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TCRP Report 19

Guidelines for the Location and Design of Bus Stops

Transportation Research Board
National Research Council

TRANSIT COOPERATIVE RESEARCH PROGRAM

Report 19

Guidelines for the Location and Design of Bus Stops

TEXAS TRANSPORTATION INSTITUTE
TEXAS A&M RESEARCH FOUNDATION
TEXAS A&M UNIVERSITY
College Station, TX

Subject Area

Public Transit
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TRANSIT COOPERATIVE RESEARCH PROGRAM

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 Transit 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 Academy of Sciences, 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.

Research problem statements for TCRP are solicited periodically but may be submitted to TRB by anyone at any time It is the responsibility of the TOPS Committee to formulate the research program by identifying the highest priority projects. As part of the evaluation, the TOPS Committee defines funding levels and expected products.

Once selected, each project is assigned to an expert panel, appointed by the Transportation Research Board. The panels prepare project statements (requests for proposals), select contractors, and provide technical guidance and counsel throughout the life of the project. The process for developing research problem statements and selecting research agencies has been used by TRB in managing cooperative research programs since 1962. As in other TRB activities, TCRP project panels serve voluntarily without compensation.

Because research cannot have the desired impact if products fail to reach the intended audience, special emphasis is placed on disseminating TCRP results to the intended end users of the research: transit agencies, service providers, and suppliers. TRB provides a series of research reports, syntheses of transit practice, and other supporting material developed by TCRP research. APTA will arrange for workshops, training aids, field visits, and other activities to ensure that results are implemented by urban and rural transit industry practitioners.

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.

TCRP REPORT 19

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NOTICE

The project that is the subject of this report was a part of the Transit Cooperative Research Program conducted by the Transportation Research Board with the approval of the Governing Board of the National Research Council. Such approval reflects the Governing Board's judgment that the project concerned is appropriate with respect to both the purposes and resources of the National Research Council.

The members of the technical advisory panel selected to monitor this project and to review this report were chosen for recognized scholarly competence and with due consideration for the balance of disciplines appropriate to the project. The opinions and conclusions expressed or implied are those of the research agency that performed the research, and while they have been accepted as appropriate by the technical panel, they are not necessarily those of the Transportation Research Board, the National Research Council, the Transit Development Corporation, or the Federal Transit Administration of the U.S. Department of Transportation.

Each report is reviewed and accepted for publication by the technical panel according to procedures established and monitored by the Transportation Research Board Executive Committee and the Governing Board of the National Research Council.

Special Notice

The Transportation Research Board, the National Research Council, the Transit Development Corporation, and the Federal Transit Administration (sponsor of the Transit Cooperative Research Program) do not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the clarity and completeness of the project reporting.

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FOREWORD

By Staff
Transportation Research Board

TCRP Report 19, *Guidelines for the Location and Design of Bus Stops*, will be of interest to individuals and groups with a stake in the location and design of bus stops. This includes those associated with public transportation organizations, public works departments, local departments of transportation, developers, and public and private organizations along or near bus routes.

The primary objective of this research was to develop guidelines for locating and designing bus stops in various operating environments. These guidelines will assist transit agencies, local governments, and other public bodies in locating and designing bus stops that consider bus patrons' convenience, safety, and access to sites as well as safe transit operations and traffic flow. The guidelines include information about locating and designing bus stops and checklists of factors that should be considered.

The research began with a literature review and the identification of stakeholders' concerns through mail and telephone surveys and face-to-face interviews. A review of 28 transit agency manuals on bus stop design and location provided the basis for an appraisal of current practice. Observations made at more than 270 bus stops during regional visits to Arizona, Michigan, and California were supplemented with traffic field studies conducted at 14 bus stops and pedestrian field studies conducted at 10 bus stops. Computer simulation of bus stops on suburban highways was also used to develop the findings.

The guidelines include three sections: the "big picture," street-side design, and curb-side design.

- **The big picture** section of the guidelines addresses the need for cooperation and coordination among stakeholders during the design and location of bus stops. Such efforts result in mutually satisfying outcomes for diverse interests and can preclude many problems that often arise.
- **The street-side** section discusses matters such as curb radii and when to consider installing the various bus stop configurations (curb-side, nub, bus bay, open bus bay, and queue jumper bus bay) and different bus stop locations (near-side, far-side, and midblock). This section of the guidelines addresses possible effects of bus stop location and design on bus operations and traffic flow.
- **The curb-side** section addresses community integration; pedestrian access to bus stops; placement of bus stops in the right of way; environmental treatments; bus shelter designs; shelter construction materials; and amenities, such as lighting, benches, vending machines, trash receptacles, telephones, bus route and schedule information, and bicycle storage facilities.

The guidelines also include two appendixes that present the results of the street-side and curb-side studies.

A secondary objective of this research project was to develop or assemble the most comprehensive and technically current information on bus stop design. The research team prepared a final report that presents the research approach and findings, including the results of the literature review, review of transit agency manuals, and survey findings. This report, which is not published, is available, on loan, from TCRP.

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ACKNOWLEDGMENTS

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The research reported herein was performed under TCRP Project A-10 by the Texas Transportation Institute. Texas A&M Research Foundation was the contractor for this study. Kay Fitzpatrick, Associate Research Engineer, Texas Transportation Institute, was the principal investigator. The other authors of this report are Kevin Hall, Assistant Research Scientist; Dennis Perkinson, Assistant Research Scientist; Lewis Nowlin, Assistant Research Scientist; and Rodger Koppa, Associate Research Engineer, all of the Texas Transportation Institute. Other TTI staff who assisted with this project include Pat Beck, Alan Black, Melinda Butts, Jon Collins, Steve Farnsworth, Shirley Kalinec, Stacy King, Joseph Koothrappally, Molly Marshall, Maria Medrano, Angelia Parham, Kelly Quy, Jason Vaughn, and Jennifer White. The work was performed under the general supervision of Dr. Fitzpatrick.

The authors wish to acknowledge the many individuals who contributed to this research by participating in the mail-out surveys, the phone survey, the regional visits, the field data-collection efforts, and the review of the developed guidelines.

The research team is especially grateful for the contributions of William Capps, Alan Danaher, Ed Demming, Charles Felix, Mark Fedorowic, Joe Garcia, E. J. Hynick, Chuck Italino, Michele Korf, Suzanne LaPlant, Chris Leighty, Steve Miraglio, Matilde Miranda, Dennis O'Malley, Larry Shobe, Wayne Tanda, Mayuko Tzanavaras, James Unites, Kiyo Ushino, Bill Volk, Duncan Watry, Christopher White, and Ronald K. Wong.

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INTRODUCTION

Chapter 1

NEED FOR THIS RESEARCH

The bus stop is the first point of contact between the passenger and the bus service. The spacing, location, design, and operation of bus stops significantly influence transit system performance and customer satisfaction.

In recognition of the importance of bus stop location and design, the Transit Cooperative Research Program (TCRP) sponsored research to develop guidelines for use in designing and locating bus stops. The objective of this research was to develop guidelines for locating and designing bus stops in various operating environments. These guidelines can assist transit agencies, local governments, and other public bodies in locating and designing bus stops that consider bus patrons' convenience, safety, and access to sites, as well as safe transit operations and traffic flow. The guidelines include a compilation of information necessary for locating and designing bus stops, as well as checklists of factors that must be taken into consideration. The guidelines list the advantages and disadvantages of various bus stop treatments and discuss the trade-offs among different alternatives.

These guidelines also provide an approach to integrating transit and development. By assembling the information into a single document, public agencies and developers can more easily incorporate transit needs into the design and operations of streets and highways, as well as in land development. Finally, these guidelines should help transit, state, and local agencies in selecting bus stop amenities.

Chapter 1

INTRODUCTION

SOURCES OF MATERIAL

This research includes evaluations of current policies regarding bus stop design and location, reviews of the relevant literature, and extensive interviews and site visits. Appreciation goes to those who assisted in this study, including those who responded to our surveys, met with us during the regional visits, helped with the data collection efforts, and provided reviews of these guidelines. Documentation of the research performed during the development of these guidelines is contained in *Location and Design of Bus Stops, TCRP Project A-10 Final Report*, and Appendixes D and E of this document. The *Final Report* is available for loan on request from TCRP. It includes the following:

- Summary
- Introduction
- Findings
- Interpretation, Appraisal, Application
- Conclusions and Suggested Research
- Appendix A - Literature Search
- Appendix B - Review of Transit Agency's Manuals
- Appendix C - Survey Findings

Several excellent manuals are currently being used by various cities and transit agencies. These manuals, along with the literature, were reviewed during the development of these guidelines. Some figures and text used in these guidelines are reproductions or expansions of material contained elsewhere. The contributions of the following documents in the development of these guidelines are recognized:

- *Bus Stop Handbook: Street Improvements for Transit*, Valley Metro, Regional Public Transportation Authority, Phoenix, Arizona, December 1993.

- *Tri-Met Bus Stops and Passenger Amenities Guidelines*, Tri-Met Transit Development and Planning and Scheduling Departments, Portland, Oregon area, November 1994.

- *Bus Passenger Facilities - Street Improvement Guidelines*, Regional Public Transportation Authority, Draft, Phoenix, Arizona, March 1989.

- *Planning for Transit, A Guide for Community and Site Planning*, Regional Transportation Commission of Washoe County, Nevada, June 1992.

INTRODUCTION

Chapter 1

ORGANIZATION OF GUIDELINES

These guidelines provide a useful and practical tool for the location and design of bus stops. **Chapter 1** introduces the materials included within this document. **Chapter 2** provides a general overview of the broad issues associated with the location and design of bus stops. Special emphasis is placed on the need for coordination and cooperation between public officials and private interests to enhance community acceptance of transit operations and to improve patron access, comfort, and convenience.

The guidelines are organized to reflect the two major issues associated with bus stop design and placement: street-side factors and curb-side factors. Street-side factors are those factors associated with the roadway that influence bus operations. Curb-side factors are those factors located off the roadway that affect patron comfort, convenience, and safety.

To enhance vehicle and system performance, street-side factors are discussed in **Chapter 3**. Bus vehicle characteristics, including vehicle size and turning radii, are provided. In addition, discussions are included on various bus stop designs and when to consider each design. **Chapter 4** addresses the curb-side factors. General discussions of amenities and various curb-side design strategies are included. For quick and easy reference to the factors that influence the final design and placement of a bus stop, checklists are included at the end of Chapters 3 and 4 for street-side and curb-side issues. The final chapter of the guidelines **(Chapter 5)** is the Glossary of terms used in the guidelines.

In addition to the guidelines, this report includes the findings from the street-side and curb-side studies in Appendix D (Street-Side Studies) and Appendix E (Curb-Side Studies), respectively.

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THE BIG PICTURE

Chapter
2

UNIVERSAL CONCERNS

As the first point of contact between the passenger and the transit service, the bus stop is a critical element in a transit system's overall goal of providing timely, safe, and convenient transportation.

Several universal concerns of both users and providers of transit services include the following:

> **Transit system performance:** Travel time for a bus trip has four components: the time it takes to walk to the bus stop, the wait time for the bus, the actual in-vehicle travel time, and the time to walk to the destination. Each is affected by the bus stop location and the frequency of the bus stops.
>
> **Traffic flow:** Bus stop location and design affect the flow and movement of other vehicles. A well-designed bus stop can allow passengers to board and alight without the bus significantly impeding or delaying adjacent traffic.
>
> **Safety:** Safety is the freedom from danger and risk. In the transit environment it includes an individual's relationship to buses and general traffic, and the bus' relationship to other vehicles. Pedestrian safety issues include the nearness of a bench to the flow of traffic on a busy street or safely crossing the street to reach the bus stop. Bus reentry into the flow of traffic safely is an example of an operational safety concern. Thus, pedestrians, bus passengers, buses, and private vehicles can all be involved in concerns for safety at or near a bus stop.
>
> **Security:** Security refers to an individual's feeling of well being. Security is affected by lighting at bus stops, bus stop visibility from the street and from nearby land uses, and bus stop locations with hiding places. Security involves neighborhood residents, bus patrons, and bus drivers.

These are the functional and performance-related concerns in public transportation. Each must be addressed to achieve the goal of timely, safe, and convenient public transportation and to satisfy the needs of the service area. More importantly, to those who plan bus stops, each area of concern is influenced by the bus stop location and design decisions.

Chapter 2

THE BIG PICTURE

LIVABLE COMMUNITIES

The transit system must be integrated into the everyday life of a community to realize its full potential. Consideration should be given to long-term design and system performance, which can enhance the interaction of transit with communities. Only in this way can transit become an accepted part of the infrastructure and contribute to the creation of a "livable community."

> **The goal of the Livable Communities Initiative is to strengthen the link between transit and communities by improving personal mobility, transportation system performance, and the quality of life in communities by**

- strengthening the link between transit planning and community planning, including land use policies and urban design supporting the use of transit, and ultimately providing physical assets that better meet the community needs;

- stimulating increased participation in the decision-making process by community organizations, minority and low-income residents, small and minority businesses, persons with disabilities, and the elderly;

- increasing access to employment, education facilities, and other community destinations through high-quality, community-oriented, and technologically innovative transit services and facilities; and

- leveraging resources available through other federal, state, and local programs.

Transit is an integral part of livable communities. Specifically, the efficient placement of bus stops near major destinations and within easy access provides a viable transportation alternative to the automobile by making the entire transit trip shorter and more pleasant.

Thus, the key to successful and productive integration of transit into the fabric of everyday community life includes the location and design of bus stops.

THE BIG PICTURE

Chapter **2**

THE PLAYERS

The key players in bus stop location and design are as follows:

Transit agency - The transit agency is usually the primary provider of transit service.

City government - The authority with jurisdiction over the streets and sidewalks in the transit service area is usually a city, but county or state agencies are sometimes involved.

Developers - Developers provide new construction and growth in the transit service area. Development may be either residential or commercial. Though both are concerned with access, the specific nature of those concerns may vary between residential and commercial development.

Employers - Employees and retail customers are potential transit riders. Employers benefit when their employees and customers can travel to work easily and efficiently.

Neighborhood groups - Neighborhood residents are potential consumers of transit service, and potential supporters of transit, whether they use this service or not.

Key destinations - These are the trip generators (central business districts, schools, shopping areas, public buildings, medical facilities, etc.) for those who work at these locations, and for those who use the services provided at these locations.

While the individual priorities of these players may vary, the players have the same interest in the potential benefit of timely, safe, and convenient transit service. They are the stakeholders in bus stop location and design. Although specific methods must vary to suit each particular situation, the challenge is to use their common interest to productively involve relevant players so that efficient transit service can result.

Chapter 2

THE BIG PICTURE

IDENTIFICATION OF NEED

Issues transit agencies consider when determining whether a bus stop is needed include the following:

Transit Agency Policy
- Route types (definitions and criteria)
- Guidelines for stop installation (boardings and alightings, headways, land use)
- Special cases/Exceptions (neighborhood requests, hospitals, procedures)

Equity
- Title 6 - Civil Rights Act of 1964 (equity in level of service among different segments of the community)
- Public Relations (perceptions, media attention, community leaders)
- Transit dependent areas (demographics, socioeconomics, unique needs)

Accessibility/ADA
- Access to the stop (sidewalks, curb cuts, pedestrian crossings)
- Access to amenities (shelter dimensions, width of walkways)
- Access at the stop (level loading area, lift deployment space)

Various factors relating to transit operations are also important in determining the need for a bus stop. Some of the more important factors are

Trip Generation/Land Use - How many potential bus passengers?

Walking Distance - How far do passengers have to walk?

Boardings and Alightings - How many passengers are getting on and off?

Dwell Time - How long does the bus dwell at the stop?

Travel Time - How long is the trip from the origin to the rider's destination?

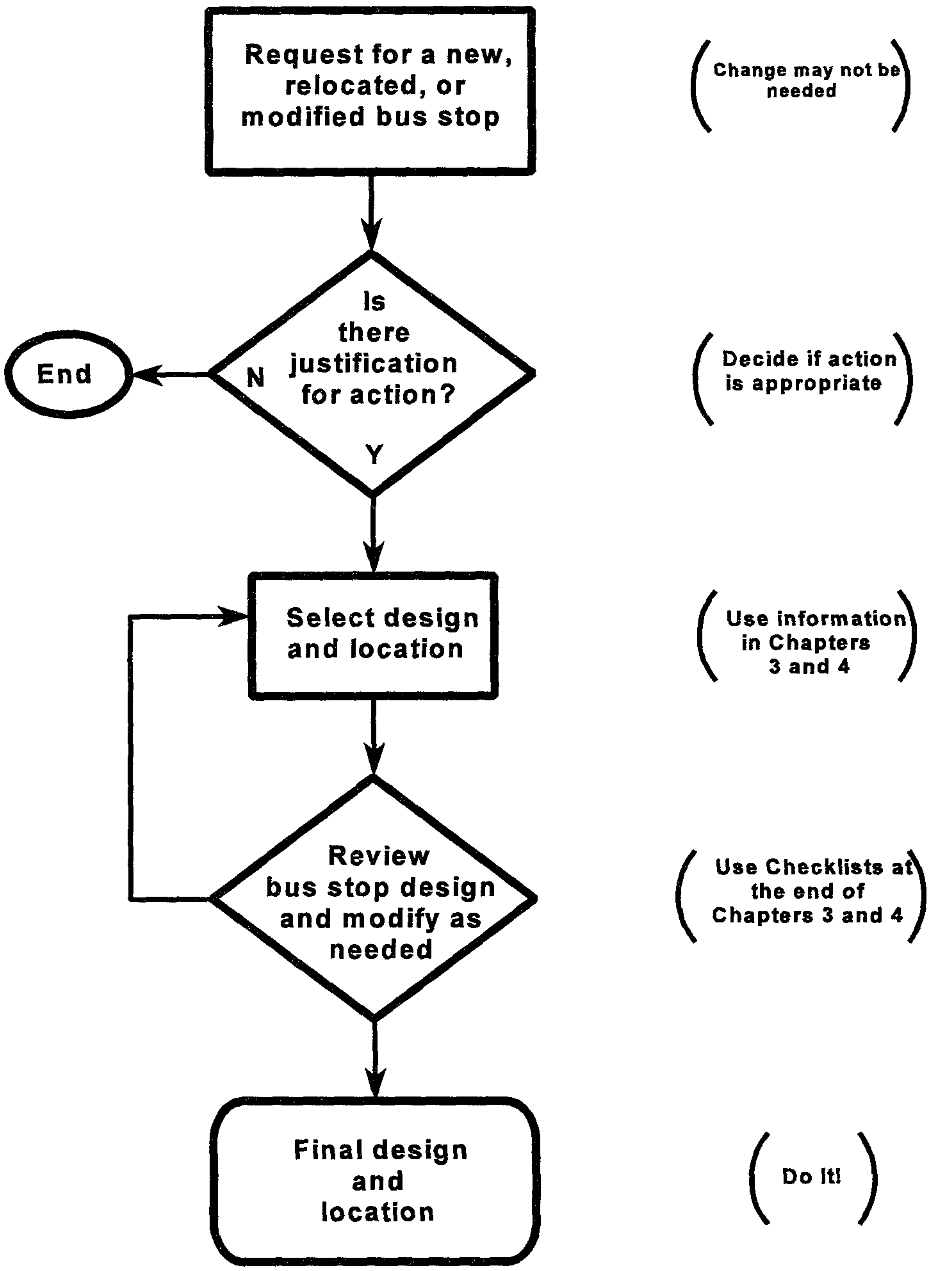
Transfer Potential - How many routes serve this stop?

