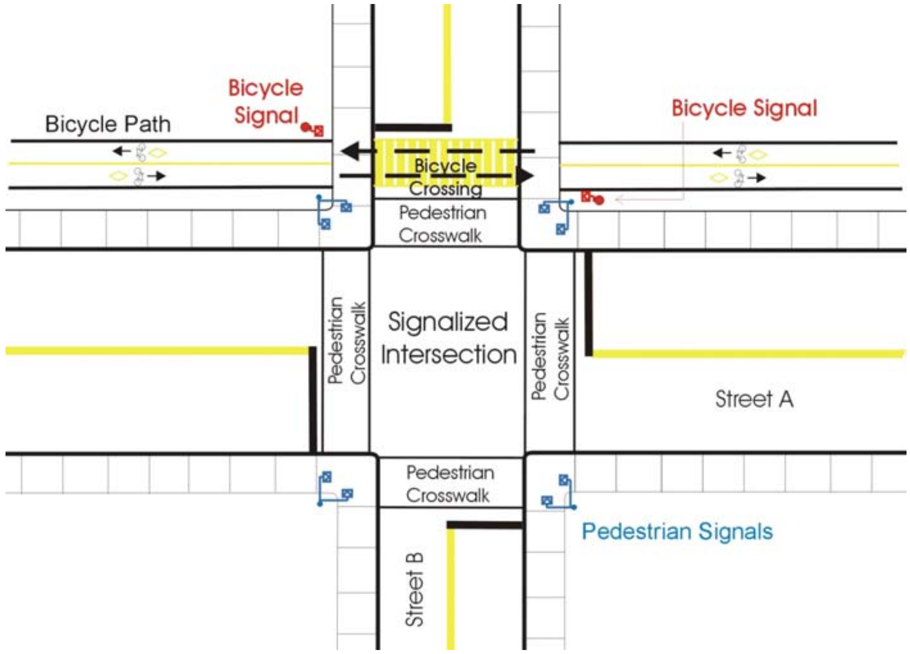


FIGURE 4.7:
Separated Bicycle Path Parallel to Arterial Street Crossing an Intersection
Source: Marshall Macklin Monaghan Limited

4.3.2 Mid-Block Trail Crossings

The implementation of bicycle signals at locations where an off-street bicycle path or multi-use trail meets a public roadway would allow for the safe crossing of both cyclists and pedestrians. Existing protected mid-block crossings typically provide vehicular signal displays on the main road, and pedestrian signals only for the crossing. The use of bicycle signals may be particularly appropriate should there be considerable distance to the nearest signalized intersection. The provision of a bicycle-specific display together with signs and markings at these locations would help to acknowledge the significance of cyclists as well as pedestrians. Cyclists would have a "bike-only" crossing, forming a direct connection with the bike trail. **Figure 4.8** illustrates a modified mid-block crossing that should be considered for cyclists and pedestrians, showing the location of bicycle, pedestrian and traffic signals.

Loop detectors or push buttons could be used to initiate a traffic signal change. A semi actuated control mode would be best suited for mid-block crossings rather than pre-timed operation since bicycle volumes on the trail may vary significantly throughout the day. Signal timings for the bicycle signals could be based on the actual crossing time for a cyclist, and be distinct from the minimum pedestrian walk time. Some jurisdictions currently use a minimum of 10 seconds for the bicycle "green" indication, but the length of this display should be tailored to the actual geometry of the intersection.

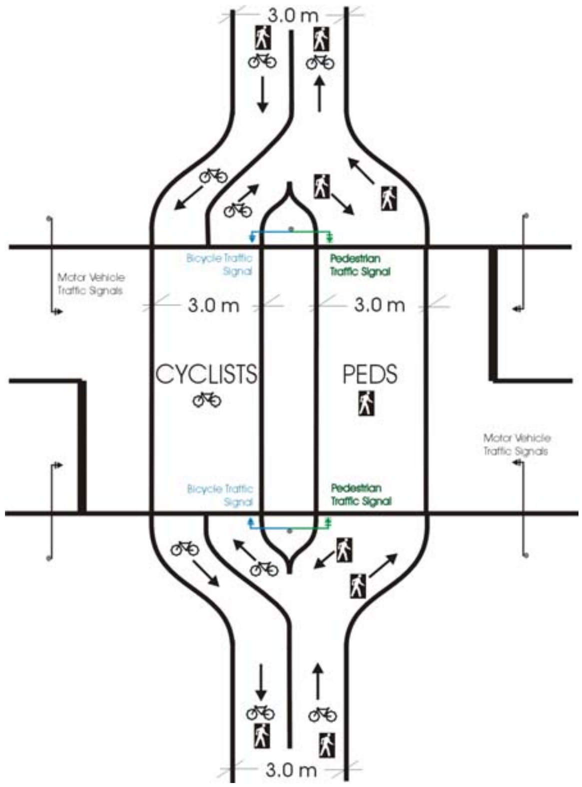


FIGURE 4.8:
Pedestrian and Bicycle Path Mid-Block Crossing
Source: Marshall Macklin Monaghan Limited

The warrant for signalizing a mid-block trail crossing should be consistent with that of intersection pedestrian signals (IPS) or "half signals".

Bicycle signal heads should be cantilevered over the trail, and set back from the edge of the roadway. The poles used to suspend the bicycle heads could be used as the location for the bicycle and pedestrian call buttons if they are conveniently positioned adjacent to the trail.

The stop bar for motor vehicles should be a minimum of 5.0 metres from the edge of the crossing. The width of the crossing should be equal to the width of the trail for continuity. The actual trail width at the entry and exit to the crossing should be double that of the normal trail. For example, a 3.0 m trail should be split into a 3.0 m pedestrian and a 3.0 m cycling path immediately prior to the roadway crossing. Thus, the separate displays for pedestrians and cyclists would apply to the respective crossing areas.

4.3.3 Contra-Flow Facilities

Where provisions are made for bicycles in the opposing travel direction on a one-way street, a bicycle signal could be used to accommodate them at intersections. Typically only pedestrian signals would be provided if the vehicular movement was prohibited, but the incorporation of bicycle signals would greatly enhance the operation of the bikeway facility.

The bicycle signal head should ideally be placed on the same pole as is used for the pedestrian signals, and it should be cantilevered to the edge of curb. The height of the bicycle signal should be approximately that of the pedestrian signal head. This will allow for the signal display to be directly within the field of view of any cyclist that is approaching or stopped at the intersection.

A bicycle stop bar should be placed on the near side of the intersection approximately 1.0 m from the pedestrian crosswalk. The stop bar may also be signed "Cyclists Stop Here on Red". It is important to direct cyclists to stop in advance of the stop bar at an appropriate location, especially if detector loops are used to actuate this leg of the intersection or if a separate bicycle phase is utilized.

Figure 4.9 illustrates a typical application of a bicycle traffic signal for a contra-flow bicycle lane at an intersection.

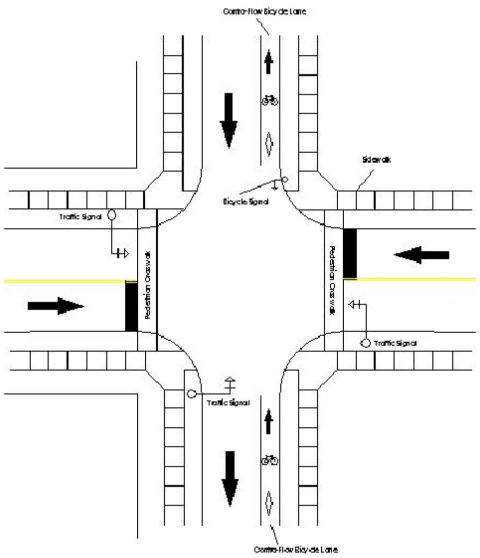


FIGURE 4.9:
Diagram of Contra-Flow Bike Lanes
Source: Marshall Macklin Monaghan Limited

Quadrupole or diagonal quadrupole detector loops should be placed in advance of the stop bar in the area where cyclists will come to rest. The designer may wish to place the detector loops under or even beyond the stop bar if it is believed that cyclists will stop downstream of the stop bar. For example, this could be the case if a utility pole beyond the stop bar provides a convenient object to balance against, which precludes the need to dismount or unclip from pedals.

4.3.4 Advanced Bicycle Phasing

Bicycle signals have also been used at intersections with advanced stop bars for bicycles, allowing a head start for cyclists proceeding through the intersection before motorists are given a green indication. The installation of bicycle traffic signals for an advanced bicycle phase could help to reduce confusion experienced by drivers who may proceed through the intersection during a bicycle phase if a standard green display was used on the bicycle signal head. Bicycle signals should be placed on a separate pole from the motor vehicle traffic signals, and placed at a lower elevation adjacent to the bicycle lane on the opposite side of the street. This will ensure that the bicycle signal is clearly in the "cone of vision" of an approaching or waiting cyclist.

4.4 NOT RECOMMENDED

4.4.1 Bike-Only "Scramble" Phase

Many European countries have introduced, with success, separate bicycle-only or bicycle "scramble" phases in locations where significant bicycle traffic approaches from all directions. However, these "omni-directional" bicycle-only phases not only tend to increase the overall delay for cyclists approaching an intersection, but they also increase the potential for bicycle to bicycle collisions, since equal priority is given to conflicting bicycle movements.

This exclusive bike-only or "scramble" phase is not a recommended option for the installation of bicycle signals. The addition of a bicycle-only phase into a traffic signal cycle can cause significant delays at an intersection for all users. Not only are all pedestrians and motor vehicles delayed due to the bike-only phase, but cyclists are also delayed since they typically arrive at an intersection during the "vehicle/pedestrian" phases of the signal. Additionally, since no priority is given to cyclist movements during the scramble phase, the potential for right-angle cyclist-to-cyclist collisions increases due to the numerous conflicting movements. **Figure 4.10** illustrates the bicycle "scramble" phase.

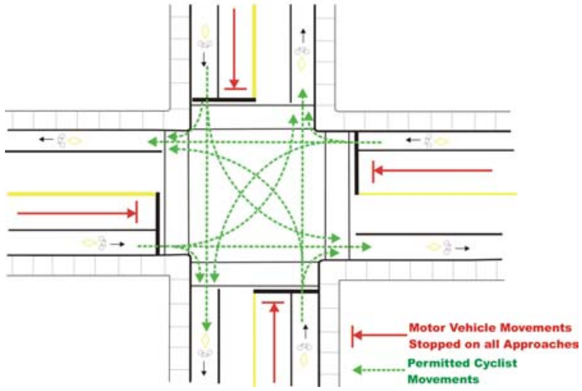


FIGURE 4.10
Bicycle Scramble Phase
Source: Marshall Macklin Monaghan Limited, 2003

4.4.2 Cyclist Movements on the Cross of Single Lane "Tee" Intersections

As noted in the Chapter 2.0, it has been suggested that cyclists travelling along the "outer" side of the cross of a Tee intersection (Major Street), be allowed to proceed during the green indication for the stem of the Tee (minor street). Since cyclists travelling along this side of the intersection do not interfere with any turning movements from the minor street, they could be permitted to move simultaneously with these motor vehicles on the conflicting phase. However, cyclists would directly conflict with pedestrians crossing the major street. Situations with no pedestrian crossings could still prove to be potentially dangerous for cyclists. Although there would theoretically be no conflicting movements between cyclists and motorists, a vehicle making a left turn from the stem of the Tee that happened to turn "wide", as illustrated in **Figure 4.11**, could collide with a cyclist proceeding through the intersection on this conflicting phase. Although this unique form of control would improve the level of service for cyclists, the increased potential for cyclist/motor vehicle collisions, and the promotion of conflicting crossing movements makes this proposal a non-feasible option under any of the following circumstances.

1) Where a non-actuated pedestrian crossing exists in parallel with the stem of the Tee;

2) Where an equal number of approach and discharge lanes are present for left turns from the stem of the Tee; or

3) Where a two-way bicycle facility exists across the outer edge of the cross of the Tee.

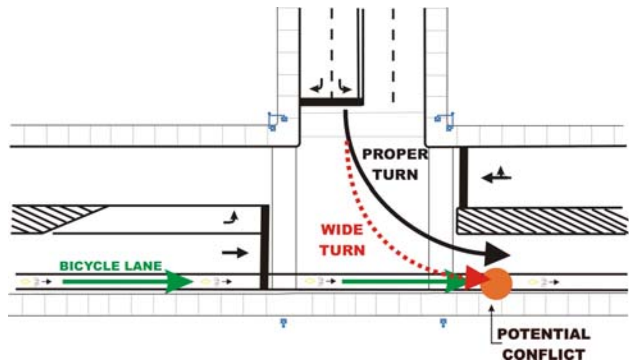


FIGURE 4.11
Potential Conflicts at Tee Intersections
Source: Marshall Macklin Monaghan Limited, 2003

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[i] Safety of Cyclists in Urban Areas, L. Herrstedt et al, Traffic Safety on Two Continents Conference, 1993.

[ii] Bicycle Transportation – A Handbook for Cycling Transportation Engineers, 2nd Edition. John Forester. MIT Press, Cambridge, Massachusetts. 1994.

[iii] The Toronto Bike Plan – Shifting Gears, Toronto, Ontario, 2001.

[iv] Traffic Control Devices, MTQ, 1999.

[v] MUTCD 2000, Millennium Edition – Part 9: Traffic Controls for Bicycle Facilities. U.S. Department of Transportation/Federal Highway Administration. December 2000.

[vi] Innovative Bicycle Treatments – An Informational Report. Institute of Transportation Engineers. 2001.

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APPENDIX A

References

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2. *John S. Allen, The Herald Square Bike Lane. "Getting across or just getting by?"* www.bikexprt.com*, March 1986*

3. *Detection Technology for IVHS-Volume 1: Final Report Addendum; National Transportation Library – US Department of Transportation, 2003*

4. *Traffic Signal Green Time and Clearance Interval Requirements for Bicycle-Motor Vehicle Mixed Traffic*: Bicycle Signal Timing Task Force - City of Toronto, July 12, 2000

5. *Innovatory Cycle Scheme Preston – Ringway Signalled Cycle Facility, London – Strand / Waterloo Bridge Signalled Cycle Facility:* Traffic Advisory Unit Leaflet, Department of Transportation, London UK, December, 1986

6. *Traffic Signal Bicycle Detection Study*: City of San Diego, 1985

7. *BePolite – a New Approach for Controlling Traffic Signals for Bicycles:* City of Helsinki, Traffic Planning Division, www.hel.fi/ksv/entire/repBepoliteControl.htm December 28th, 1999

8. *New "Bike Signal" Lights for Intersections:* Media Release, Smyth Brendan – Australian Capital Territory, www.pedalpower.org.au/lobby/bikesignals.pdf July 18th, 2001

9. *Recommendations for traffic provisions in built-up areas ASVV:* C.R.O.W., The Netherlands, March 1998

Other Data Collected

- City of Montreal (Intersection layouts and photographs for 19 intersections with bicycle signals)
- City of Ottawa (Traffic signal drawings, phasing diagrams, traffic counts, signal timings)
- City of Toronto Bicycle/Motor Vehicle Collision history
- City of Calgary (Bicycle collision history)
- Province of Quebec PQ, Bicycle Signal Standards
- Transportation Association of Canada (TAC) traffic signal guidelines for bicycles reference manual

APPENDIX B

Signal Timing Requirements for Bicyclists:

Bicycle Signal Timing Task Force

Transportation Services uses this formula for establishing the length of the all-red interval at signalized intersections. The approach speed used in this formula is the posted speed limit for motor vehicles.

