TCRP REPORT 117

TRANSIT COOPERATIVE RESEARCH PROGRAM

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Design, Operation, and Safety of At-Grade Crossings of Exclusive Busways

TRANSPORTATION RESEARCH BOARD
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TRANSIT COOPERATIVE RESEARCH PROGRAM

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Design, Operation, and Safety of At-Grade Crossings of Exclusive Busways

Kimberly A. Eccles
VANASSE HANGEN BRUSTLIN, INC.
Raleigh, NC

IN ASSOCIATION WITH

Herbert S. Levinson
HERBERT S. LEVINSON TRANSPORTATION CONSULTANTS
New Haven, CT

CENTER FOR URBAN TRANSPORTATION RESEARCH
Tampa, FL

LIVABLE STREETS, INC.
Tampa, FL

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The nation's growth and the need to meet mobility, environmental, and energy objectives place demands on public transit systems. Current systems, some of which are old and in need of upgrading, must expand service area, increase service frequency, and improve efficiency to serve these demands. Research is necessary to solve operating problems, to adapt appropriate new technologies from other industries, and to introduce innovations into the transit industry. The Transit Cooperative Research Program (TCRP) serves as one of the principal means by which the transit industry can develop innovative near-term solutions to meet demands placed on it.

The need for TCRP was originally identified in *TRB Special Report 213—Research for Public Transit: New Directions,* published in 1987 and based on a study sponsored by the Urban Mass Transportation Administration—now the Federal Transit Administration (FTA). A report by the American Public Transportation Association (APTA), Transportation 2000, also recognized the need for local, problem-solving research. TCRP, modeled after the longstanding and successful National Cooperative Highway Research Program, undertakes research and other technical activities in response to the needs of transit service providers. The scope of TCRP includes a variety of transit research fields including planning, service configuration, equipment, facilities, operations, human resources, maintenance, policy, and administrative practices.

TCRP was established under FTA sponsorship in July 1992. Proposed by the U.S. Department of Transportation, TCRP was authorized as part of the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA). On May 13, 1992, a memorandum agreement outlining TCRP operating procedures was executed by the three cooperating organizations: FTA, the National Academies, acting through the Transportation Research Board (TRB); and the Transit Development Corporation, Inc. (TDC), a nonprofit educational and research organization established by APTA. TDC is responsible for forming the independent governing board, designated as the TCRP Oversight and Project Selection (TOPS) Committee.

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The TCRP provides a forum where transit agencies can cooperatively address common operational problems. The TCRP results support and complement other ongoing transit research and training programs.

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- John Fisher, P.E., P.T.O.E., Assistant General Manager, Office of Transportation Operations, Department of Transportation, City of Los Angeles, California
- Kathleen Sanchez, Transportation Planning Manager, Metropolitan Transportation Authority, Los Angeles, California
- Morteza Delpasand, P.E., Transportation Engineer, Department of Transportation, City of Los Angeles, California
- Robert H. Torres, Corporate Safety Manager, Corporate Safety, Metropolitan Transportation Authority, Los Angeles, California
- R. Scott Page, Transportation Planning Manager IV, Regional Transit Planning, Metropolitan Transportation Authority, Los Angeles, California
- Hitesh Patel, P.E., Director, Construction Project Management, Metropolitan Transportation Authority, Los Angeles, California
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F O R E W O R D

By Dianne S. Schwager
Staff Officer
Transportation Research Board

TCRP Report 117: Design, Operation, and Safety of At-Grade Crossings of Exclusive Busways will be of interest to transit agencies, roadway designers, city traffic engineers, and urban planners, as well as consultants for these groups and agencies. The material in this report provides considerable information and useful guidance for improving the safety and performance of exclusive busways. *TCRP Web-Only Document 36,* available on the TRB website (http://www.trb.org/news/blurb_detail.asp?id=7720), contains Appendixes A through I of the contractor's final report.

Exclusive busways in separate rights-of-way may have at-grade crossings with roadways or pedestrian and bicycle facilities. This report provides guidelines for the safe design and operation of at-grade crossings of exclusive busways. The guidelines are based on a detailed literature review, interviews with selected transit agencies, and site visits to Cleveland, Los Angeles, Miami, Orlando, and Richmond (British Columbia). The guidelines are intended to assist transit, traffic engineering, and highway design agencies in planning, designing, and operating various kinds of busways through roadway intersections. This report includes guidance for at-grade intersections along (1) busways within arterial street medians; (2) physically separated, side-aligned busways; (3) busways on separate rights-of-way; and (4) bus-only ramps. The intersections discussed include highway intersections, midblock pedestrian crossings, and bicycle crossings. The resulting guidance provides information that can be applied to enhance safety at busway crossings while maintaining efficient transit and highway operations, and minimizing pedestrian delay.

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CHAPTER 1

Introduction

This report provides design and operation guidelines for at-grade crossings of exclusive busways. In support of these guidelines, this report also provides general principles of safety, design, and operation of busways and information on design controls. The guidelines are based on a detailed literature review, interviews with selected transit agencies, and site visits to Cleveland, Los Angeles, Miami, Orlando, and Richmond (British Columbia). As such, these guidelines are, in part, a reflection of where we are today with exclusive busway at-grade intersections. The guidelines may need to be modified as more at-grade crossings of exclusive busways are constructed or as advances are made in traffic control devices, buses, and facilities.

The guidelines are intended to assist transit, traffic engineering, and highway design agencies in planning, designing, and operating various kinds of busways through street and roadway intersections.

Background

Grade-separated busways have operated in Ottawa and Pittsburgh for more than 30 years. More recently, at-grade busways have been placed in service in several cities including Los Angeles, Miami, Orlando, and Richmond, and a busway is being built in the median of Euclid Avenue in Cleveland. Additional at-grade busways are likely to be built as part of ongoing bus rapid transit (BRT) initiatives.

BRT systems are defined by a set of attributes that improve service speed, identity, and reliability and that are viewed by the public as superior to regular bus service. These features include

- An exclusive, reserved, or priority running way that is generally free from traffic congestion and delay and that provides a sense of performance;
- Fewer stops;
- Reduced dwell times at stops;
- Improved travel times and schedule reliability;
- Increased comfort and aesthetically pleasing vehicles;
- An understandable route structure; and
- More and better information provided to existing and potential riders.

Higher speeds and greater service reliability can be achieved where buses are operated in dedicated lanes or dedicated facilities (busways). When stations, rather than bus stops are developed; when fares are collected prior to boarding the vehicles; when the routes are simple; and when real-time operating information is available to the public, BRT systems can be viewed as similar to rail systems but with the flexibility of a bus and significantly lower development costs.

Exclusive busways that are located in separate rights-of-way or within the medians of wide streets usually have grade crossings at intersecting roadways and/or pedestrian and bicycle facilities. These grade crossings have the same function requirements as traditional intersections. They must accommodate the movements of conflicting streams of traffic, pedestrian and vehicle, conveniently and safely. The challenge is to manage and accommodate the movement safely while maintaining efficient intersection operations. The movements of conflicting traffic streams must be separated in time and space. Needs of bus passengers, pedestrians, and other users of the intersection should be considered. Because there are few exclusive busways in the North American environment, confusion and a lack of respect by motorists on intersecting streets may result. Moreover, bus volumes are usually low when compared to general traffic; motorists or pedestrians traveling across the busway may be lulled into a false sense of security.

Ideally, buses operating on busways should have preference over conflicting traffic (because they move more people), similar to the preference given to light rail transit. It is not clear, however, that motorists, bicyclists, and pedestrians on crossing roadways perceive busways in the same manner that they perceive a light rail service, which typically has preference over general purpose traffic.

There is no generally accepted set of guidelines and procedures to increase safety at busway intersections while permitting relatively high-speed operations. Therefore, agencies have had to develop their own criteria to implement busways.

Objective of Study

The research objective was to develop guidance that can be used by transit and highway agencies in the operations, planning, and functional designs of at-grade crossings of busways in physically separated rights-of-way by roadways, bike paths, or pedestrian facilities. The resulting guidance should provide information that can be applied to enhance safety at busway crossings while maintaining efficient transit and highway operations and minimizing pedestrian delay.

Scope of Study

A broad range of exclusive busways are located in separated rights-of-way. Busways can provide the fastest, most reliable operation if all intersections with roadways or pedestrian and bicycle facilities are grade separated. However, exclusive busways also exist with at-grade crossings for all intersecting roadway or pedestrian and bicycle facilities, and busways exist with varied crossings (i.e., some at-grade and some grade-separated crossings). Many factors, such as traffic volumes, bus service frequency, environmental issues, costs, and access, affect the decision to have an at-grade crossing, as opposed to a grade-separated crossing. The scope of this report is guidance once the decision has been made to provide an at-grade crossing of an exclusive busway in a physically separated right-of-way. The guidance is a reflection of current practices and facilities of the transit systems included in this research project.

This report assumes that all pertinent factors have been considered and that an engineering study has determined that an at-grade crossing is the appropriate design for the intersection. Grade-separated crossings are outside of the scope of this report.

This report includes guidance for at-grade intersections along (1) busways within street medians; (2) physically separated, side-aligned busways; (3) busways on separated rights-of-way; and (4) bus-only ramps. They include highway intersections, midblock pedestrian crossings, and bicycle crossings.

Organization of Report

This report is organized into eight chapters with supporting appendixes. Chapter 2 describes the four types of intersections addressed in the report. Chapter 3 identifies some general principles of safety and design that should be considered. Chapter 4 provides design controls and guidelines for the intersection geometry. Chapters 5 and 6 address traffic control devices and operational practices. Chapter 7 presents designs for each of the four intersection types. Chapter 8, the final chapter, discusses other considerations including enforcement, education, bus operating procedures, and considerations for busways in the *Manual on Uniform Traffic Control Devices.*

The report is supported by a number of appendixes. Appendixes A and B provide interim products of the research, a literature review and a synthesis of practice. Appendixes C through G provide the results of the case studies. Appendix H describes a functional analysis that supports Chapter 3, and Appendix I provides some supporting information for Chapter 4. These appendixes have been published as *TCRP Web-Only Document 36,* available on the TRB website (http://www.trb.org/news/blurb_detail.asp?id=7720).

CHAPTER 2

Types of Systems

At-grade intersections along busways can be classified into four types of intersections: (1) median busway intersections, (2) side-aligned busway intersections, (3) separated right-of-way intersections, and (4) bus-only ramps. (A given busway may have several of these types of intersections.) Each of these intersections is described in the following sections.

Median Busways

An exclusive busway that travels in the median of a roadway between opposing flows of vehicle traffic is classified as a median busway. The busway in Richmond, British Columbia, portions of the Orange Line in Los Angeles; and the busway under construction on Euclid Avenue in Cleveland are examples of median busways in North America. Median busways are common throughout South America; Bogotá, Columbia, and Curitiba, Brazil, have noteworthy examples.

Median busways generally have very wide intersections to accommodate both directions of general-purpose traffic, the busway lanes, and the median separation on one or both sides of the busway. They may also have platforms and left-turn lanes. Generally, a curb-to-curb envelope of 75 to 90 feet is needed to also accommodate left-turn lanes. When left turns can be prohibited, the cross section would be several feet shorter. If sufficient width exists near intersections and bus volumes are high, one or two extra lanes on the busway can be provided for express buses to pass local service buses.

Busways are removed, both midblock and at intersections, from the curbside friction that may slow down operations; however, several safety and operations issues should be addressed. These issues include left-turn management, traffic signal placement, long pedestrian crossing distances, and possible cross-street traffic queuing over the busway. Median busways conflict with the direction placement principle of traffic: buses travel straight through an intersection to the left of left-turning motor vehicle traffic, resulting in a direct conflict between left-turning vehicles and same-direction transit vehicles. This conflict can be resolved through traffic controls that protect or prohibit left turns. However, the traffic control must be clearly separated for the two groups. Specifically, left-turning motorists should not be able to see the traffic control for buses, so that they are not confused about which control governs their movements at the intersection.

Pedestrians and bicyclists should be channeled to designated crossings at the intersections to discourage illegal crossing at other locations. Barriers or fences can potentially resolve midblock crossing concerns.

Side-Aligned Busways

An exclusive busway that travels parallel and closely spaced to an existing roadway, with some physical separation between the busway and general-purpose traffic is classified as a side-aligned busway. The maximum distance between the roadway and the busway, usually at the discretion of the designing agency, is likely to range from 100 to 400 feet. Intersections of side-aligned busways are so closely spaced to the intersections of the parallel roadway that they typically operate together as one intersection. If the two intersections operate independently, the busway is not side-aligned, but is instead considered separated right-of-way. A busway that is less than 100 feet from the general-purpose road results in a four-way street that can be confusing to motorists and pedestrians. Examples include northern portions of the South Miami-Dade busway, the LYMMO busway in Orlando, and portions of the Orange Line in Los Angeles.

A side-aligned busway intersection is very wide. Clear physical separation between the parallel roadway, the side-aligned busway, and their intersections with the cross street is essential.

A side-aligned busway is generally constructed along corridors where the right-of-way is available. It consists of an exclusive two-lane roadway where each lane is reserved for one direction for buses to travel. If the right-of-way is sufficient, separation between the two directions should be increased to provide an additional buffer between the buses and their mirrors.

The main safety concern results from motorists on the parallel roadway turning right across the busway and potentially into the path of an approaching bus. At intersections where the busway and parallel roadway have little separation, motorists are often prohibited from making right turns during the green signal phase for buses and must wait in a right-turn lane. At intersections with more separation, motorists turning right have to stop at the busway. Another concern with side-aligned busways is the potential for queues along the cross street to spill back over the busway. These concerns must be addressed by traffic control devices that reinforce the prohibition of vehicles blocking the busway.

Separated Right-of-Way Busways

Separated right-of-way busways operate on alignments independent of any parallel roadway: the busway is not in the median area and is not in proximity to a general-purpose roadway (i.e., it is at least 400 feet away; the actual distance depending on the discretion of the agency). Examples include portions of the Ardmore busway in suburban Philadelphia, portions of the Orange Line in Los Angeles, and the southern portion of the South Miami-Dade Busway.

At these locations, speed and motorist and pedestrian expectations are the primary concerns, especially where the intersections are not signalized. Intersections of separated right-of-way busways tend to be less wide than other types of busway intersections, because only the lanes for the buses are required. The intersection must accommodate the busway traffic, one or two directions of cross-street traffic, and pedestrian movements. Because of the sometimes light busway volumes (e.g., several minutes between buses), intersecting motorists and crossing pedestrians may be inclined to overlook the possibility of vehicles approaching along the busway.

Midblock pedestrian and bicycle crossings of busways are also classified as separated right-of-way busway intersections.

Bus-Only Ramps

For some systems, buses may have their own ramps to enter or exit the general traffic flow. The junction between the roadways and the ramps are also considered busway intersections. An example of this type of intersection is near the Airport Station of the Richmond 98 B-Line and along Pittsburgh's South, East, and West busways. Discouraging and precluding illegal entry is the main reported concern with these intersections.

CHAPTER 3

General Principles of Safety and Design

Busway intersections should provide safe and efficient movement of buses, general traffic, pedestrians, bicyclists, and other non-motorized users. Busway design should adapt and build upon the criteria and guidelines set forth in AASHTO's *A Policy on Geometric Design of Highways and Streets* (*1*), ITE's *Traffic Engineering Handbook* (*2*), and various Transportation Research Board publications.

Busway intersection design also must consider several unique aspects of busway operations: (1) buses often operate at less frequent intervals (relative to motor vehicles); (2) busways located near or adjacent to parallel streets increase motorist and pedestrian conflicts and confusion and can complicate traffic signal sequences; and (3) buses operating within arterial street medians may result in additional turning-movement conflicts and longer walking distances for pedestrians.

This chapter presents general safety and design considerations that are particularly relevant for intersections of exclusive busways.