THE BIG PICTURE

Chapter 2

LOCATION AND DESIGN FLOWCHART

Bus stop design and location decisions begin with the request or the recognition that a new or modified bus stop is needed. The process concludes with the implementation of numerous interrelated decisions. A flow chart of the decision process is shown below.



Chapter 2

THE BIG PICTURE

COORDINATION AND COOPERATION—Hypothetical Medical Center

Both transit and city officials agree that advantages exist when coordination occurs among governmental entities and with neighborhood organizations, developers and others. Most major successes (i.e., design and access, proper placement) involved a good, close working relationship between the transit agency and the city.

Hypothetical Medical Center Example

Locating bus stops at land uses surrounded by large parking lots is a common occurrence. This situation is especially evident along suburban arterials developed with current zoning regulations that encourage the building of extensive parking lots in front of the land use. The large parking lots serve as barriers between the bus stop and the land use. Bus patrons must walk through an uninviting environment (i.e., long stretches of asphalt, between parked cars) to reach the building or bus stop. The size of the parking lot also discourages the transit vehicle from boarding and alighting passengers directly adjacent to the building due to the potential for increased points of conflict with general vehicular traffic and pedestrians in the parking lot. The bus travel time and distance would also increase considerably if route deviations into parking lots occurred at every stop.

An example of the need to coordinate the location of the bus stop with the land use is illustrated by the hypothetical medical development on the following pages. Because elderly or medically disabled individuals may use this bus stop more than other bus stops along the route, it is critical that bus patrons are provided with a safe and direct route from the bus stop to the hospital.

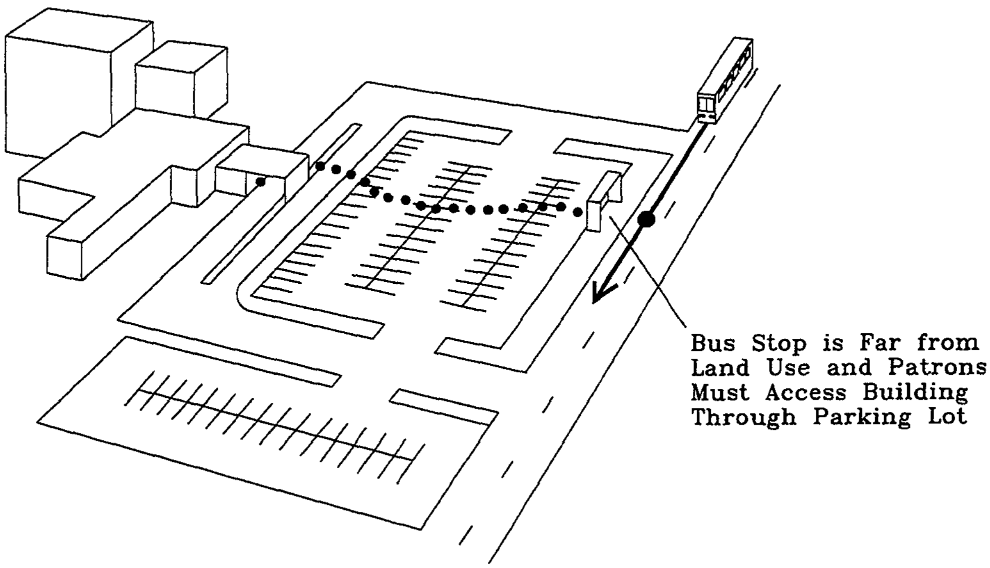
The examples show the potential problems and solutions associated with coordinating a bus stop with this type of development. Both existing and new development scenarios are presented and advantages and disadvantages of each potential solution are listed below. The large number of solutions for the same problem highlights the fact that each site can have multiple solutions. Coordination among the different players involved (i.e., transit agency, city, medical center, developer) can enhance the comfort and safety of bus patrons getting to this stop and can improve transit service to this site.

THE BIG PICTURE

Chapter 2

COORDINATION & COOPERATION—Hypothetical Medical Center

Hypothetical Medical Center: Providing access without coordination and cooperation.



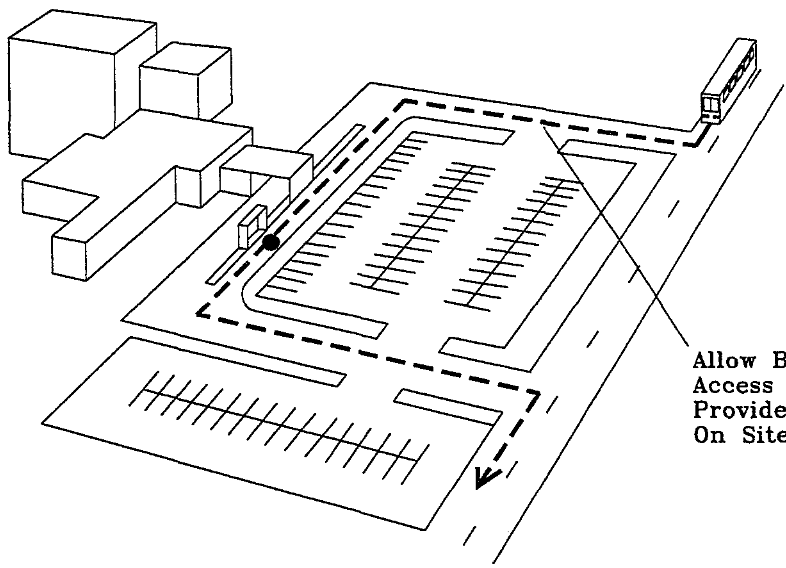
Positives:

- (+) Bus remains on a main thoroughfare, minimizing total travel time along the bus route.
- (+) Bus stop is more visible to passing vehicles and helps advertise the availability and location of public transit.

Negatives:

- (-) Patrons must walk through a vast parking lot to reach the medical center.
- (-) Potential exists for vehicular and pedestrian conflicts as patrons walk through parking lot.
- (-) Parking lot is uninviting and offers little in the way of environmental comfort.
- (-) Security of patrons may be compromised as they walk through parking lot.

Hypothetical Medical Center: Deviating the route.



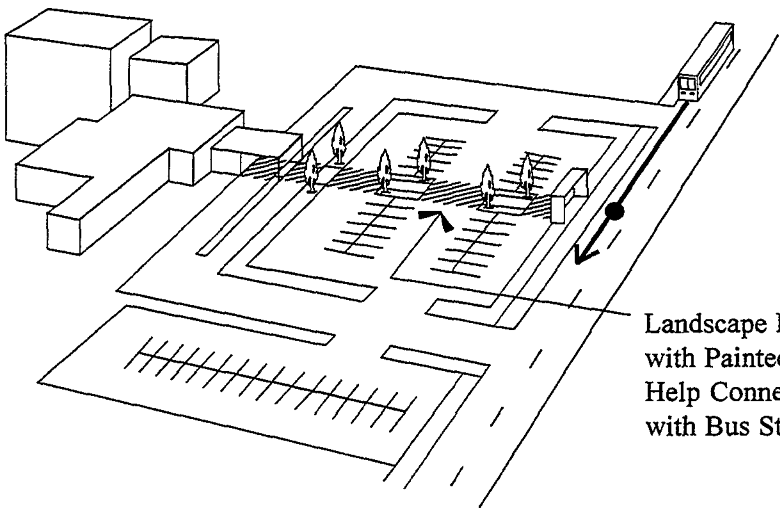
Positives:

- (+) Permits bus route to access land uses more directly.
- (+) Potential for shared use of overhang for bus patrons during inclement weather.
- (+) Reduces walking time and distance from the land use to the bus stop.
- (+) Reduces the potential for vehicular/pedestrian conflicts in the parking lot.
- (+) Patron security may be enhanced through proximity to land use. Indirect surveillance from the land use may be increased and the number of potential hiding places is removed by placing the stop adjacent to the building.

Negatives:

- (-) Bus/general vehicle conflicts may increase by having the route deviate into the parking areas.
- (-) Route travel time and distance are increased.

Hypothetical Medical Center: Installing a pedestrian promenade through the parking lot.



Positives:

- (+) Bus vehicle remains on a main thoroughfare, minimizing trip time and distance.
- (+) Reduces opportunity for pedestrian/vehicular conflicts in parking lot by constructing a well-defined pedestrian corridor.
- (+) Patron comfort is enhanced by providing shade trees along a promenade.
- (+) Security of patrons may be enhanced if the promenade is well-lit.

Negatives:

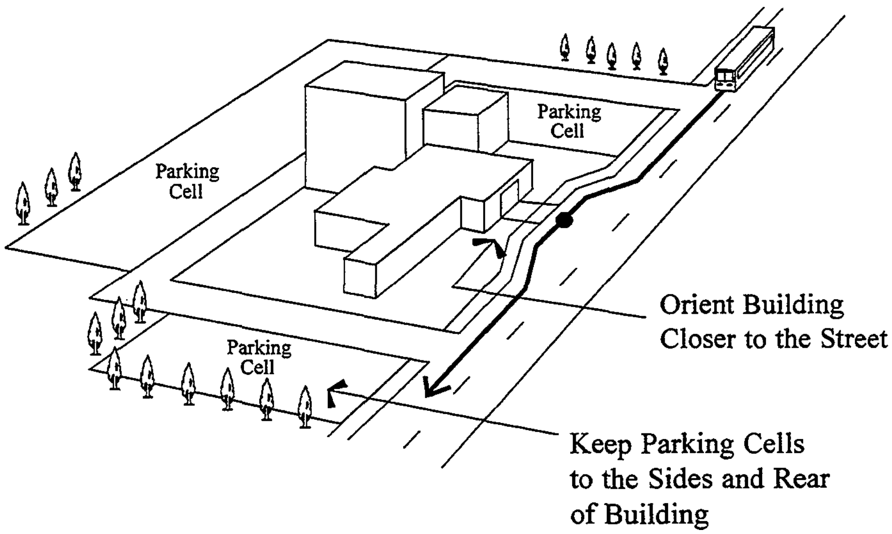
- (-) Does not reduce walking distance or time between the land use and the bus stop.
- (-) Patron security may still be compromised if the promenade is not well used, well-lit, or sight-lines are restricted by vegetation.

Chapter 2

THE BIG PICTURE

COORDINATION & COOPERATION—Hypothetical Medical Center

Hypothetical Medical Center: Orienting building closer to the street and having parking to the rear and sides of the facility.



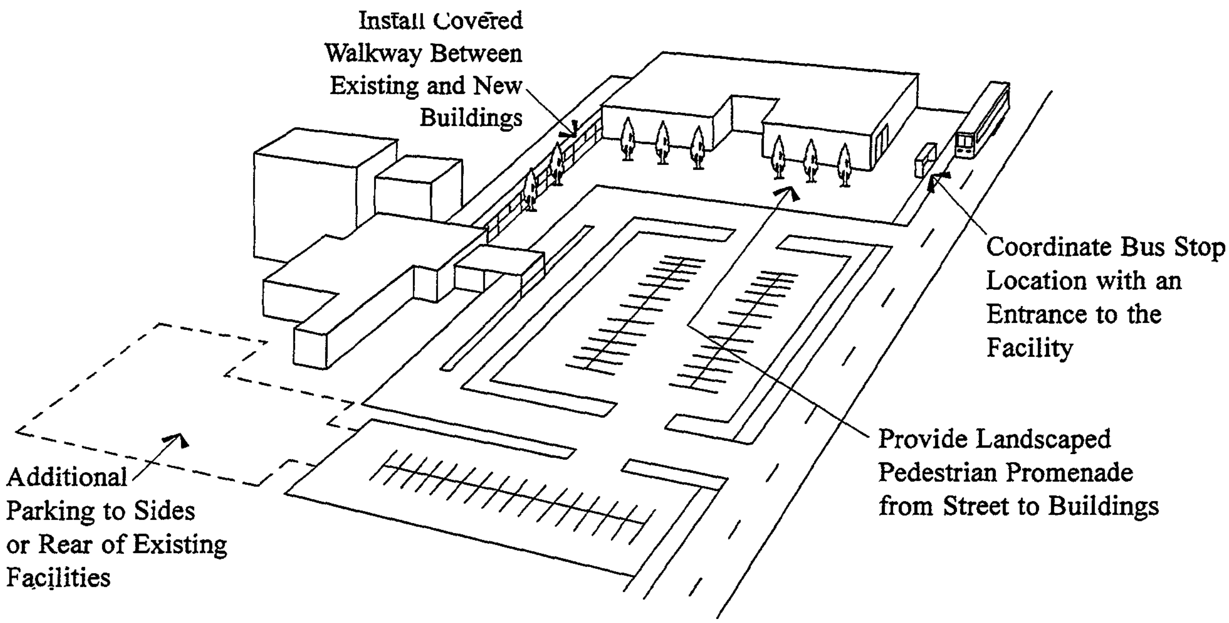
Positives:

- (+) Transit passenger walking time and distance is reduced since the building is near the road.
- (+) Patron security is enhanced by having indirect surveillance from the building and passing vehicular traffic.
- (+) Potential for pedestrian/vehicular conflicts are reduced between the land use and the bus stop.
- (+) Potential for shared use of the building facilities, such as overhangs and atriums, by bus patrons during inclement weather.
- (+) Bus remains on main route by eliminating the need to deviate into a parking lot.

Negatives:

- (-) Challenges traditional land use practices, which may make communities more reluctant to implement such a strategy.
- (-) Confusion may develop concerning responsibilities for the maintenance and up-keep of a bus stop that is near a major generator of activity.

Hypothetical Medical Center: Expanding facility.



Positives:

- (+) Bus vehicle remains on a main thoroughfare.
- (+) Pedestrian access to bus stop is enhanced by juxtaposing building with bus stop and having pedestrian promenades.
- (+) Bus patron comfort is enhanced by the addition of shade trees along the promenade and the installation of a covered walkway between buildings.
- (+) Reduces bus patron exposure to poor weather.

Negatives:

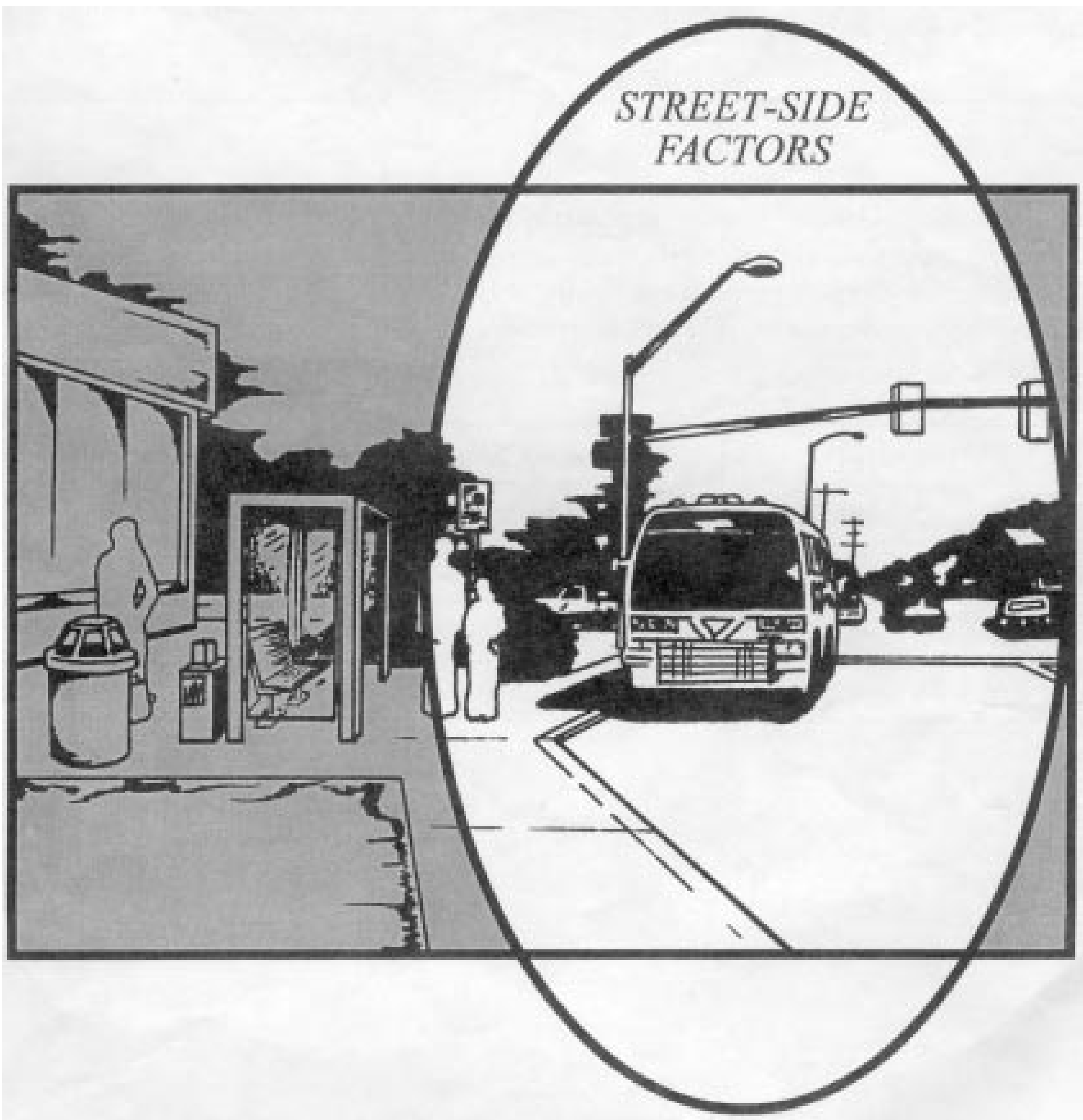
- (-) Pedestrian improvements are costly to construct.
- (-) Requires coordination among many different "players."
- (-) Orientation of new building and parking may challenge traditional land use practices.

STREET-SIDE FACTORS

Chapter 3

ORGANIZATION

Street-side factors include those factors associated with the roadway that influence bus operations. This chapter begins with discussion of bus stop placement. Next is information on bus stop zone design types. Following the detailed presentation of the different types of bus stops (e.g., bus bays, nubs, etc.) is discussion of vehicle characteristics. This is followed by information on how roadway and intersection design can accommodate the unique qualities of buses. The chapter ends with information on safety and a checklist for evaluating street-side factors.