D. Signal Timing Requirements For Bicyclists

When determining signal timing requirements, both left-turn and through traffic must be considered.

(1) Through Green Interval

When a bicyclist approaches an intersection on a red display, stops, and is waiting for a green display, he/she must take the following action:

(a) perceive and react to a change in the signal display;
(b) accelerate; and
(c) clear the intersection.

A bicyclist accelerating from a stop (at 0.5 m/s^2)(Ref. 3) would reach cruising speed (7.4 m/s) (Ref. 3) in a distance of approximately 55 metres. Since the majority of intersections in Toronto are less than 55 metres in width, it was assumed that the bicyclist would accelerate at a constant rate and would never achieve full cruising speed within the intersection.

The following equation has been developed to calculate minimum green time requirements for bicyclists:

$$\text{Minimum Green Time} = t_r + \sqrt{2\left(\frac{D_L + L}{a}\right)} - T_c \qquad \text{(Equation 3)}$$

Where:

t_r = Perception/Reaction Time (use 2.6 seconds typical)
D_L = Longest crossing distance in metres.
L = Bicycle Length (use 1.8 metres typical)
a = Bicyclist Acceleration Rate (use 0.5 m/s^2 typical)
T_c = Total Clearance Period (amber plus all-red duration; 6 seconds typical)

The minimum green time that is currently used to meet minimum motor vehicle requirements is 9 seconds. Based on the preceding formula an intersection would have to be greater than 37 metres in width before the 9 second minimum green would be inadequate for bicyclists.

Appendix A illustrates the green time requirements for bicyclists at various crossing distances.

(2) Through Amber Interval

A bicyclist entering an intersection at the very end of the green interval has the duration of the amber plus the all-red interval to clear the intersection safely. The amber interval duration is calculated based on the time required for a vehicle to come to a safe stop. Vehicles travelling at higher speeds require longer amber periods because they require greater stopping time.

Based on the amber interval formula contained in the OTM(Ref. 1) and the parameters selected from Table 3 the amber interval requirement for bicyclists is 2.54 seconds. This value was calculated using Equation 1, as follows:

$$\text{Amber Interval} = t + \frac{V}{2a}$$
$$= 1 + \frac{7.4}{2(2.44)}$$
$$= 2.54s$$

The minimum amber interval duration used in Toronto is 3 seconds. Therefore, the current minimum amber duration should be sufficient for bicyclists in all cases. An illustration of the amber interval requirements for bicycles and motor vehicles is shown in Appendix B.

(3) All-Red Interval
In order to accommodate bicyclists, the all-red interval should be calculated as per the following formula developed by the Task Force as a variation of a similar OTM (Ref. 1) formula for motor vehicles:

$$\text{All Red Interval} = \frac{D_L + L}{V} - Y_{Diff} \qquad \text{(Equation 4)}$$

Where:

D_L = Longest crossing distance in metres;
L = Bicycle Length (use 1.8 metres typical)
V = Bicyclist Speed (use 4.7 m/s typical)
Y_{Diff} = Vehicle amber requirement - Bicycle amber requirement (If $Y_{diff} < 0$ then $Y_{diff} = 0$)

The all-red formula was developed by modifying the formula recommended by the OTM(Ref. 1) to include a portion of the vehicle amber interval as part of the all-red clearance time for bicyclists. This difference in the amber interval (Y_{Diff}) represents the portion of the motor vehicle amber display which is not required by bicyclists for their amber requirement and can therefore be allocated to satisfy a portion of the bicycle all-red requirement used to service bicycle clearance. The original all-red interval formula is shown previously (see Equation 2).

The all-red interval requirements for bicyclists have been calculated for a range of intersection widths as shown in Appendix C. This table can be used as a guide if a longer all-red interval is deemed necessary.

Increases in the all-red interval beyond the motor vehicle clearance requirement should be made with care as there may be impacts on other road users. These impacts include :

(a) Safety concerns because bicyclists and/or motorists may perceive the longer all-red as a signal malfunction and proceed against a red indication;
(b) Safety concerns because bicyclists and/or motorists may become accustomed to the longer clearance period and disregard the signal displays; and
(c) Intersection efficiency concerns because overall intersection delay will increase when less green time is available.

In order to minimize these impacts increases in the all-red interval beyond the motor vehicle requirement should be limited to one second in most cases. In some circumstances, increases beyond one second may be acceptable. For example, at Lake Shore Boulevard East and

Sherbourne Street in the City of Toronto there was a concern that there was insufficient clearance time provided for cyclists proceeding north or south through the intersection. This concern was brought to the former Metro Central Traffic Regions attention by a collision involving a northbound cyclist and a westbound vehicle proceeding on a green indication. The intersection of Lake Shore Boulevard East and Sherbourne Street is 52 metres in width. The vehicle all-red requirement was calculated using the OTM(Ref. 1) and was determined to be 4 seconds. The existing all-red interval that was being provided was 2 seconds in duration. At this intersection, the all-red interval was subsequently increased from 2 to 6 seconds.

The concerns expressed previously with respect to an increase in the all-red of this magnitude were alleviated at this intersection due to the following factors:

(a) the signal phasing at this location was a three phase operation and hence the longer all-red period following the north-south phase was not noticeable to road users; and

(b) the geometry at this location makes it difficult for eastbound and westbound road users to see the north and south side signal indications.

Before and after amber/all-red violation studies indicated that there was no increase in the number of amber/all-red violations following the all-red interval increase at this intersection.

(4) Left-turn requirements
The current practice of Transportation Services is to provide the following minimum timing for left-turn displays:

(a) The flashing advance green display is composed of:

Flashing advance green	5 seconds
Solid advance green	3 seconds

(b) The left-turn arrow display is composed of:

Left-turn green arrow	6 seconds
Left-turn amber arrow	3 seconds
Left-turn red	2 seconds

These minimum times are calculated using typical motor vehicle operating parameters. Using an acceleration value of 0.5 m/s^2(Ref. 3) a bicyclist would be able to travel 5.49 metres during a minimum flashing advance green of 5 seconds and solid advance green of 3 seconds.

This distance was calculated using the Minimum Green Time Formula (Equation 3) as follows:

$$5 = 2.6 + \sqrt{2\left(\frac{D_L + 1.8}{0.5}\right)} - 3$$

$$D_L = 5.49 \text{ metres}$$

Left-turning distances for bicyclists at signalized intersections are typically in the range of 20-30 metres. If left-turn phasing requirements were to be increased to accommodate bicyclists, minimum flashing advanced green times could be as high as 15 seconds.

Increasing left-turn phase times to this magnitude would result in unacceptable increases to intersection delay for all other road users. In situations where there is low left turn traffic volume, such a long, under used priority phase may be perceived as a signal malfunction by motorists waiting at their approach who are unaware of the arrow display, but are facing a corresponding red display. This may prompt a potential disregard for the red signal display. Therefore, based on the probable impacts, it is recommended that left-turn timing not be extended to provide adequate time for bicyclists to complete a left-turn. Instead, additional work needs to be completed to determine alternative methods of treating left-turning bicyclists at signalized intersections.

One alternative that may be considered is the "indirect left turn" treatment for bicyclists at signalized intersections. This technique has been used at the intersection of Bloor Street East and Sherbourne Street in the City of Toronto. The indirect left turn provides cyclists with the opportunity to make a left turn movement in two stages – similar to a pedestrian left turning movement. For example, a bicyclist proceeding to make a northbound left turn at an intersection would complete the following movements: Stage 1 – proceed through the intersection on the north-south green phase and wait in a refuge area on the far side of the intersection, and Stage 2 – wait until the following green phase (east-west green) and proceed through the intersection on a green display. An illustration of the two-stage crossing sign that has been installed at Bloor Street East and Sherbourne Street is attached in Appendix E.

E. Impacts Of Timing Changes On Other Road Users

The potential impacts of increasing the duration of the green, amber and all-red displays to accommodate bicycle traffic on other road users must be addressed.

(1) Increased minimum green time

An increase in green time in order to accommodate bicyclists would result in the following:

(a) slight increase in overall intersection delay for motorists, pedestrians, transit users and cyclists;
(b) slight decrease in "progression" opportunities for main street traffic.

The impacts of increasing the side-street green time, based on the formula provided, would have to be assessed on an intersection by intersection basis. However, based on previous calculations, an increase would only be required at intersections greater than 37 metres in width.

(2) Increased amber time

The existing minimum amber time of three seconds is sufficient for motor vehicles and bicycles in all cases. An increase in the minimum amber duration would do little to assist cyclists and may encourage other road users to enter an intersection near the end of an amber display, in an unsafe manner.

(3) Increased all-red time

Although an increase in the all-red will assist bicyclists in their efforts to safely clear an intersection, several studies [Ref. 3,4,6] suggest that the safety benefits of an increase in the all-red interval is offset by the safety impacts to other road users.

Increases to the all-red interval in the order of magnitude suggested in Appendix C are considered unacceptable for the largest number of a signalized intersection crossings due to the potential safety and operational impacts which have been previously mentioned.

It is therefore recommended that any increase in the all-red duration should be limited to one second beyond the motor vehicle requirement as specified in the OTM[Ref. 1]. Any increase in the all-red interval beyond one second should be made with extreme care to ensure that the safety impacts previously mentioned are adequately addressed. Before and after amber/all-red violation

APPENDIX C

Warrants

Frequency of Collision Types
City of Toronto, ON

Collision Type	Number of Cases	Percentage
Drive out at Controlled Intersection	284	12.2
Motorists Overtaking	277	11.9
Motorists Opens Vehicle Door	276	11.9
Motorist Left Turn - Facing Cyclists	248	10.7
Motorist Right Turn (Not at Red Light)	224	9.6
Motorists Right Turn at Red Light	179	7.7
Drive out from Lane or Driveway	179	7.7
Ride out at Controlled Intersection	65	2.8
Wrong Way Cyclist	59	2.5
Ride out at Midblock	51	2.2
Motorists Left Turn - In Front of Cyclists	48	2.1
Ride Out from Sidewalk	44	1.9
Cyclist Lost Control	44	1.9
Cyclist Left Turn in Front of Motorist	41	1.8
Cyclist Strikes Stopped Vehicle	39	1.7
Motorist Reversing	37	1.6
Cyclist Overtaking	31	1.3
Cyclist Caught in Intersection	30	1.3
Ride Out from Lane or Driveway	29	1.3
Drive Into/Out of On-Street Parking	28	1.2
Cyclist Left Turn - Facing Traffic	11	0.5
Other (Not Classified)	101	4.3
Unknown (Insufficient Information)	247	

Source: City of Toronto Bicycle/Motor Vehicle
Collision Study,
City of Toronto, 2003

or

– > 800 veh./hr for an intersection with four or more approaches.

Warrant 6: Minimum pedestrian volume

This warrant must be evaluated when the study is being carried out because pedestrians are having trouble crossing the major highway.

This warrant is satisfied when the following conditions a) and b) are both met:

Condition a)

The total pedestrian volume (children, schoolchildren, adults) for both crosswalks of the major highway during a single day:

– ≥ 80 pedestrians/hr for any 3-hour period. Moreover, the point defined by the total vehicle volume in both approaches of the major highway and by the time T necessary for a pedestrian to cross this highway must be above the curve in the graph shown in Chart 8.5–13, for every 3 hours of counting;

or

– ≥ 90 pedestrians/hr for any 2-hour period. Moreover, the point defined by the total vehicle volume in both approaches of the major highway and by the time T necessary for a pedestrian to cross this highway must be above the curve in the graph shown in Chart 8.5–13, for every 2 hours of counting;

or

– ≥ 110 pedestrians/hr for any given hour. Moreover, the point defined by the total vehicle volume in both approaches of the major highway and by the time T necessary for a pedestrian to cross this highway must be above the curve in the graph shown in Chart 8.5–13, for the given hour of counting.

Condition b)

The intersection (or crosswalk) is at least 100 m from any upstream or downstream signing that controls the traffic flow.

When traffic lights are justified under Warrant 6, pedestrian signals must also be installed.

The standards for installing traffic signals for a crosswalk located between two intersections are outlined in section 8.5.3.8.

An example of a warrant 6 evaluation is provided on the next page.

Warrant 7: Minimum volume of schoolchildren

This warrant must be evaluated when the study is being carried out because schoolchildren are having trouble crossing the major highway.

Student and vehicular volumes must be surveyed during the three periods students enter or leave school (morning, noon and evening) over at least fifteen minutes, then converted into hourly volumes[4]. These volumes are then compared one on one or in combination to the two volume conditions listed in warrant 6.

When traffic lights are justified under Warrant 7, pedestrian signals must also be installed.

The standards for installing traffic signals for a crosswalk located between two intersections are outlined in section 8.5.3.8.

4. For example, if the period during which schoolchildren are crossing is of 30 minutes duration, the volumes of schoolchildren and of vehicular traffic must be measured during these 30 minutes and then multiplied by 2.

EXAMPLE

Evaluation of warrant 6

Let us assume the following data at an intersection where the time T required for pedestrians to cross the street is 20 seconds, as calculated using the formula in Chart 8.5–13. The closest intersection with traffic lights is 150 m away, and the closest intersection with Stop signs is 400 m away.

	Counting hours	Pedestrian volume Total for both crosswalks (pedestrians/hr)	Vehicle volume Total for both approaches (vehicles/hr)
(1)	8:00 - 9:00	60	1 200
(2)	9:00 - 10:00	130	200
(3)	11:00 - 12:00	90	600
(4)	12:00 - 13:00	75	400
(5)	16:00 - 17:00	95	800
(6)	17:00 - 18:00	82	200

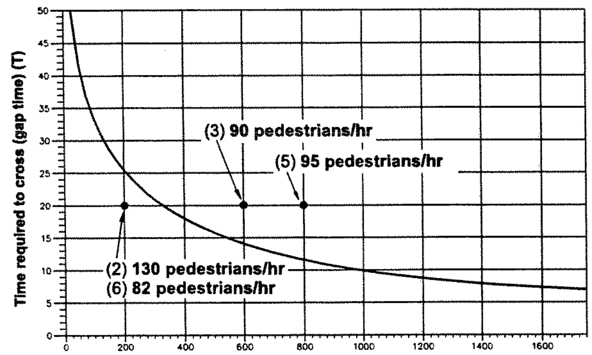
Evaluation of condition a):

1st evaluation:

1. Are there at least 80 pedestrians/hr over **at least 3 hours**?

   Yes: 9:00 - 10:00, 11:00 - 12:00, 16:00 - 17:00, and 17:00 - 18:00
2. Is the total vehicle volume in both approaches above the curve in Chart 8.5–13 over **at least 3 of those hours**?

   No, since only 2 of the 4 hours of counting (11:00 - 12:00 and 16:00 - 17:00) are above the curve, as shown in the following figure:



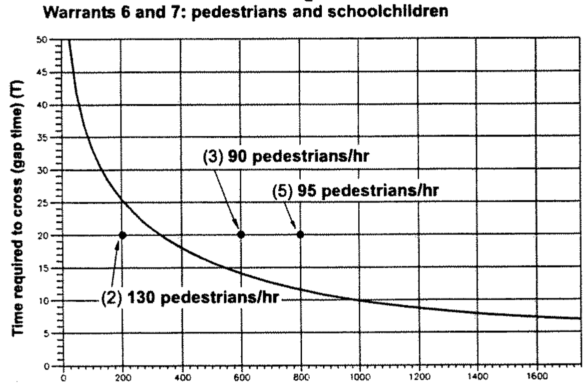
Therefore, this first evaluation does not satisfy condition a).