Overview of Key Safety Issues at Busway Intersections

Signal and Stop Sign Violation

At all intersections, not just busway intersections, potential violation of traffic control devices is a serious safety concern. At signal-controlled intersections, drivers who violate the traffic signal, namely the red signal indication, pose a safety hazard to other users of the intersection. Similarly, at stop-controlled intersections, vehicles failing to stop at the intersection pose a safety hazard to themselves and other users of the intersection. At busways intersections, these violations can pose an even greater threat because of the difference in the size of the vehicles using the intersection.

Understanding Traffic Control Devices

Busway intersections can be new and confusing environments to some users and, if users are unclear about the meaning of traffic control devices, particularly traffic signals, safety concerns can develop. If traffic signals are not appropriately designed and installed, motorists may confuse the meaning of the signal indications.

Violation of Turn-Movement Prohibition

At some busway intersections, turn movements may need to be prohibited either completely or during certain intervals, for example, right turn on red at side-aligned busway intersections. For intersections where the busway and parallel street are in proximity, right turns on red are prohibited so that vehicles do not turn into the path of buses on the busway. Violations of these turn prohibitions can present serious safety concerns. The prohibition should be clearly conveyed to motorists.

Pedestrian and Bicycle Considerations

Busway intersection users include bus operators, motorists, pedestrians, bicyclists, and other motorized users. Pedestrians and bicycles are vulnerable road users; their protection should be considered at all busway intersections.

Pedestrians and bicyclists are less predictable than motorists in their movements. They are also less visible than vehicles, particularly at night. Bus operators must be trained to anticipate that pedestrians may cross against signals, outside of crosswalks, and/or in front of buses.

Busway intersections and designated midblock pedestrian crossings must be designed and operated to facilitate the safe crossing of these users. The safety of pedestrians with impairments also should be considered. For example, audible signals may be provided for pedestrians with visual impairments, particularly at signalized midblock pedestrian crossings that may lack some of the auditory cues (e.g., the sound "wall" of cross-street traffic) present at traditional intersections.

Placement of Intersections and User Expectancy

Drivers approaching an intersection rely on visual cues and/or experience to alert them to the presence of intersections. The visual cues are necessary so that the driver can make the appropriate action at the intersection or react to others' actions. Similarly, non-motorized users such as pedestrians and bicyclists must have cues that they are approaching an intersection. Some of these cues may include non-visual cues, such as traffic noise.

User actions at intersections include stopping for a traffic control device, checking for conflicting traffic, turning, and yielding to other intersection users, to name a few. For an intersection to operate safely and efficiently, all intersection users must act and react appropriately, based on a clear understanding of the actions to be taken.

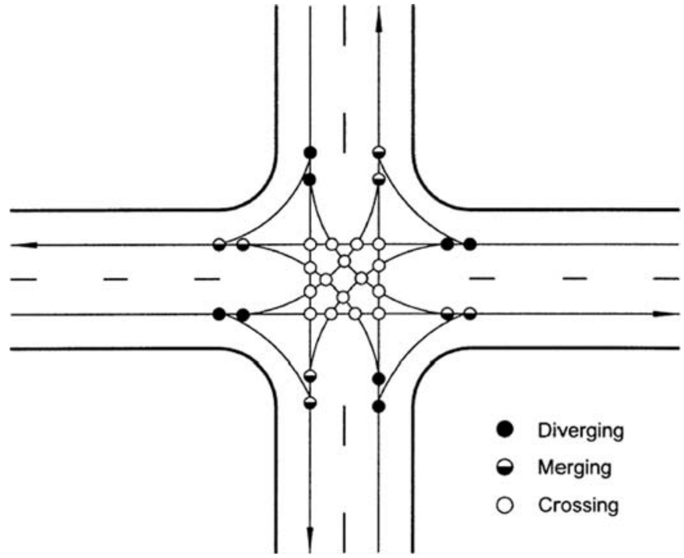
Busway intersections, particularly separated right-of-way intersections, may lack some of the visual cues normally used by drivers to detect the presence of an intersection. Because busways are not available roadways for general-purpose traffic and may be narrower than crossing roadways, drivers may assign busway intersections *lower status* and may not realize that the intersections exist. This problem is particularly an issue for relatively low-volume busways. If drivers often pass an intersection without having to stop, they may expect that they will never have to stop.

Unauthorized Entry

Unauthorized entry onto a busway, both intentional and unintentional, poses a serious safety risk to users—motorists may turn into the path of an oncoming bus. Appropriate measures should be taken both to alert motorists to the hazards of entering the busway and to provide positive guidance to vehicles traveling through intersections to minimize unintentional entry.

Conflict Points at Intersections

The number of conflict points at an intersection is related to the number of conflicting movements at the intersection including vehicle movements, bus movements, and pedestrian movements. Many busway intersections have more movements than traditional intersections. Figure 3-1 illustrates the 32 vehicle-to-vehicle conflict points (8 merge points, 8 diverge points, and 16 crossing points) at a traditional, four-leg intersection.



Source: *Signalized Intersections: Informational Guide* (3).

Figure 3-1. Conflict points at a traditional intersection.

The number of conflict points increases substantially as the number of legs increase. A three-leg intersection has 9 conflict points; a four-leg intersection has 32; and a five-leg intersection has 79. Similarly, adding a busway movement to an intersection increases the number of conflict points. A side-aligned busway intersection has four or more additional conflict points, depending on the separation distance. Median arterial busway intersections have an additional 12 vehicle-to-vehicle conflict points. The number of conflict points is even higher if turns are allowed into or out of the busway. Pedestrian conflict points, which are not included, can increase the number of conflict points by five or more per leg.

Removing buses from general-purpose lanes to a busway eliminates all of the non-intersection conflict points and some of the intersection conflict points that buses traveling in the general-purpose lanes experience. For example, a bus traveling in the general-purpose lanes has to make a number of merge and diverge movements at bus stops. A bus along the busway does not have these conflict points. This reduction in conflict points improves safety for the buses and for passengers boarding and alighting.

Design Principles and Guidelines

Provide Simple Intersection Designs

Busway intersections can be confusing to users because of the number of movements. Simple designs will help to minimize this confusion. Some basic design considerations include the angle of the intersection and the number of intersection legs. Right-angle intersections should be encouraged for best sight distance. Crossings with angles of less than 75 degrees should be limited to merging and diverging movements.

The number of intersecting intersection legs should be kept to a minimum. Intersections with more than four legs should be avoided. As discussed previously, the number of conflicts increases geometrically with the number of intersection legs.

Provide Clear Visual Cues to Make Busway Intersections Conspicuous

As discussed in the overview of key safety considerations, the conspicuity (visual cues) of the busway intersection is important. Users approaching an intersection normally rely on visual cues to enable them to act or react to traffic control devices or other users appropriately. Pedestrians and bicyclists also must have visual cues as they approach intersections. Roadway designs and traffic controls should make busway intersections conspicuous to all users.

Conspicuity can be achieved in several ways. The foremost visual cues are usually provided by traffic control devices such as stop signs or traffic signals. The *Manual on Uniform Traffic Control Devices* (MUTCD) gives guidelines for their appropriate placement so they are visible to approaching motorists and pedestrians.

Other visual cues include the cross-street pavement, moving or waiting cross-street traffic, pedestrian signals, curbs and gutters at corners of intersections, crosswalks and other pavement markings, street name signs, splitter islands on the approach to intersections, turn bays, and overhead lane assignment signals. These cues, while sometimes lacking at busway intersections, are desirable and should be provided to the maximum extent practical. Other measures that can be taken at busway intersections, particularly separated right-of-way busway intersections, include

- Illuminating intersections to improve nighttime visibility;
- Providing overhead flashing beacons at unsignalized locations;
- Providing curbs and gutters on approaches to intersections;
- Using contrasting pavement color for busways (e.g., red);
- Using contrasting pavement texture along intersecting streets on busway approaches (e.g., concrete pavement or rumble strips); and
- Pavement markings and signage on streets crossing the busway.

The use of traffic control devices such as signs and signals to increase conspicuity is addressed in more detail in Chapter 5.

Maximize Driver and Pedestrian Expectancy

Expectancy can be achieved by having consistent designs and placement of traffic control devices at successive intersections to the maximum extent possible. Busway intersection geometry should be generally similar from location to location. Safe stopping and decision sight distance should be adequate where complex decisions are required. Traffic signal controls, placement, phasing, and timings should be generally consistent from location to location.

Separate Conflicting Movements

Conflicting movements should be either prohibited or separated in space, time, or both space and time. Conflict points can be separated by the use of traffic control devices such as signals to assign right-of-way, exclusive signal phases, channelized turn lanes, and raised medians and islands. For example, providing protected left-turn movements instead of permitted left-turn movements separates in time the left-turning movement from conflicting movements such as opposing through traffic, busway traffic, or pedestrian movements. Alternatively, left-turn movements could be prohibited at the intersection to avoid the conflict altogether.

Turns into and out of busway intersections for buses should be strongly discouraged. Prohibiting buses from making turns at busway intersections greatly reduces the number of conflicts involving buses, which is particularly important given their size, weight, and maneuverability.

Minimize Street Crossings

Overall, the best way to reduce conflicts with busways is to reduce the number of crossings of the busway. Crossings can be reduced by creating cul-de-sacs, requiring U-turns for minor streets, and spacing busway intersections widely.

The spacing of intersections will depend on each area's roadway configuration, local travel, and the importance of various streets in the surrounding roadway network. Suggested ranges for busway intersection spacing are presented in Table 3-1.

Table 3-1. Suggested spacing for busway intersection by surrounding environment.

Surrounding Land Use	Minimum	Desirable
Urban	1/8 mile	1/4 mile
Suburban	5/8 mile	1/2 mile
Rural	1/2 mile	≥1 mile

Incorporate Design Features that Improve Safety for Vulnerable Users

Divider islands are used to separate busway lanes from adjacent travel lanes along median busways. However, they also provide refuge for pedestrians at intersections and should be designed with adequate dimensions for the expected pedestrian volumes. Many median busway intersections will have very large crossing distances. Pedestrian refuges in medians and other dividers will help to facilitate safe crossings. The walking speed of pedestrians, particularly older pedestrians and pedestrians with mobility impairments, should be considered in the signal timing.

Intersection designs should accommodate pedestrians with impairments, in accordance with the Americans with Disabilities Act, by (1) providing pedestrian ramps at intersections, (2) using contrasting pavement texture at critical locations such as truncated domes, and (3) using accessible pedestrian signals at appropriate locations.

Coordinate Geometric Design Features and Traffic Control Devices

The design and installation of traffic control devices such as signals, signs, pavement markings, and signage should be coordinated with the intersection geometry. Traffic signal placement and phasing should consider the needs of through, turning, and busway traffic.

Where traditional signal displays are used for busway vehicles, these indications should not be visible to other movements. Visibility of these displays is particularly a concern for median busway and side-aligned busway intersections.

Signs and pavement markings should be placed where the user can see the devices and have adequate time to react appropriately.

Functional Analysis at Busway Intersections

To provide a safe environment for all users of a busway intersection, the needs of those users must be understood. One method of identifying the needs of users is to conduct a functional analysis for the crossings. A functional analysis, also called a task analysis, identifies the information requirements of each user, the source of that information, and the actions that are required of the user. From this information, inappropriate behaviors/actions can be anticipated and potential countermeasures can be identified to deter the inappropriate actions.

This method is based on an IDA (Information–Decision–Action) model, a simplistic human behavior analysis procedure used in the human factors arena to identify systematically the needs of a user in response to a given situation. This model takes on different elements for the specific task at hand. The primary application of this model in transportation is to identify what information (e.g., signs, signals, pavement markings) a user needs to correctly decide how to maneuver through a transportation scenario (such as a busway crossing) safely. This approach is used in a number of similar applications including *NCHRP Report 470: Traffic-Control Devices for Passive Railroad-Highway Grade Crossing* (*4*) and *NCHRP Report 130: Roadway Delineation Systems* (*5*).

Appendix H presents functional analyses for four intersection designs: a median busway intersection, a side-aligned busway intersection, an independent (separate right-of-way) busway intersection, and a midblock pedestrian crossing.

Many needs were identified in these functional analyses. However, the critical need of all users identified in these functional analyses was the need to know of the presence of the busway at the intersection. Chapter 5, Traffic Control Devices, provides suggested devices to provide this information to users.

CHAPTER 4

Intersection Geometry Controls and Guidelines

Intersection design geometry should permit the safe and efficient movement of cars, buses, trucks, pedestrians, and bicyclists. It should consider the characteristics of all users, the surrounding environment, and appropriate public agency policies and resources. The resulting design process leads to a coordination of intersection geometry and traffic control devices. It results in appropriate sight distance, lane widths and clearances, and length of turning radius and islands. This chapter describes these elements of design and is primarily based on *A Policy on Geometric Design of Highways and Streets* (*1*).

Intersection design should consider both the physical and functional areas of an intersection. The physical area includes the actual intersection while the functional area of an intersection also includes perception reaction distance, maneuver distances, and queue storage distances.

Human and Driver Factors

Human and driver factors such as perception reaction time, eye height, and pedestrian walking speeds are important design controls for intersections. These factors are shown in Table 4-1.

Vehicle Characteristics

Vehicle characteristics such as length, width, height, wheel base, and acceleration/deceleration influence key intersection design elements including lane width, turning radius, storage requirements, and safe stopping sight distance. These basic characteristics are presented in Table 4-2.

The dimensions and turning radius for vehicles commonly found at urban and suburban intersections are set forth in Table 4-3. These values were extracted from AASHTO's *A Policy on Geometric Design* (*1*). Please note that this table does not represent all vehicles.

Detailed design characteristics of 40-foot, 45-foot, and 60-foot (articulated) buses compiled from various sources are shown in Table 4-4. These buses do not represent all possible buses and characteristics but instead represent a range of common buses.

These dimensions translate into the following design criteria for trucks and buses.

Height

The maximum vehicle height is about 12 to 13 feet for urban buses and 13.5 feet for trucks. This height translates into a minimum of 14- to 16-foot vertical clearances, respectively, when allowance is made for pavement resurfacing.

Width

The maximum vehicle width is 8.5 feet. When outside mirrors are added on both sides, vehicle envelopes become larger. Bus envelopes, for example, typically become 10 to 10.5 feet. Therefore, 11 feet is suggested as the minimum lane width for buses and tractor-trailer trucks. In cities where buses have greater outside mirror-to-mirror dimensions, wider lanes may be desirable.

Length

The *minimum* station (stop) length should be at least 50 feet for 40- to 45-foot buses and 65 feet for 60-foot articulated buses. If more than one bus is expected to dwell at the station, longer stations are necessary. Designs should provide for at least two loading positions, resulting in station lengths of 100 feet (for 40- to 45-foot buses) and 140 to 150 feet (for 60-foot buses).

Turning Radius

The AASHTO data suggest a minimum outside turning design radius of 45 feet. However, as shown in Table 4-4,

Table 4-1. Driver and human factors.

Factor	Value
Perception/Reaction Time	1.0 - 4.0 secs
Driver Height of Eye	3.5 ft
Pedestrian Walking Speeds	3.0 - 4.0 ft/sec

Source: Adapted from *A Policy on Geometric Design of Highways and Streets* (*1*) and *Traffic Engineering Handbook* (*2*).

Table 4-2. Effect of vehicle characteristics on intersection design.

Vehicle Characteristics	Intersection Design Elements Affected
Length	Length of storage lanes Length of bus stops and stations
Width	Width of lanes Width of turning roadways
Height	Placement of overhead traffic signals and signs Vertical clearance under overcrossings
Wheelbase/Overhang	Island nose placement Corner radius Width of turning roadways
Acceleration Rates	Acceleration tapers and lane lengths
Deceleration Rates and Braking Capabilities	Deceleration tapers and lane lengths Safe stopping sight distance

Source: Adapted from *NCHRP Report 279* (*6*).

modern buses (with overhang) require up to 51 feet outside turning radius. Bicycle racks on buses would add about 1.5 feet. These data suggest a minimum outside turning radius of at least 55 feet if buses will be turning at intersections.

Actual horizontal curve design for buses (and trucks) should consider a simple curve with tapered or three centered compound curves wherever possible.