Chapter 3

STREET-SIDE FACTORS

PLACEMENT CONSIDERATIONS—Stop Spacing

Bus stop spacing has a major impact on transit vehicle and system performance. Stop spacing also affects overall travel time, and therefore, demand for transit. In general, the trade-off is between:

Close stops (every block or 1/8 to 1/4 mile), short walk distances, but more frequent stops and a longer bus trip.	Versus	Stops farther apart, longer walk distances, but more infrequent stops, higher speeds, and therefore, shorter bus trips.

The determination of bus stop spacing is primarily based on goals that are frequently subdivided by development type, such as residential area, commercial, and/or a central business district (CBD). Another generally accepted procedure is placing stops at major trip generators. The following are typical bus stop spacings used. The values represent a composite of prevailing practices.

Environment	Spacing Range	Typical Spacing
Central Core Areas of CBDs	300 to 1000 feet	600 feet
Urban Areas	500 to 1200 feet	750 feet
Suburban Areas	600 to 2500 feet	1000 feet
Rural Areas	650 to 2640 feet	1250 feet

STREET-SIDE FACTORS

Chapter **3**

PLACEMENT CONSIDERATIONS—General Considerations

After ridership potential has been established, the most critical factors in bus stop placements are safety and avoidance of conflicts that would otherwise impede bus, car, or pedestrian flows.

In selecting a site for placement of a bus stop, the need for future passenger amenities is an important consideration (see Chapter 4). If possible, the bus stop should be located in an area where typical improvements, such as a bench or a passenger shelter, can be accommodated in the public right-of-way. The final decision on bus stop location is dependent on several safety and operating elements that require on-site evaluation. Elements to consider in bus stop placement include the following:

Safety:

- Passenger protection from passing traffic
- Access for people with disabilities
- All-weather surface to step from/to the bus
- Proximity to passenger crosswalks and curb ramps
- Proximity to major trip generators
- Convenient passenger transfers to routes with nearby stops
- Proximity of stop for the same route in the opposite direction
- Street lighting

Operating:

- Adequate curb space for the number of buses expected at the stop at one time
- Impact of the bus stop on adjacent properties
- On-street automobile parking and truck delivery zones
- Bus routing patterns (i.e., individual bus movements at an intersection)
- Directions (i.e., one-way) and widths of intersection streets
- Types of traffic signal controls (signal, stop, or yield)
- Volumes and turning movements of other traffic
- Width of sidewalks
- Pedestrian activity through intersections
- Proximity and traffic volumes of nearby driveways

Chapter 3 STREET-SIDE FACTORS

PLACEMENT OF BUS STOP—Far-Side, Near-Side, and Midblock Stops

Determining the proper location of bus stops involves choosing among far-side, near-side, and midblock stops (see Figure 1). Table 1 presents a comparison of the advantages and disadvantages of each bus stop type. The following factors should be considered when selecting the type of bus stop:

- Adjacent land use and activities
- Bus route (for example, is bus turning at the intersection)
- Bus signal priority (e.g., extended green suggests far side placement
- Impact on intersection operations
- Intersecting transit routes
- Intersection geometry
- Parking restrictions and requirements
- Passenger origins and destinations
- Pedestrian access, including accessibility for handicap/wheelchair patrons
- Physical roadside constraints (trees, poles, driveways, etc.)
- Potential patronage
- Presence of bus bypass lane
- Traffic control devices

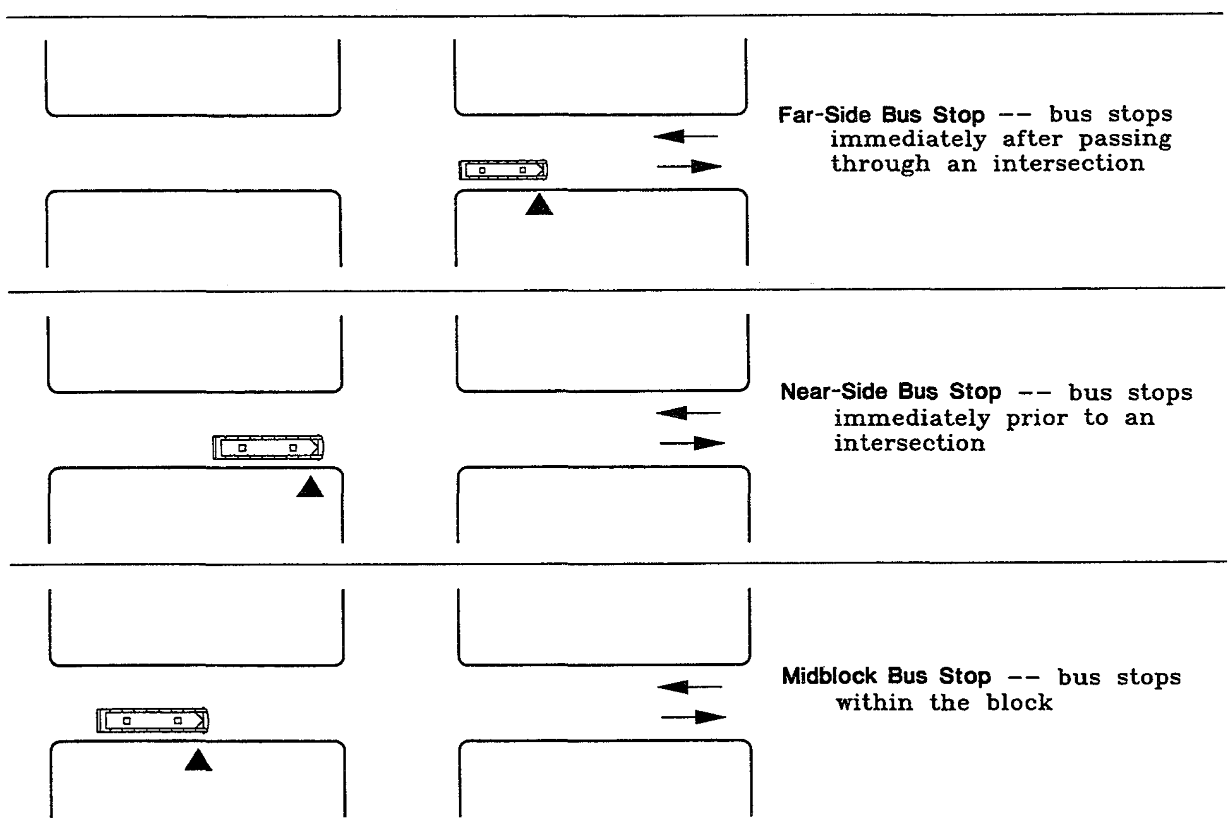


Figure 1. Example of Far-Side, Near-Side, and Midblock Stops.

STREET-SIDE FACTORS

Chapter 3

PLACEMENT OF BUS STOP—Far-Side, Near-Side, and Midblock Stops

Table 1. Comparative Analysis of Bus Stop Locations.

	Advantages	Disadvantages
Far-Side Stop	• Minimizes conflicts between right turning vehicles and buses • Provides additional right turn capacity by making curb lane available for traffic • Minimizes sight distance problems on approaches to intersection • Encourages pedestrians to cross behind the bus • Creates shorter deceleration distances for buses since the bus can use the intersection to decelerate • Results in bus drivers being able to take advantage of the gaps in traffic flow that are created at signalized intersections	• May result in the intersections being blocked during peak periods by stopping buses • May obscure sight distance for crossing vehicles • May increase sight distance problems for crossing pedestrians • Can cause a bus to stop far side after stopping for a red light, which interferes with both bus operations and all other traffic • May increase number of rear-end accidents since drivers do not expect buses to stop again after stopping at a red light • Could result in traffic queued into intersection when a bus is stopped in travel lane
Near-Side Stop	• Minimizes interferences when traffic is heavy on the far side of the intersection • Allows passengers to access buses closest to crosswalk • Results in the width of the intersection being available for the driver to pull away from curb • Eliminates the potential of double stopping • Allows passengers to board and alight while the bus is stopped at a red light • Provides driver with the opportunity to look for oncoming traffic, including other buses with potential passengers	• Increases conflicts with right-turning vehicles • May result in stopped buses obscuring curbside traffic control devices and crossing pedestrians • May cause sight distance to be obscured for cross vehicles stopped to the right of the bus • May block the through lane during peak period with queuing buses • Increases sight distance problems for crossing pedestrians.
Mid-block Stop	• Minimizes sight distance problems for vehicles and pedestrians • May result in passenger waiting areas experiencing less pedestrian congestion	• Requires additional distance for no-parking restrictions • Encourages patrons to cross street at midblock (jaywalking) • Increases walking distance for patrons crossing at intersections

Chapter 3 STREET-SIDE FACTORS

BUS STOP ZONE DESIGN TYPES—Types of Stops

Various configurations of a roadway are available to accommodate bus service at a stop. Figure 2 illustrates different street-side bus stop design while Table 2 presents their advantages and disadvantages.

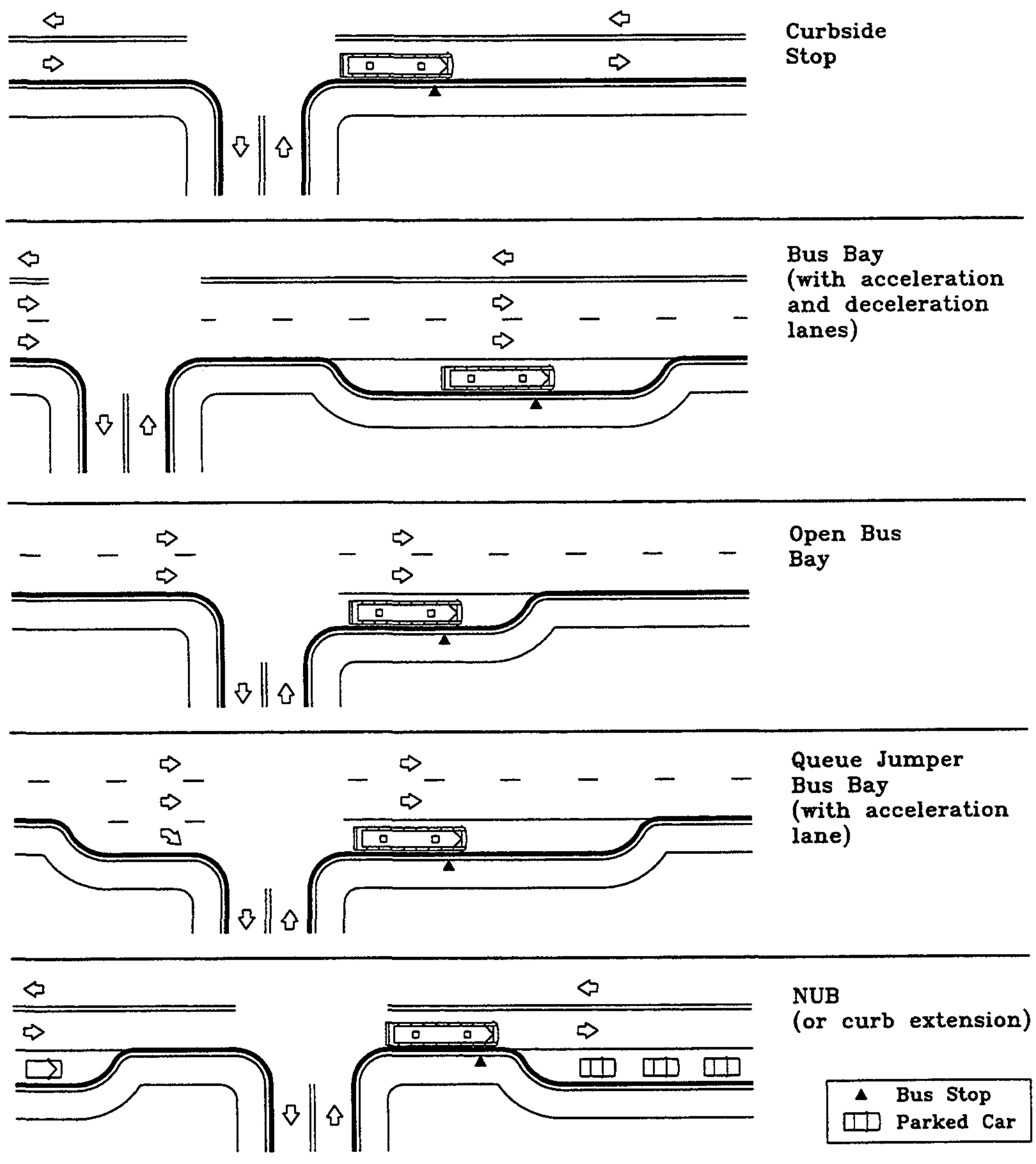


Figure 2. Street-Side Bus Stop Design.

Table 2. Comparative Analysis of Types of Stops.

Type of Stop	Advantages	Disadvantages
Curb-side	• Provides easy access for bus drivers and results in minimal delay to bus • Is simple in design and easy and inexpensive for a transit agency to install • Is easy to relocate	• Can cause traffic to queue behind stopped bus, thus causing traffic congestion • May cause drivers to make unsafe maneuvers when changing lanes in order to avoid a stopped bus
Bus Bay	• Allows patrons to board and alight out of the travel lane • Provides a protected area away from moving vehicles for both the stopped bus and the bus patrons • Minimizes delay to through traffic	• May present problems to bus drivers when attempting to re-enter traffic, especially during periods of high roadway volumes • Is expensive to install compared with curbside stops • Is difficult and expensive to relocate
Open Bus Bay	• Allows the bus to decelerate as it moves through the intersection • See Bus Bay advantages	• See Bus Bay disadvantages
Queue Jumper Bus Bay	• Allows buses to bypass queues at a signal • See Open Bus Bay advantage	• May cause delays to right-turning vehicles when a bus is at the start of the right turn lane • See Bus Bay disadvantages
Nub	• Removes fewer parking spaces for the bus stop • Decreases the walking distance (and time) for pedestrians crossing the street • Provides additional sidewalk area for bus patrons to wait • Results in minimal delay for bus	• Costs more to install compared with curbside stops • See Curb-side disadvantages

Chapter 3

STREET-SIDE FACTORS

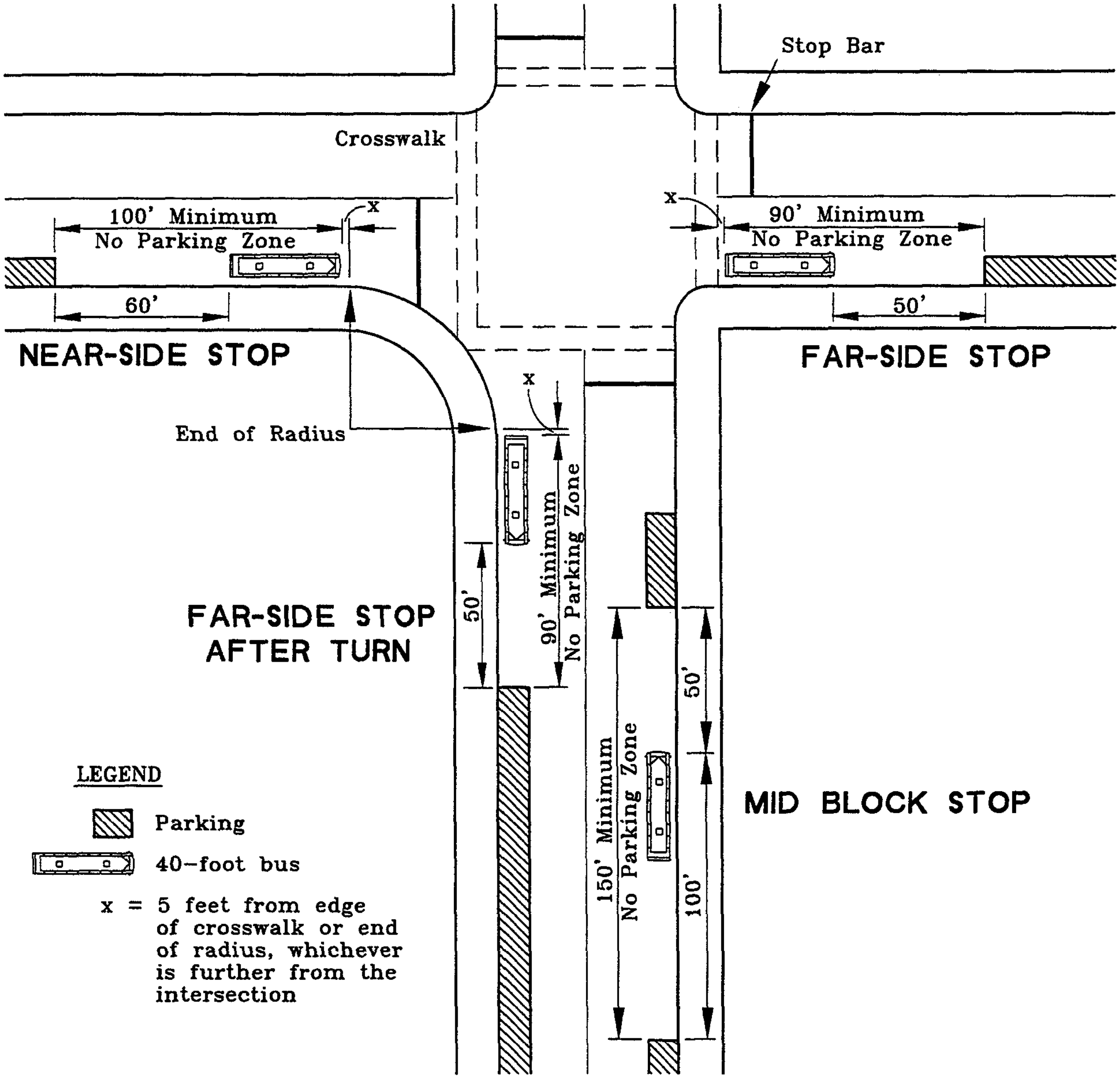
BUS STOP ZONE DESIGN TYPES—Curb-Side Bus Stop Zone Dimensions

A bus stop zone is the portion of a roadway marked or signed for use by buses when loading or unloading passengers. The lengths of bus stop zones vary among different transit agencies. In general, bus stop zones for far-side and near-side stops are a minimum of 90 and 100 feet, respectively, and midblock stops are a minimum of 150 feet. Far-side stops after a turn typically have a minimum 90-foot zone, however, a longer zone will result in greater ease for a bus driver to position the bus. Bus stop zones are increased by 20 feet for articulated buses. Representative dimensions for bus stop zones are illustrated in Figure 3.

More than one bus may be at a stop at a given time. The number of bus-loading positions required at a given location depends on 1) the rate of bus arrivals and 2) passenger service time at the stop. Table 3 presents suggested bus stop capacity requirements based on a range of bus flow rates and passenger service times. For example, if the service time at a stop is 30 seconds and there are 60 buses expected in the peak hour, two bus loading positions are needed. The arrival rate is based on a Poisson (random) arrival rate and a 5 percent chance the bus zone capacity will be exceeded.

Table 3. Recommended Bus Stop Bay Requirements.