2nd evaluation:

1. Are there at least 90 pedestrians/hr over **at least 2 hours**?

   Yes: 9:00 - 10:00, 11:00 - 12:00, and 16:00 - 17:00
2. Is the total vehicle volume in both approaches above the curve in Chart 8.5–13 over **at least 2 of those hours**?

   Yes: 11:00 - 12:00 and 16:00 - 17:00, as shown in the following figure:



Therefore, this second evaluation satisfies condition a).

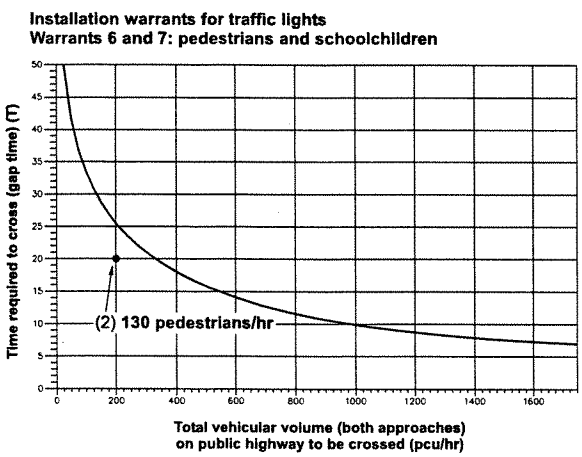
3rd evaluation:

1. Are there at least 110 pedestrians/hr over **at least 1 hour**?

   Yes: 9:00 - 10:00

2. Is the total vehicle volume in both approaches above the curve in Chart 8.5–13 over **at least 1 hour**?

   No, since the 1 hour count (9:00 - 10:00) is below the curve, as shown in the following figure:



Therefore, this third evaluation does not satisfy condition a).

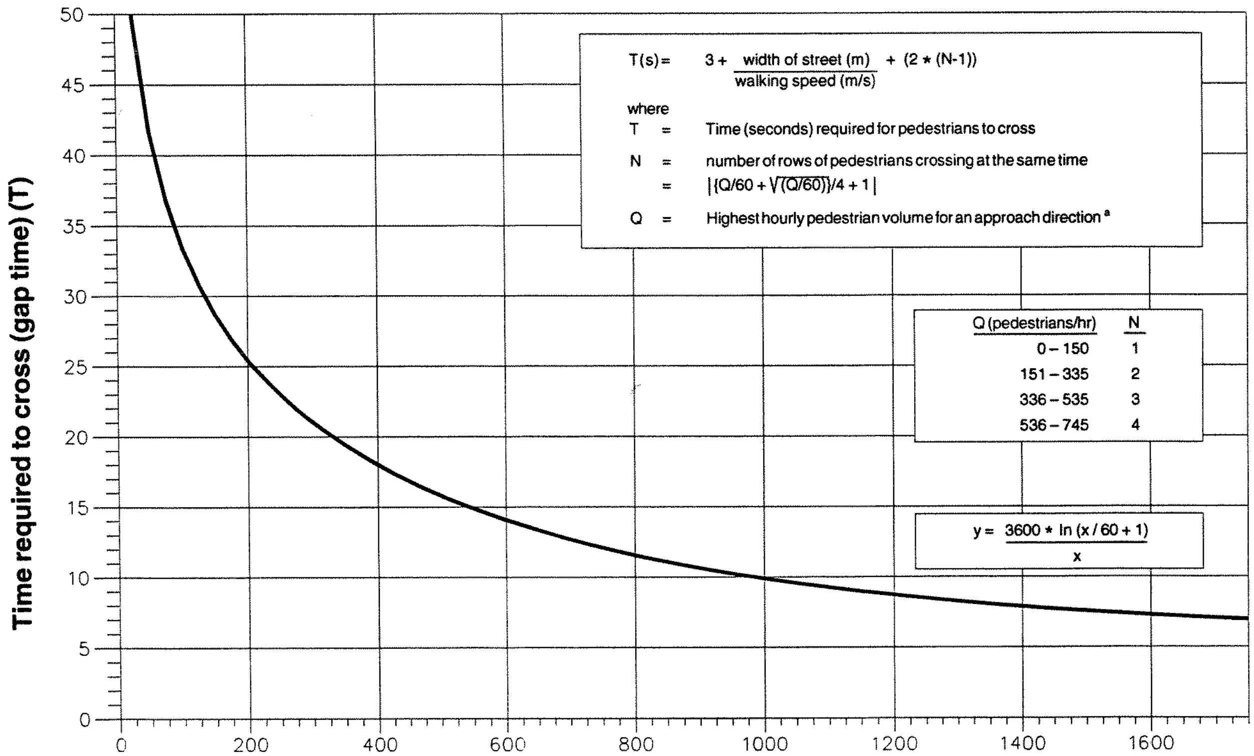
Evaluation of condition b):

Is the intersection located at least 100 m from any traffic signals controlling traffic upstream or downstream?

Yes, since the closest intersection with traffic lights is 150 m away, and the closest intersection with Stop signs is 400 m away.

Therefore, the installation of a traffic light would be justified at that intersection, since both conditions a) and b) are satisfied.

Chart 8.5–13
Installation warrants for traffic lights
Warrants 6 and 7: pedestrians and schoolchildren



Total vehicular volume (both approaches) on public highway to be crossed (pcu/hr)

This chart has been calculated on the basis of a average pedestrian waiting time of 60 seconds and of the time T required to cross the highway, which is a function of the width of the highway and the required pedestrian walking speed at a location. All points lying above the curve indicate that pedestrians wait over 60 seconds to cross. However, this curve has been calculated assuming a random vehicle arrival rate. It follows that this chart may not be used if the actual vehicle arrival rate is not random (for example, if it is influenced by upstream traffic lights). To satisfy this warrant in that case, field studies must be conducted to determine whether the average delay exceeds 60 seconds during the same hours for which vehicular traffic counts were obtained. The time required to cross the highway is calculated using the formula shown in this chart.

Note :

[a] The pedestrian volume used for calculating T is different from the total pedestrian volume calculated in condition a) of warrant 6. It is only part of the total volume.

APPENDIX D

Figures

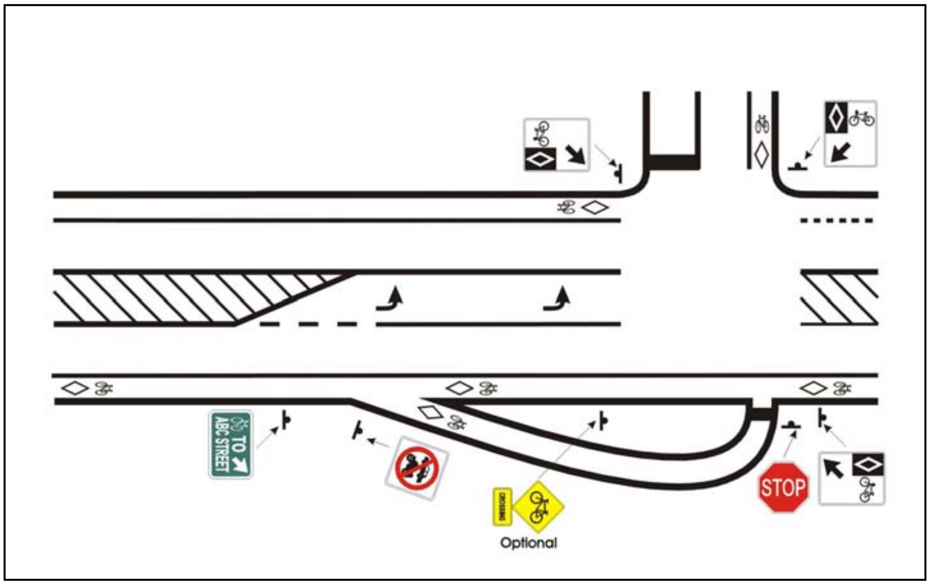


FIGURE 2.1

Bicycle "Jug-Handle"Left Turn

Source: Transportation Association of Canada (TAC), Dec. 1998

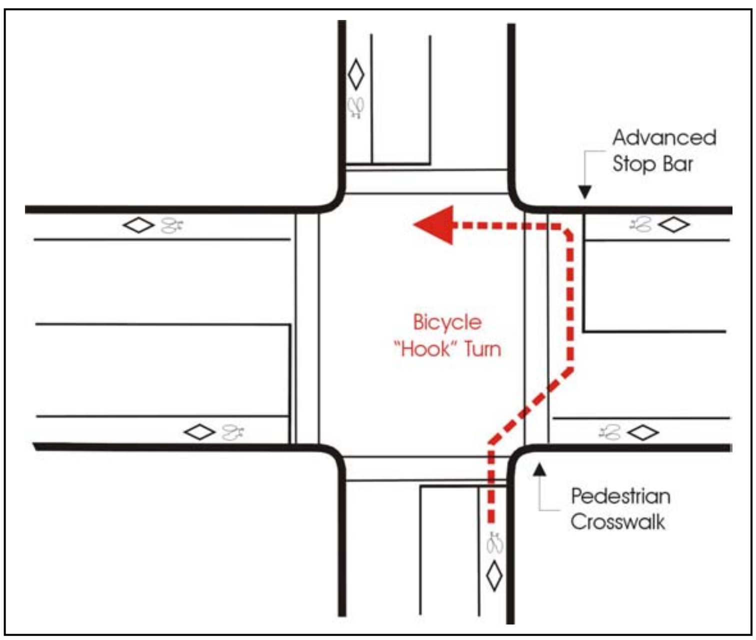


FIGURE 2.2

Bicycle "Hook Turn" with" Advanced Stop Bar"

Source: Marshall Macklin Monaghan Limited

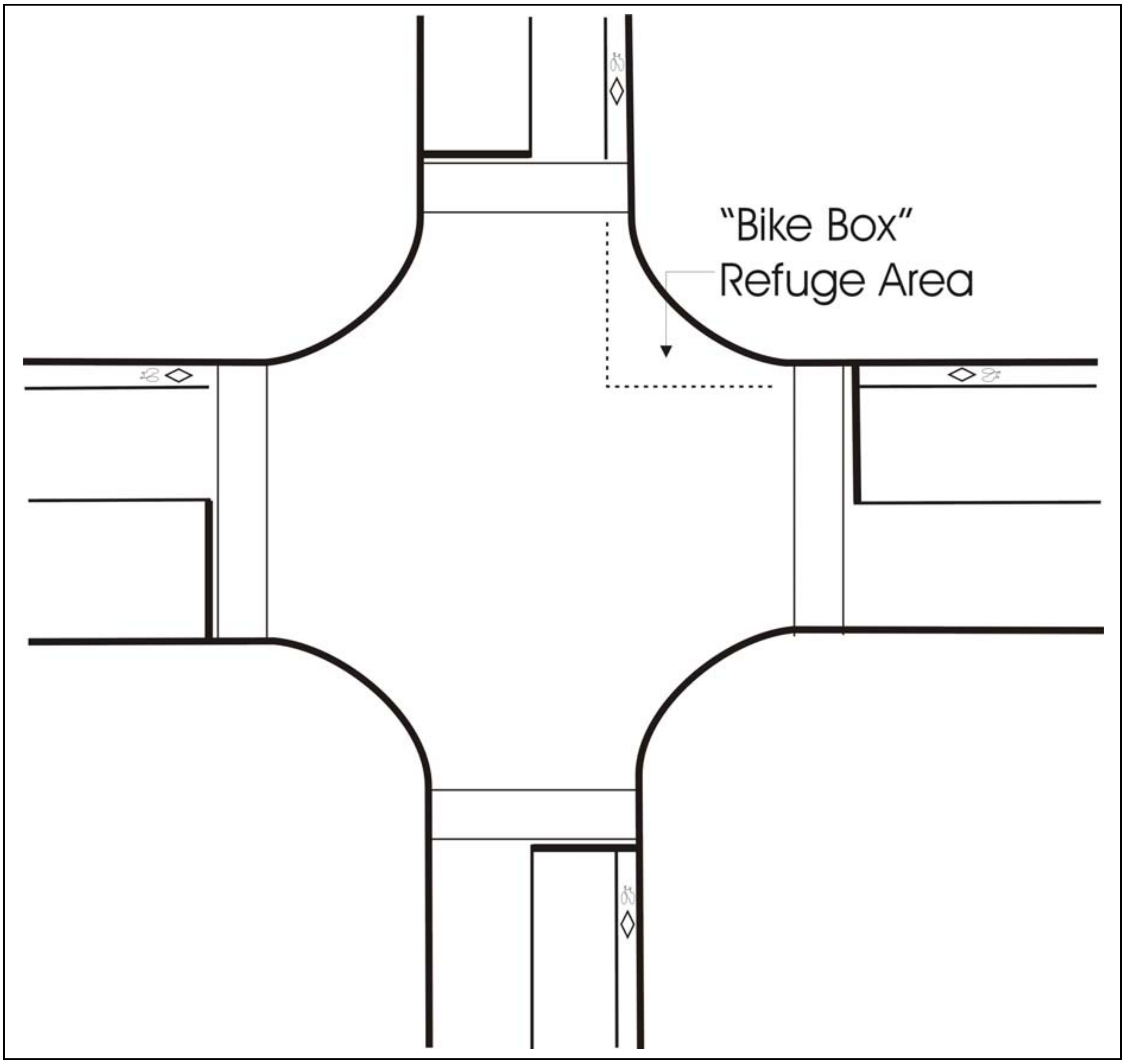
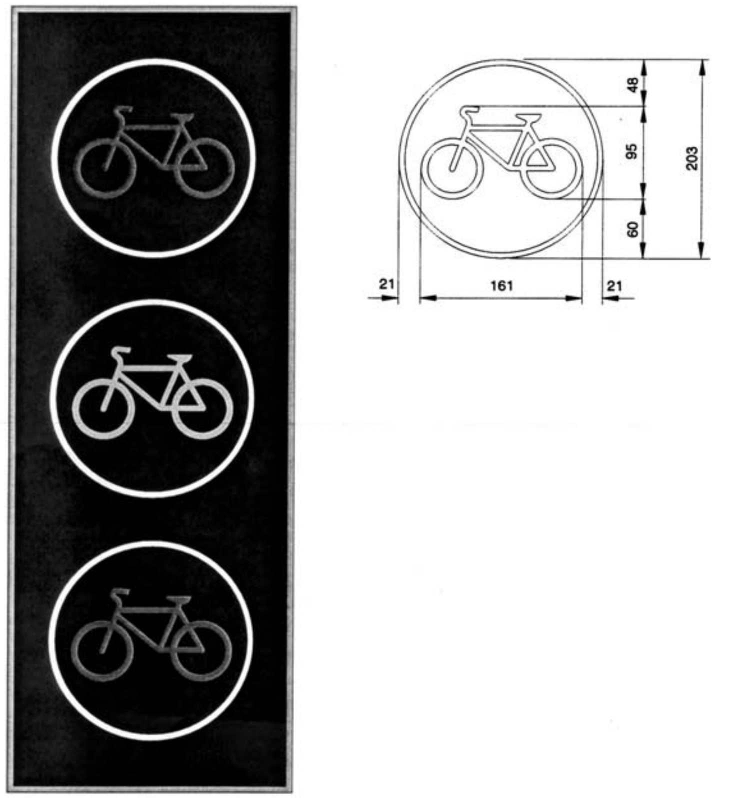


FIGURE 2.3
"Bike-Box" Cyclist Refuge Area
Source: Marshall Macklin Monaghan Limited



Notes:
– Proportions must be maintained.
– All distances are in millimetres.