Design Designations

"Design designations" form the basic controls for which an intersection is designed. They normally cover elements such as degree of access control, design drivers and vehicles, design years, design daily and peak-hour volumes, and design speeds. Design designations for intersections reflect those for the roadways along which the busway intersections are located.

Design Driver

Bus operators on busways are professional drivers who are trained to be more aware of potential conflicts than other motorists. However, at busway intersections, motorists on the crossing streets, although licensed, have no professional training and may be unfamiliar with the surrounding environment. These motorists should be considered as the controlling intersection design drivers.

Design Vehicle

The design vehicle is the largest vehicle expected at the intersection, with reasonable frequency, during the design year. At intersections of state highways and city streets that serve buses with relatively few large trucks, a city transit bus or intercity bus may be used as the design vehicle, depending on local circumstances.

Turning radii of design vehicles are important in designing corner radii, channelizing islands, and turning roadways.

Table 4-3. Design vehicle dimensions for select vehicles.

Type	Symbol	Height (ft)	Width (ft)	Length (ft)	Minimum Turning Radius Inside (ft)	Minimum Turning Radius Design (ft)
Passenger Car	P	4.25	7.0	19.0	14.4	24.0
Single Unit Truck	SU	11-13.5	8.0	30.0	28.3	42.0
Intercity Bus	BUS-40	12.0	8.5	40.0[(A)]	27.6	45.0
Intercity Bus	BUS-45	12.0	8.5	45.0[(A)]	25.5	45.0
City Transit Bus	CITY-BUS	10.5	8.5	40.0[(A)]	24.5	42.0
Conventional School Bus	S-BUS 36	10.5	8.0	35.8	23.8	38.9
Large School Bus	S-BUS 40	10.5	8.0	40.0	25.4	39.4
Articulated Bus	A-BUS	11.0	8.5	60.0[(A)]	21.3	39.8
Intermediate Semitrailer	WB-40	13.5	8.0	45.5	19.3	40.0
Intermediate Semitrailer	WB-50	13.5	8.5	55.0	17.0	45.0
Motor Home and Boat Trailer	MHB	12.0	8.0	53.0	35.1	50.0

(A) Add 1.5 feet in length where buses are equipped with bicycle racks.
Source: *A Policy on Geometric Design* (*1*).

Table 4-4. Design characteristics for 40-, 45-, and 60-foot buses.

Characteristic	40-ft Regular Bus	45-ft Regular Bus	60-ft Articulated Bus
Length	40 ft	45 ft	60 ft
Width without mirror	8.2-8.5 ft (A)	8.5 ft (A)	8.5 ft (A)
Height (to top of air conditioning) for design	9.9-11.5 ft (B)	12.5 ft (C)	11 ft (B)
Overhang			
Front	7.2 ft	7.9 ft	8.8-8.9 ft
Rear	9.3 ft	9.8 ft	8.6-9.7 ft
Wheelbase (rear)	25 ft	22.9 ft	23.3-24.5 ft
Driver's Eye Height	7 ft (C)	7 ft (C)	7 ft (C)
Weight			
Curb Weight	27,000-28,200 lbs	38,150 lbs	38,000 lbs
Gross Weight	36,900-40,000 lbs	55,200 lbs	66,600 lbs
Ground to Floor Height	2.3 ft	2.3 ft	2.3 ft
Passenger Capacity			
Seats	45-50	50	76
Standees (Crush Load)	20	28	38
Turning Radius			
Inside	24.5-30 ft	24.5-30 ft	27.3 ft
Outside (D)	42-47 ft	42-47 ft	39.8-42 ft
Outside with Overhang	45.5-51 ft	45.5-51 ft	44.3 ft
Doors - Number (typical)	2	2	2-3
Width of each door	2.3-5 ft	2.5-5 ft	2.5-5 ft
Angles (degrees)			
Approach	10°	10°	10°
Breakover	10°	10°	10°
Departure	9.5°	9.5°	9.5°

(A) With mirrors envelope becomes 10 to 10.5 feet.
(B) Use 16 feet as minimum governing design clearance.
(C) Use 3.5 feet design.
(D) Add 1.5 feet where buses are equipped with bicycle racks.
Exact dimensions may vary by bus manufacturer.
Source: TCRP Project D-09 Phase II Draft Guide (*7*).

AASHTO publishes templates that delineate minimum turning radii and suggest paths for each design vehicle. These templates should be used to check the provision of adequate maneuvering space.

Bus turns into and out of the busway will depend upon specific service design features. There may be circumstances where buses need to enter and leave busways at intersections, and suitable provisions should be made for these movements. However, the number of such locations should be kept to a minimum as discussed in Chapter 3. In addition, some intersections should be designated for emergency turning movements. The Los Angeles Department of Transportation designated a few key intersections where operators can make turns to leave the busway in emergency situations.

Design Year

Designs for new transit and highway facilities are normally based on a minimum 20-year time horizon. However, roadway and intersection design improvements should have at least a 10-year horizon. Operational improvements, such as bus lanes or traffic signal changes, should have at least a 2- to 5-year horizon. Designs also should be assessed for "base year" conditions—conditions for the year that the intersection improvements and busway are placed in service.

Design Volumes

The design hourly volume (DHV) is the projected volume that is used for design. DHV is typically expressed as a percentage of the expected average daily traffic. The 30th highest hour of the year is traditionally used for design.

However, in urban and suburban areas, the morning and evening peak hours provide a sound basis for establishing intersection requirements and assessing intersection operations. Volume should be obtained by 15-minute intervals, for each intersection movement, for each type of vehicle.

Design Speed

Roadway and busway intersections and alignment features depend upon the designated design speed, i.e., the speed selected to establish the geometric features of the roadway. Design speed depends upon the functional class of the roadway, topography, and land use. It ranges from 20 to 70 mph in 10-mph increments.

Design speeds for busways generally range from 40 to 50 mph, although lower speeds may be necessary in constrained environments. Arterial street and roadway speeds usually fall in this range, but may be as low as 30 mph in some situations.

Capacity Considerations

Busway intersections should provide sufficient roadway, walkway, and station capacities to serve anticipated demands and operate at reasonable levels of service. Detailed computational procedures and guidelines are set forth in the *Highway Capacity Manual (8)* and the *Transit Capacity and Quality of Service Manual (9)*. Both manuals base their analyses on peak 15-minute flow rates expressed in vehicles (or people) per hour. Both state that operating at maximum capacities results in long delays and poor reliability.

Intersection Capacity

The capacity of each intersection approach depends upon (1) the number and efficiency of each moving travel lane; (2) the nature and extent of interferences such as signal timing, cross-street requirements and left-turn conflicts with opposing traffic; and (3) the headways (or saturation flows) that reflect traffic composition and grades. Because each lane may perform differently, computations are best done on a lane-by-lane basis.

Intersection Levels of Service

Signalized intersection performance should be assessed in terms of the control delay that results from the red signal times and queues of traffic. This control delay depends upon the volume (demand) to capacity ratio and the red time per cycle. Levels of service (LOS) are measured in the amount of control delay and range from LOS A (less than 10 seconds per vehicle) up to LOS F (more than 80 seconds per vehicle). LOS C and D are the desired maximum service levels for urban and suburban conditions (up to 55 seconds per vehicle). A maximum volume to capacity ratio of 0.85 is also suggested as the upper limit of system adequacy.

Transit Capacity

Quality of service for transit passengers is defined as the overall measures or perceived performance of a transit service from the passenger's point of view. It reflects what a potential passenger considers when deciding whether to use transit. The considerations include (1) whether transit service is available, and, (2) if available, how transit will compare with competing modes. Table 4-5 provides the framework for defining fixed-route and demand-responsive quality of service ratings.

The actual passenger capacity of a transit route or stop depends upon the number of vehicles that can be processed and the number of people that can be served. It is measured along the way and at stops, terminals, and junctions near stations (i.e., the critical locations that govern capacity). The highest achievable minimum headway along a route governs the number of transit vehicles or units that can be processed. Busway stops and stations normally govern the number of buses that can be accommodated along a busway.

Typically, the passenger demand during the peak 15 minutes at the maximum load section establishes the service frequency for a given loading standard. Then, whether this service frequency can be processed through the busiest points of passenger activity along the line needs to be determined.

From a busway intersection perspective, it is essential to provide enough berths (loading positions) at each stop and to provide passing capabilities at stops or stations where space permits. Detailed computational procedures are contained in the *Transit Capacity and Quality of Service Manual* (*9*).

Table 4-5. Transit quality of service framework.

Transit Service	Transit Stop	Route Segment	System
Fixed-Route Measures			
Availability	Frequency	Hours of Service	Service Coverage
Comfort and Convenience	Passenger Load	Reliability	Transit vs. Automobile Travel Time
Demand-Responsive Measures			
Availability	Response Time	Span of Service	
Comfort and Convenience	On-Time Performance	Trips Not Served	Transit vs. Automobile Travel Time

Source: *Transit Capacity and Quality of Service Manual* (*9*).

Table 4-6. Pedestrian levels of service on walkways.

LOS	Space per Person (ft^2)	Average Speed (ft/min)	Flow per Unit Width (p/ft/min)	Volume/ Capacity
A	≥35	260	0–7	0.0–0.3
B	25–35	250	7–10	0.3–0.4
C	15–25	240	10–15	0.4–0.6
D	10–15	225	15–20	0.6–0.8
E	5–10	150	20–25	0.8–1.0
F	< 5	<150	Variable	Variable

Source: Adapted from *Transit Capacity and Quality of Service Manual* (*9*).

A general guide is to provide at least two berths for each direction at busway stations.

Pedestrian Capacity Levels

Pedestrian service levels and capacities are key inputs into designing bus stops/stations, walkways, stairways leading to and from stations, and general pedestrian movements in the station and intersection influence areas.

Service levels for pedestrians using walkways are shown in Table 4-6. This table provides the speeds and flows for various units of effective sidewalk width. The maximum capacity given in the *Transit Capacity and Quality of Service Manual* (*9*) is 25 pedestrians per foot per minute (p/ft/min). However, few sidewalks in the United States and Canada have rates that exceed 15 pedestrians per foot per minute. All rates are based on the clear or effective width after deducting for obstructions.

CHAPTER 5

Traffic Control Devices

Traffic control devices are essential complements to the design and operations of busway intersections. They assign right-of-way to conflicting movements of buses, motor vehicles, pedestrians, and bicyclists; specify permitted and prohibited movements; and provide other necessary information and guidance. They include traffic signals, active and passive signs, pavement markings, and gates. This chapter is based primarily on the MUTCD (*10*).

Intersection Control

General Considerations

At-grade busway crossings can be classified as signalized, stop-controlled, yield-controlled, or uncontrolled intersections. Most busway intersections in North America are signal controlled for all users at the intersection. However, there are a few stop-controlled intersections, including some intersections along the South Miami-Dade busway, and a few uncontrolled midblock pedestrian crossings.

Signalization is the preferred method of control for busway intersections because it provides clear right-of-way assignment. However, for some intersections, particularly separated right-of-way busway intersections, signalization may not be warranted. The relatively low volume of buses on the busway may not be sufficient to warrant signalization based on Section 4C.01 of MUTCD. Although buses generally have a higher occupancy than motor vehicles, signalization warrants are currently based on the number of vehicles, not the number of persons. A person-based warrant has been proposed to the National Committee on Uniform Traffic Control Devices (NCUTCD) for this and similar situations; however, it has not yet been accepted into the MUTCD. The development of a person-based warrant is desirable for busway intersections and should be considered further.

In conducting the engineering study to determine if a signal is warranted, pedestrian volumes at the intersection and their increase once the busway is completed should be considered.

Stop-Controlled Busway Intersections

If an intersection cannot be signalized, stopping cross-street traffic is preferred in the interest of busway operations. The type of stop control (i.e., two way or four way) depends on the volume of the intersection, the available gaps, and station placement. In most cases, stopping the cross-street traffic without stopping the busway traffic is not practical because the cross-street volumes are likely much higher than the busway volumes. Conversely, because of the length and driving characteristics of most busway vehicles, finding an acceptable gap in the cross-street traffic may be difficult for bus operators at intersections where only busway traffic is stop controlled. Therefore, four-way-stop control may be necessary.

Separated right-of-way busway intersections may lack some of the visual cues of an intersection including the presence of cross-street traffic. At these intersections, care must be taken to ensure that the intersection control is communicated to the users and that the intersection is clearly identified. Supplementary traffic control devices such as flashing beacons, transverse rumble strips, advance Stop Ahead signs, or Stop Ahead pavement markings may be necessary.

Because the operating characteristics of a bus on a busway are comparable to light rail operation, Section 10C.04 of the MUTCD, which provides guidance for the use of stop control at light rail crossings, should be reviewed when selecting the appropriate intersection control for busways. Notably, this section provides guidance that stop control be used when light rail transit speeds do not exceed 40 km/h (25 mph).

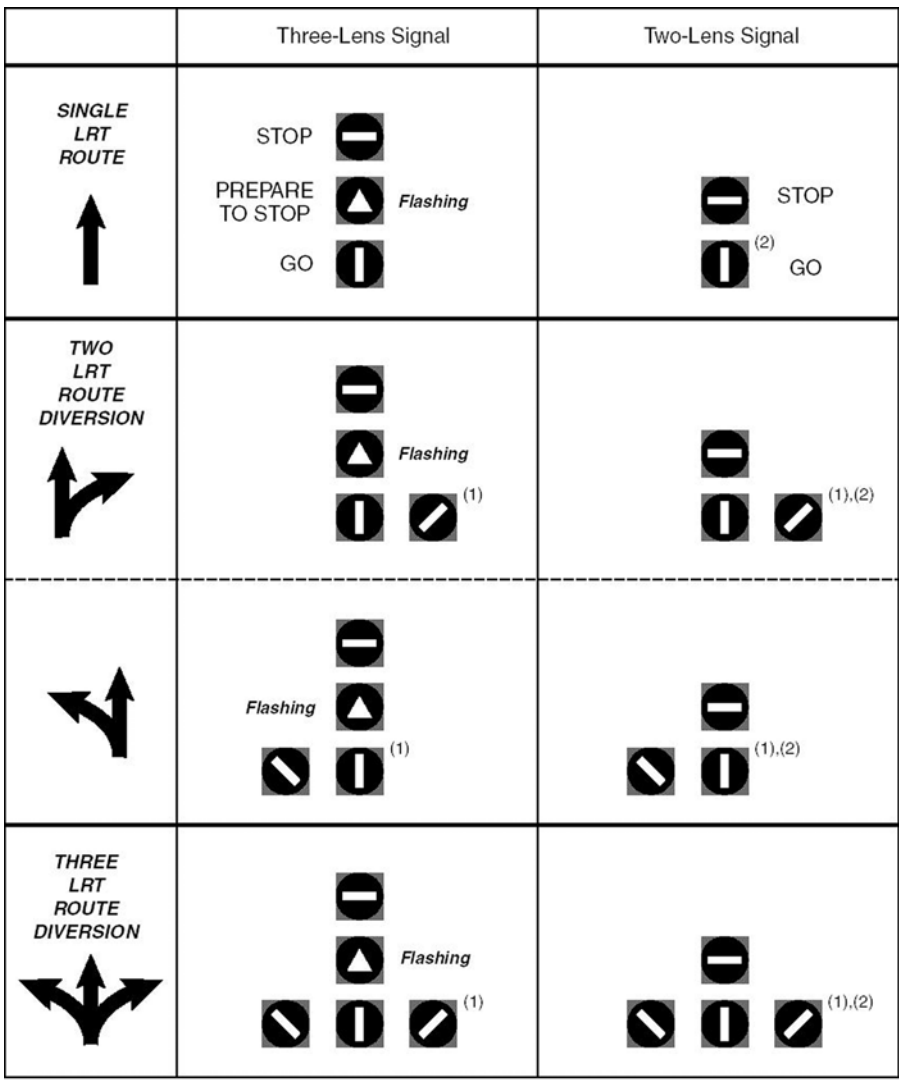
Signal-Controlled Busway Intersections

Currently two types of traffic signals are used to control buses at busway intersections: standard vehicle signals and light rail transit signals. Light rail transit signals are the preferred type of control for the buses on the busway, although some agencies use standard vehicle signals. Engineering judgment that considers the surrounding environment should be used to select the appropriate signal display.