Peak-Hour Bus Flow	Capacity Required (Bays) When Service Time at Stop Is				
	10 Seconds	20 Seconds	30 Seconds	40 Seconds	60 Seconds
15	1	1	1	1	1
30	1	1	1	1	2
45	1	1	2	2	2
60	1	1	2	2	3
75	1	2	2	3	3
90	1	2	2	3	4
105	1	2	3	3	4
120	1	2	3	3	5
150	2	3	3	4	5
180	2	3	4	5	6



Notes:

1) Add 20 feet to bus stop zones for an articulated bus.
2) Increase bus stop zone by 50 feet for each additional standard 40-foot bus or 70 feet for each additional 60-foot articulated bus expected to be at the stop simultaneously. See Table 3 for the suggested bus stop capacity requirements based on a range of bus flow rates and passenger service times.

Figure 3. Typical Dimensions for On-Street Bus Stops.

Chapter 3 STREET-SIDE FACTORS

BUS STOP ZONE DESIGN TYPES—Bus Bay

A bus bay (or turnout) is a specially constructed area separated from the travel lanes and off the normal section of a roadway that provides for the pick up and discharge of passengers (see Figure 4). This design allows through traffic to flow freely without the obstruction of stopped buses. Bus bays are provided primarily on high-volume or high-speed roadways, such as suburban arterial roads. Additionally, bus bays are frequently constructed in heavily congested downtown and shopping areas where large numbers of passengers may board and alight.

Figure 4. Example of a Bus Bay.

Bus bays should be considered at a location when the following factors are present:

- Traffic in the curb lane exceeds 250 vehicles during the peak hour,
- Traffic speed is greater than 40 mph,
- Bus volumes are 10 or more per peak hour on the roadway,
- Passenger volumes exceed 20 to 40 boardings an hour,
- Average peak-period dwell time exceeds 30 seconds per bus,
- Buses are expected to layover at the end of a trip,
- Potential for auto/bus conflicts warrants separation of transit and passenger vehicles,
- History of repeated traffic and/or pedestrian accidents at stop location,
- Right-of-way width is adequate to construct the bay without adversely affecting sidewalk pedestrian movement,
- Sight distances (i.e., hills, curves) prevent traffic from stopping safely behind a stopped bus,
- A right-turn lane is used by buses as a queue jumper lane,
- Appropriate bus signal priority treatment exists at an intersection,
- Bus parking in the curb lane is prohibited, and
- Improvements, such as widening, are planned for a major roadway. (This provides the opportunity to include the bus bay as part of the reconstruction, resulting in a better-designed and less-costly bus bay.)

Evidence shows that bus drivers will not use a bus bay when traffic volumes exceed 1000 vehicles per hour per lane. Drivers explain that the heavy volumes make it extremely difficult to maneuver a bus out of a midblock or near-side bay, and that the bus must wait an unacceptable period of time to re-enter the travel lane. Consideration should be given to these concerns when contemplating the design of a bay on a high-volume road. Using acceleration lanes, signal priority, or far-side (versus near-side or midblock) placements are potential solutions.

BUS STOP ZONE DESIGN TYPES—Bus Bay Dimensions

The total length of the bus bay should allow room for an entrance taper, a deceleration lane, a stopping area, an acceleration lane, and an exit taper (see Figure 5). However, the common practice is to accept deceleration and acceleration in the through lanes and only build the tapers and the stopping area. Providing separate deceleration and acceleration lanes is desirable on suburban arterial roads and should be incorporated in the design wherever feasible.

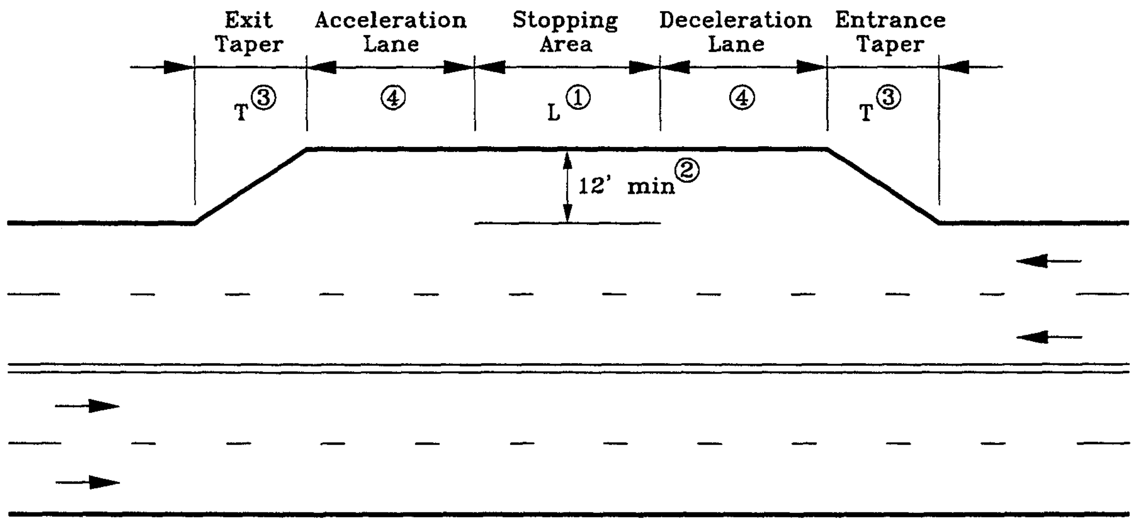
An acceleration lane in a bay design allows a bus to obtain a speed that is within an acceptable range of the through traffic speed and more comfortably merge with the through traffic. The presence of a deceleration lane enables buses to decelerate without inhibiting through traffic. Typical bus bay dimensions (minimum and recommended) are shown in Figure 5. Where bike lanes are provided, a bus bay should include a marked through lane to guide bicyclists along the outside of the bus bay.

Following are some guidelines on where to locate bus bays (e.g., far side or near side):

- Far-side intersection placement is desirable (may vary with site conditions). Bus bays should be placed at signal-controlled intersections so that the signal can create gaps in traffic.

- Near-side bays should be avoided because of conflicts with right-turning vehicles, delays to transit service as buses attempt to re-enter the travel lane, and obstruction of traffic control devices and pedestrian activity.

- Midblock bus bay locations are not desirable unless associated with key pedestrian access to major transit-oriented activity centers.



Notes:

1) Stopping area length consists of 50 feet for each standard 40-foot bus and 70 feet for each 60-foot articulated bus expected to be at the stop simultaneously. See Table 3 for the suggested bus stop capacity requirements based on a range of bus flow rates and passenger service times.
2) Bus bay width is desirably 12 feet. For traffic speeds under 30 mph, a 10-foot minimum bay width is acceptable. These dimensions do not include gutter width.
3) Suggested taper lengths are listed in table below. Desirable taper length is equal to the major road through speed multiplied by the width of the turnout bay. A taper of 5:1 is a desirable minimum for an entrance taper to an arterial street bus bay while the merging or re-entry taper should not be sharper than 3:1.
4) Minimum design for a busy bay does not include acceleration or deceleration lanes. Recommended acceleration and deceleration lengths are listed in the table below.

Through Speed (mph)	Entering Speed[a] (mph)	Length of Acceleration Lane (Feet)	Length of Deceleration Lane[b] (Feet)	Length of Taper (Feet)
35	25	250	184	170
40	30	400	265	190
45	35	700	360	210
50	40	975	470	230
55	45	1400	595	250
60	50	1900	735	270

[a] Bus speed at end of taper, desirable for buses to be within 10 mph of travel lane vehicle speed at the end of the taper.
[b] Based on 2.5 mph/sec deceleration rate.

Figure 5. Typical Bus Bay Dimensions.

Chapter 3

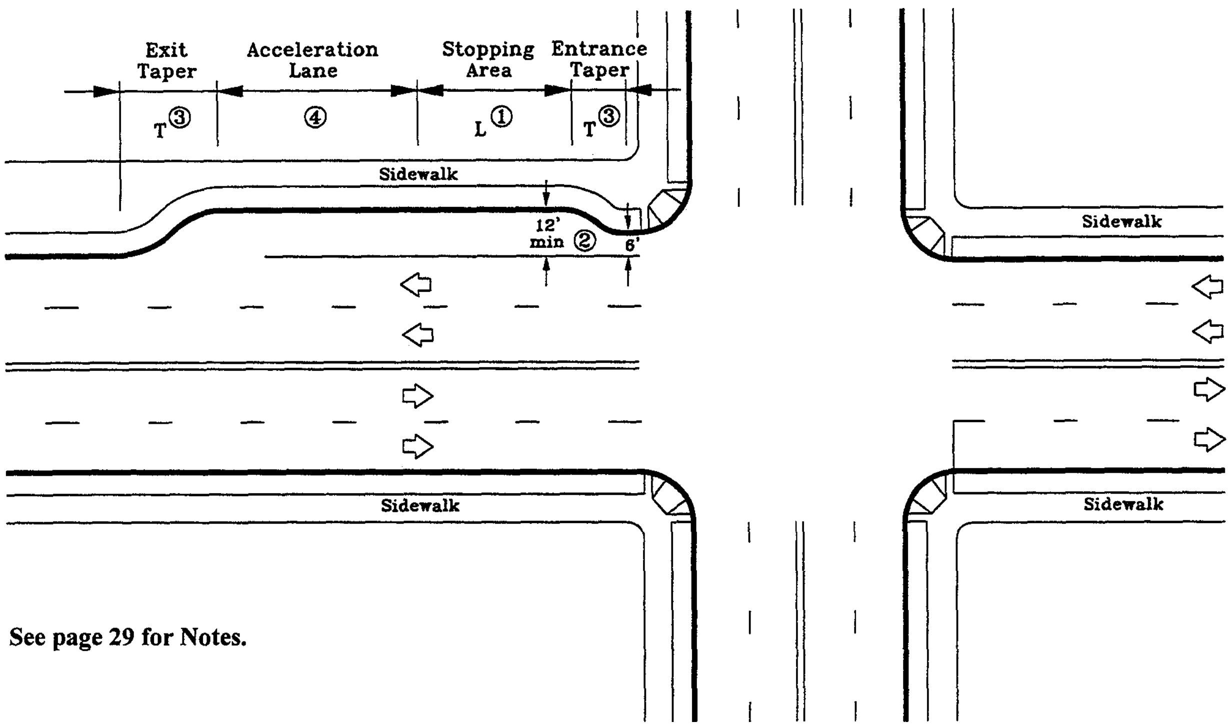
STREET-SIDE FACTORS

BUS STOP ZONE DESIGN TYPES—Open Bus Bay

The open bus bay design is a variation of the bus bay design. In an open bus bay design, the bay is open to the upstream intersection (see Figure 6 for an example). The bus driver has the pavement width of the upstream cross street available to decelerate and to move the bus from the travel lane into the bay. Advantages of this design include allowing the bus to move efficiently into the bay as well as allowing the bus to stop out of the flow of traffic. Re-entry difficulties are not eliminated; however, they are no more difficult than with the typical bus bay design. A disadvantage for pedestrians is that the pedestrian crossing distance at an intersection increases with an open bus bay design because the intersection width has been increased by the width of the bay.

Figure 6. Bus Approaching an Open Bus Bay.

Another alternative to the bus bay design is a partial open bus bay (or a partial sidewalk extension). This alternative allows buses to use the intersection approach in entering the bay and provides a partial sidewalk extension to reduce pedestrian street-crossing distance. It also prevents right-turning vehicles from using the bus bay for acceleration movements. Figure 7 illustrates the design for a partial open bus bay.



See page 29 for Notes.

Figure 7. Partial Open Bus Bay.

Chapter 3

STREET-SIDE FACTORS

BUS STOP ZONE DESIGN TYPES—Queue Jumper Bus Bay

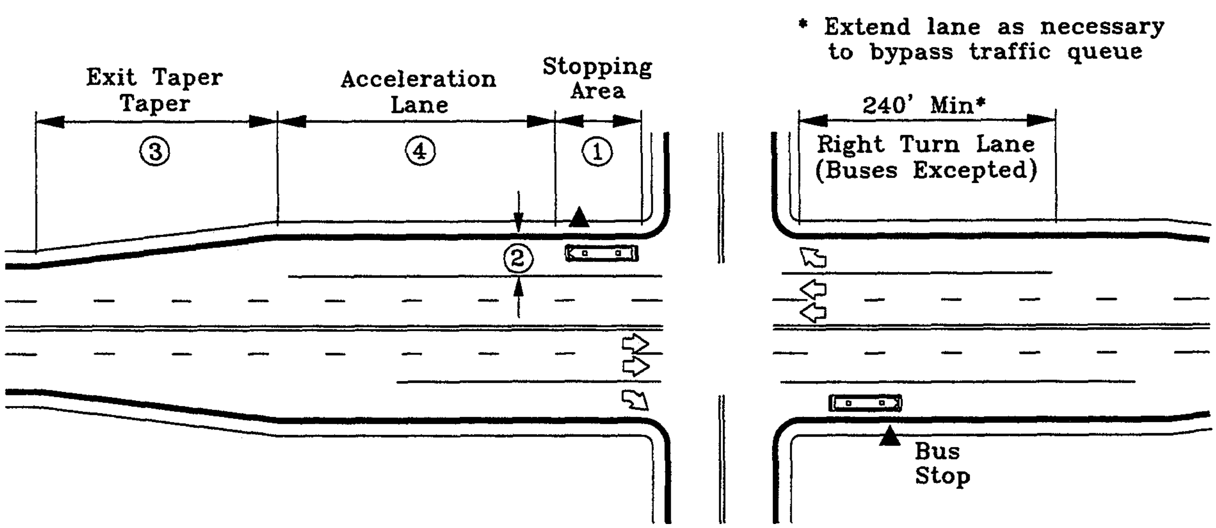
Queue jumper bus bays provide priority treatment for buses along arterial streets by allowing buses to bypass traffic queued at congested intersections. These bus stops consist of a near-side, right-turn lane and a far-side open bus bay. Buses are allowed to use the right-turn lane to bypass traffic congestion and proceed through the intersection. The right-turn lane could be signed "Right Turns Only—Buses Excepted." Queue jumpers provide the double benefit of removing stopped buses from the traffic stream (to benefit general traffic operations) and guiding moving buses through congested intersections (to benefit bus operations). Figure 8 is a photograph of a queue jumper bus bay while Figure 9 illustrates the layout for a queue jumper bus bay.

Figure 8. Example of a Queue Jumper Bus Bay.

According to the transit agencies that use queue jumper bus bays, these bays should be considered at arterial street intersections when the following factors are present:

- High-frequency bus routes have an average headway of 15 minutes or less;
- Traffic volumes exceed 250 vehicles per hour in the curb lane during the peak hour;
- The intersection operates at a level of service "D" or worse (see the Transportation Research Board's *Highway Capacity Manual* for techniques on evaluating the operations at an intersection); and
- Land acquisitions are feasible and costs are affordable.

An exclusive bus lane, in addition to the right-turn lane, should be considered when right-turn volumes exceed 400 vehicles per hour during the peak hour.



Notes for Comments 1, 2, 3, and 4 are on page 29.

Figure 9. Queue Jumper Bus Bay Layout.

Chapter 3 STREET-SIDE FACTORS

BUS STOP ZONE DESIGN TYPES—Nub

Nubs are a section of sidewalk that extend from the curb of a parking lane to the edge of the through lane (see Figure 10). Nubs have been used as traffic-calming techniques and as bus stops. When used as a bus stop, the buses stop in the traffic lane instead of weaving into the bus stop that is located in the parking lane—therefore, they operate similarly to curb-side bus stops. Nubs offer additional area for patrons to walk and wait for a bus and provide space for bus patron amenities, such as shelters and benches. Other names used for nubs include "curb extensions" and "bus bulbs."

Nubs reduce pedestrian crossing distances, create additional parking (compared with typical bus zones), and mitigate traffic conflicts between autos and buses merging back into the traffic stream. Nubs should be designed to allow for an adequate turning radius for right-turn vehicles. Figure 11 is a schematic of a typical bus stop nub design.

Nubs should be considered at sites with the following characteristics:

- High pedestrian activity,
- Crowded sidewalks,
- Reduced pedestrian crossing distances, and
- Bus stops in travel lanes.

Figure 10. Example of a Nub.

Nubs have particular application along streets with lower traffic speeds and/or low traffic volumes where it would be acceptable to stop buses in the travel lane. Collector streets in neighborhoods and designated pedestrian districts are good candidates for this type of bus stop. Nubs should be designed to accommodate vehicle turning movements to and from side streets.