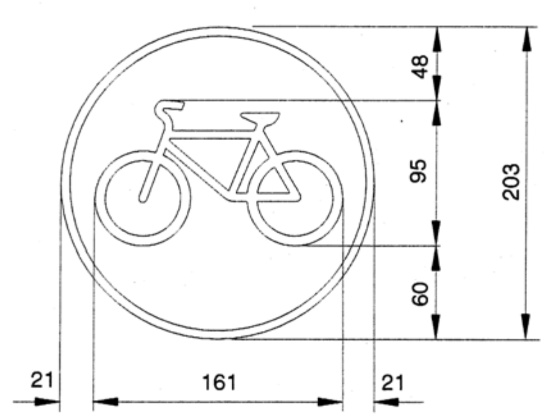


FIGURE 3.1 / 4.1
Bicycle Signal Head - Quebec Standard

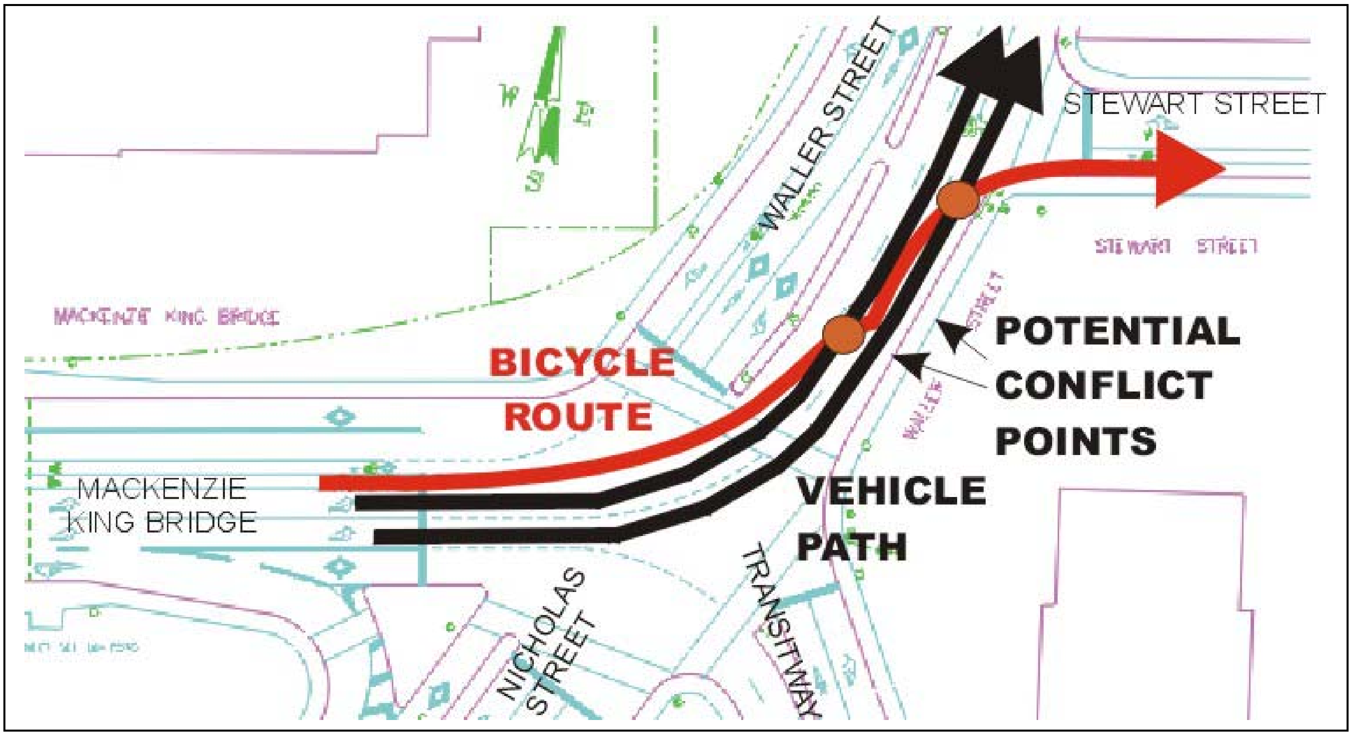


FIGURE 3.2
Mackenzie King Bridge & Waller Street/Nicholas Street Intersection Layout
City of Ottawa, ON Canada

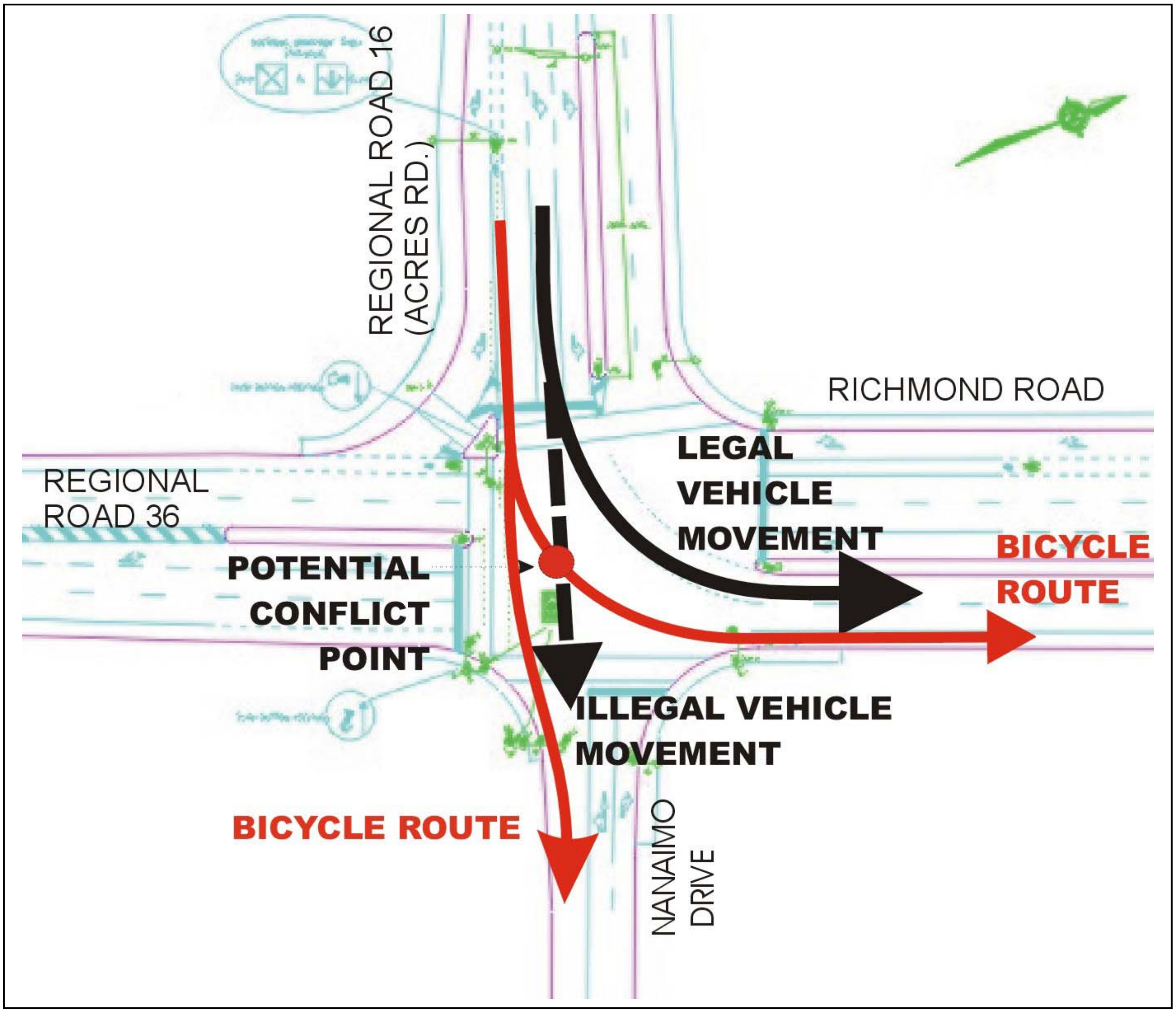


FIGURE 3.3

Nanaimo Drive/Acres Rd (R.R. 16) & Richmond Road (R.R. 36) Intersection Layout
City of Ottawa, ON Canada

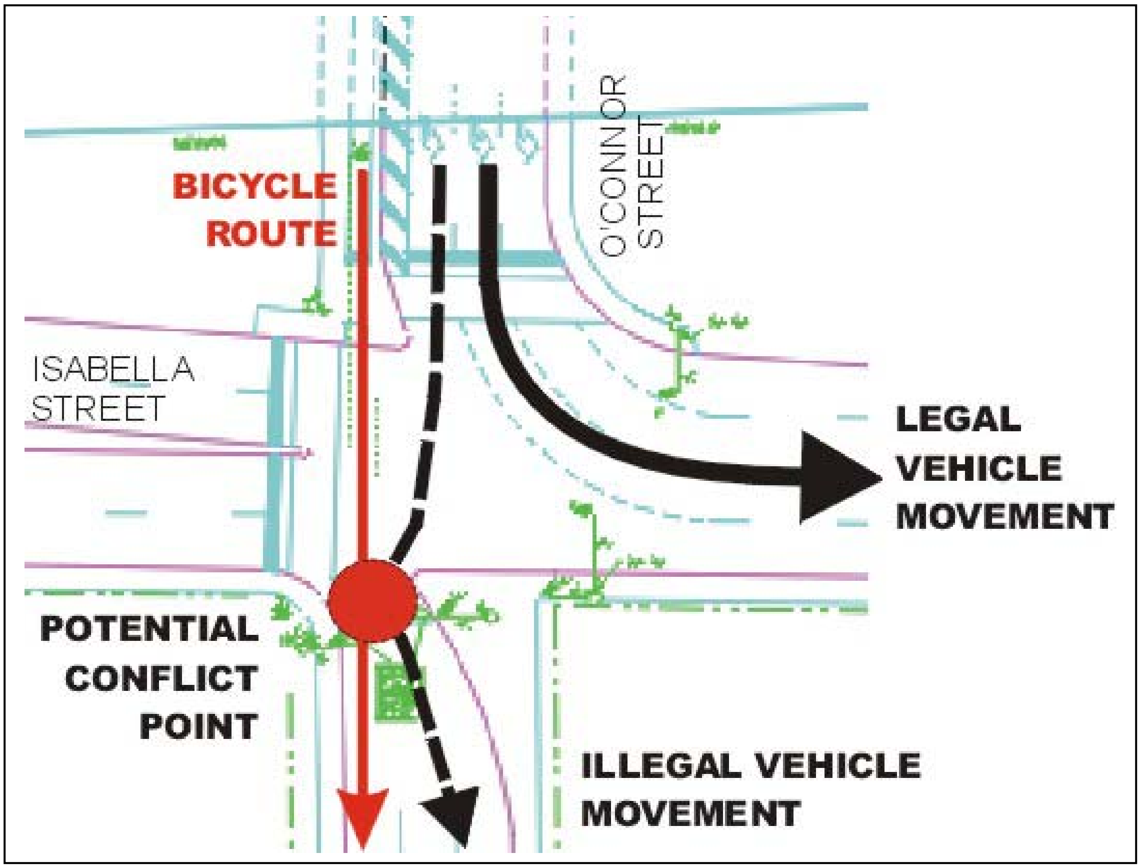


FIGURE 3.4

Isabella Street and O'Connor Street Intersection Layout
City of Ottawa, ON Canada