The South Miami-Dade Busway is an example of a busway that uses standard vehicle signals to control buses at the intersections. Buses approaching the intersection are controlled by the same standard red-yellow-green signals that are used for general vehicle traffic. The agencies who use this type of signal note that, because buses are also vehicles, the signal for the buses should be a standard signal.

If standard traffic signals are used, care should be taken to ensure that the bus signal indications are not visible by other movements. If other movements can see the bus signal indication, they may mistake the bus indication for their own. This potential is particularly a concern for median busway intersections and side-aligned busway intersections. For example, at median intersections, if left-turning vehicles on the parallel roadway mistake the busway green for their own, they may turn across the path of an approaching bus. The Richmond 98 B-Line, which uses standard signals for bus control, experienced a problem with left-turning vehicles when the system first opened. To mitigate this safety concern, the signals were changed to programmable signals so that the parallel general traffic could not see the bus signal indication.

Guidance for the use of light rail signals to control light rail transit vehicles can be found in Section 10D.07 of the MUTCD. The light rail signal indications, which are illuminated white bars, are displayed in Figure 5-1. These signals are subsequently referred to as white bar signals to avoid confusion with light rail applications.



Notes:
All aspects (or signal indications) are white.
(1) Could be in single housing.
(2) "Go" lens may be used in flashing mode to indicate "prepare to stop".
Source: MUTCD Section 10D.07 (*10*).

Figure 5-1. Light rail transit signal indications.

The Orlando Lynx LYMMO system is an example of a busway that uses white bar signals for the busway intersections. An example of a bus signal in Orlando's system is provided in Figure 5-2.

If white bar signals are used, all bus operators who will travel on the busway need training in the meaning of the signal indications. If an operator has not driven the route recently, he or she may need a refresher course in the signal indications. Training also may be needed for others who may use the busway, for example, emergency or maintenance vehicle drivers. Additionally, because pedestrians often take their cue from vehicle signals when pedestrian signals are not present at an intersection, all intersections should be equipped with functioning pedestrian signals.

The following questions should be considered when selecting the type of traffic signal to use at busway intersections:

- Will other users (e.g., maintenance vehicles) of the busway have to interpret the signal indication?
- Can the signal indications be viewed by other users at the intersection, particularly at night or in high-wind conditions when programmable visibility signals may become misaligned?
- Is there a benefit to having wayward motorists or other unauthorized users be able to interpret the signal indication to ensure a safe exit from the busway?
- Does the use of white bar signals help to differentiate the busway from other lanes at the intersection?

Intersection traffic control for general-purpose traffic at busway intersections is the same as non-busway intersections. Additional traffic controls may be installed to prohibit certain movements at busway intersections. Such controls may include dynamic right- or left-turn prohibition (e.g., bus-activated, internally illuminated signs).

Figure 5-2. Orlando LYMMO's bus signal.

Pedestrian and other non-motorized users should be controlled by pedestrian signals, particularly if white bar signals are used as previously discussed. Pedestrian countdown displays may be useful on pedestrian signal controls. These displays count down the number of seconds remaining in the pedestrian change interval. Countdown signals are particularly beneficial at median busway intersections where transit passengers depart the intersection from a median station and may not need the entire pedestrian clearance interval to cross the remaining half of the intersection.

Static and Active Signs

Signs are used to convey various types of information to all users at busway intersections. Signs can be used to

- Deter unauthorized entry,
- Provide advance warning of the busway crossing,
- Warn of approaching buses,
- Identify the busway,
- Deter vehicles from queuing over the busway,
- Prohibit certain movements at the intersection, and
- Identify the appropriate traffic signal head to the associated movement.

These regulatory, informational, and warning messages are primarily communicated to intersection users with static signs. Active signs also can be helpful when it is especially important to attract the attention of motorists and pedestrians.

Because of the additional information that needs to be conveyed at busway intersections, more signs are needed than at traditional intersections. Care should be taken to avoid visual clutter, which contributes to motorist confusion, at busway intersections.

Deterring Unauthorized Entry

At the entrances to the busway for all three major types of intersections (i.e., median, side-aligned, and separated) and bus-only ramps, a Do Not Enter (MUTCD designation R5-1) sign should be used on the right-hand side of the busway to deter unauthorized entry. The MUTCD allows for a second Do Not Enter sign on the left side of the busway, particularly where traffic approaches from an intersecting roadway. The sign should be supplemented with a Transit Vehicles Exempt plaque. Some agencies have used additional signs to indicate which vehicles are authorized on the busway. A simple supplementary plaque accomplishes the objective of precluding transit vehicles from the Do Not Enter sign with the least amount of visual clutter.

At separate-alignment intersections or at some closely spaced side-aligned intersections, turn prohibition signs are appropriate including No Turns (R3-3), No Right Turn (R3-1), and No Left Turn (R3-2). Internally illuminated signs may also be appropriate when turn prohibitions are conditional based on an approaching bus or during a certain signal phase.

Some agencies also use signs that display information about the penalties associated with unauthorized entry to the busway and No Motor Vehicles signs (R5-3). The use of these signs should be considered in relation to the amount of visual clutter at the intersection. Additionally, transit vehicles are motor vehicles. To provide a clear, concise message to drivers, No Motor Vehicles signs should be placed elsewhere and should not be used at busway intersections.

Warning Signs

Advance warning signs that identify the presence of the busway intersection are useful at separated busway intersections and at some closely spaced, side-aligned intersections. They are not needed at median arterial busway intersections.

Currently, the MUTCD has not defined an advance warning sign for busway crossings. Therefore, a few agencies have developed their own advance warning signs. The Los Angeles Department of Transportation (LADOT) developed a standard diamond-shaped, yellow advance busway crossing sign. This sign is displayed in Figure 5-3. The bus graphic on the sign is based on the outline of the Orange Line buses.

The Florida Department of Transportation has also developed a similar sign based on the South Miami-Dade buses.

At separated busway intersections, advance traffic control signs may be necessary to warn of the upcoming traffic control device. These signs include the Stop Ahead (W3-1), Yield Ahead (W3-2), and Signal Ahead (W3-3) signs. A warning beacon may be used with these signs to emphasize the message. At signalized intersections, a Be Prepared to Stop (W3-4)

Figure 5-3. LADOT advance busway warning sign used at Orange Line intersections.

sign may be useful if sight distance is limited, particularly if supplemented by a warning beacon that is interconnected with the traffic control signal. If it is interconnected, the supplementary plaque When Flashing should be used.

Busway Street Name Signing

The busway should have a sign or symbol that clearly identifies the busway intersection. Such a sign is particularly important for independent intersections or closely spaced, side-aligned intersections where conspicuity of the crossing is a concern. Based on the experiences of the busway operators surveyed, the sign could employ the same color and design as other road or street name signs in the area, although a larger sign may be desirable for increased visibility. Using similar color and design helps to reinforce the busway intersection as a legitimate intersection, deserving the same respect as other intersections. Another school of thought is to use a busway sign or symbol that is not the same in color and design as other road or street name signs. The reasoning for using a non-standard sign is to identify the busway intersection as a different type of intersection. Agencies may want to consider a non-standard sign if there is a large concern with vehicles accidentally turning into the busway. In selecting the type of street name sign that is used, the agency should consider the unique characteristics of the intersection, the collective set of traffic control devices and other visual cues at the intersection, and the potential for various unsafe maneuvers by intersection users.

Right Turn on Red Prohibition

Prohibiting right turns on red across the busway is critical to safe operation of side-aligned busway intersections. Vehicles that violate the right turn prohibition may conflict with approaching buses. The right turn prohibition must be clearly communicated to the motorists.

Right turns can be prohibited with a graphical No Turn on Red (R10-11) or a non-graphical sign (R10-11a or R10-11b). The sign should be installed near the appropriate signal head. In situations where the busway phase is concurrent with the parallel through-traffic phase, a separate signal head and separate lane is needed for the right turn.

TCRP Report 90: Bus Rapid Transit (*11*) adapted three signs from the MUTCD that may be useful for busway intersections to supplement other traffic control devices aimed at deterring right turns on red. The signs have been modified to depict parallel busways intersecting with cross-street traffic. These proposed warning signs are pictured in Figure 5-4.

Traffic Signal Identification

Signs to identify the traffic signals associated with certain movements at the intersection may be necessary. Left Turn

Source: *TCRP Report 90,* Volume 2 (*11*).

Figure 5-4. Three proposed traffic signs for busway intersections based on light rail signs.

Signal signs (R-10L) are useful at median busway intersections for the left-turn movements across the busway from the general-purpose lanes. Right Turn Signal signs (R-10R) are useful for right turns from parallel roadways at side-aligned busway intersections. At median arterial intersections, the busway signal also may need to be identified with a Bus Signal sign. An example of a bus signal sign at an Orange Line intersection in Los Angeles is presented in Figure 5-5.

Signs Directed at Pedestrians, Bicyclists, and Other Non-Motorized Users

The signs directed at non-motorized users that deter pedestrians from crossing at inappropriate locations, identify designated crossing locations, and provide information on the use of pedestrian push buttons (e.g., R9-3a, R9-3, and R10-3b) are the same at busway intersections as at traditional intersections.

The LADOT developed a special warning sign for use at pedestrian midblock crossings of busways. The approaching-bus pedestrian warning sign, the same size and shape as the pedestrian signal, is mounted adjacent to the pedestrian signal. It is presented in Figure 5-6. An LED (light-emitting diode) indication of the front of a bus flashes when a bus is approaching the crossing. The effectiveness of this device is unknown; however, one author expressed concern that pedestrians may confuse the flashing bus sign with the flashing raised hand of the pedestrian signal. A steady bus indica-

Figure 5-5. Bus signal sign mounted next to bus signal at intersection of Orange Line busway, Los Angeles.

Figure 5-6. Bus-activated warning sign (black with orange symbol) for pedestrian midblock crossings of Orange Line busway, Los Angeles.

tion, or a sign that flashes and then becomes steady, may be more appropriate.

Pavement Markings

Pavement markings with the words "BUS ONLY" should be used at the entrance to the exclusive busway (Figure 5-7). This marking will help to deter unauthorized entry into the busway as a supplement to signs. Some agencies in North America use other, similar messages on the pavement to identify the busway lanes; however, the words "BUS ONLY" convey the message in a simple and concise manner.

It may be beneficial to use pavement markings in the actual intersection to deter vehicles from queuing over the busway intersections. Such queuing is particularly a concern at side-aligned intersections. Some intersections along the Orange Line busway in Los Angeles have pavement markings with the words "KEEP CLEAR." Cross-hatching in the intersection may produce the same effect.

As noted previously, median arterial busway intersections are wider than traditional intersections. In such intersections, pavement markings can be used to guide left-turning motorists through their turns, will help to keep them from turning into the busway.

Cleveland plans to use raised, red pavement reflectors to deter motorists from turning left into their median busway from the cross streets. The reflectors will be placed on a 45-degree diagonal across the entrance to the busway. Motorists turning left will see the red indication of the reflectors during their turn. This application of pavement reflectors is potentially useful for other median arterial busway intersections.

Figure 5-7. "BUS ONLY" pavement markings at LYMMO intersection, Orlando, Florida.

Other Traffic Control Devices

Automatic Gating Considerations

Automatic crossing gates such as those used at some light rail transit (LRT) at-grade crossings have been discussed as a potential traffic control device to separate conflicting movements at busway intersections. Crossing gates are currently not used at busway intersections in North America.

Section 10D.03 of the MUTCD provides guidance that, on highway-LRT at-grade crossings, automatic crossing gates should be used together with flashing-light signals where light rail vehicle speeds exceed 60 km/h (35 mph). If used for busway intersections, gates would be placed across the path of cross-street traffic in advance of the busway intersection to physically deter entry into the intersection during the busway phase at separated or some side-aligned intersections. Crossing gates are not practical for cross-street traffic at median arterial intersections.

Issues to be considered regarding the use of crossing gates include efficiency, placement, liability, maintenance costs, consistency in use, and motorist and pedestrian compliance. Crossing gates will reduce the overall efficiency of the intersection. The time required to raise and lower the gates adds lost-time to the cycle length at signalized intersection and increases intersection delay at both signalized and unsignalized intersections.

For some busway intersection alignments, the placement of crossing gates would not be useful. For example, the cross-street traffic entering the median busway intersection does not need further deterrent than that provided by parallel traffic at traditional intersections because the busway operates in the median of the general-purpose lanes. At side-aligned busway intersections, right-turning vehicles from the parallel mainline is the primary concern rather than cross-street traffic, which crossing gates control.

The following concerns regarding automatic gates were expressed by the agencies interviewed:

- Liability for damages could arise from the failure of the automatic gates.
- If the gates were used at one intersection, they would need to be used at all intersections.
- The cost to install and maintain these devices would be prohibitive.
- Pedestrians and some motorists may not comply with the gates if they were used for a busway instead of a light rail crossing.

Agencies may be held liable for any damages that arise from the failure of automatic gates. If crossing gates are used at one intersection, they may need to be used al all intersections. The cost to install and maintain these devices would be prohibitive. Also, pedestrians and some motorists may not comply with the gates if they are used for a busway instead of a light rail crossing.

Gates may be appropriate at bus-only ramps to deter unauthorized entry. This application is different from the crossing gate applications that would prevent vehicles from traveling across the busway. Instead, the gates would be placed at the entrance to the ramp and would remain down until an approaching bus activates them and would close shortly after the bus enters.

In summary, automatic gates diminish the efficiency of intersection operations and may be a liability or maintenance issue. They may be applicable at bus-only ramp entrances where there are intrusion issues. Their application should be evaluated on a case-by-case basis.

Colored Pavement

Colored pavement may be an effective traffic control device to deter unauthorized entry into busways and increase the visibility of busway intersections. Many busway agencies in North America indicated they would like to use colored pavement but cited cost as the leading reason it was not used.

Some busway agencies used other methods to differentiate the busway pavement from the side or cross-street pavement. The Orlando LYMMO system uses a distinctive gray, textured pavement to differentiate the bus lanes. The Los Angeles Orange Line has installed concrete pavement at intersections. The contrast in color from the concrete of the intersection and the asphalt concrete of the travel lanes increases the visibility of the busway intersections. Although not a busway, the San Francisco LRT uses red pavement for the first 50 feet on a median alignment. The rest is standard concrete.

Summary

Table 5-1 presents suggested traffic control devices by type of busway intersections. Additional traffic control devices that may be useful are presented in italics.

Table 5-1. Suggested traffic control devices at busway intersections by type of busway.

Purpose of Traffic Control Device	Median Busways	Separate Right-of-Way Busways	Side-Aligned Busways	Bus-Only Ramps
Control Basic Movements	White bar signals	Standard or white bar signals	White bar signals	Uncontrolled
Prohibit Unauthorized Entry	Dual Do Not Enter (R5-1) signs with supplementary Transit Vehicles Exempt plaque Bus Only pavement markings *Diagonal red reflectors* *Keep Clear sign or similar in intersection*	Dual Do Not Enter (R5-1) signs with supplementary Transit Vehicles Exempt plaque Bus Only pavement markings No Turns (R3-3) sign No Right Turn (R3-1) sign No Left Turn (R3-2) sign *Keep Clear sign or similar in intersection*	Dual Do Not Enter (R5-1) signs with supplementary Transit Vehicles Exempt plaque Bus Only pavement markings No Turns (R3-3) sign No Right Turn (R3-1) sign No Left Turn (R3-2) sign *Keep Clear sign or similar in intersection*	Dual Do Not Enter (R5-1) signs with supplementary Transit Vehicles Exempt plaque Bus Only pavement markings
Warning	N/A	Advance Busway Crossing Sign (undesignated)	Advance Busway Crossing Sign (undesignated)	N/A
Identify Intersection	*Color or textured pavement*	"Busway" using standard street signing convention *Color or textured pavement*	"Busway" using standard street signing convention *Color or textured pavement*	*Color or textured pavement*
Prohibit Right Turn on Red	N/A	N/A	No Turn on Red (R10-11 or R10-11a) sign *Modified LRT (W10-2b) signs* *Modified LRT blank-out (R3-1a) sign*	N/A
Identify Traffic Signal (if used)	Bus Signal sign Left Turn Signal (R-10L) sign if arrow is not used	N/A	Right Turn Signal (R-10R) sign if arrow is not used	N/A

CHAPTER 6

Operational Practices

This chapter presents general considerations for operating signalized, at-grade crossings of exclusive busways. It is closely related to the chapter on traffic control devices.