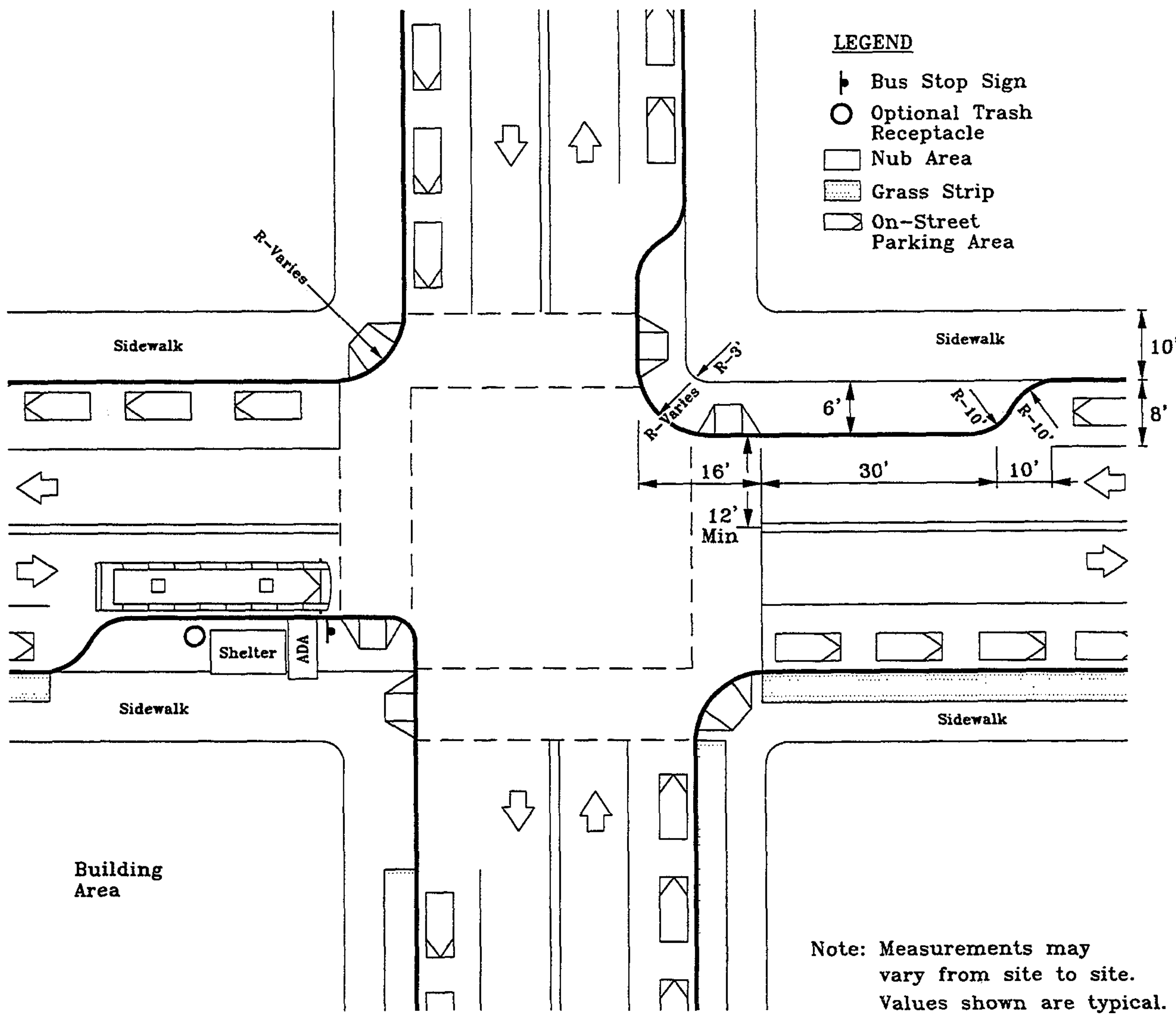
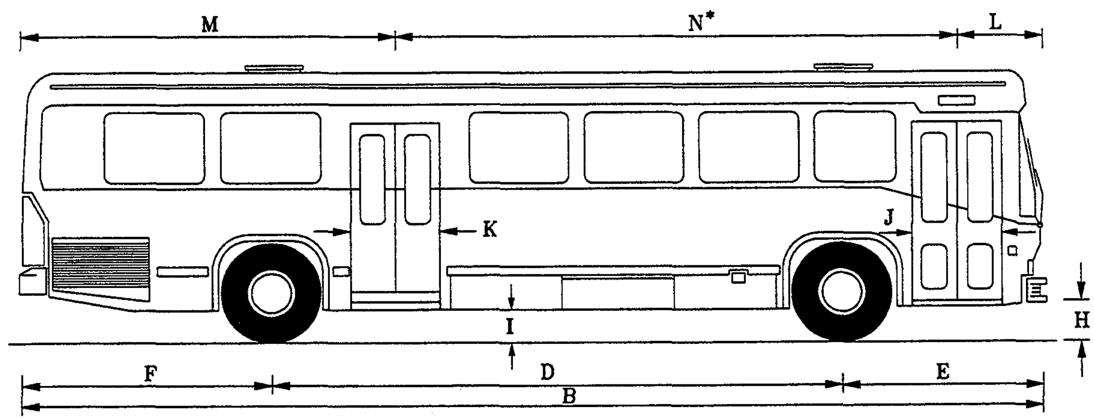


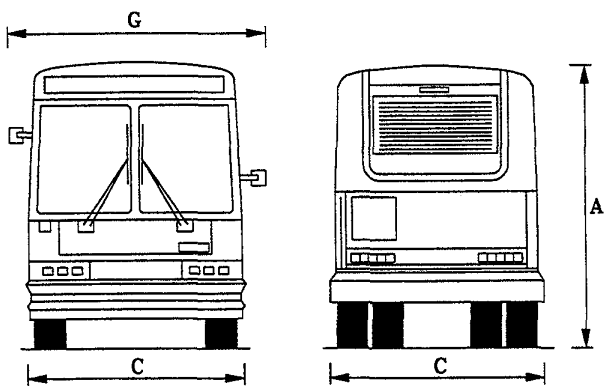
Figure 11. Typical Dimensions for a Nub.

Chapter 3 STREET-SIDE FACTORS

VEHICLE CHARACTERISTICS—Vehicle Types and Dimensions

In the design of facilities for buses, it is important to define a design vehicle that represents a compilation of critical dimensions from those vehicles currently in operation. These dimensions are used when designing roadway features. For example, the weight of the expected vehicle is important to pavement design. The following two basic bus types are commonly used by transit service providers: 1) 40-foot "standard" bus; and 2) 60-foot articulated bus.





ITEM		
A	Overall Height	10' 9"
B	Overall Length	40' 0"
C	Overall Width	8' 6"
D	Wheel Base	23' 9"
E	Front Axle to Bumper	7' 3-3/4"
F	Rear Axle to Bumper	9' 4-3/4"
G	Edge Mirror to Mirror	10' 2"
H	Step to Ground, Entrance	1' 5"
I	Step to Ground, Exit	1' 4-1/2"
J	Clear Door Opening, Entrance	2' 6"
K	Clear Door Opening, Exit	2' 2-1/2"
L	Centerline Door to Front	3' 0"
M	Centerline Door to Rear	17' 11-1/4"
N	Centerline Door to Door	19' 8"

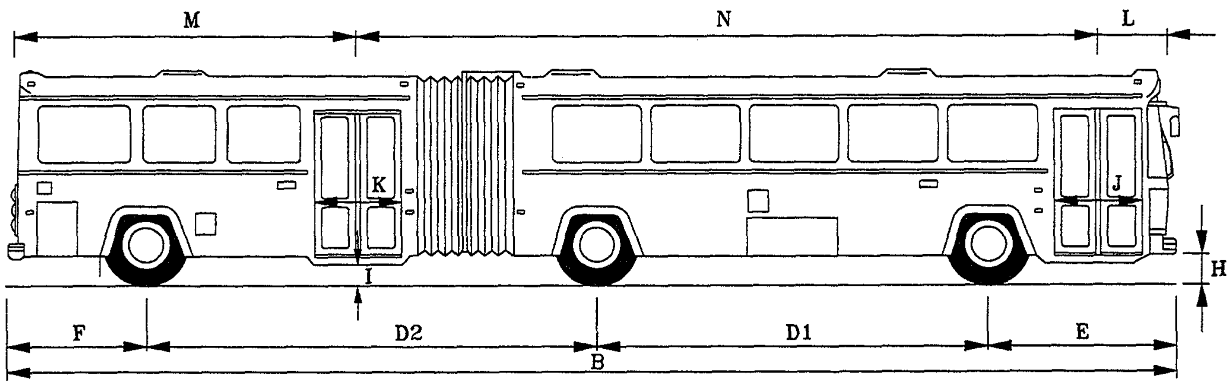
NET/GROSS VEHICLE WEIGHT **	
Front Axle	7,420/11,980
Rear Axle	18,060/24,660
Seating Capacity	51
Standing Capacity	25

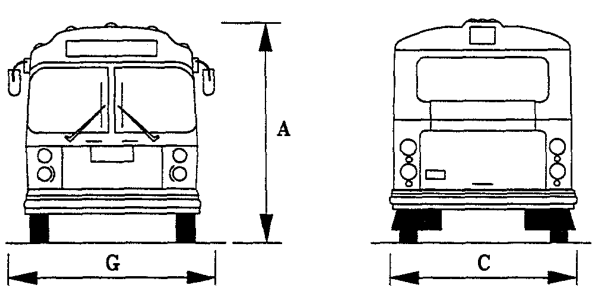
NOTES

* Varies for different types of 40' buses
** Net Weight is "Road Ready" Without Passengers
Gross Includes Passengers

Figure 12. Typical Dimensions for 40-Foot Bus.

The standard 40-foot bus and the 60-foot articulated bus are generally the largest buses in a transit fleet and represent the most common designs. (Currently, manufacturers are also producing 30- and 35-foot buses.) Key roadway design features, such as lane and shoulder widths, lateral and vertical clearances, vehicle storage dimensions, and minimum turning radii are typically based on the standard 40-foot bus. The articulated bus, while longer, has a "hinge" near the center of the vehicle that allows maneuverability comparable to the 40-foot bus. Figures 12 and 13 show the dimensions for a 40-foot and 60-foot bus, respectively.





NET/GROSS VEHICLE WEIGHT*	
Front Axle	11,800/16,420
Rear Axle	12,130/16,420
Center Axle	14,970/24,250

MAXIMUN BEND ANGLE	
Horizontal	± 36 deg
Vertical	± 11 deg

Seating Capacity	70

ITEM		
A	Overall Height	10' 4"
B	Overall Length	59'10"
C	Overall Width	8' 6"
D	Wheel Base (D1/D2)	18'7"/24'0"
E	Front Axle to Bumper	8'8"
F	Rear Axle to Bumper	8'8"
G	Edge Mirror to Mirror	10' 6"
H	Step to Ground, Entrance	1' 2"
I	Step to Ground, Exit	1' 2"
J	Clear Door Opening, Entrance	3' 8"
K	Clear Door Opening, Exit	3' 6"
L	Centerline Door to Front	3' 6"
M	Centerline Door to Rear	21'4"
N	Centerline Door to Door	35'0"

* Net Weight is "Road Ready" Without Passengers
Gross Includes Passengers

Figure 13. Typical Dimensions for 60-Foot Articulated Bus.

STREET-SIDE FACTORS

VEHICLE CHARACTERISTICS—Turning Radium Template

Design templates for minimum turning paths for single-unit (40-foot) and articulated (60-foot) buses are shown in Figures 14 and 15, respectively. The templates are usable for either left turn or right turn designs depending on how the template is oriented (i.e., either face-up for right turn design or face-down for left turn design).

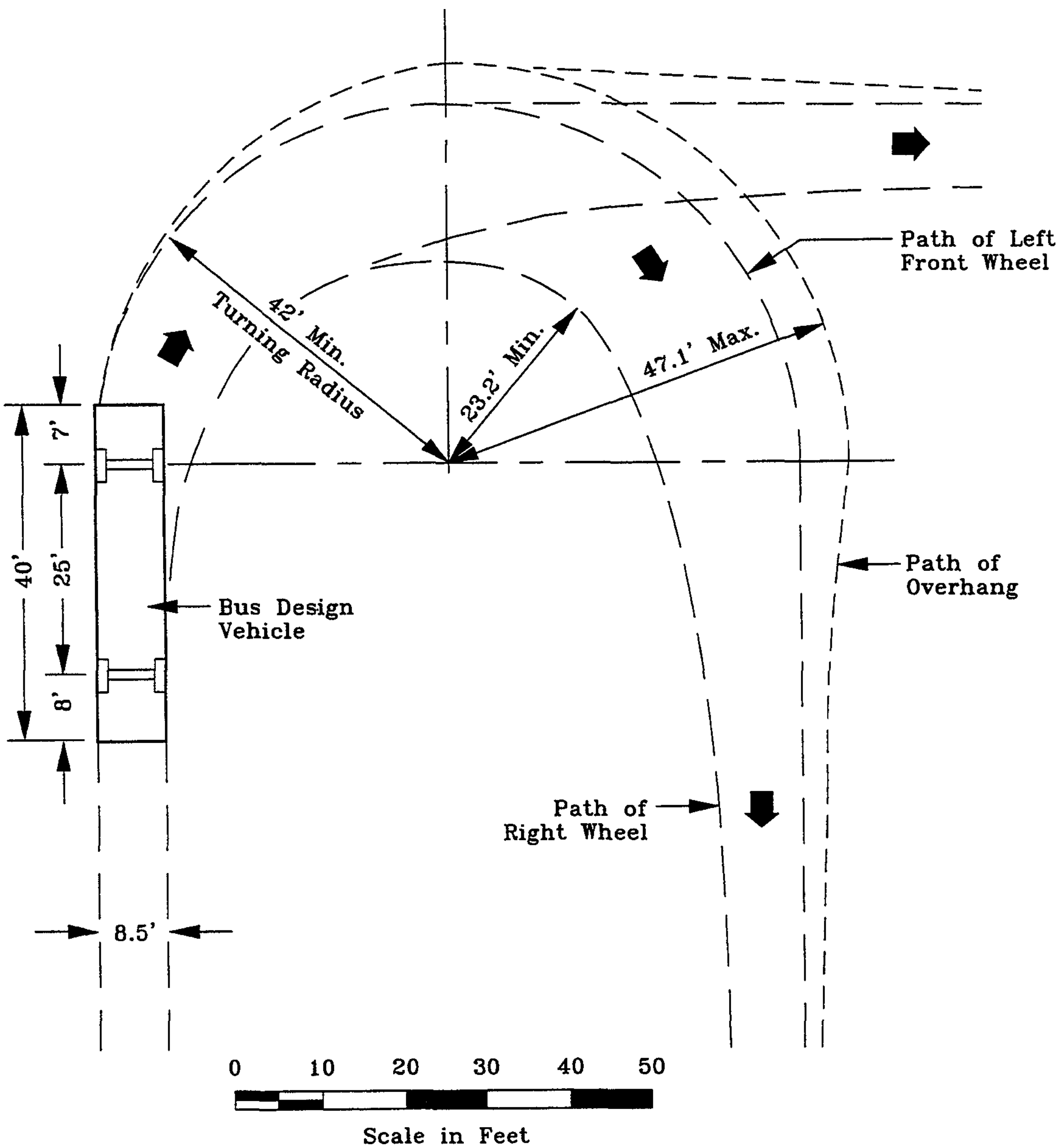


Figure 14. Design Template for Single-Unit (40 foot) Bus.

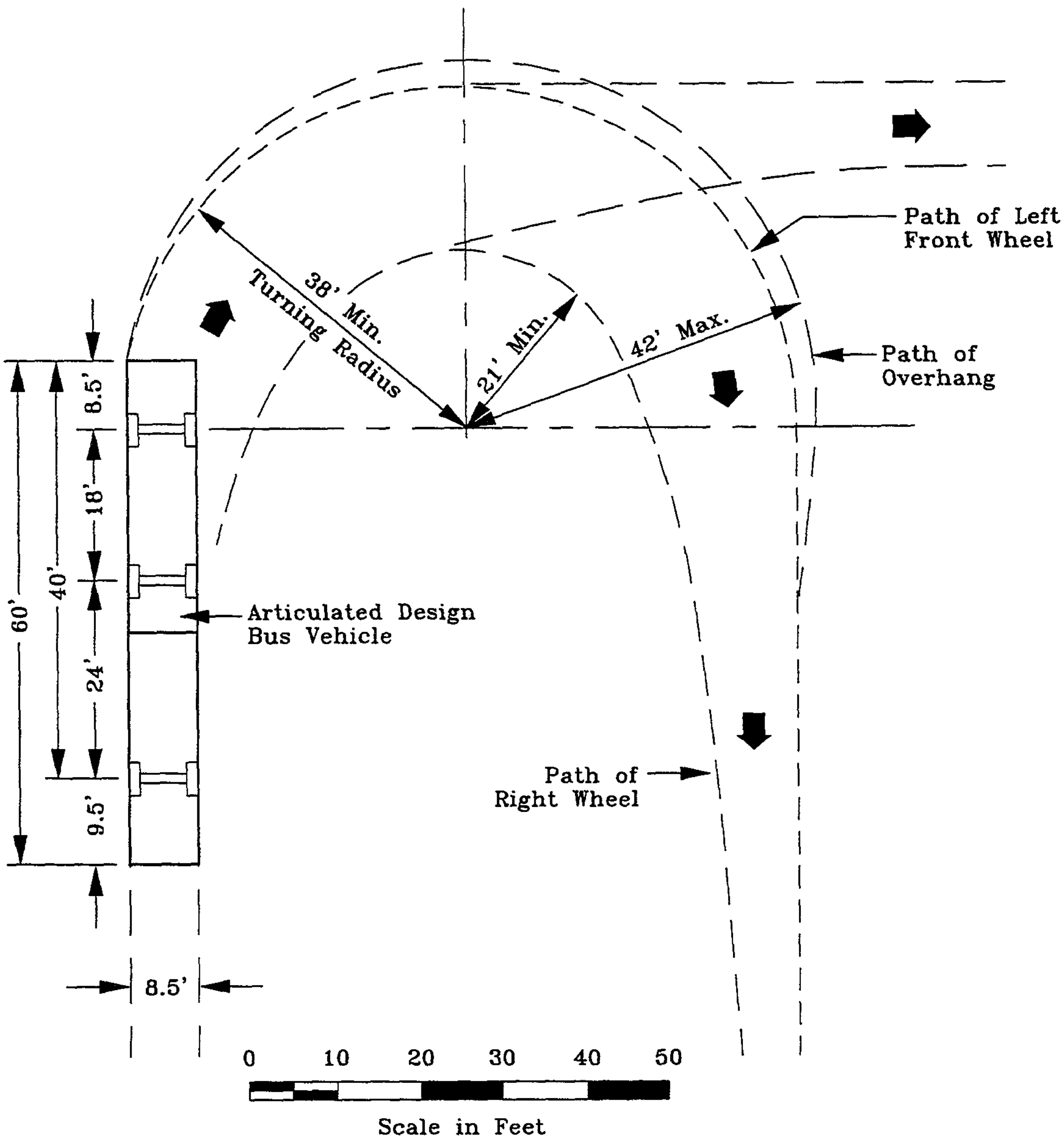


Figure 15. Design Template for Articulated (60-foot) Bus.

STREET-SIDE FACTORS

VEHICLE CHARACTERISTICS—Wheelchair Lift

Presently, the most common lifts used on buses are conventional wheelchair lifts. Figure 16 illustrates the use of a wheelchair lift. Since the wheelchair lift may be at the front or rear door, bus stop designs need to allow for either possibility. Figure 17 shows the critical dimensions for a wheelchair lift.

Low floor buses can be adjusted so the floor height is approximately 10 inches above the street level. Bus passengers in wheelchairs are then able to reach the sidewalk by using a ramp deployed from the floor of the bus. The length of the ramp typically extends 2 to 3 feet from the edge of the bus for a standard height curb.

Figure 16. Wheelchair Lift in Operation.

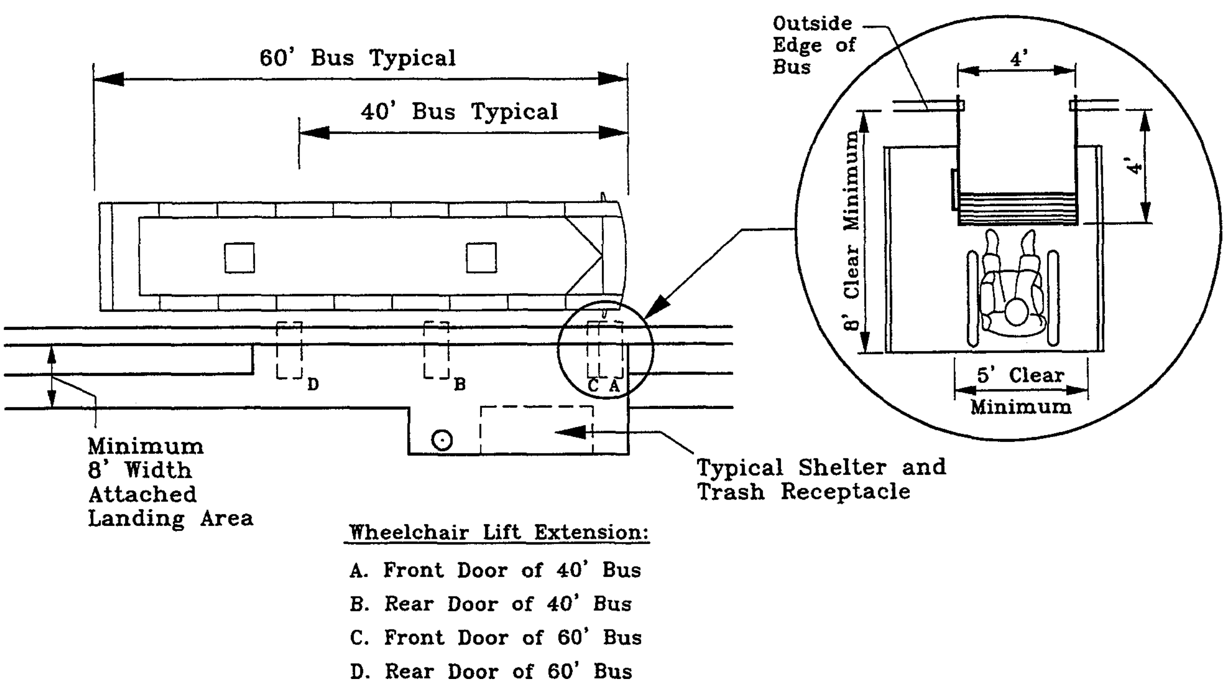


Figure 17. Wheelchair Lift Dimensions.