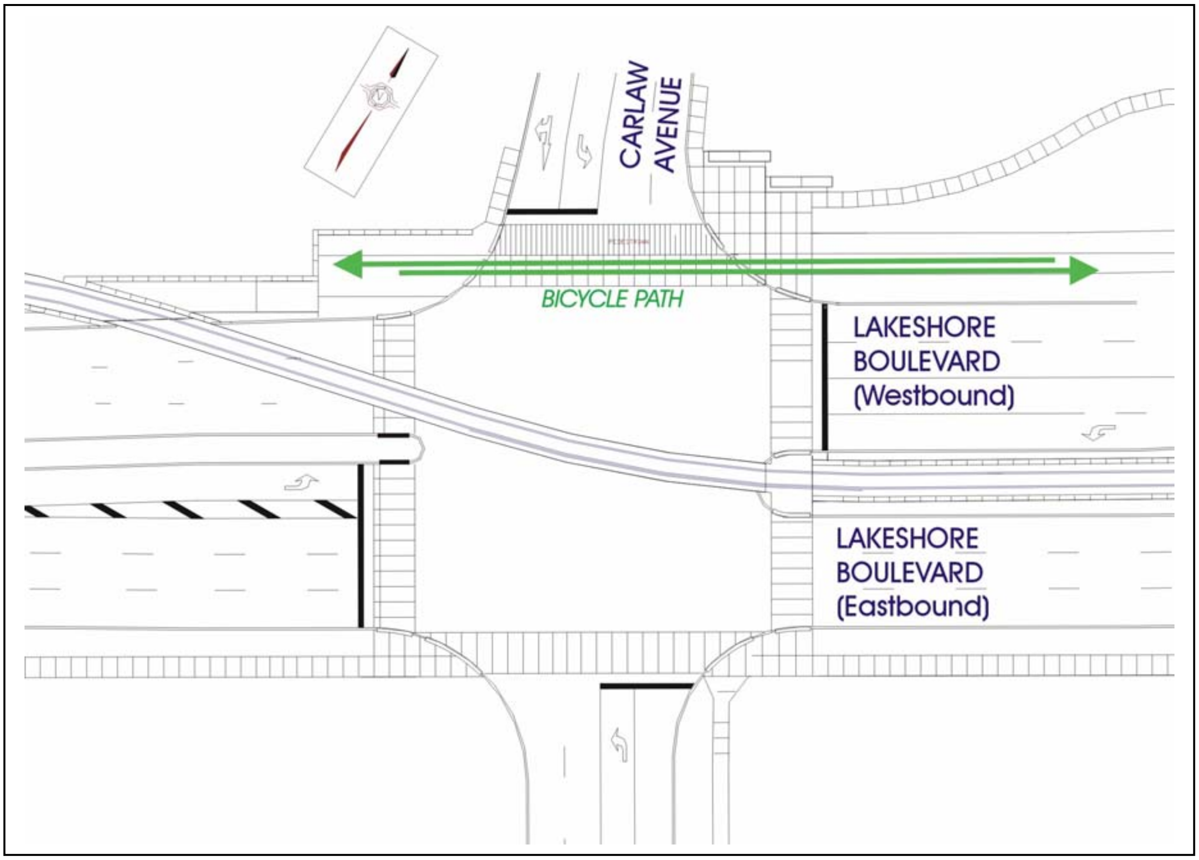


FIGURE 3.5

Lakeshore Boulevard and Carlaw Avenue Intersection Layout

City of Toronto, ON Canada

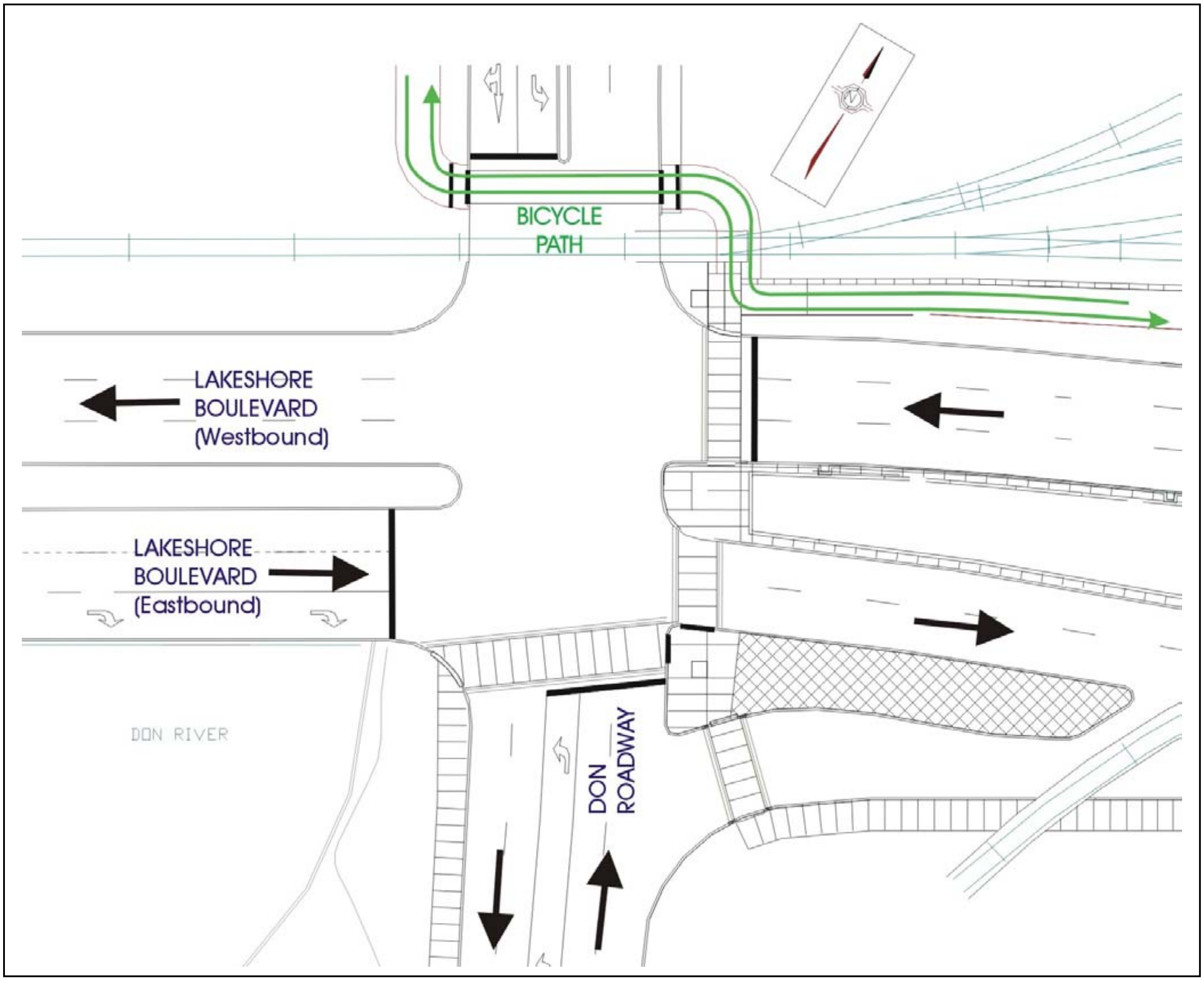


FIGURE 3.6
Lakeshore Boulevard and Don Roadway Intersection Layout
City of Toronto, ON Canada

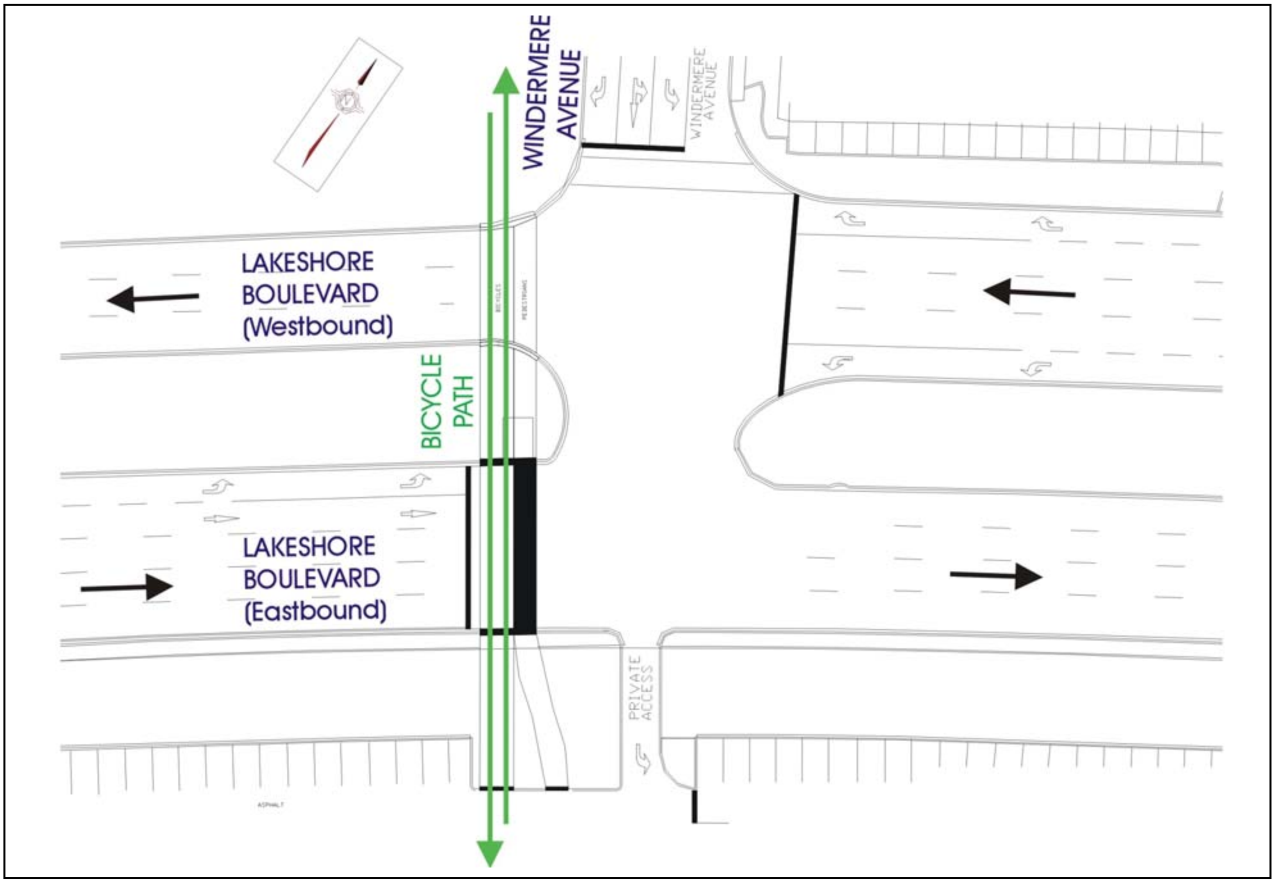


FIGURE 3.7
Lakeshore Boulevard and Windermere Avenue Intersection Layout
City of Toronto, ON Canada

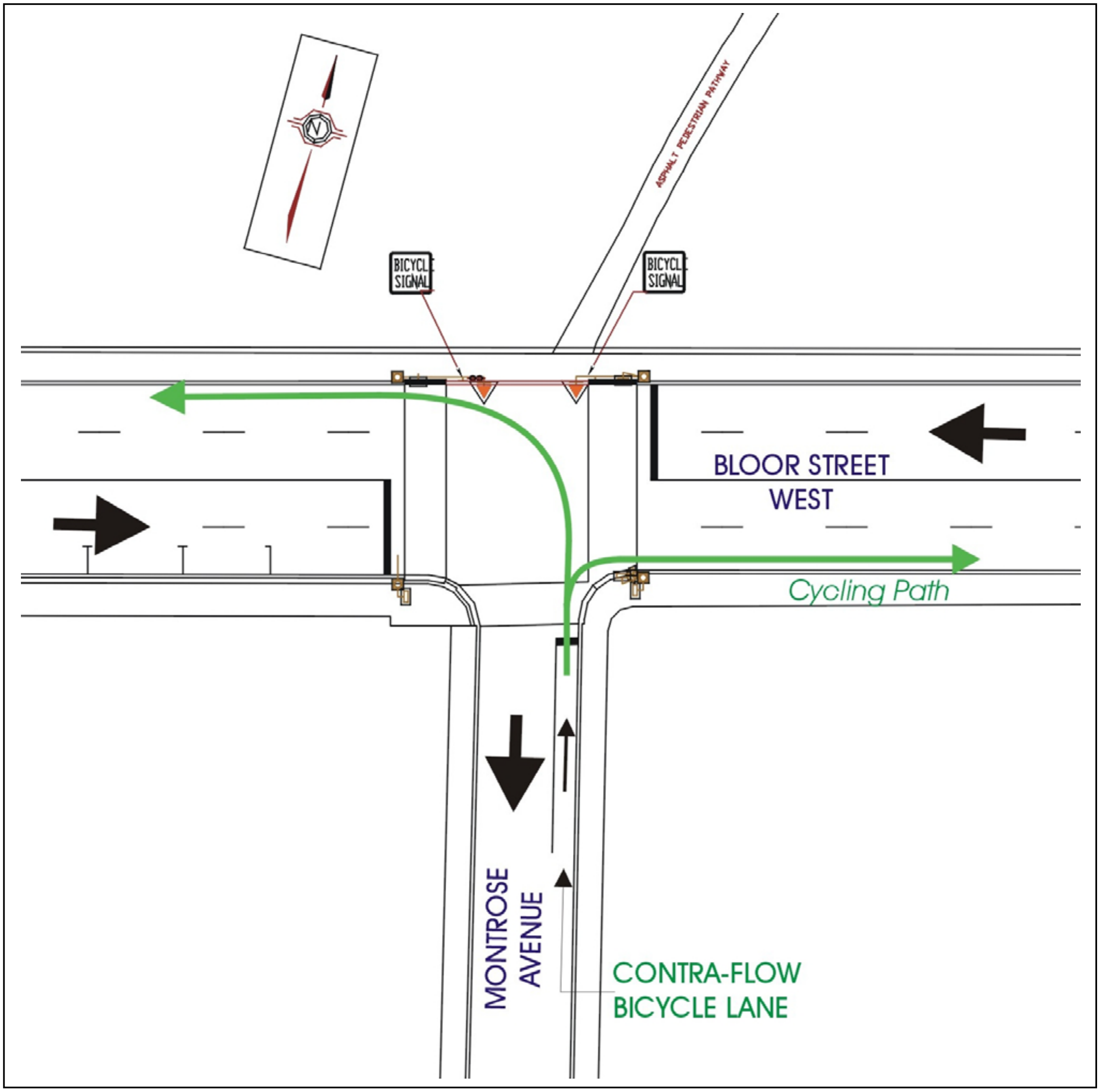


FIGURE 3.8
Bloor Street West and Montrose Avenue Intersection Layout
City of Toronto, ON Canada

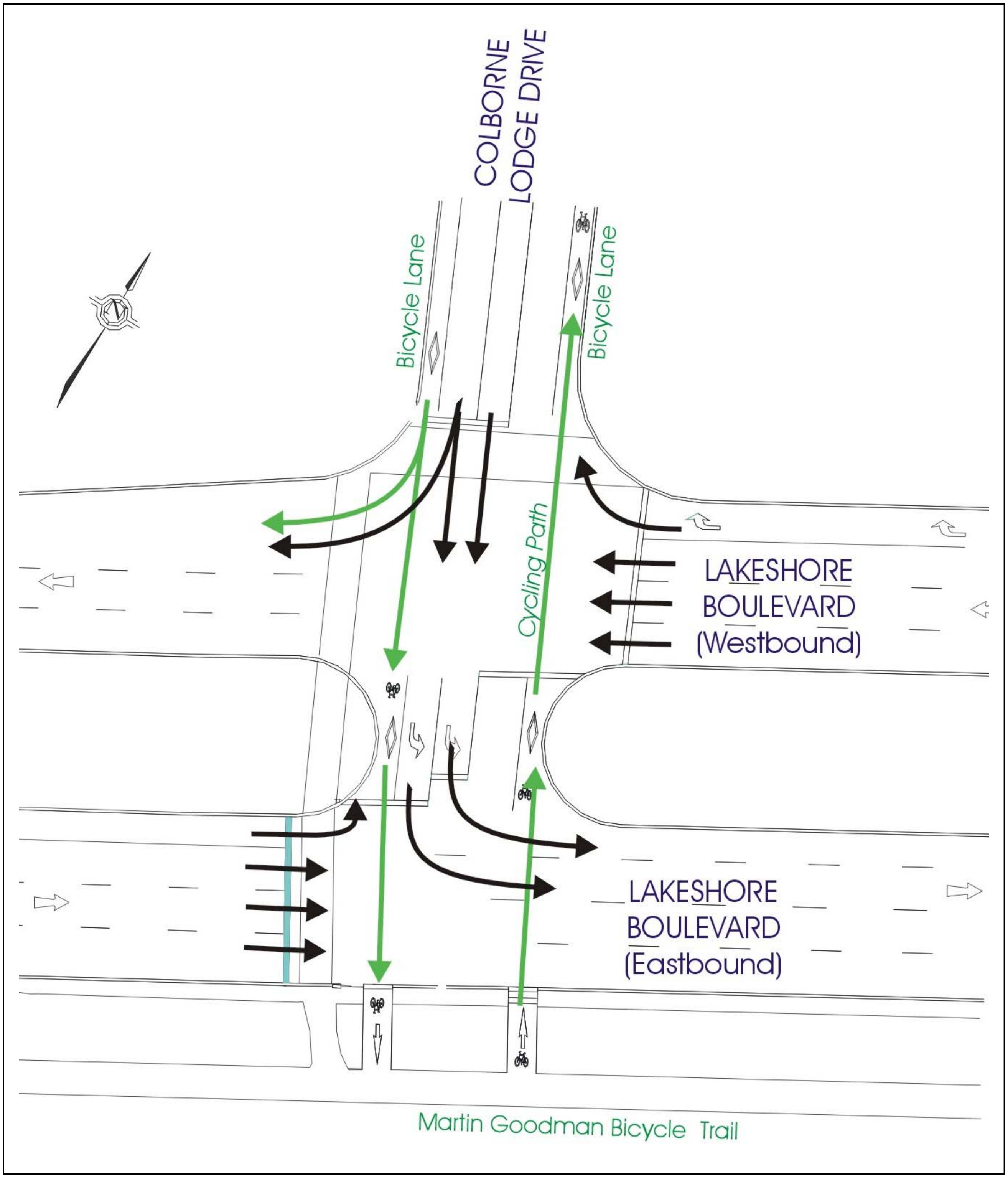


FIGURE 3.9

Lakeshore Boulevard and Colborne Lodge Drive Intersection Layout
City of Toronto, ON Canada