Signal Placement and Positioning

The MUTCD, Section 4D, provides guidance for the placement and positioning of traffic signals at traditional intersections (*10*). Additional guidance is provided in Chapter 13 of the *Traffic Engineering Handbook* (*2*) and in the *Traffic Control Devices Handbook* (*12*) and is not repeated here. Instead, this section presents additional considerations for busway intersections given their unique design and particular safety issues. As a general rule, the placement of traffic signal displays should be consistent from intersection to intersection, to improve driver and pedestrian expectancy.

Median Busway Intersections

The primary signal placement concern at busway intersections is the placement and positioning of the busway signal in relation to the same-direction, parallel-street traffic signals so that motorists do not confuse the busway signals with their own. This concern is particularly important for left-turning motorists. Separating the bus signal horizontally or vertically (where practical) from the left-turn signal can help to avoid confusion with the signals. Chapter 5, Traffic Control Devices, identified some options for this including the use of white bar signal indications. White bar signals provide a distinct message that motorists are not trained to understand. Other possibilities include programmable visibility lenses, louvers, or visors. Of these methods, white bar signals are the most desirable. The MUTCD recommends using signal visors in lieu of signal louvers. As a result, signal louvers are not discussed here.

Programmable visibility lenses, also called visibility-limited signals, limit the field of view of a signal (*13*). They allow greater definition and accuracy of the field of view than louvers. They are particularly well suited for lateral (horizontal) separation. In this case, the lateral separation is between the busway signal and the left-turn lane. Programmable lenses must be clearly targeted at the intended lane and should only be used with rigid mountings such as a mast arm or pole. Regular in-field maintenance should be conducted to ensure the alignment of the signal. Some agencies using visibility-limited signals at busway intersections have received complaints from motorists that note the signals in the parallel lane are malfunctioning.

Visors are used to improve the visibility of signals in direct sunlight by providing additional contrast between the signal lens and the background. The MUTCD requires their use when the angle between intersection roadways is relatively small. However, the signal indications can likely still be viewed by parallel directions of travel as in the case of median busway intersections.

As part of the case study visits, agencies were asked if positioning the busway signals in another location would help to separate their view from motorists. All studied agencies preferred to have the busway signals directly over the center of the busway lane.

Side-Aligned Busway Intersections

As with median busway intersections, limiting the view of busway signals from the same-direction, parallel traffic is a safety concern at side-aligned busway intersections and the same countermeasures are appropriate. At side-aligned busway intersections, the primary concern is right-turning vehicles from the parallel street.

Another concern at side-aligned busway intersections is the spacing of the intersection of the cross street and the busway and the cross street and the parallel street. Depending on the spacing, two sets of signals, operating from one controller, are likely needed for the cross street. Cross-street motorists may be looking downstream at the parallel roadway signal and may not see the busway signal. The distance between these two signals is the longitudinal separation or the distance separation. Programmable signals are useful in limiting the longitudinal visibility and can be used in this scenario. As with separated right-of-way intersections, larger signal heads and back plates can increase the visibility of these intersections.

Separated Right-of-Way Intersections

As previously discussed, the primary safety concern at separated right-of-way busway intersections are signal violations by vehicles on the cross-street approach. Therefore, traffic signals for the cross-street traffic should be designed for greatest visibility and conspicuity.

Signal heads placed in accordance with the MUTCD should be visible to all motorists approaching the intersection. Although the MUTCD requires a minimum of two signal faces be provided for the major movement on an approach, placing one signal head over each lane for multilane roadways will improve their visibility. When a signal head is positioned over the middle of a lane, it is in the center of the motorist's cone of vision, thereby increasing its visibility. The additional signal head further increases the likelihood that a motorist will see the signal display for the approach.

The MUTCD does not require that signals be placed overhead rather than mounted on poles. However, overhead-signal displays generally provide better conspicuity and are in the motorists' direct line of sight. The view of pole-mounted signals is more likely to be occluded by another vehicle approaching the intersection. Pole-mounted signals may be useful as supplements to the overhead signals, particularly if there are concerns about sight distance.

Another method to increase the visibility of traffic signals is to install 12-inch signal lenses instead of 8-inch signal lenses, a 125% increase in the area of the signal face. Measures also may be needed to prevent sun glare.

Conspicuity of the traffic signal is another consideration. Two methods that are applicable at separated right-of-way busway intersections are back plates on the signal heads and the use of LED lenses. Back plates improve the conspicuity of the signal by providing a black background around the signals, thereby enhancing the contrast. LED units are brighter than incandescent bulbs. They also are very energy efficient and have a longer life, increasing the replacement interval (*13*).

Left- and Right-Turn Treatments

Treatments for turning motor vehicles are a concern at median busway intersections and at side-aligned busway intersections. At separated right-of-way intersections, no turns are made by general traffic; therefore, this section does not address separated right-of-way intersections.

Left Turns from the Parallel Street

Left turns by motorists from the parallel roadway, across busway intersections, should always be protected, without exception. The optimal phasing for the protected left turn whether before the parallel through-vehicle phase (leading) or after (lagging) is disputable. The concern for a leading left-turn phase is that vehicles may attempt to make a left turn at the end of the protected phase, in essence trying to "beat the signal," and turn into the path of an oncoming bus. However, a concern for a lagging phase is that left-turning motorists may move in response to the moving of parallel through traffic. The most recent study of the effect of leading versus lagging left-turn phasing on crashes, although not in relation to busways, found that phasing should be based on considerations other than left-turn head-on crash potential (*14*). A TCRP study on the integration of light rail signals into city streets found that motorists violated red left-turn arrow indications in left-turn lanes parallel to light rail when the leading left-turn signal phase was preempted by an approaching light rail vehicle (*15*). Although the median busway intersections along the 98 B-Line in Richmond, British Columbia, have leading left-turn phasing, violations of red left-turn arrow indications have not been found to be a problem; however, the 98 B-Line does not preempt signal phases. Similarly, no problems have been found to date on the Orange Line in Los Angeles, which uses leading left-turn phasing at the median busway intersections.

Left Turns from the Cross Street

Left turns from the cross street can be protected, permitted, or protected-permitted depending on the characteristics of the intersection and the signal phasing employed. If the cross street has high opposing volumes and the available gaps for a left turn are limited, protected-only phasing should be used to avoid left-turn queues backing up over the busway at the end of the cross-street phase. Another option is to use split phasing for the cross-street movements.

Left-Turn Prohibition

Sometimes, it may be necessary to prohibit left turns at median busway intersections or left turns from the parallel street of side-aligned busway intersections. Reasons for prohibiting left-turning movements include

- Median intersection design does not have adequate room to accommodate turning radius;
- Intersection right-of-way is not sufficient to provide a dedicated left-turn lane;

- The signal cycle does not have sufficient time to allow a left-turn phase and accommodate all of the traffic demands at the intersection; and
- Left-turning vehicles queue over the busway because of downstream traffic congestion.

If left turns are prohibited, a green through-arrow signal should be used for the through signal indications, particularly for the signal on the left lane. The intersections also should use appropriate turn-prohibition signs as discussed in Chapter 5 and should prohibit U-turns.

If left turns at the intersection are a concern for either safety or operations, other options are available for providing the left turns away from the intersection. Unconventional intersection designs such as jughandles and median U-turns can be used. Figure 6-1 illustrates the vehicle movements at a jughandle intersection.

One-way street networks for cross-street traffic also will reduce the turn movements at intersections and thereby reduce the number of conflicts at each intersection.

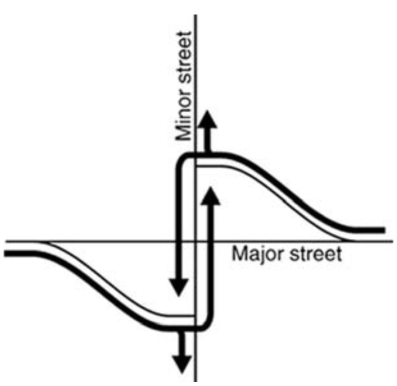
If left turns are prohibited altogether at the intersection, both left turns and U-turns may need to be allowed at downstream intersections to compensate for this prohibition. In essence, prohibiting the left turns at one intersection may shift the problem to another intersection.

Generally, left turns should not be prohibited entirely along a busway corridor. Motorists will seek out other methods to accomplish their turns that may include violating the prohibitions, which will cause a severe safety problem.

Right-Turn Prohibition

At some side-aligned busway intersections, right turns from the parallel street may need to be prohibited, particularly if the right-turn-on-red prohibition is often violated or if there is not sufficient room for a right-turn-only lane.

As with the left-turn prohibition, a green through arrow should be used for the through signal indications, particularly for the signal head on the right side of the approach. The appropriate turn-prohibition signs should also be used as discussed in Chapter 5.



Source: *Signalized Intersections* (*3*).

Figure 6-1. Vehicle movements at a jughandle intersection.

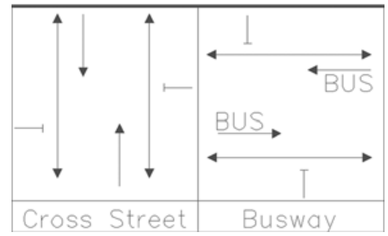


Figure 6-2. Two-phase signal phasing for separated right-of-way busway intersections.

Signal Operation

Phasing

Example signal phasing plans are provided in this section. These phases are only intended to be examples as the unique geometry, traffic volumes, bus volumes, and pedestrian and bicycle volumes should be considered for each intersection.

An example of a basic signal phasing for a separated right-of-way busway intersection is displayed in Figure 6-2. A very simple signal phasing is used. A separated right-of-way intersection generally only has two phases: the cross-street phase and the busway phase. In most cases, no turns are allowed at the intersection so additional phases are not needed. If the intersection is used as an exit point from the busway, the bus operators could make permissive turns during the busway phase without adding any phases. If the intersection is used as an entry point to the busway, an additional bus-only turning phase would be added.

An example of a signal phasing for a median busway intersection is displayed in Figure 6-3. The left turns from the mainline follow the busway and through-vehicle phase. These are lagging left turns. This example assumes that there is adequate pedestrian storage and facilities in the median to accommodate pedestrians crossing to the median during the left-turn phase. A variation on this example is to operate cross traffic in separate phases (i.e., split phases).

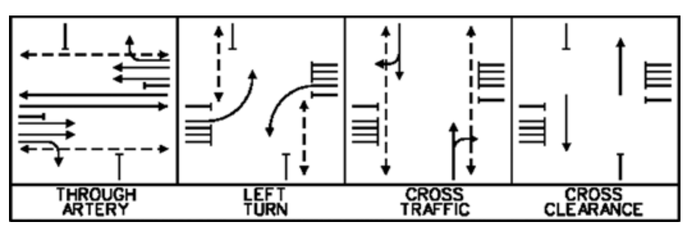


Figure 6-3. Example signal timing for median busway intersection.

An example of a signal phasing for a side-aligned busway intersection is displayed in Figure 6-4. In this example, vehicles are not allowed to store between the intersection of the cross street with the busway and the intersection of the cross street with the parallel roadway. Cross-street traffic operates in separate phases. Although not pictured, significant clearance intervals are needed after each of the side street phases to ensure that vehicles completely clear the busway intersection. The crossing opportunities for pedestrians are limited across the mainline.

Cycle Length

The cycle length depends on the traffic volumes at the intersection and the block spacing where the intersection is part of a coordinated system. The more phases in the signal, the longer the cycle length. Longer cycle lengths should generally be avoided to reduce overall intersection delay.

Generally, cycle lengths should not exceed 90 seconds at smaller intersections and 120 seconds at larger, more complex intersections. Longer cycle lengths increase the delay of intersection users. Pedestrians are particularly sensitive to delay and may violate the pedestrian signal if the delay is too long.

At median busway intersections, the time needed for pedestrians to cross the general-purpose lanes and the busway will likely be the limiting factor. The cycle length should be as short as possible while giving pedestrians enough time to cross the intersection safely.

Yellow and All-Red Intervals

As defined by the MUTCD, the yellow change interval is the first interval following the green interval during which the yellow signal indication is displayed. The exclusive function of the yellow change interval is to warn traffic of an impending change in the right-of-way assignment. The yellow interval should be of sufficient length to allow time for motorists to see the yellow signal indication and decide whether to stop or enter the intersection. It should allow motorists farther away from the signal to decelerate comfortably in advance of entering the intersection and motorists closer to the signal to enter the intersection during the yellow indication. Some agencies also use an all-red clearance interval after the yellow interval during which all signal indications display the red indication.

The yellow and all-red intervals are collectively known as the change period. There is currently no nationally recognized recommended practice for determining the change period length. The following kinematic equation is used by many agencies to calculate the change period, *CP*:

$$CP = t + \frac{V}{2a + 64.4g} + \frac{W + L}{V} \qquad [6\text{-}1]$$

Where

t = motorist perception-reaction time, generally 1 second;
V = speed of the approaching vehicle, in ft/s;
a = deceleration rate, typically 10 ft/s^2;
g = grade of approach, in percentage divided by 100 (downhill is negative);
W = width of the intersection, in feet; and
L = length of vehicle, typically 20 feet.

One well-recognized practice for using this equation is to allocate the first two terms to the yellow interval and the third term to the all-red interval. This practice will work well for busway intersections. However, two important changes should be made to the inputs. First, when the change period is calculated for busway movements, the length of the vehicle should be changed to the length of the buses operating on the busway.

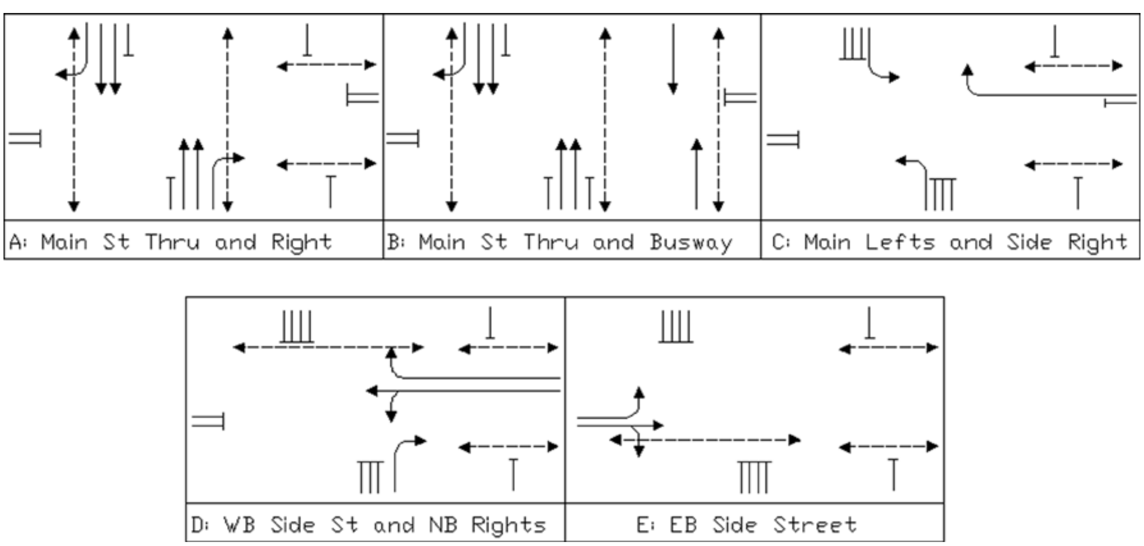


Figure 6-4. Example phasing for a side-aligned busway intersection with no storage.