STREET-SIDE FACTORS

Chapter **3**

VEHICLE CHARACTERISTICS—Bikes on Buses

Several transit agencies now have on-vehicle bus storage programs. In some cases, passengers are allowed to bring their bicycles into the interior of the bus. In others, a bicycle rack is attached to the front of the bus (see Figure 18). These racks generally hold two bicycles. Busturning radius design needs to allow for the additional length of a bus with a bicycle rack attached (generally 3 feet).

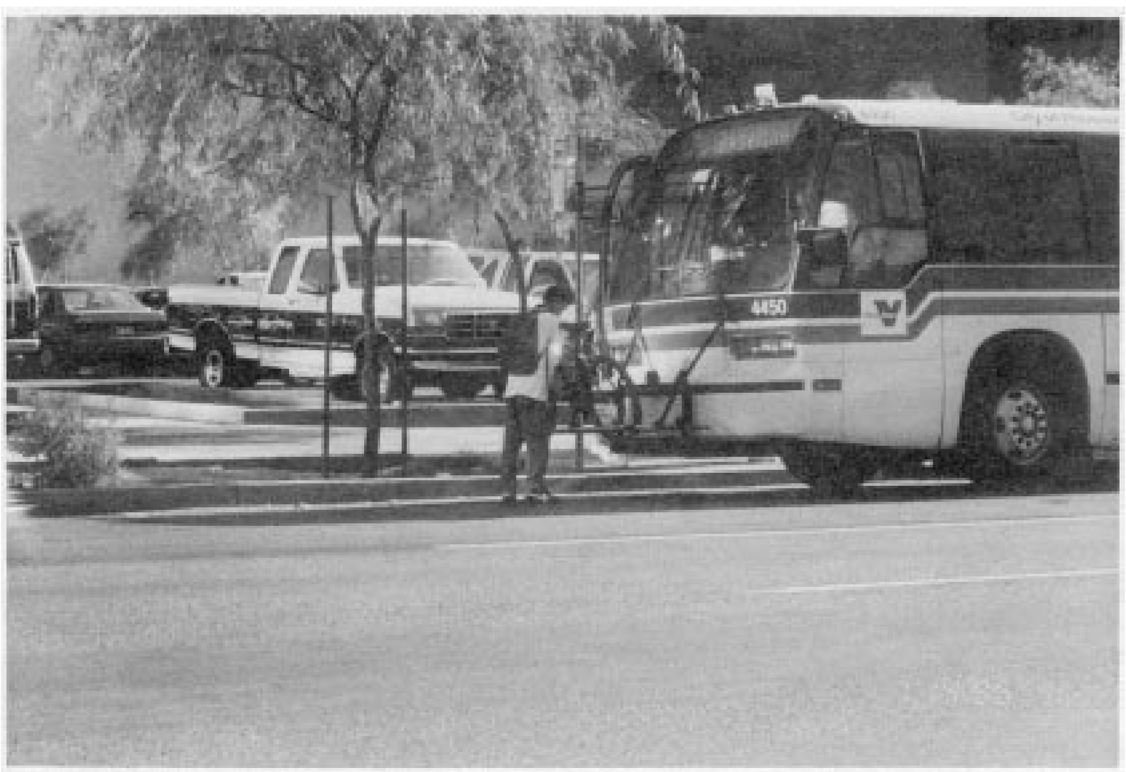


Figure 18. Front-Mounted Bike Rack in Use.

Chapter 3

STREET-SIDE FACTORS

ROADWAY AND INTERSECTION DESIGN—Roadway Design

Roadways and intersections with bus traffic and bus stops should be designed to accommodate the size, weight, and turning requirements of buses. The safety and operation of a roadway improve when these elements are incorporated into the design.

Because of their need to make frequent stops, buses generally travel in the traffic lane closest to the curb. Therefore, consideration of the following bus clearance requirements in roadway design is important.

- Overhead obstructions should be a minimum of 12 feet above the street surface;
- Obstructions should not be located within 2 feet of the edge of the street to avoid being struck by a bus mirror;
- A traffic lane used by buses should be no narrower than 12 feet in width because the maximum bus width (including mirrors) is about 10.5 feet; and.
- Desirable curb lane width (including the gutter) is 14 feet.

Selection of the roadway grade is related to topography and cut and fill material considerations. Typically, the maximum grade for 40-foot buses is between 6 and 8 percent. The recommended grade change between a street and a driveway is less than 6 percent.

An appropriate curb height for efficient passenger-service operation is between 6 and 9 inches. If curbs are too high, the bus will be prevented from moving close to it and the operations of a wheelchair lift could be negatively affected. If curbs are too low or not present, elderly persons and passengers with mobility impairments may have difficulty boarding and alighting. The effective use of low floor buses is also influenced by the height of the curb.

Roadway pavements (or shoulders, if that is where the buses stop) need to be of sufficient strength to accommodate repetitive bus axle loads of up to 25,000 pounds. Exact pavement designs will depend on site-specific soil conditions. Areas where buses start, stop, and turn are of particular concern because of the increased loads associated with these activities. Using reinforced concrete pavement pads (see Figure 19) in these areas reduces pavement failure problems that are common with asphalt. The pad should be a minimum of 11 feet wide (12 feet desirable) with a pavement section designed to accept anticipated loadings. The length of the pad should be based on the anticipated length of the bus that will use the bus stop and the number of buses that will be at the stop simultaneously.

Figure 19. Example of a Bus Pad.

The corner curb radii used at intersections (see C in Figure 20) can affect bus operations when the bus makes a right turn. Some advantages of a properly designed curb radius are as follows:

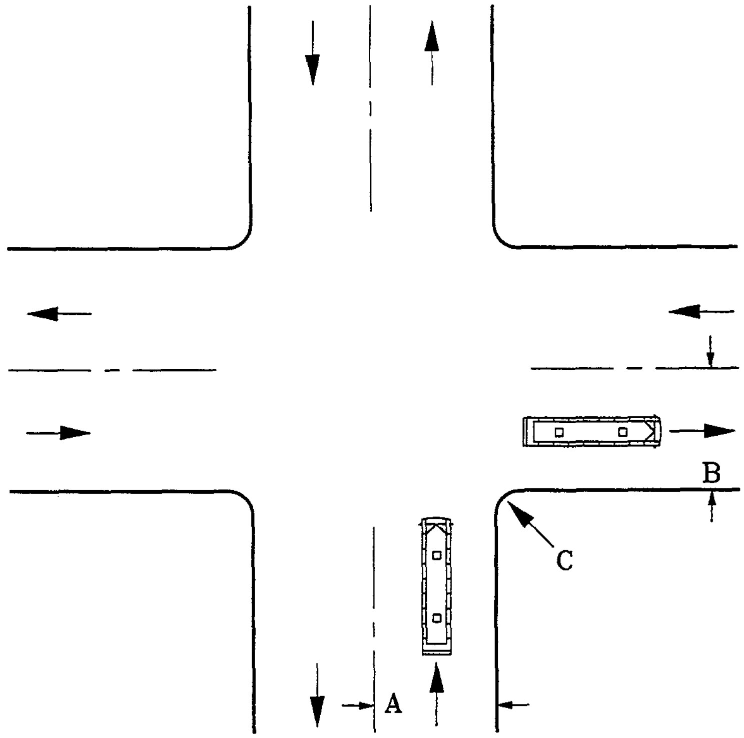
- Less bus/auto conflict at heavily used intersections
  (buses can make turns at higher speeds and with less encroachment);
- Higher bus operating speeds and reduced travel time; and
- Improved bus patron comfort.

A trade-off in providing a large curb radius is that the crossing distance for pedestrians is increased. This greater crossing distance increases the pedestrians' exposure to on-street vehicles and can influence how pedestrians cross an intersection, both of which are safety concerns. The additional time that a pedestrian is in the street because of larger curb radii should be considered in signal timing and median treatment decisions.

The design of corner curb radii should be based on the following elements:

- Design vehicle characteristics, including bus turning radius;
- Width and number of lanes on the intersecting street;
- Allowable bus encroachment into other traffic lanes;
- On-street parking;
- Angle of intersection;
- Operating speed and speed reductions; and
- Pedestrians.

Figure 20 shows appropriate corner radii for transit vehicles and various combinations of lane widths. This figure can be used as a starting point; the radii values should be checked with an appropriate turning radius template before being incorporated into a final design.



A Approach Width (feet)	B Entering Width (feet)	C Radii* (feet)
12 (1 lane)	12 16 20 24	50 45 40 35
16 (1 lane with 4-foot shoulder)	12 16 20 24	45 40 30 25
20 (1 lane with parking)	12 16 20 24	40 35 30 25

* Assumes no parking on cross street and minimal lane encroachment on opposing travel lanes.

Figure 20. Recommended Corner Radii.

Chapter
3

STREET-SIDE FACTORS

ROADWAY AND INTERSECTION DESIGN—Driveways

Bus stops are commonly located near intersections. Driveways leading to gasoline stations and other developments are also common at intersections. Ideally, bus stops should not be located close to a driveway; however, if the situation cannot be avoided:

- Attempt to keep at least one exit and entrance driveway open for vehicles accessing the development while a bus is loading or unloading passengers.
- Locate the stop to allow good visibility for vehicles leaving the development and to minimize vehicle/bus conflicts. This is best accomplished by placing the stop on the far side of the driveway.
- Locate the stop so that passengers are not be forced to wait for a bus in the middle of a driveway.
- Locate the stop so that patrons board or alight directly from the curb rather than from the driveway.

Transit agencies should work closely with local and state jurisdictions to preserve a safe loading zone for passengers from either a driveway being moved or the construction of new driveways. Cooperation in finding an alternative stop is recommended when driveways moves are unavoidable and may severely affect the bus stop. Driveways within bus bays are of special concern. Relocating a bus bay is expensive and may shift a sometimes unwanted burden to the adjacent property owner.

Figure 21 shows undesirable driveway situations where either visibility is restricted or the only drive into a parking area is blocked. The figure also shows acceptable driveway situations where visibility is enhanced and access is allowed.

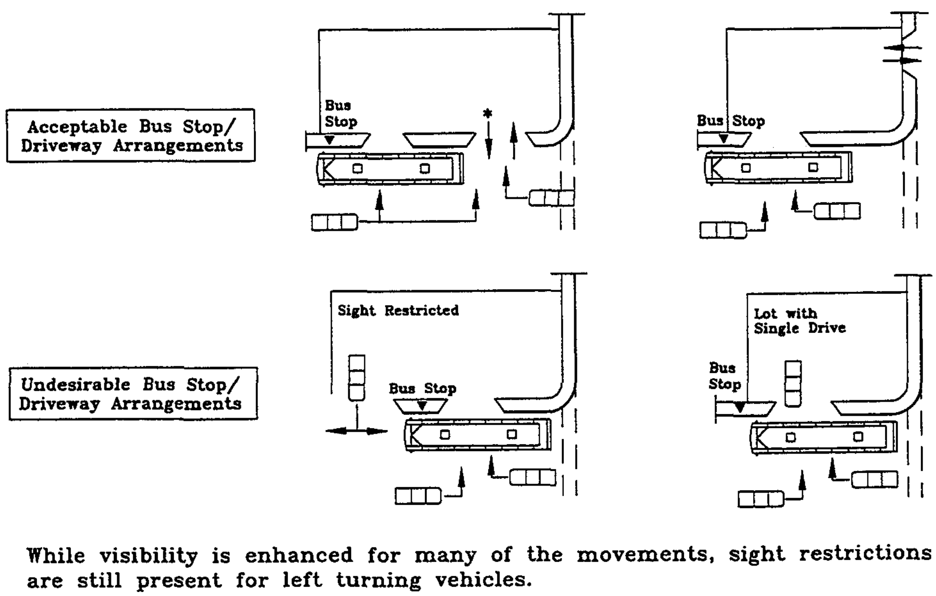


Figure 21. Bus Stop Locations Relative to Driveways.

STREET-SIDE FACTORS

ROADWAY AND INTERSECTION DESIGN—Traffic Signals

Bus stops are frequently located at signalized intersections. Traffic signal design should accommodate buses and bus passengers. The following should be considered in designing traffic signal systems in new developments or upgrading/redesigning signals at existing intersections:

- Location of bus stops should be coordinated with traffic signal pole and signal head location. Bus stops should be located so that buses do not totally restrict visibility of traffic signals from other vehicles. (These problems can be effectively addressed by using far-side bus stops.)

- The use of a far-side, curbside stop at a signalized intersection can cause vehicles stopping behind the bus to queue into the intersection. A far-side bus bay is preferred at a signalized intersection.

- Since all bus passengers become pedestrians upon leaving the bus, it is important to have "WALK" and "DON'T WALK" indicators at signalized intersections at bus stops.

- When traffic-actuated signals are installed, pedestrian push buttons should also be installed to (1) activate the "WALK" and "DON'T WALK" indicators or (2) extend the signal's green indicator so that additional time needed by the pedestrian to cross the street is provided.

- Near-side stop areas are often located between the advance detectors for a traffic signal and the crosswalk. Detectors should be located at the bus stop to enable the bus to actuate the detector and the signal controller to obtain or extend the green light. Without a detector, a bus is forced to wait until other traffic approaching from the same direction actuates the signal controller.

- Timing of traffic signals should also reflect the specific needs of buses. Longer clearance intervals may be required on higher speed roadways with significant bus traffic. Vehicle passage times must provide adequate time for a bus to accelerate from the bus stop into the intersection. Intersections adjacent to railroad tracks should incorporate the need for buses to stop at railroad crossings into their timing and detection.

STREET-SIDE FACTORS

ROADWAY AND INTERSECTION DESIGN—Sign Locations

Proper signs at bus stops are an important element of good transit service. Signs serve as a source of information to patrons and operators regarding the location of the bus stop and are excellent marketing tools to promote transit use. For example, letter styles, sign appearance, and color choice should be unique to the transit system so that passengers can readily identify bus stops. Doublesided signs which provide for visibility from both directions and reflectorized signs for night time visibility are preferred.

Bus stop signs should be placed at the location where people board the front door of the bus. The bus stop sign shows the area where passengers should stand while waiting for the bus. It also serves as a guide for the bus operator in positioning the vehicle at the stop. The bottom of the sign should be at least 7 feet above ground level and should not be located closer than 2 feet from the curb face. Figure 22 shows typical bus stop sign placement standards.

Transit agencies and local and/or state jurisdictions should coordinate efforts when deciding locations for bus stops and sign posts. In some cases, a shared sign post can be used to reduce the number of obstructions in high pedestrian volume locations. Bus stop signs are also commonly located on a shelter or existing pole (such as a street light). The signs should not be obstructed by trees, buildings, or other signs. Bus stop sign posts that are not protected by a guardrail or other feature should be a break-away type to minimize injuries and vehicular damage, and to facilitate replacement of the post.

Pavement markings associated with bus stops are generally installed and maintained by local authorities. The most common marking is a yellow or red painted curb at the bus stops. Stop lines and/or crosswalk markings are also desirable when the bus stop location is at an intersection.

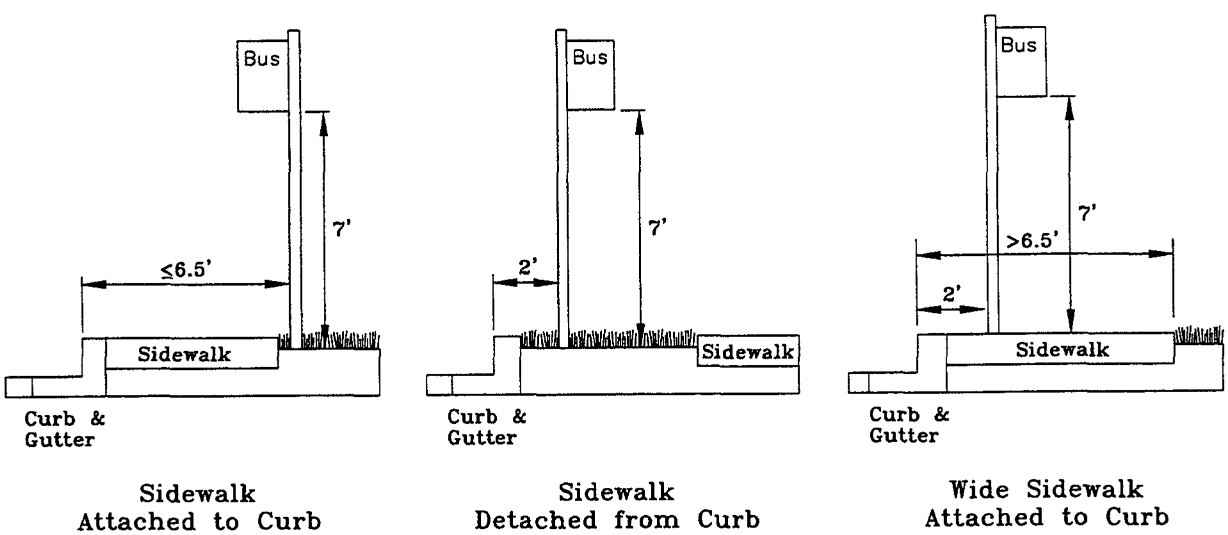
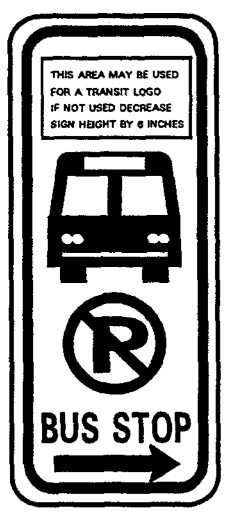


Figure 22. Guidelines for Bus Stop Sign Placement.