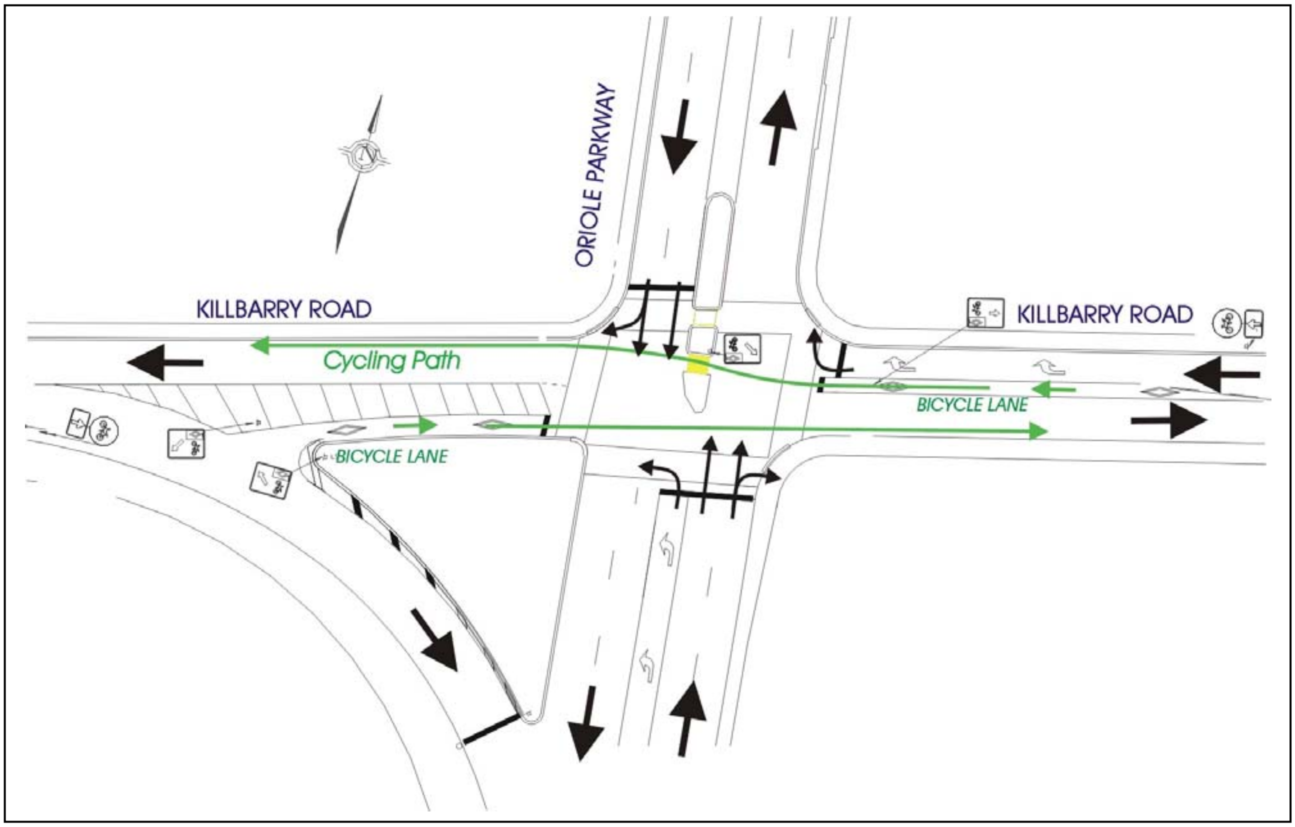


FIGURE 3.10
Oriole Parkway and Killbarry Road Intersection Layout
City of Toronto, ON Canada

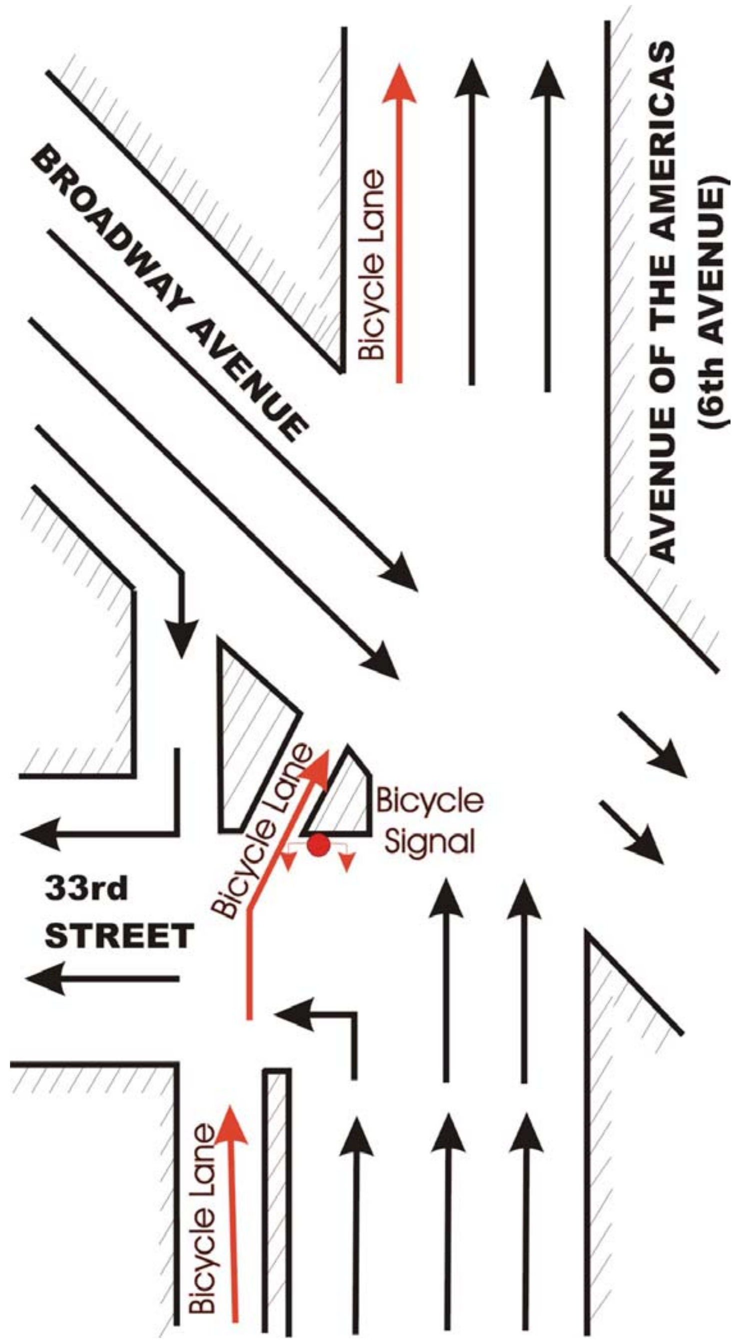


FIGURE 3.11

Herald Square Permitted Movements
(Not lane configurations)

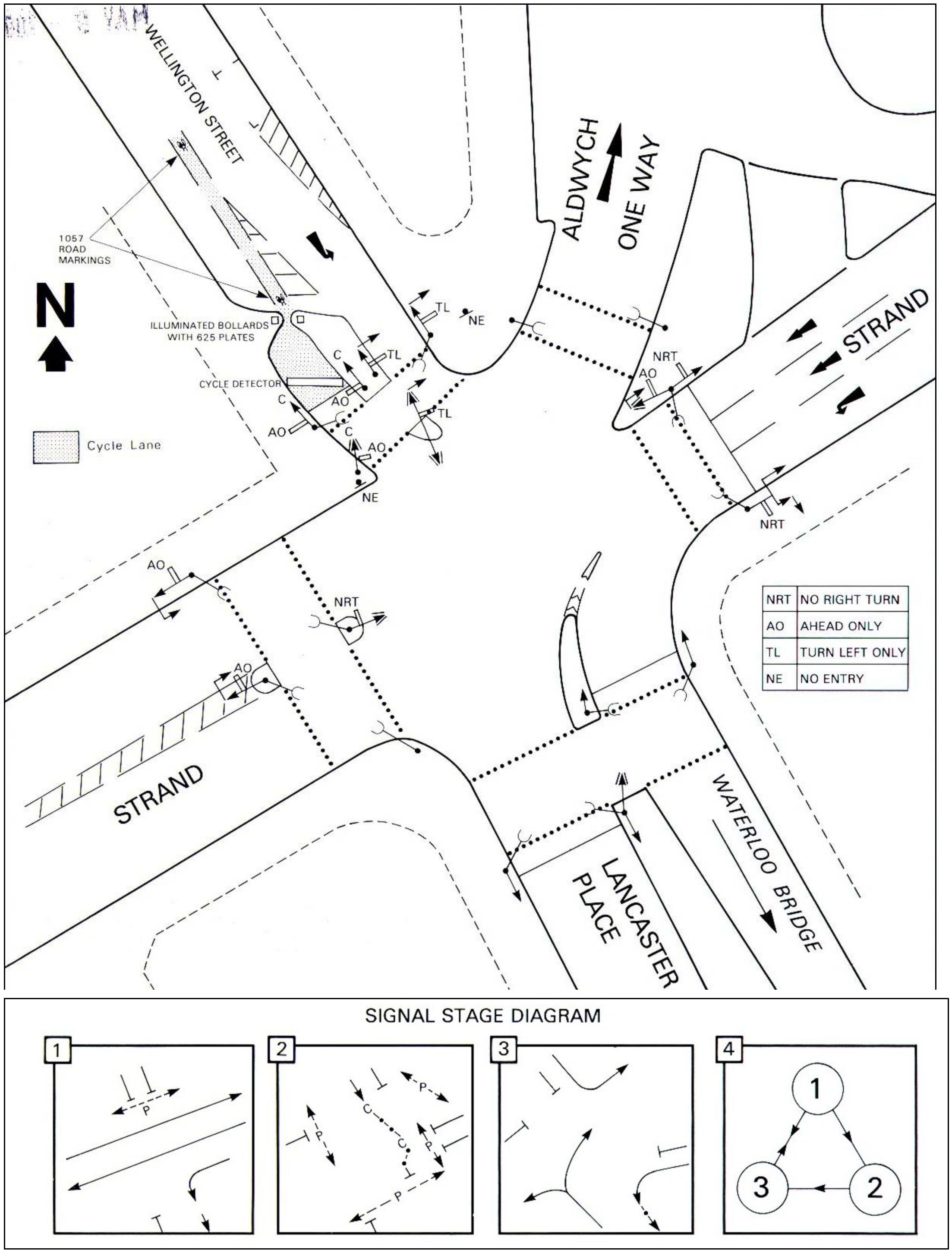


FIGURE 3.12

Stand / Wellington / Lancaster Place Intersection Layout and Signal Staging Diagram
City of London, England, UK

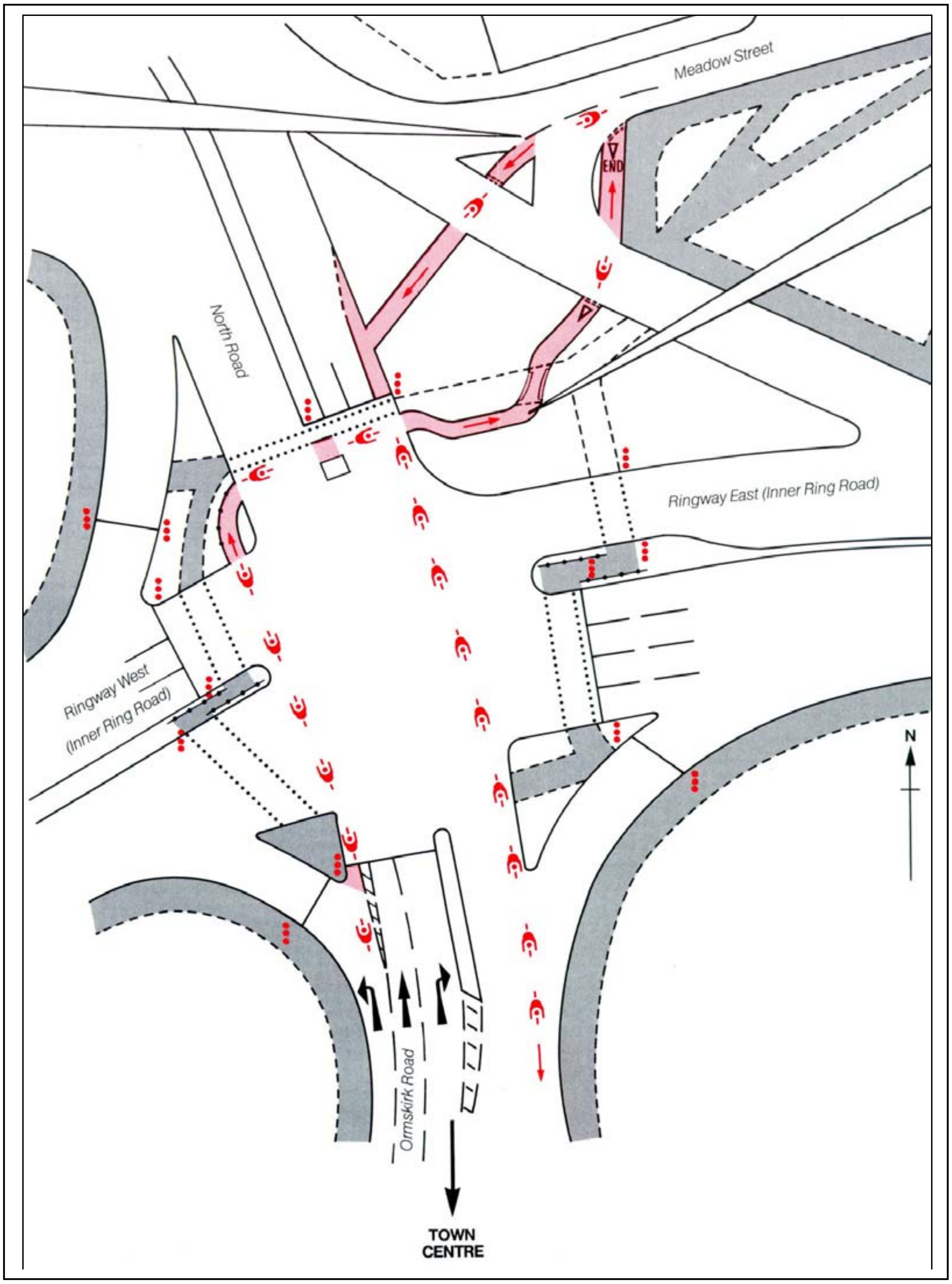


FIGURE 3.13

Ring Road Intersection Layout (Preston, UK)

Source: Department of Transportation, Traffic Advisory Unit (TAU); London, UK, 1986