While most transit buses are 40 feet long, many busways use articulated buses that are up to 60 feet long. Second, median and side-aligned busway intersections are much wider than traditional intersections. The longest travel path for each phase should be considered as the intersection width. The travel path should be calculated from the stop bar of the movement all the way to the far side of the crosswalk on the receiving approach (*16*).

In most cases, this calculation will result in long change periods. The MUTCD provides guidance that the red clearance interval should have a duration not exceeding 6 seconds. However, this is guidance, not a standard.

Signal Coordination

System Progression

A well-timed corridor signal system benefits intersection operations and safety. It reduces overall intersection delay, reduces stops, and decreases emissions. A progressed corridor may also reduce traffic signal violations.

Progression of roadways that cross busway intersections may also benefit the safety of the busway. At side-aligned and separated right-of-way busway intersections, motorists may fail to see the busway intersection and violate the signal. A well-progressed system could eliminate the need for cross-street traffic to stop at these intersections.

Busway Priority and Preemption

The MUTCD defines preemption control as the transfer of normal operation of a traffic control signal to a special control mode of operation. Priority control is a means by which the assignment of right-of-way is obtained or modified. The systems visited as part of the case studies used a variety of busway priority systems to reduce travel delays on the busway, but no preemption systems.

Transit signal priority (TSP) can include extending the green interval for the busway, providing an early green phase for the busway by shortening the green interval of another movement, providing the busway phase before the phase of another movement, or inserting a special phase to assist the bus in entering the travel stream ahead of the platoon of traffic.

There are two types of TSP systems: unconditional and conditional. Unconditional TSP provides the bus with priority every time the bus approaches the intersection. This system is less expensive because it can be implemented with infrastructure-based detection such as loop actuation. Depending on the type, sensitivity, and offset distance of the detection system used, detection systems that are only infrastructure-based could cause unnecessary actuation by buses traveling in the opposite direction. Combining the infrastructure detection with a transponder on the vehicle can reduce the number of false actuations.

An example of an unconditional TSP system is the Euclid Corridor median busway in Cleveland, Ohio. It will have an unconditional TSP system including green extensions, early green, and the ability to jump phases. The green extension will be 10 seconds long. The detection is coordinated with the BRT bus door closing at stations. The TSP will not be used at a few intersections along the corridor where the cross streets are part of a coordinated system.

Initially, the Euclid Corridor Transportation Project team considered using loop detection at the intersections. However, loop detection involves considerable maintenance and is difficult to reprogram. Instead, video detection by a variable focal length camera will be used. The programmable detection zone will be set at each of the intersections and can be modified if needed. The video detection will sense the presence of the bus and then communicate directly to the signal system. There is no need for communication between the bus and the signal system. However, the video system will not differentiate between an unauthorized vehicle and a bus.

Conditional TSP systems can operate with a schedule-adherence system or a headway-based system. Priority is only provided to the bus if it is behind schedule by some predetermined amount of time (e.g., 4 minutes) or if the headway between buses is longer than desired. Conditional priority can be very difficult to employ because the system must have a method of communication among the bus, a central processing center, and the signal. The advantage is that it reduces the unnecessary demands on the cycle length. It can be controlled so that there are a maximum number of cycles where priority is provided. This type of priority is well suited for congested intersections where intersection delay is an important concern.

Surrounding Road Networks

Congested downstream intersections on the mainline and the cross street could cause queuing over the busway intersections. Steps should be taken to avoid such congestion as it impacts both the safety and operation of the intersection. Steps may involve changing the signal timings at the downstream intersection or modifying the signal timings at the busway intersection in response to these queues. For example, far-side loop actuation can be used to sense the presence of a queue in a receiving lane. The traffic movement that is received by that lane can be held until the queue clears. Traffic control devices and enforcement also can be used to deter motorists from entering the intersection under these circumstances.

CHAPTER 7

Busway Intersection Design

This chapter provides design guidelines for various busway intersections. These guidelines apply the basic principles and policies set forth in the previous chapters.

As discussed in Chapter 2, there are four basic types of at-grade busway intersections: (1) median intersections, (2) side-aligned intersections, (3) separated right-of-way intersections, and (4) bus-only ramps. Each type of intersection is described in the following sections.

Median Busway Intersections

Busways located in the median of a roadway are median busways. The busway is physically separated from the general-purpose traffic on both sides. This type of busway removes the buses from curbside conflicts. This design concept is widely used in South America. The 98 B-Line in Richmond, British Columbia, is an example of a median busway in North America.

This design concept requires a curb-to-curb width of at least 80 feet, although wider cross sections are more desirable to accommodate turning movements and median separation.

Safety Issues

The median busway can increase the complexity of the intersection. This type of intersection has a very wide crossing distance for pedestrians. Pedestrian refuge should be provided in the median, particularly if there is a station at the intersection.

Left turns are a concern at this type of intersection. Because of the proximity of the median busway to the left-turn lanes from the parallel roadway, left-turning motorists may confuse the bus signal with their own if standard signals are used. Also left turns from the cross street may inadvertently turn into the busway if the appropriate path guidance, usually pavement markings, is not provided. If the intersection is congested, these left-turning vehicles from the cross street may back up over the busway.

Basic Geometry

The intersection geometry must fully integrate transit operations and traffic control devices. The controlling design factor is the placement of arterial left-turn lanes and busway stops. There are generally three options for their placement:

- Left-turn lanes on the near side and bus stops on the far side of the same intersection
- Left-turn lanes and busway stops at separate intersections
- Signalized indirect left turns (such as Michigan lefts or jug handles) with all left turns moved away from the busway intersection

A busway can incorporate one or more of these options. In designing the intersection, the effect of the design on transit operations and traffic control devices must be considered.

Physical separation between the busway and the general-purpose traffic by raised islands with mountable curbs is desirable. A minimum separation of 4 feet will provide space for signs and some refuge for pedestrians, although 6 feet or greater is preferred for pedestrian storage. When space is extremely limited, channelization such as flexible posts placed in predrilled holes, raised pavement buttons, or wide rumble strips can be used to provide the physical separation requirements. Orlando's LYMMO system uses double rows of raised pavement buttons.

Bus stations should provide at least two loading positions (100 feet for regular buses and 140 to 150 feet for articulated buses). Stops may be located on the far side and should be at least 8 feet wide, although a 10-foot width is preferred.

Pedestrian access should be at signalized locations only. Landscaping, fencing, and other devices should be used to channel pedestrians to cross at the intersection. The Euclid corridor median busway in Cleveland will use the platform height to channel pedestrians leaving the station to cross at the intersection. The platform will be raised 14 inches off the ground to deter pedestrians from leaving the station from the platform.

Traffic Control

Median busway intersections should always operate under signal control. This control is necessary to assign right-of-way to the multiple conflicting movements at the intersection, including pedestrian movements.

White bar signals are preferred for busway control because motorists, particularly left-turning motorists, will be less likely to confuse them with parallel-roadway traffic signals.

Example Intersection

Figure 7-1 presents an example of a median busway intersection. There are far-side stops for each direction. Left turns are allowed from the parallel roadway in a lagging, protected-only phase. The bus phase is concurrent with the parallel-roadway through phase.

White bar signals are used to control the busway. Standard signals are used for roadway traffic. Selective-view programmable lenses are used on the parallel roadway so that motorists do not mistake adjacent lane signals (i.e., left-turning motorists do not mistake the through-vehicle signals) for their own.

This example intersection has separate right-turn bays for right turns from the parallel roadway. In many situations, the available right-of-way will be limited and the use of right-turn bays may not be practical with the available space.

Please note that Figure 7-1 does not present a complete traffic control device plan.

Side-Aligned Busway Intersections

The intersections of a cross street and a busway located adjacent to a parallel roadway are called side-aligned busway intersections. Side-aligned busway intersections are typically

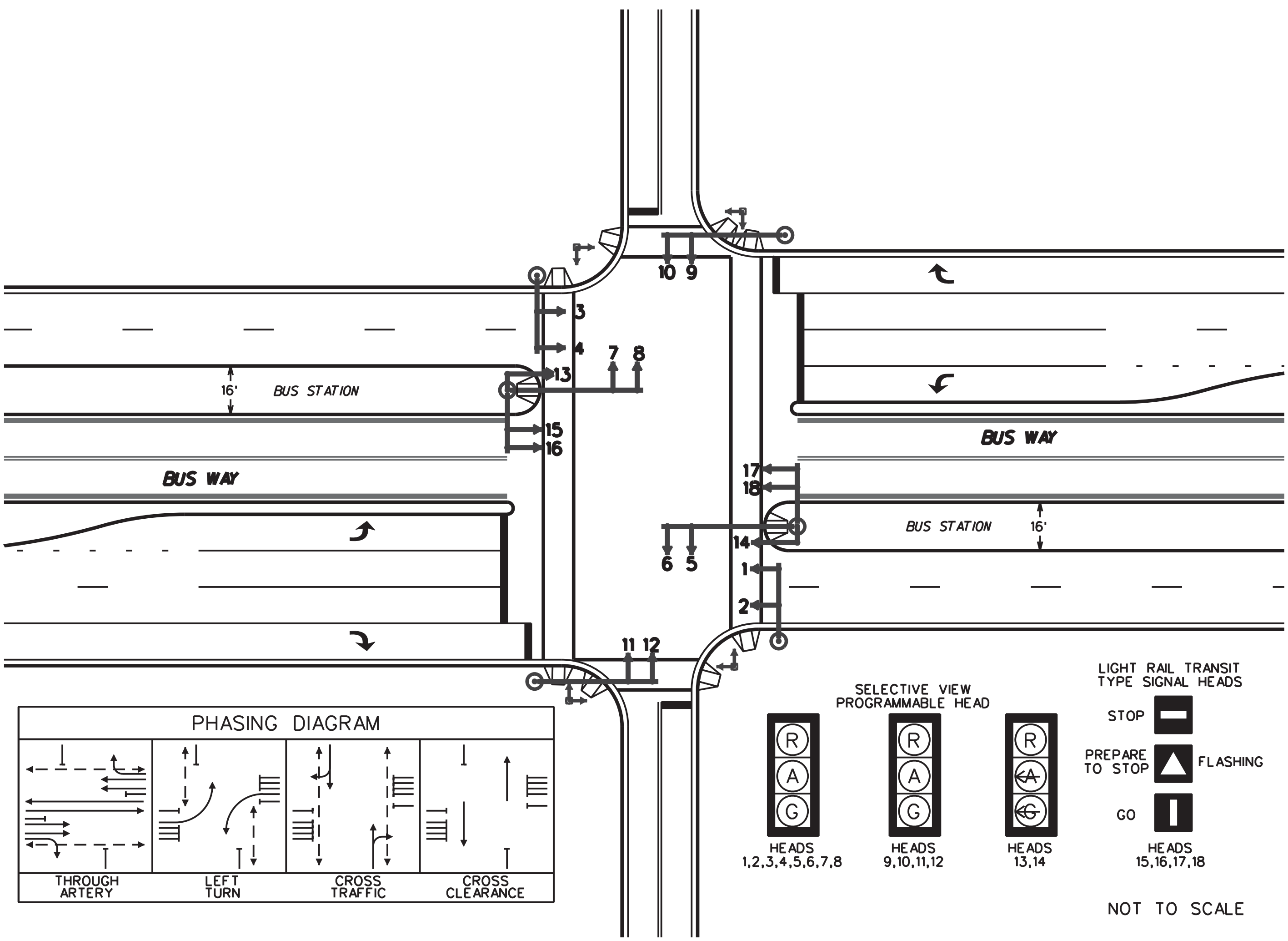


Figure 7-1. Example of a median busway intersection.

located between 50 and 400 feet from the parallel roadway. The two intersections usually function together as one intersection. Depending on the distance between the parallel roadway and the busway, vehicle storage may be allowed on the cross street between the two.

Safety Issues

This intersection design can be confusing to motorists who are unfamiliar with this type of intersection. Traffic control devices such as lane assignment signs, pavement markings, and traffic signal heads should be used prudently to assist the motorist. Visual clutter should be reduced.

Right turns from the parallel street onto the cross street can conflict with the busway during the bus phase. If adequate storage is not available between the intersections, right turns on red should be prohibited. Violation of this prohibition can have serious safety consequences.

Traffic queuing over the busway intersection from the parallel-street intersection is also a concern. The two intersections must be coordinated so that vehicles do not wait for the parallel-street intersection over the busway. The busway and cross-street intersection must be equipped with traffic signals.

Basic Geometry

The geometry of the busway and the cross street is similar to the geometry for the separated right-of-way intersection. No turns from the cross street are allowed at this intersection. Turns may be allowed from the busway; however, the number of conflict points at the intersection will increase and, therefore, turns should be limited or avoided all together if possible. Along the parallel street, right- and left-turn lanes or bays are essential to provide a safe refuge area for vehicles to wait during the red phase. Both of these turns should operate in a protected phase. If these lanes are not provided, then the right and left turns from the parallel street onto the cross street that leads to the busway should be prohibited.

Traffic Control

Traffic signal control along the cross street at the busway and at the parallel street are the preferred control for this type of intersection. The signal phasing between the two intersections should be coordinated to avoid vehicles queuing over the busway.

Buses on the busway can move during the same phase as the parallel-street through movement. During this phase, the conflicting left turns from the parallel street should be prohibited. Conflicting right turns should be prohibited if storage between the two intersections is not adequate for the vehicles. A clearance phase should be provided for cross-street traffic before the busway phase when the distance between the busway and the parallel street is less than 200 feet.

Example Intersection

Figure 7-2 presents an example of a side-aligned busway intersection parallel to a major arterial. In this example, vehicle storage between the two intersections is not allowed. Therefore, right turns on red are prohibited from the arterial. The bus phase can be concurrent with the through-vehicle phase for the parallel arterial or a separate phase. Leading left turns are used.

White bar signals are used to control the busway. Standard signals are used for vehicle traffic. The vehicle signals at the busway intersections use a green arrow for the through indication to emphasize the turn prohibitions. All signals are equipped with back plates. Although not pictured in Figure 7-2, other traffic control devices such as busway crossing warning signs should be used. Please note that this figure does not present a complete traffic control device plan.

Separated Right-of-Way Busway Intersections

Separated right-of-way busway intersections are also referred to as isolated busway intersections. These intersections are not situated close to other intersections or roadways. A two-way busway, potentially with passing lanes at the intersection, intersects a cross street. The intersection is signalized or stop controlled.

Safety Issues

A few potential safety issues should be considered in the design of this type of busway intersection based on the reported experiences of agencies that use this design.

The first issue is the recognition of the busway crossing as an intersection by motorists, pedestrians, and bicyclists. Users may not expect buses to cross from what may look like a secondary street. The intersection should be highly visible and should be designed with the same elements as other intersections (e.g., street name signing, curb and gutter, and stop bars). If the intersection is not visible, motorists may inadvertently violate the traffic control devices. Similarly, if the intersection is not recognized as such, motorists will be more likely to violate the traffic control devices intentionally.

The second issue is related to the type of intersection control devices at the intersection. The busway volumes may not be sufficient to warrant a traffic signal based on currently established warrants for signalization, which are based on vehicle volumes not person volumes. If stop control is used at the intersection, inappropriate gap acceptance may cause a safety concern.