Traffic regulations prohibit parking, standing, or stopping at bus stops. These regulations can be established only when authorized by appropriate laws or ordinances. In general, an ordinance is needed to authorize and require a transit agency to establish bus stop locations and to designate bus stops with the appropriate signs. Another ordinance prohibits other vehicles from stopping, standing, or parking in officially designated and appropriately signed bus stops. An allowance for passenger vehicles to stop to load or unload passengers in the bus stops may be included.

The *Manual on Uniform Traffic Control Devices (MUTCD)* (maintained by the Federal Highway Administration) includes general specifications for no parking signs at bus stops and curb markings to indicate parking restrictions, as well as guidelines for the placement of the signs. Suggested signs in the *MUTCD* are shown in Figure 23. The R7-107a sign is a permissible alternative design for the R7-107 sign shown in the *MUTCD.* Other alternative designs discussed in the *Manual* may include a transit logo, an approved bus symbol, a parking prohibition, the words BUS STOP, and right-, left-, and double-headed arrows. The preferred bus symbol color is black, but other dark colors may be used. Additionally, the transit logo may be shown on the bus face in the appropriate colors instead of placing the logo separately. The reverse side of the sign may contain bus routing information.

The *MUTCD* also discusses the use of curb markings to indicate parking restrictions. At the option of local authorities, special colors (none are specified in the *MUTCD*) may be used for curb markings. When signs are not used, restrictions should be stenciled on the curb.



R7-107a
12" x 30"

R7-107
12" x 18"

Figure 23. ***MUTCD*** **Bus Stop Signs.**

Chapter 3

STREET-SIDE FACTORS

SAFETY

As with all aspects of roadway design and bus operations, an important element in the design of bus stops is safety. General safety considerations for bus stops include the following:

- The bus stop must be located so that passengers may alight and board with reasonable safety.
- The stopped bus will affect sight distance for pedestrians using the parallel and transverse crosswalks at the intersection.
- The stopped bus will also affect sight distance for parallel traffic and cross traffic. For instance, at a near-side stop, vehicular right turns are facilitated and sight distance is improved when the bus stop is set back from the crosswalk.
- The bus affects the traffic stream as it enters or leaves a stop.

A recently completed study on pedestrian accidents found that approximately 2 percent of pedestrian accidents in urban areas and 3 percent in rural areas are related to bus stops. These accidents generally involved pedestrians who stepped into the street in front of a stopped bus and were struck by vehicles moving in the adjacent lane. This situation develops when the line of sight between the pedestrian and an oncoming vehicle is blocked, or when the pedestrian simply does not look for an oncoming vehicle. This type of accident can be reduced by relocating the bus stop from the near side of an intersection to the far side, thus encouraging pedestrians to cross the street from behind the bus instead of in front of it. This makes pedestrians more visible to motorists approaching from behind the bus. Not only can far-side bus stops reduce the potential for bus stop accidents involving pedestrians, they are also less likely to obscure traffic signals, signs, and pedestrian movements at intersections, as opposed to near-side bus stops. Also, conflicts between buses and right-turning vehicles can be reduced by using far-side bus stops. Problems may occur, however, when cars illegally park in far-side bus stops preventing buses from completely clearing the cross street.

Along with the minimum desirable curb length, the condition of the curb lane and the curb height can influence the safety and efficiency of bus-passenger operation. When poor pavement conditions exist in the curb lane, bus drivers often avoid it and stop the buses away from the curb. Boardings and alighting operations away from the curb are more hazardous for riders than curb operations, especially for elderly persons and passengers with disabilities during inclement weather. The additional hazard appears to result from the increased height between the ground and the first step of the bus and from moving vehicles (such as bicycles) between the curb and the bus.

Lighting is important for safety. A brightly lit bus stop makes it easier for the transit operator to observe waiting passengers and allows motorists to see boarding and alighting pedestrians. Because the step well is the most hazardous area on a transit vehicle for accidents, a brightly lit well will assist boarding and alighting passengers as they judge distances and locations of steps and curbs. Auxiliary lighting in the step well is required on new buses, but it will be years before this feature is universal.

The bus stop should be located either before the turn lane (for through routes) or at the far side of the intersection in areas that have a dedicated right-hand turn lane. Transit agencies should work closely with local and state jurisdictions wherever traffic improvements affect the safety of a bus stop. The addition of turn lanes will often require advance planning for incorporating transit accommodations as part of the highway project and/or for relocating the bus stop to an acceptable location.

Chapter 3

STREET-SIDE FACTORS

STREET-SIDE PLACEMENT CHECKLIST

Several items should be considered when designing and locating a bus stop on a roadway. The following checklist of street-side items should be reviewed with each design because it brings together related issues that can have a significant impact on the safe operations of the bus stop.

- **Standardization:** One of the most critical factors in the street-side design and placement of a bus stop involves standardization or consistency. Standardization is desirable because it results in less confusion for bus operators, passengers, and motorists. Consistency in design, however, can be difficult to achieve since traffic, parking loss, turning volume, community preference, and political concerns can influence the decisions.

- **Periodic Review:** A periodic review of bus stop conditions (both street side and curb side) is recommended to ensure the safety of bus passengers. This will encourage the timely reporting of items such as missing bus stop signs and poor pavement.

- **Near-Side/Far-Side/Midblock Placement:** Each type of placement has advantages and disadvantages. In general, each bus stop location should be evaluated individually to decide the best placement for the stop.

- **Visibility:** Bus stops should be easy to see. If the bus stop is obscured by nearby trees, poles, or buildings, the bus operator may have difficulty locating the stop. More importantly, however, motorists and bicyclists may not know of its existence and will be unable to take necessary precaution when approaching and passing the stop. In addition, visibility to pedestrians crossing a street is also an important consideration in areas that permit "right turns on red."

- **Bicycle Lanes and Thoroughfares:** When a bike lane and a bus stop are both present, the operators need to be able see cyclists in both directions while approaching the stop. Sufficient sight distance for cyclists to stop safely upon encountering a stopped bus is also needed.

- **Traffic Signal and Signs:** Bus stops should be located so that buses do not restrict visibility of traffic signals and signs from other vehicles. Because all bus passengers become pedestrians upon leaving the bus, pedestrian signal indicators should be considered at nearby signalized intersections.

STREET-SIDE FACTORS

Chapter **3**

STREET-SIDE PLACEMENT CHECKLIST

- ◻ **Roadway Alignment:** Horizontal and vertical roadway curvature reduces sight distance for bus operations, motorists, bicyclists, and pedestrians. Additionally, bus stops located on curves make it difficult for the bus operator to stop the bus parallel to the curb and safely return to the driving lane. Where possible, bus stops should be located on sections of relatively straight and flat roadway. Trees and poles should not obstruct the visibility of the bus operator for cross traffic and passenger and pedestrian movement.

- ◻ **Driveways:** Avoid locating bus stops close to a driveway. If placing a bus stop close to a driveway is unavoidable (for example, to lessen the loss of parking in a commercial area), keep at least one driveway open to vehicles accessing the adjacent development while a bus is loading or unloading passengers. Also, locate bus stops to allow full visibility for vehicles leaving an adjacent development and to minimize vehicle/bus conflicts. Placing bus stops on the far side of driveways will minimize conflicts; however, sight distance for left-turning vehicles from the driveway will still be a concern.

- ◻ **Location of Pedestrian Crosswalks:** A minimum clearance distance of 5 feet between a pedestrian crosswalk and the front or rear of a bus at a bus stop is desirable.

- ◻ **Location of the Curb:** Where possible, locate stops where a standard curb height of 6 inches exists. Bus steps are designed with the assumption that the curb is the first step. It is more difficult for elderly persons and passengers with mobility impairments to board and alight from the bus if the curb is absent or damaged.

- ◻ **Street Grades:** Where possible, bus stops should not be located on an upgrade in a residential area, since the bus engine noise created when the vehicle accelerates from a stop will bother area residents. Placing bus stops on steep grades should be avoided if slippery winter conditions prevail.

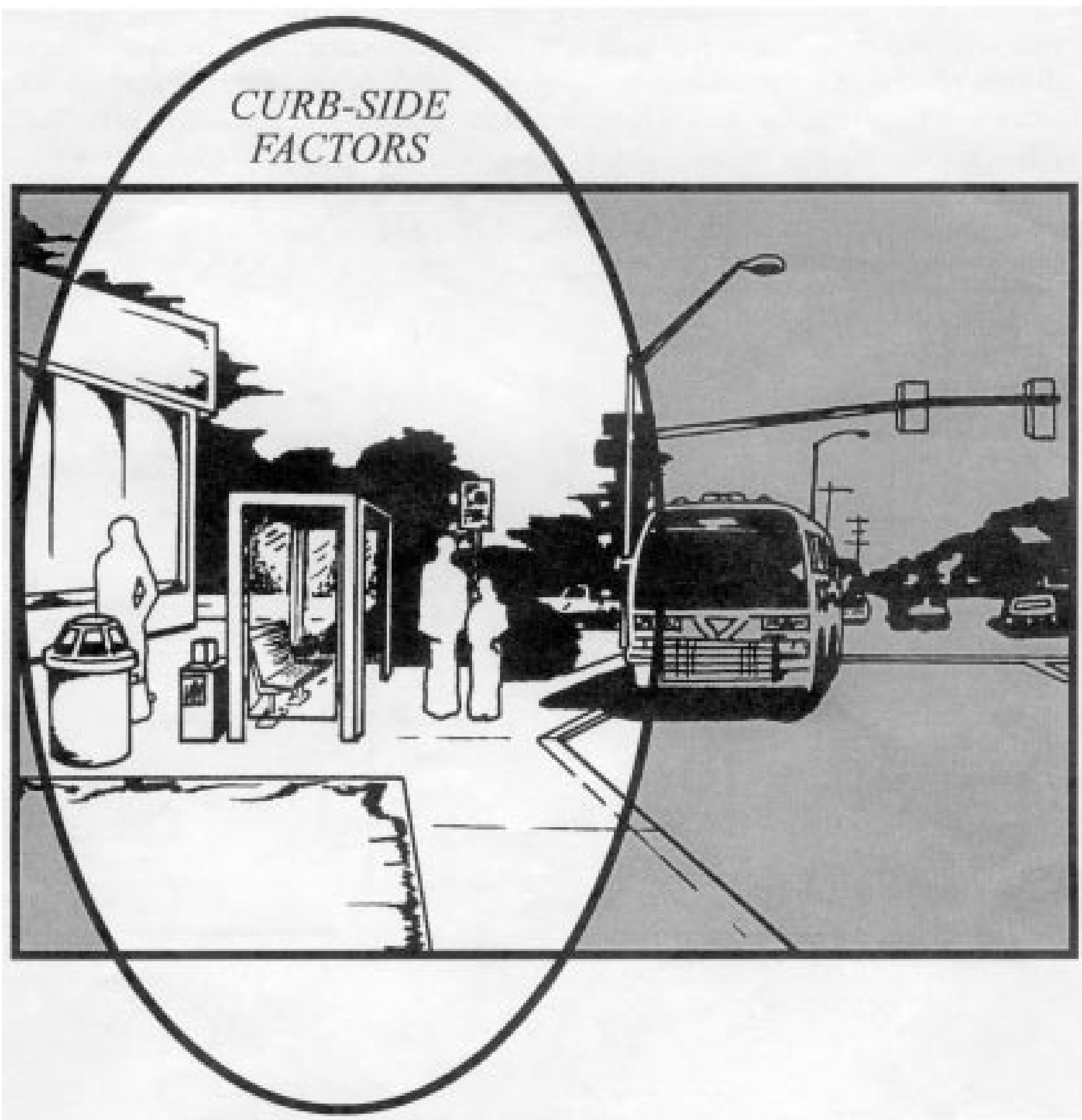
- ◻ **Road Surface Conditions:** Since alighting passengers generally move from their seats when the bus decelerates on approach to a bus stop, do not locate a bus stop where the roadway is in poor condition such as areas with broken pavement, potholes, or ruts or where a storm drain is located. The resultant motion of the bus in such a situation may cause bus passengers to fall and injure themselves. Boarding and standing passengers are also susceptible to falls or injuries where poor pavement conditions or low drainage basins exist.

CURB-SIDE FACTORS

Chapter 4

ORGANIZATION

Curb-side factors include those factors and issues that can affect the comfort, safety, and convenience of bus patrons. The information in this chapter can be used by transit professionals to provide safe, clean facilities at the bus stop. The chapter also provides information on how to choose bus stop locations that improve access and convenience in pedestrian-friendly communities. Areas of discussion include shelter design and placement, amenities, and enhancing bus patron comfort at bus stops. Also of value to transit professionals are tables that compare the advantages and disadvantages of the various amenities that can be included at the bus stop. A checklist provided at the end of the chapter refers to the various curb-side elements associated with bus stop design and location.



Chapter 4

CURB-SIDE FACTORS

PEDESTRIAN ACCESS—Patron Access

Providing defined access to and from the bus stop is important. Sidewalks should be constructed of impervious non-slip material and should be well drained. Access to the bus stop from the intersection or land use should be as direct as possible. When possible, sidewalks and bus stops should be coordinated with existing street lights to provide a minimum level of lighting and security. To accommodate wheelchairs, sidewalks should be a minimum of 3 feet wide (preferably 4 to 5 feet wide) and equipped with wheelchair ramps at all intersections. Other improvements include defined pedestrian crosswalks and signals at intersections. Pedestrian enhancements, such as sidewalks, should be coordinated with roadway improvements to help improve bus patron comfort and convenience.

Installation of a discontinuous sidewalk from the intersection to the bus stop is one way to achieve greater patron access to the bus stop in areas with limited or no sidewalk coverage. Although, the sidewalk may not continue toward the next land use or along the roadway, this strategy is the first step toward providing complete access to the bus stop. This ensures that access to the bus stop is not through uneven grass or exposed soil, which can be further impaired by poor drainage and surface changes during inclement weather. People who are elderly or have disabilities may find access to the bus stop difficult as well. See Figure 24 for an example.

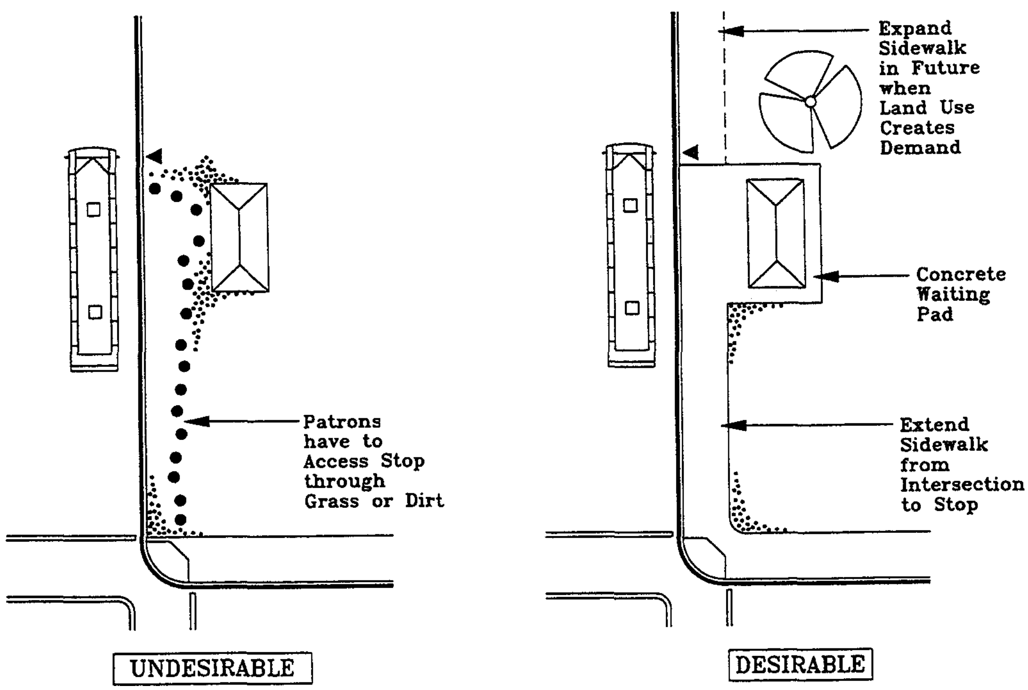


Figure 24. Example of Providing Access In Developing Regions.

Bus patrons should encounter defined pathways from the sidewalk to the back-face of the curb. To prevent poor access from the sidewalk to the curb, a waiting pad and an accessway from the waiting pad to the curb should be installed. When the sidewalk is parallel and directly adjacent to the curb, the waiting pad should be installed directly behind the sidewalk. However, when the sidewalk is far from the curb, paved access from the waiting pad to the curb is necessary. The waiting pad and accessway should be constructed of impervious non-slip material, preferably concrete or asphalt, and have proper drainage. Figure 25 presents two different waiting pad location scenarios for providing paved connections between the bus waiting pad and the curb.

Patrons should not have to walk through grass or exposed soil to reach the bus. In such cases, the areas between the sidewalk, bus stop, and curb can become worn and decline to muddy areas during inclement weather. Snow accumulation from road clearings during the winter months can also create additional access problems in the space between the sidewalk and curb.

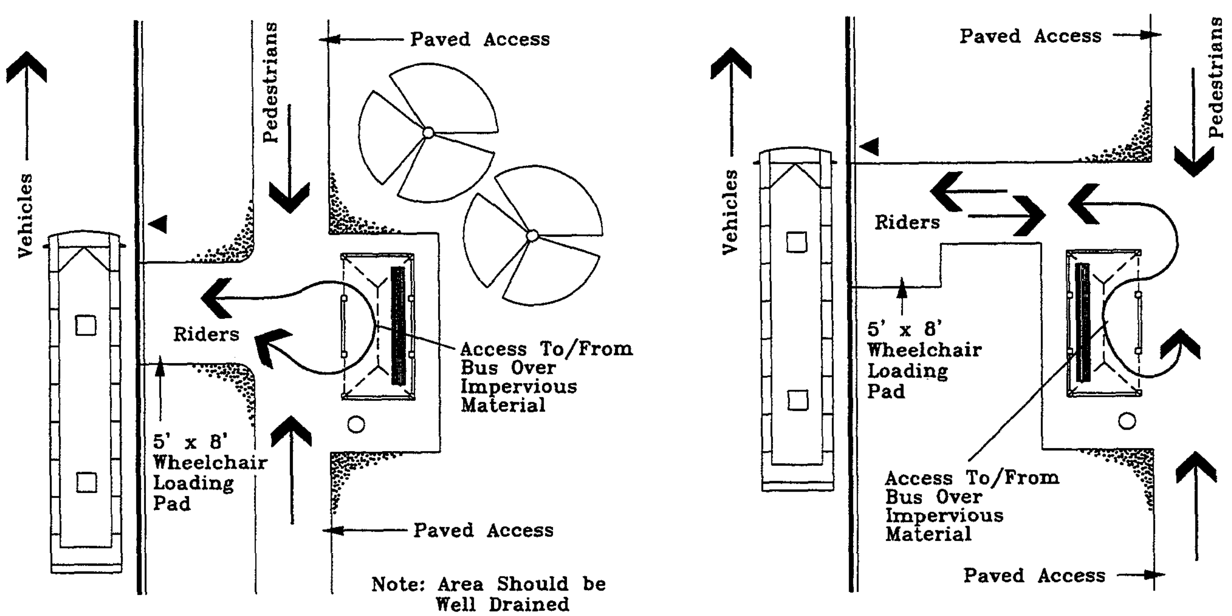


Figure 25. Examples of Providing Access from the Waiting Pad to the Curb.