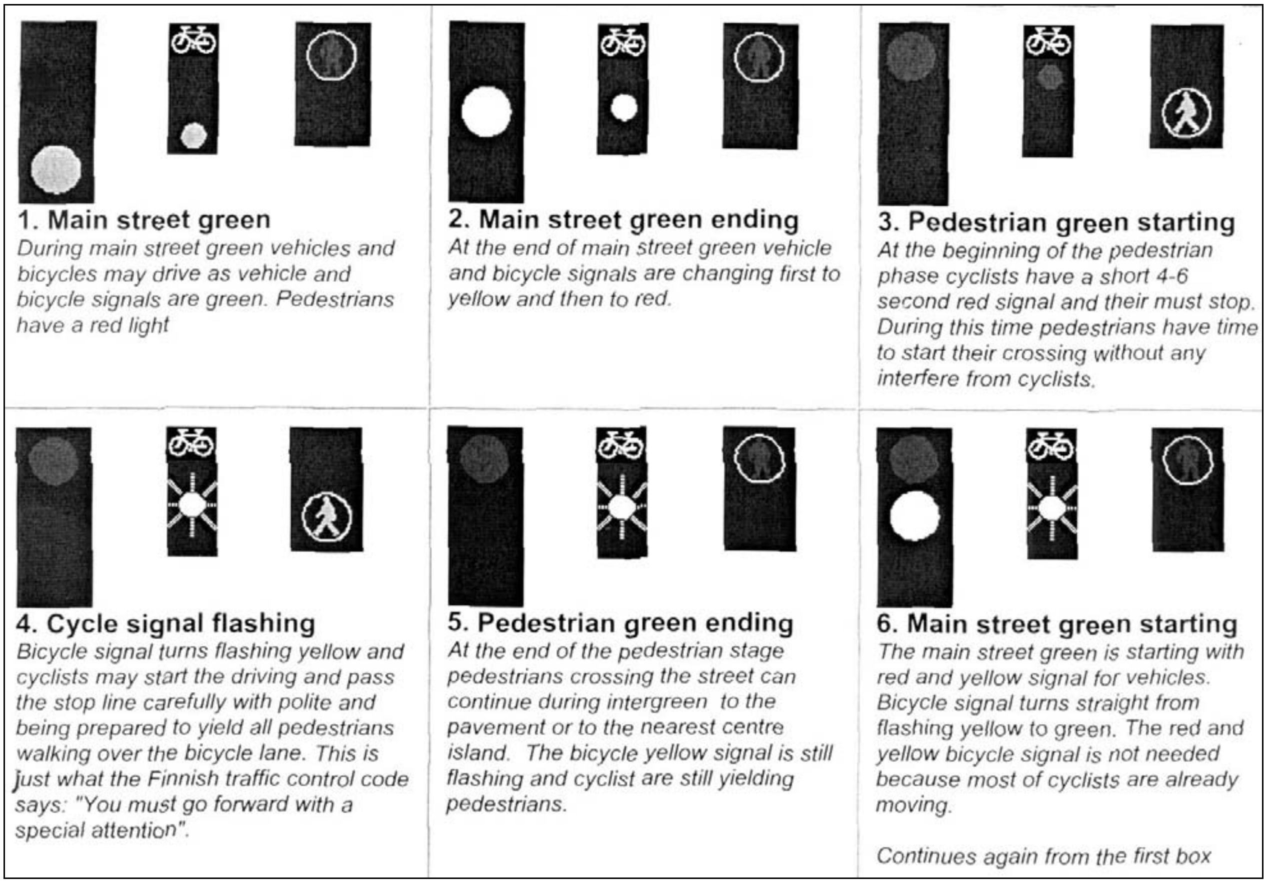


FIGURE 3.14
Helsinki BEPOLITE phasing sequence
Source: City of Helsinki, Traffic Planning Division, 1999

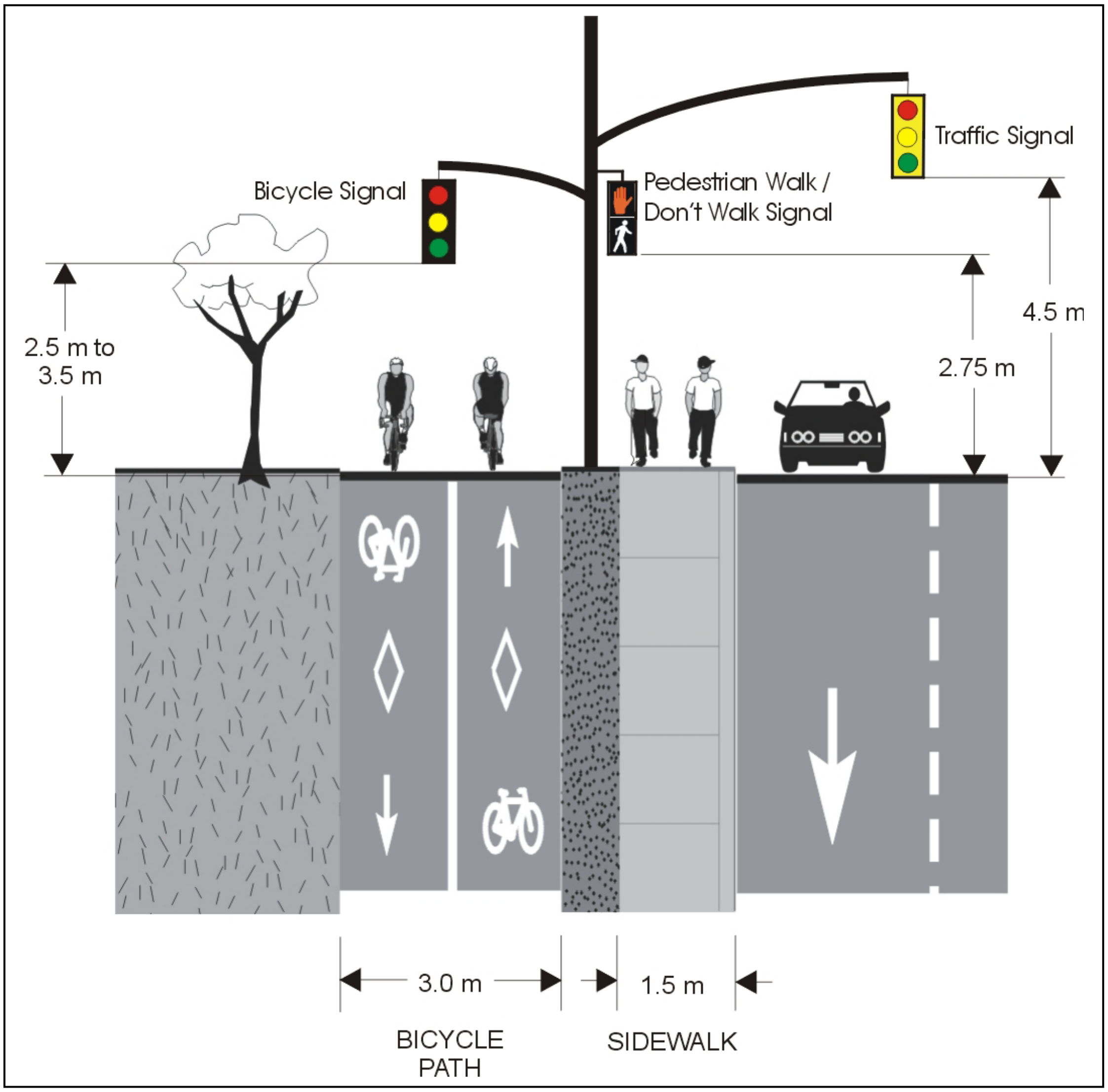


FIGURE 4.2

Typical Mounting Heights for Bicycle Traffic Signals
Source: Marshall Macklin Monaghan Limited

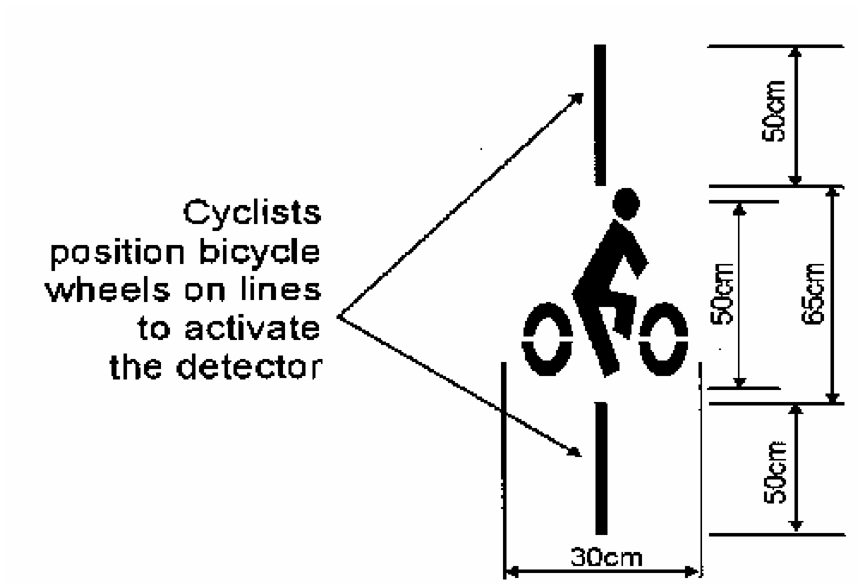


FIGURE 4.3

Recommended Pavement Markings for a Bicycle Actuation Location.
Source: City of Nanaimo Bicycle Facilities Design Guidelines – Appendix I; Urban Systems, Fall 2001, www.city.nanaimo.bc.ca/a_parks/pdf/appendix.pdf

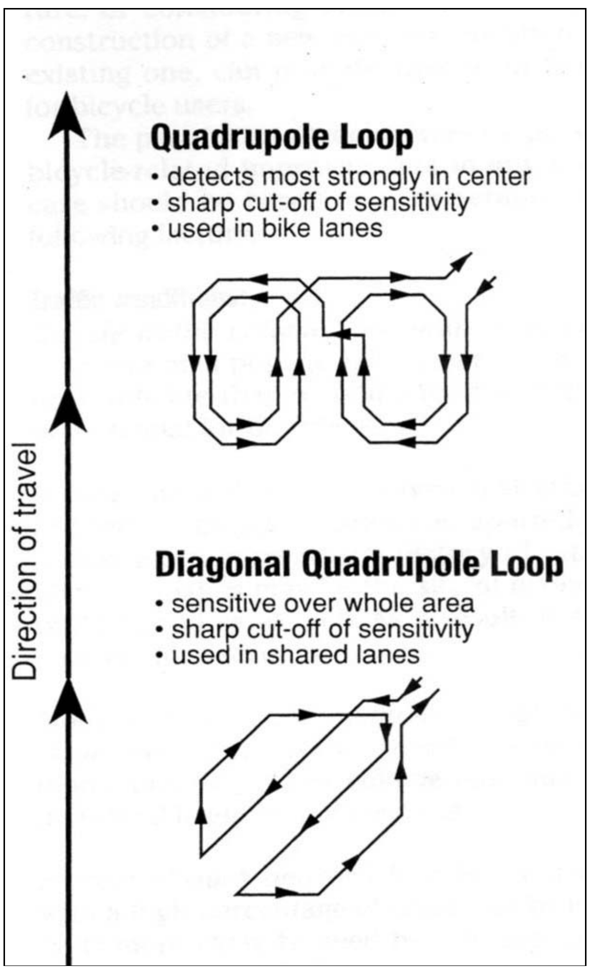


FIGURE 4.4

Quadrupole and Diagonal Quadrupole Detectors.
Source: Traffic Signal Bicycle Detection Study; City of San Diego, 1985

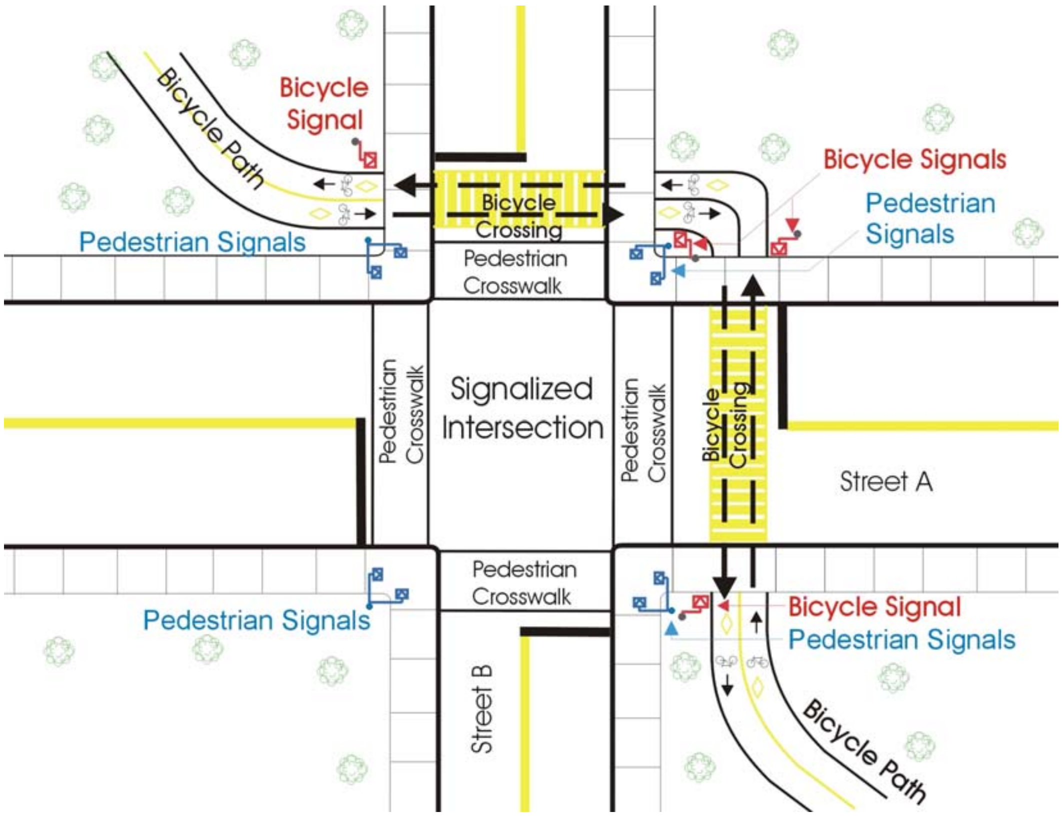


FIGURE 4.5:

Off-Street Bicycle Path Meeting a Signalized Intersection.

Source: Marshall Macklin Monaghan Limited

FIGURE 4.6

Warning sign for turning motorist to be aware of crossing cyclists.