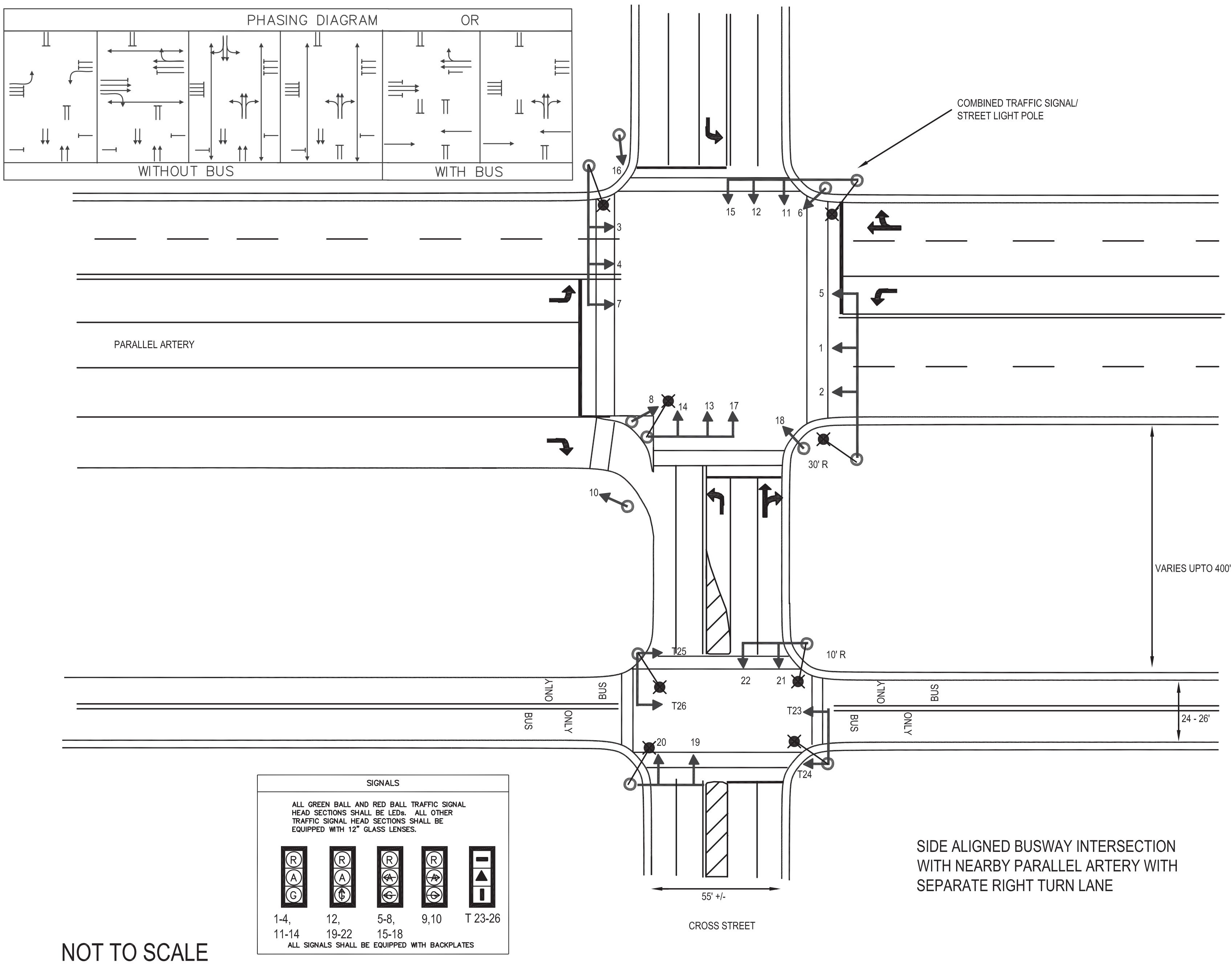


Figure 7-2. Example of a side-aligned busway intersection.

Basic Geometry

The basic geometry for this type of intersection is a two-lane busway intersecting a two- to four-lane roadway. If there is a stop at the intersection, the busway may have passing lanes at the station. Far-side stations are preferred with this design.

Signalized Intersections

Signal control is the preferred method of intersection control, particularly if the cross street is a major street. White bar traffic signals are preferred for busway control, although signals are not as important for this type of busway intersection because there are not any parallel vehicle movements. The use of semi-actuated controls or TSP for the busway will allow the busway a green phase on demand after the minimum green phase for the cross street. When the cross street is part of a coordinated system, the bus-actuated phase operates within established background cycles.

Because traffic signal violations are a concern at this type of intersection, the use of 12-diameter signal displays with back plates is appropriate. Turns are not allowed at these intersections; therefore, a through green arrow, yellow ball, and red ball are the preferred signal displays.

Pedestrian signals may be necessary where there are crosswalks. If the busway phase is actuated, pedestrian actuation is needed for the parallel pedestrian movement.

Stop-Controlled Intersections

Stop sign control for the cross street may be necessary at some low-volume intersections. If used, stop sign control should be used in combination with such strategies as stop-ahead signs, flashing beacons, and transverse rumble strips to reinforce the stop sign control and the presence of the intersection.

The type of stop control (i.e., two-way or four-way) depends on the volume of the intersection and the available gaps. For transit speed and efficiency, it is preferable to stop the traffic on the cross street instead of the busway. However, in most cases, stopping the cross-street traffic without also stopping the busway traffic is not practical; the cross-street volumes are likely much higher than the busway volumes. Stop control on the busway increases the delay for the bus. Additionally, if only the busway is stop controlled, larger buses may find it difficult to locate a suitable gap in cross-street traffic. Therefore, four-way stop control may be necessary to ensure safe operation of the intersection.

Example Intersections

Signal-Controlled Intersection

Figure 7-3 presents an example of a signalized, separated right-of-way busway intersection. In this example, there are two far-side stations at the intersection, one for each direction.

No turns are allowed at this intersection. Although not displayed on this drawing, numerous signs (as discussed in the chapter on traffic control devices) would be used to communicate this message to the motorist.

White bar signals are used to control the busway approach. Standard signals are used for cross-street traffic. A green arrow is used for the through-vehicle indication. A two-phase signal is used to control traffic.

Stop-Controlled Intersection

Figure 7-4 presents a stop sign-controlled intersection. In this example, there are no stations at the intersection.

The type of stop control at a separated right-of-way intersection depends on the volume of the traffic at the intersection and the best way to safely accommodate the intersection demand. Generally, four-way stop control is preferred. In this example, the intersection is controlled by two-way stop signs on the cross street and the busway is uncontrolled.

Several traffic control devices can be used to reinforce the presence of the intersection and the traffic control for the cross-street traffic. In this example, graphic Stop Ahead warning signs are placed on the cross-street approaches. The intersection is also equipped with an overhead flashing beacon. The beacon flashes red for the cross-street approach and yellow for the busway approach. Other measures that can reinforce the stop control include transverse rumble strips, Stop Ahead pavement markings, and larger or double stop signs on the approach. Although not pictured in Figure 7-4, a busway warning is suggested for this intersection. The South Miami-Dade busway will use intersection islands on the approaches to increase the conspicuity of separated right-of-way intersections. An example of such intersection islands is included as Figure 7-5.

Bus-Only Ramp Intersections

Ramps are an important component of an exclusive, fully separated busway system. They are used where busways begin, end, branch, or connect to the surrounding road system.

Bus-only ramp types include connections from bus lanes located in freeway medians to bus terminals. Examples include the bus-only ramps in the San Francisco Bay area, the bus-only ramps from park-and-ride lots in Houston, and the bus-only ramps at the airport station in Richmond, British Columbia. Other bus ramps include connections from city streets to the beginning or end of the busway such as those used to connect to the Pittsburgh busway.

General Guidelines

Intersections of busway ramps and public roads are designed similar to other intersections. However, they require clear messages indicating that the ramps are only for bus use.

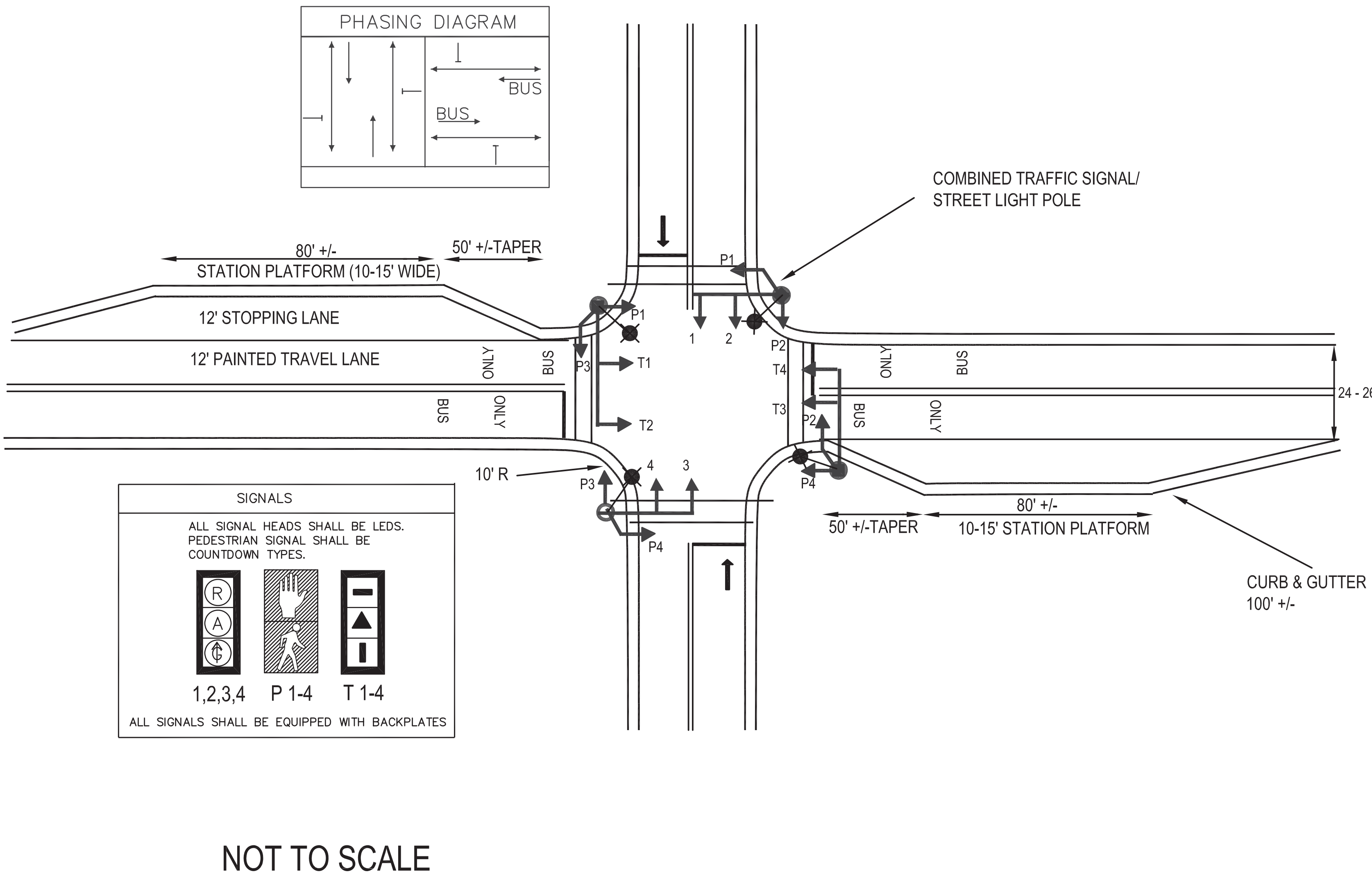
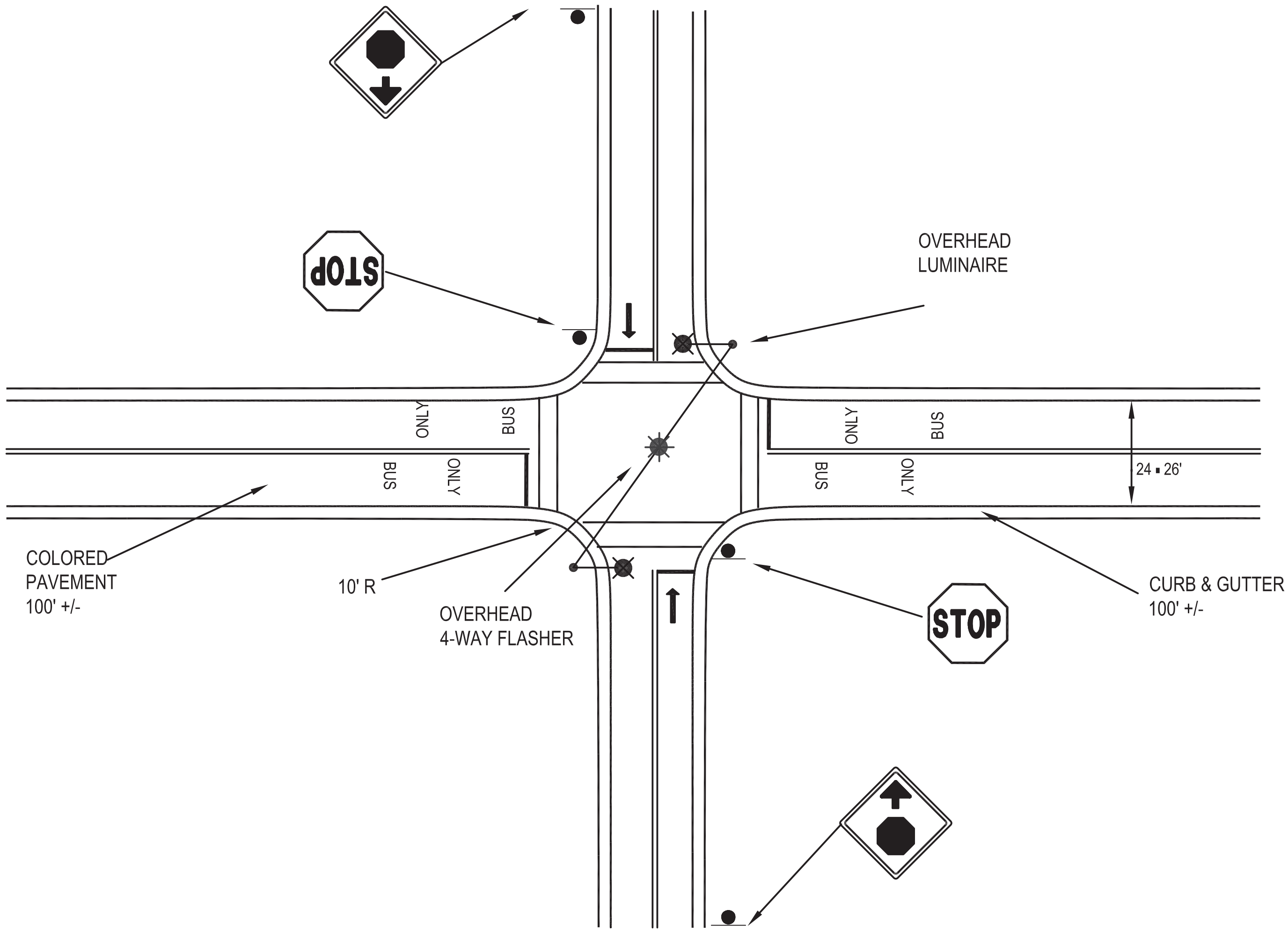


Figure 7-3. Example of a signalized, separated right-of-way busway intersection.



NOT TO SCALE

Figure 7-4. Example of a stop-controlled, separated right-of-way busway intersection.