Source: City of Montreal

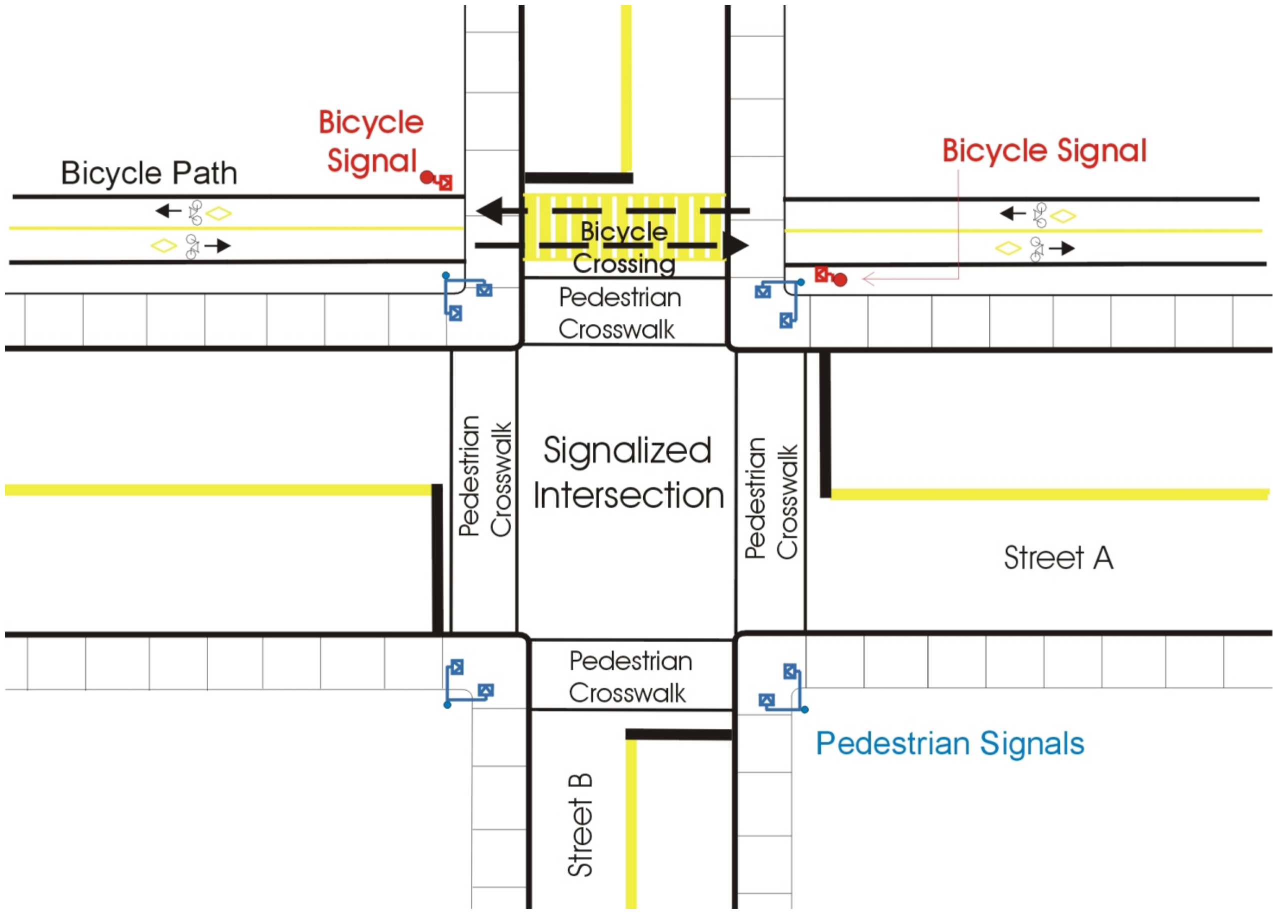


FIGURE 4.7:
Separated Bicycle Path Parallel to Arterial Street Crossing an Intersection
Source: Marshall Macklin Monaghan Limited

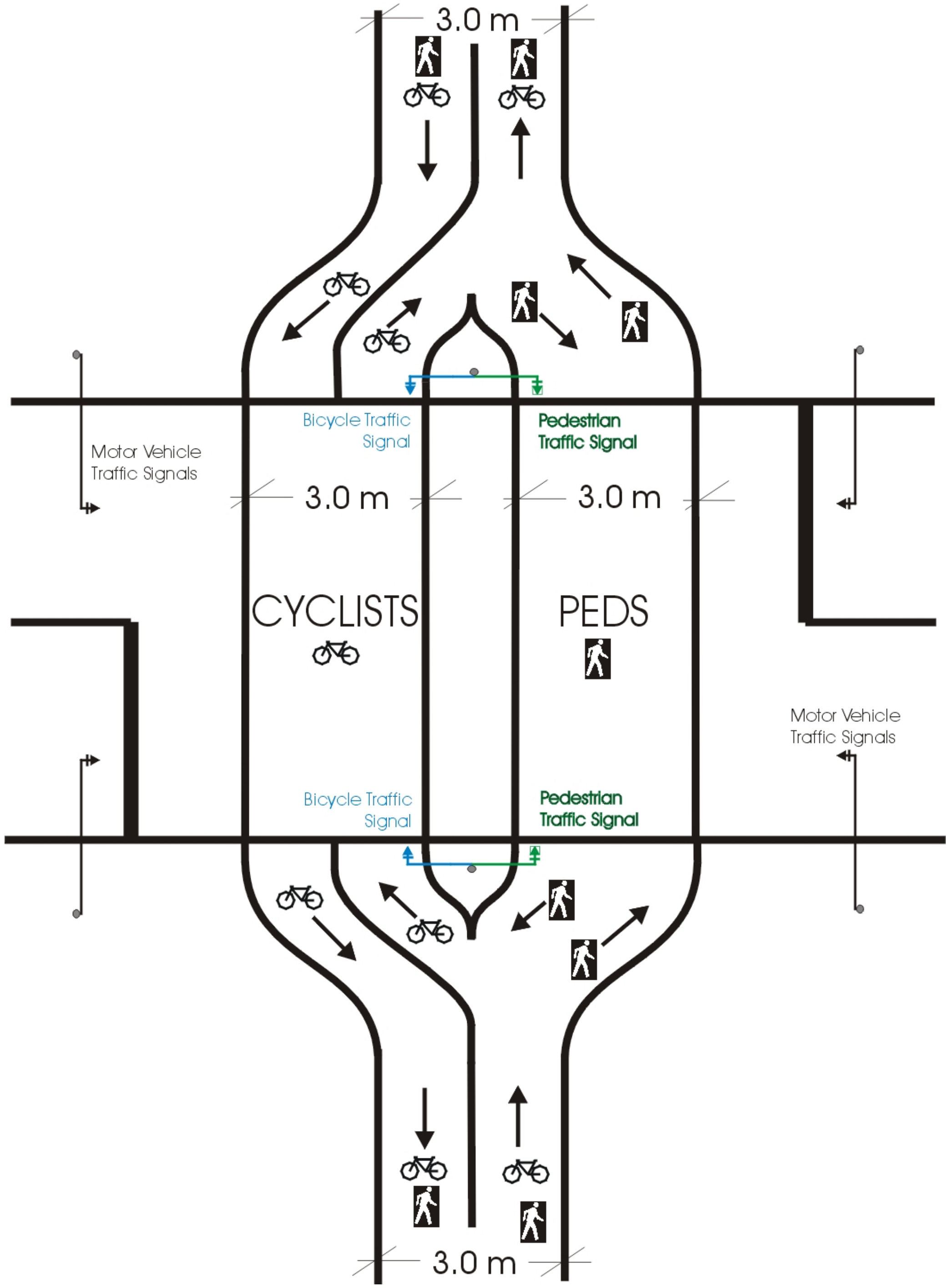


FIGURE 4.8:
Pedestrian and Bicycle Path Mid-Block Crossing
Source: Marshall Macklin Monaghan Limited

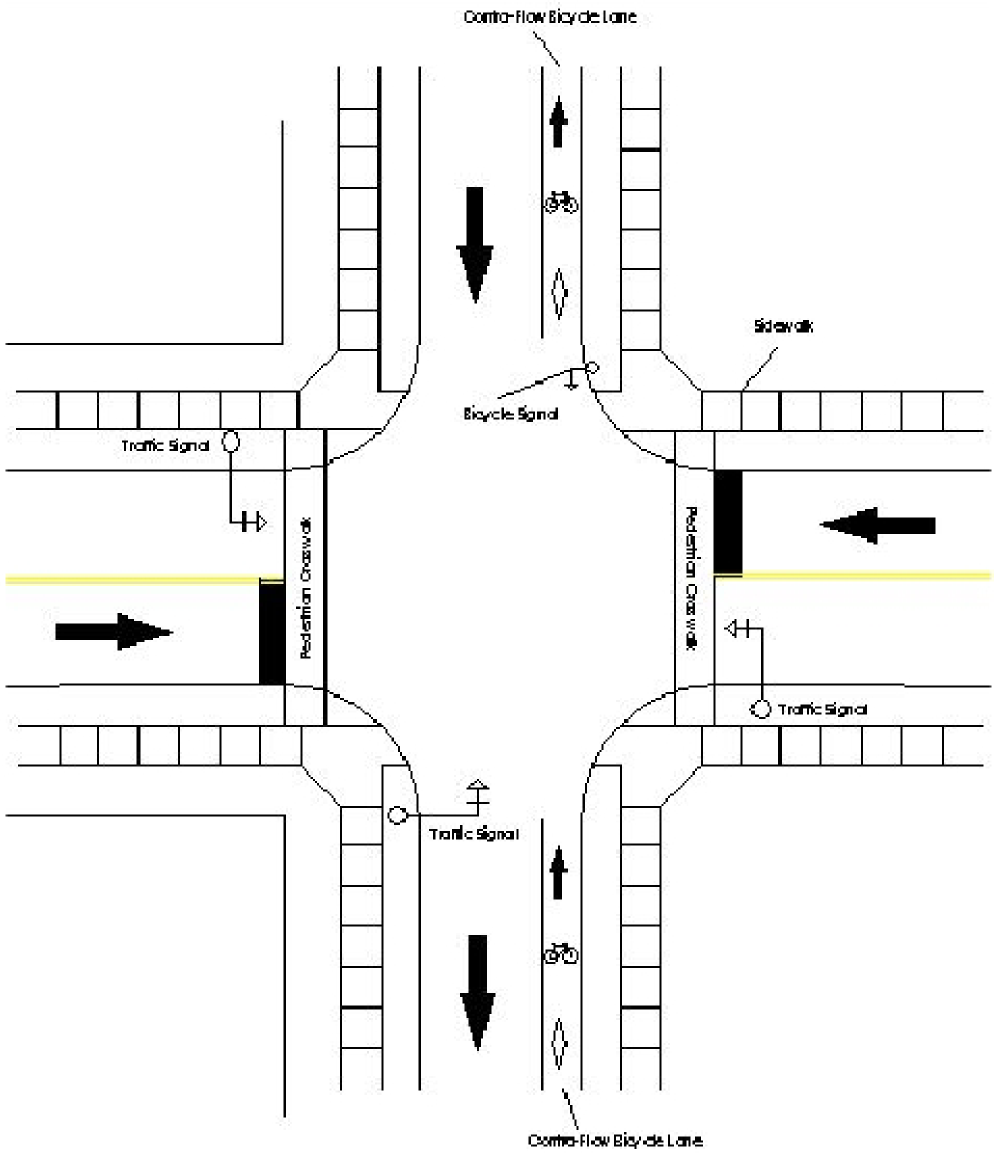


FIGURE 4.9:

Diagram of Contra-Flow Bike Lanes

Source: Marshall Macklin Monaghan Limited

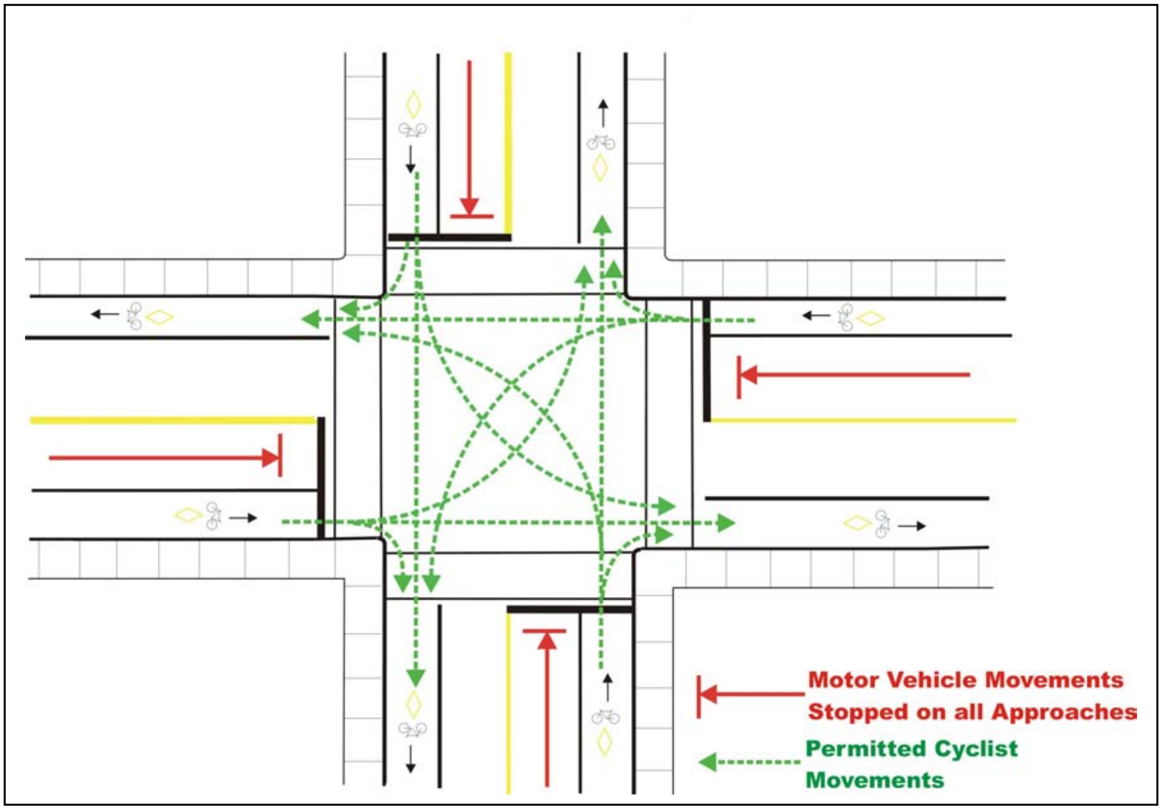


FIGURE 4.10
Bicycle Scramble Phase

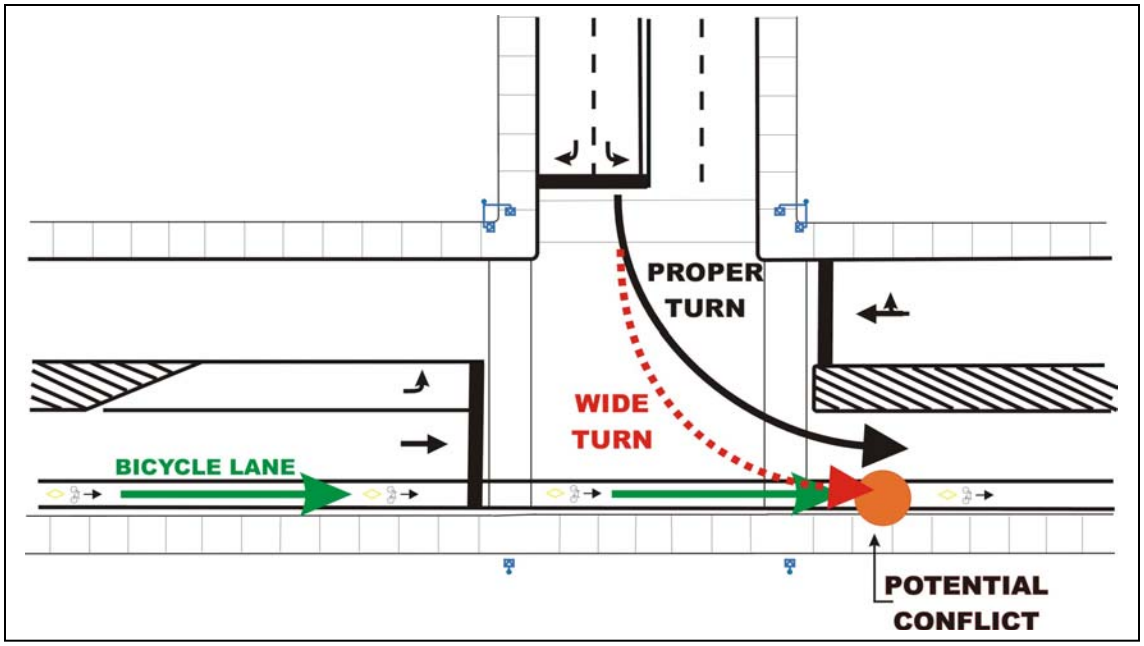


FIGURE 4.11
Potential Cyclist / Motor Vehicle Conflicts at Tee Intersections