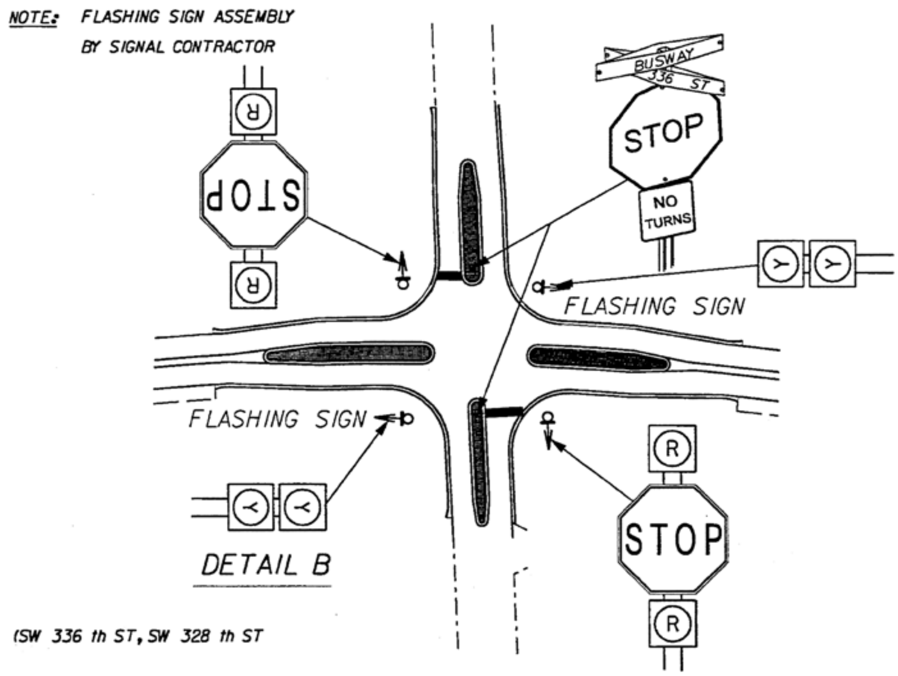


Figure 7-5. Example of stop-controlled, separated right-of-way busway intersection in South Miami Dade.

Roadway geometry and traffic control devices, while similar to other intersections, should accommodate bus turning movements with minimum encroachment on opposing travel lanes. Ramps may be one way or two ways depending upon specific circumstances.

Bus-only left-turn lanes should be provided on the cross streets. The lane should be designated for buses only by pavement markings and signs. Signing should be clear and should prohibit turns by general traffic. Dual Do Not Enter signs should be erected on the ramp entrance, with a supplementary plaque that exempts transit vehicles. Both side-mounted and overhead signs can be used.

Basic Geometry

Intersection of the busway and the connecting ramps should be similar. Turning lanes should be provided where space permits to remove buses from the through travel lanes.

Ramp design should provide adequate space to allow passing around disabled buses. Such adequate space suggests a single-lane ramp with wide shoulders or a two-lane design. Single-lane ramps should be 12 to 14 feet wide, with 10-foot shoulders on both sides.

Traffic Control

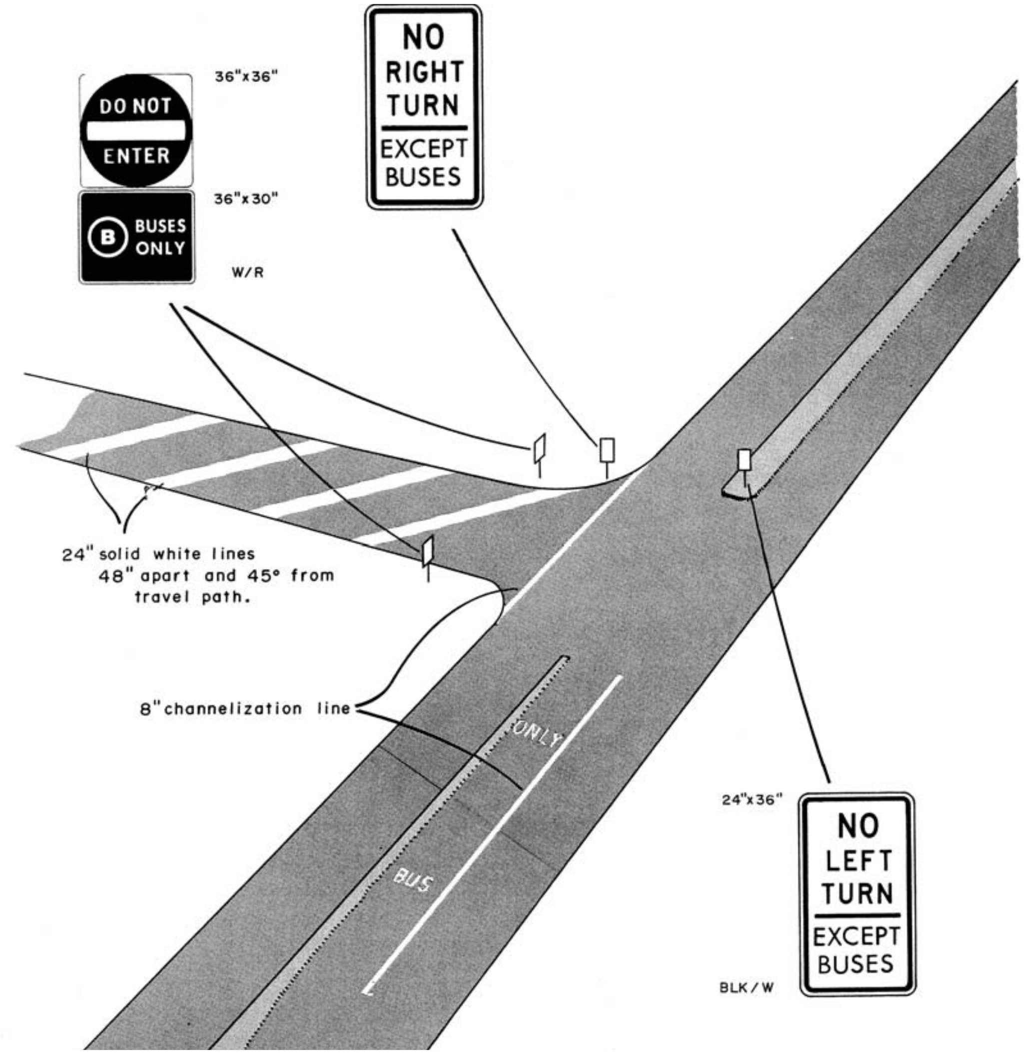
Traffic signals should be considered for situations where traffic volumes along the entry are heavy and gaps are not sufficient. Semi-actuated traffic signals operating on the cross-street background cycles should be used.

Effective enforcement of the prohibition of unauthorized entry to the busway ramp is essential to discourage errant drivers. Where violations persist, bus-activated gates may be needed. These gates should be placed across the ramp about 50 to 100 feet away from the intersection.

Example Bus-Only Ramp

Figure 7-6 presents an example of a bus-only ramp intersection from *NCHRP Report 155* (*17*). In the example, a bus-only left-turn lane is provided to enter the ramp. The intersection is uncontrolled. For low-speed, low-volume bus traffic, the offsets and even the left-turn lane could be omitted. Sufficient levels of illumination should be provided regardless of volume.

The design in Figure 7-6 would be greatly improved by the use of Bus Only pavement markings at the entrance to the ramp.



Source: *NCHRP Report 155* (*17*).

Figure 7-6. Example of a bus-only ramp intersection.

CHAPTER 8

Other Considerations

Agency Collaboration

Coordination and communication among bus, highway, and enforcement agencies is important to the safe operation of busway intersections. Many agencies may be involved in the design and operation of the intersections along a busway. Lack of coordination and communication among these agencies can result in safety problems. The traffic engineering and transit planning staff must work together.

When the system is in operation, the coordination among agencies should continue. Representatives of involved agencies should meet regularly to review data on the safety and operational performance of busway intersections and to develop compatible designs and traffic control. Collaboration is necessary to develop a multi-faceted approach to improve any deficiencies.

An example of coordination benefiting safety is in the recent design and construction of the Los Angeles Orange Line busway. The busway was developed by the Metropolitan Transportation Authority (MTA) and the Los Angeles Department of Transportation. Grant funds secured by the bus agency are paying for the improvements to the traffic control system in the corridor, which will also benefit highway users. Also, the addition of a separate bicycle facility will remove bicyclists from the vehicle traffic for the majority of the corridor. The safety of the corridor was considered as a whole, not just for buses, vehicles, or pedestrians individually. When the busway first opened, there were some safety issues that arose. The Metro Orange Line Safety Task Force was established to review current practices and procedures and, where necessary, implement changes. The Task Force includes members from Metro Operations, Metro Safety, Los Angeles Department of Transportation, Los Angeles Police Department, Los Angeles County Sheriff Department, and Metro Construction.

Procedures for Bus Operations

The operating procedures for buses on the approach to and at the intersection with roadways and pedestrian and bicycle paths can affect the safety of the intersection. Accordingly, bus operators should be trained to anticipate safety problems at intersections including pedestrians and bicyclists crossing illegally in the path of the bus, vehicles entering the busway, vehicles turning across the busway, and vehicles queuing over the busway.

Bus operators, particularly ones driving on exclusive busways, receive substantial training of the unique characteristics of their route. They are trained on the unique characteristics of the bus, the facility, traffic control devices, and individual intersections. Because of this training, unique traffic control devices (e.g., white bar signals) can be used at the intersections.

Intersection Approach Speed

Some agencies instruct their bus operators to reduce their speed on the approach to an intersection, particularly if the sight distance is limited or if there are safety concerns. For example, in response to safety concerns, South Miami-Dade operators slow their vehicles to 15 mph as they approach an intersection, even with a green signal indication. However, this procedure slows the operation of the system and may affect the signal timings. If used, this procedure should be a temporary measure until other measures (such as those discussed throughout this document) can be taken to reduce the concerns at the intersection or improve the sight distance.

Intersection Operations

When white bar signals are used along the busway, bus operators should be trained in the meaning of the signal indications. This training should include any operator who may be assigned to the bus lines using the busway. All operators should be trained in the signal operations, regardless of signal type being used, so that they understand how the system will detect their presence and any specifics of the bus phase.

For example, operators on the Orlando LYMMO busway are trained not to release passengers until the bus has progressed through to the far side of the intersection so as not to miss the bus phase. This procedure reduces the number of bus phases that are needed.

Specific Intersection Concerns

Because of the unique and complex nature of some busway intersections, operators may need to be trained on concerns at specific intersections. As part of the bus operator education, LYMMO has incorporated a simple yet effective PowerPoint presentation that helps to identify every intersection and what specific issues the bus operator will encounter. For example, the presentation indicates that, although there is no LYMMO stop at a Magnolia Avenue location, the bus operator should use caution proceeding through the intersection because of a blind spot caused by a nearby building. The presentation provides instruction on which lane the operator should use, where the operator should check for pedestrian conflicts, the location of crosswalks, mandatory stops, and bus spacing.

Enforcement

Enforcement is important at busway intersections to minimize unauthorized entry and increase compliance with traffic control devices. Enforcement activities should be coordinated among the transit agency, the highway agency, and the local law enforcement agency to ensure that the critical violations are targeted.

Unauthorized Entry to Busways

Unauthorized entry by vehicles, pedestrians, and bicyclists can create serious safety concerns. Agencies should enforce this prohibition by conducting regular line sweeps of the system and having bus operators report trespassers, or through video surveillance. In Ottawa, an extensive system of video cameras is installed along the busway and is monitored by transit police. The South Miami-Dade busway uses highly visible police vehicles on the busway to act as a deterrent to unauthorized entry and other crime.

Compliance with Traffic Control Devices

Enforcement of motorists', pedestrians', and bicyclists' compliance with signals, signs, and pavement markings is essential. Cameras that detect red-light running vehicles are widely used to enforce vehicle compliance with traffic signals at traditional intersections and should be considered at busway intersections. There may be other applications for automated enforcement such as detecting and enforcing queuing over the busway. However, enabling legislation is needed for the use of these systems in the jurisdiction. Some states do not allow the use of automated enforcement.

Targeting Enforcement

Enforcement should be targeted at potential problem locations. The Los Angeles Orange Line metro system uses a "near miss" report to identify potential safety problems. Bus operators record near misses that happen during their routes. Operators classify near misses as one of the following activities:

- Other vehicle failing to stop for red light
- Other vehicle on a parallel street turning across busway against signal
- Pedestrian crossing busway against signal
- Unauthorized vehicle traveling on busway
- Vehicle on cross street stopped across busway
- Unauthorized pedestrian/bicyclist traveling on alignment between intersections
- Bicyclist crossing busway against signal
- Pedestrian crossing busway not in crosswalk
- Vehicle attempting to enter onto busway

The operator identifies the intersection where the near miss occurred and the time and date of the near miss. The bus operations supervisors track these reports to identify potential problems before a crash occurs.

A near-miss report similar to the one used along the Orange Line can be a useful tool to identify areas for targeted enforcement, particularly of traffic control device violations such as traffic signal violations.

Public Information, Education, and Awareness

Public information and education are important to achieve safe operation of busway intersections, particularly at the opening of a facility, the addition of a segment to a facility, or when the operation is substantially modified.

Media materials such as public service announcements, newsletters, brochures, and newspaper advertisements can educate the public about the busway and the intersections along the busway. Websites and informational videos are also useful multi-media tools that can help to educate the public. Community meetings are also an important tool, particularly during the planning, design, and construction phases to ensure that the public is adequately informed and involved in the process.

Public information and community involvement are important components to the Euclid Corridor Silver Line Busway. The Euclid Avenue Corridor project team has used various forms of communications to inform the public about this project, including post cards and newsletters sent to mailing lists, media such as television spots, and community outreach. Construction alerts and updates were also printed in newspapers, aired in television spots, posted near the project, and sent to mailing lists. There is also a project website, hotline, and an email list. The project website, www.euclidtransit.org, is a good example of a tool for public education about the busway. The website is updated regularly and provides information on all upcoming events, copies of marketing materials, and contacts for additional information.

In Richmond, British Columbia, an extensive media campaign (which included radio, television, and print media) was conducted to educate the public about a U-turn configuration that was initiated along the 98 B-Line.

Busways in the MUTCD

Traffic control devices specific to busway intersections are not currently identified in the MUTCD. Based on this research, there is a need for the MUTCD to address busway intersections. A separate chapter on busway intersections similar to MUTCD Chapter 10, "Traffic Controls for Highway-Light Rail Transit Grade Crossings" could fulfill this need.

This report identifies numerous traffic control devices and related considerations for busway intersections (primarily in Chapter 5, "Traffic Control Devices"):

- Guidance on selecting the type of traffic signal (i.e., standard red-yellow-green signals versus white bar signals) for the bus indication
- Busway crossing warning signs, similar to those used by LADOT and pictured in Figure 5-3
- Warning signs modified to depict parallel busways intersecting with cross-street traffic as pictured in Figure 5-4
- Bus-activated dynamic signs warning of buses approaching for both pedestrian and vehicle applications
- Raised, red pavement reflectors to deter motorists from turning left into the median busway from the cross street similar to those that will be used in Cleveland
- Considerations for the use of automatic gates
- Considerations for the use of colored pavement

Although this list is not exhaustive, it identifies some of the gaps in the current MUTCD related to busway intersections.

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APPENDIXES

The following appendixes have been published as *TCRP Web-Only Document 36*, available on the TRB website (http://www.trb.org/news/blurb_detail.asp?id=7720):

- Appendix A, Literature Review
- Appendix B, Synthesis of Practice
- Appendix C, Cleveland Euclid Avenue Bus Rapid Transit
- Appendix D, Los Angeles County Metro Orange Line
- Appendix E, LYMMO Bus Rapid Transit Downtown Circulator
- Appendix F, South Miami-Dade Busway
- Appendix G, Richmond 98 B-Line Busway
- Appendix H, Functional Analyses
- Appendix I, Design Elements

Abbreviations and acronyms used without definitions in TRB publications:

AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
ACRP	Airport Cooperative Research Program
ADA	Americans with Disabilities Act
APTA	American Public Transportation Association
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
ATA	American Trucking Associations
CTAA	Community Transportation Association of America
CTBSSP	Commercial Truck and Bus Safety Synthesis Program
DHS	Department of Homeland Security
DOE	Department of Energy
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
IEEE	Institute of Electrical and Electronics Engineers
ISTEA	Intermodal Surface Transportation Efficiency Act of 1991
ITE	Institute of Transportation Engineers
NASA	National Aeronautics and Space Administration
NCFRP	National Cooperative Freight Research Program
NCHRP	National Cooperative Highway Research Program
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
SAE	Society of Automotive Engineers
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (2005)
TCRP	Transit Cooperative Research Program
TEA-21	Transportation Equity Act for the 21st Century (1998)
TRB	Transportation Research Board
TSA	Transportation Security Administration
U.S.DOT	United States Department of Transportation