Chapter 4

CURB-SIDE FACTORS

PEDESTRIAN ACCESS—Coordinating Access with Commercial or Business Development

A strategy to improve pedestrian access at or to bus stops is to coordinate development with the location of the bus stop. Coordination and cooperation with the landowner or developer can enhance the connectivity between the land use and the bus stop. To ensure optimum bus stop placement, coordination should occur during the planning/development phase. Pedestrian improvements include defined or designated walkways through parking lots and openings or gates through walls. Accessways can be as elaborate as a landscaped sidewalk through the parking lot or as minimal as painted walkways that caution drivers and direct pedestrians. As with any pedestrian improvement, strict adherence to mobility clearances, widths, and slopes should be followed to improve access for persons with disabilities. Safety improvements and shorter walking times can be achieved by implementing such strategies.

Another solution is to place buildings closer to the road and place parking to the rear and sides of buildings. Figure 26 is an example of coordinating transit with a hypothetical business office complex by designing defined pedestrian accessways and providing a gate through the fence. Another example of re-orienting the building or changing the location of the parking is illustrated in Chapter 2 as a Hypothetical Medical Center.

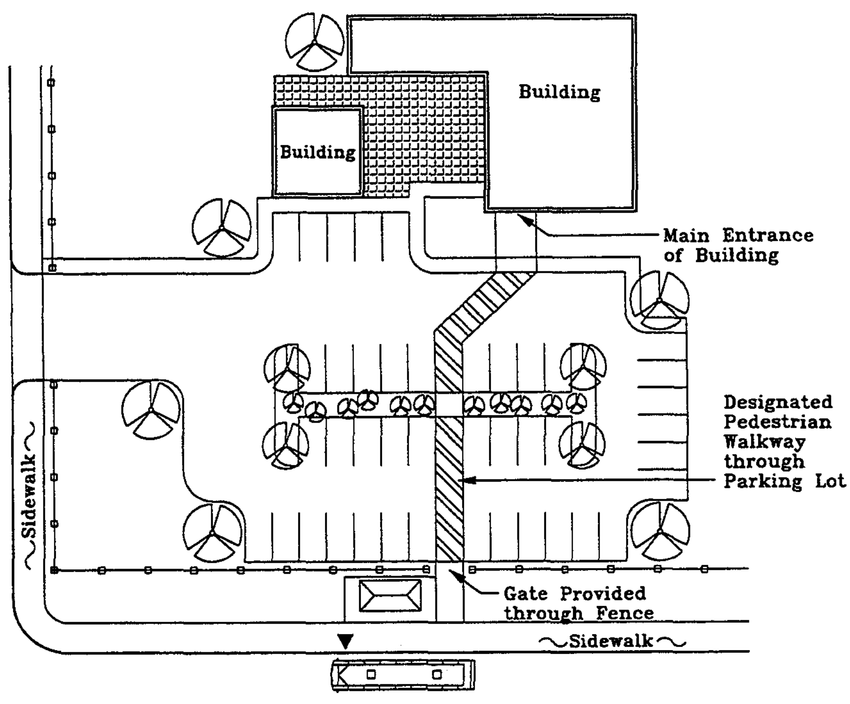


Figure 26. Pedestrian Improvements at a Hypothetical Business Complex.

Bus passengers need efficient ways to reach the bus stop from their residences. Transit agencies need to be involved early in the development approval process to reduce walking times and improve direct access to and from the bus stop. Sidewalk placement that is coordinated with land use and bus stop locations is critical to encouraging the use of transit.

Concerns over residential security have led to a proliferation of walled residential communities that restrict access to a limited number of entry and exit points. By doing so, walking times to bus stops may be increased because direct access may not be available. Circuitous or curvilinear sidewalks can also increase walking times and create coordination problems for the transit agency when choosing the final bus stop location. Curvilinear sidewalks along a street may not align with the final stop destination and may result in access problems through grass, berms, or other landscaping features.

Coordinating sidewalk design and placement is needed between developers and transit agencies to ensure direct access to a paved bus stop. Designing gates, openings through walls, and installing direct sidewalks in residential communities can be coordinated with developers to reduce walking times from the land use to the bus stop. Figure 27 is an example of coordinating access points and sidewalk design with the location of the bus stop.

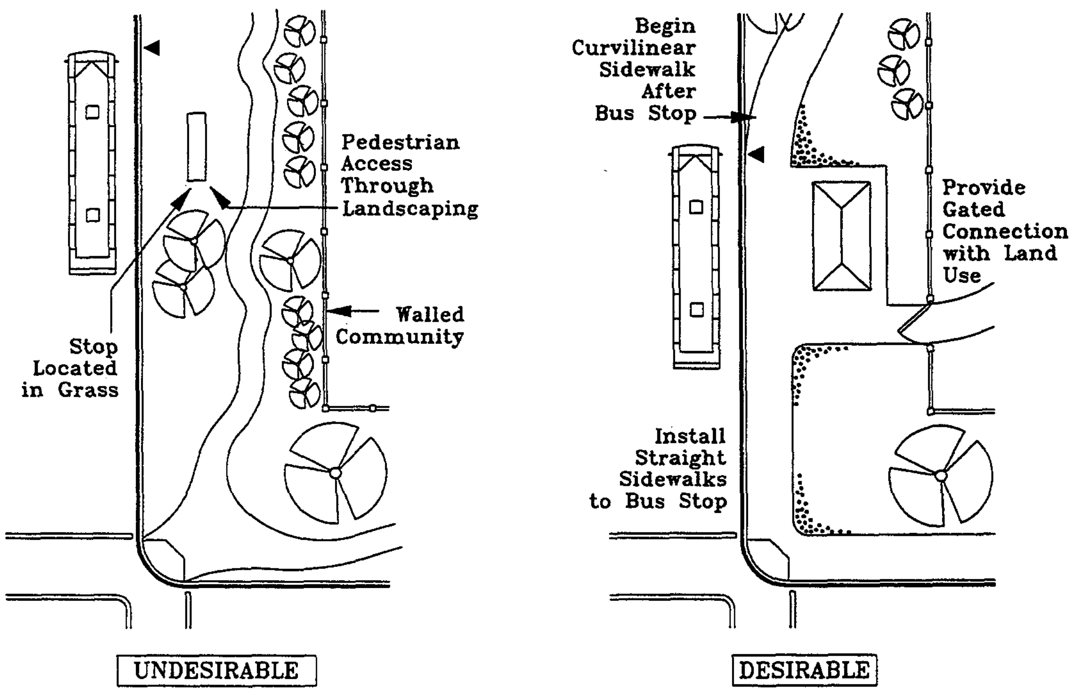


Figure 27. Example of Coordinating Transit with Residential Development Patterns.

Chapter 4

CURB-SIDE FACTORS

ADA—Accessibility Guidelines

The Americans with Disabilities Act of 1990 (ADA) is broad legislation intended to make American society more accessible to people with disabilities. It consists of five sections or titles (employment, public services, public accommodations, telecommunications, and miscellaneous). Titles II and III (public services and public accommodations) affect bus stop planning, design, and construction. Although the definition of disability under the ADA is broad, bus stop placement and design most directly affect persons with mobility and visual impairments. These impairments, which relate to the more physical aspects of bus stop accessibility, have received the most attention.

Making new stops conform to ADA physical dimension requirements is relatively easy. Modifying existing stops to comply with ADA, though desirable from an accessibility perspective, is not required under ADA. Modification of existing stops is more difficult, especially if the stops are at sites with limited easement or not subject to the transit agency's control, such as shopping malls, on state rights-of-way, or suburban subdivisions.

The ADA, however, is concerned with more than physical dimensions. It also involves accessibility from the point of origin to the final destination. For example, to get to the bus stop, individuals with limited mobility or vision need a path that is free of obstacles, as well as a final destination that is accessible. A barrier-free bus stop or shelter is of little value if the final destination is not accessible. Though the ADA does not require retrofitting transit vehicles with lifts, an accessible vehicle is clearly a critical link in the barrier-free trip. Full accessibility is more difficult to achieve when different organizations are responsible for different portions of the path (which is usually the case). Either way, the "equal access" provisions of the ADA require that the route for persons with limited mobility or vision be as accessible as the route used by those without disabilities. A person with disabilities should not have to travel further, or use a roundabout route, to get to a designated area.

Basic Principles for Bus Stop Design and Location to Conform to ADA

Basic aspects of design exist that encourage accessibility and are applicable to most situations. Specific dimensions are available from several references, some of which are listed below. Some general design considerations involve obstacles, surfaces, signs, and telephones.

Obstacles

Examine all the paths planned from the alighting point at the bus stop to destinations off the bus stop premises. Determine whether any protrusions exist that might restrict wheelchair movements. If protrusions exist and they are higher than 27 inches or lower than 80 inches, a person with a vision impairment may not be able to detect an obstacle (such as a phone kiosk) with a cane. A guide dog may not lead the person with the impairment out of the path. Although it may not be the transit agency's responsibility to address accessibility problems along the entire path, an obstacle anywhere along the path may make it inaccessible for some transit users with disabilities.

Surfaces

Surfaces must be stable, firm, and slip-resistant. Such provisions are beneficial for all transit users, but especially for those who have disabilities. Avoid abrupt changes in grade, and bevel those that cannot be eliminated. Any drop greater than 1/2 inch or surface grade steeper than 1:20 requires a ramp.

Signs

Signs providing route designations, bus numbers, destinations, and access information must be designed for use by transit riders with vision impairments. Specific guidelines are given for these signs in Section 4.30 of *Accessibility Guidelines for Buildings and Facilities, Transportation Facilities and Transportation Vehicles.* In some cases, two sets of signs may be needed to ensure visibility for most users and to assist users with sight limitations. Route maps or timetables are not required at the stop, though such information would be valuable to all passengers.

Telephones

Telephones at bus stops are not required under ADA, but if telephones are in place, they must not obstruct access to the facility and must be suitable for users with hearing impairments. At least one phone must be accessible for wheelchair users. Telephone directories must also be accessible.

Figure 28 illustrates a design approach to a bus stop with a shelter that would meet ADA requirements.

Accessible Bus Stop Pad & Shelter
Minimum Dimensions

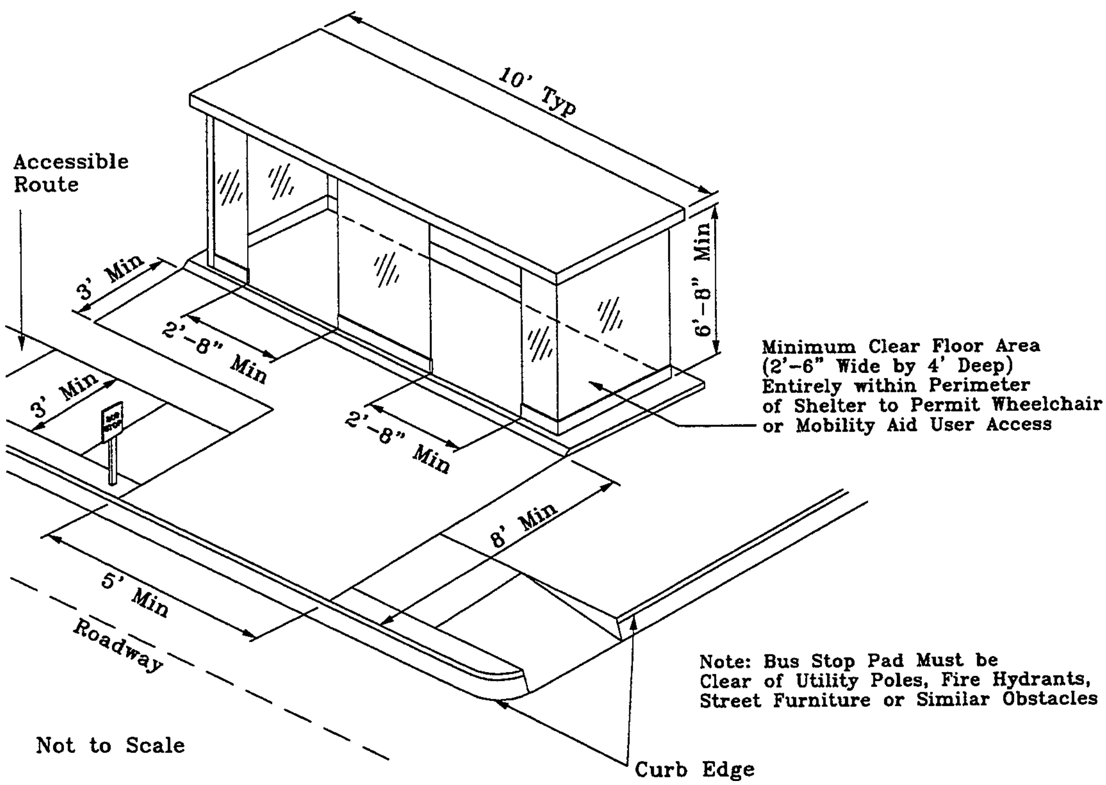


Figure 28. Shelter Design Example to Meet ADA Requirements.

Resources and References

An excellent guide to the design of bus stops (as well as other facilities) for ADA compliance is

> *Americans with Disabilities Act: Accessibility Guidelines for Buildings and Facilities, Transportation Facilities, and Transportation Vehicles.* U. S. Architectural and Transportation Barriers Compliance Board, Washington, DC, 1994. It is commonly known as the *ADA Guide.*

Another useful publication, which translates the *ADA Guide* accessibility guidelines into specific design parameters, is

> *Accessibility Handbook for Transit Facilities.* Federal Transit Administration, Report No. FTA-MA-06-0200-92-1, July 1992. Prepared by the Ketron Division of Bionetics Corp. This document is available through the National Technical Information Service (NTIS), Springfield, VA 22161.

As civil rights legislation, the ADA goes beyond physical dimensions to include policy and practice. Many of these issues will be resolved through experience and in the courts. Various sources are available for monitoring the current status of the ADA and its specific provisions. These include legal journals, ADA-specific newsletters, and World Wide Web "home pages." Examples of each are as follows:

> *Temple Law Review* and *Transportation Law Journal*—both frequently publish analyses of the original ADA legislation and recent developments, as do other legal journals.

> *TD Access & Safety Report*—provides information on access, safety, and liability relating to the transportation of people with disabilities and the transportation-disadvantaged. Published by Serif Press, Inc., 1331 H Street, NW, Washington, DC, 20005.

> Americans with Disabilities Act Document Center (http://janweb.icdi.wvu.edu/kinder/)—This website, sponsored by the National Institute on Disability and Rehabilitation Research, contains copies of ADA regulations and technical manuals prepared or reviewed by EEOC or the Department of Justice. Links to other Internet sources are also provided.

Chapter
4

CURB-SIDE FACTORS

WAITING OR ACCESSORY PADS—Sizing and Positioning

A waiting or accessory pad is a paved area at a bus stop provided for bus patrons and can contain either a bench or a bus shelter. Amenities, such as trash receptacles or bike racks, can also be located on the waiting pad. The size of the waiting pad depends on several factors. The length and width of shelters and benches, clearance requirements for street furniture, location of wheelchair lift extension (front or back door of bus), and the length of the bus are common size-determining factors. Transit agencies, typically, have one or two accessory-pad variations to accomodate different configurations and components that may be installed. Figure 29 illustrates elements that may influence the size and shape of the waiting pad.

Waiting pads are usually separated from the sidewalk to preserve general pedestrian flow. It is generally recommended that 5 feet of clearance be preserved on sidewalks to reduce potential pedestrian conflicts and limit congestion during boardings and alightings. The pad can be located on either side of the sidewalk, depending on available right-of-way space, utility poles, or buildings. In either case, a paved surface should be provided from the waiting pad to the back-face of the curb to enhance access and comfort. ADA mobility guidelines should be followed when street furniture is to be included on a waiting pad. A waiting pad should accommodate a 5-foot (measured parallel to the street) by 8-foot (measured from the back face of the curb) wheelchair landing pad that is free of all street furniture and overhangs.

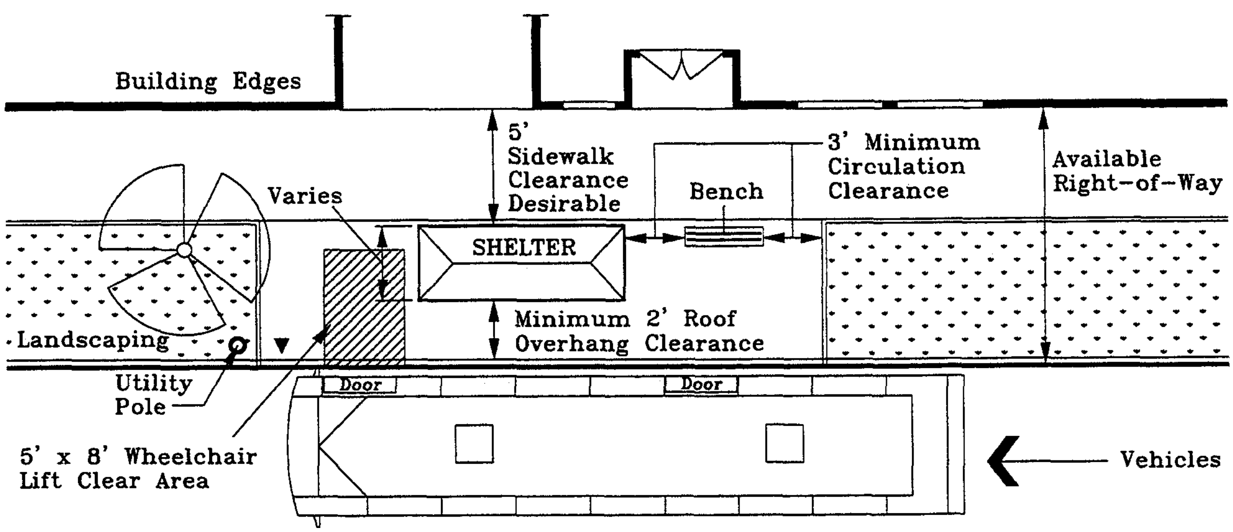


Figure 29. Example of Influential Factors on Waiting Pad Size.

Nubs, also known as bus bulbs or curb extensions, solve the problem of locating bus patron amenities in dense urban environments with considerable pedestrian traffic. A nub is essentially a sidewalk extension through the parking lane that becomes directly adjacent to the travel lane. When space limitations prevent the inclusion of amenities, nubs create additional space at a bus stop for shelters, benches, and other transit patron improvements along sidewalks. Nubs provide enough space for bus patrons to comfortably board and alight from the bus away from nearby general pedestrian traffic. Nubs also shorten the pedestrian walking distance across a street, which reduces pedestrian exposure to on-street vehicles.

Transit agencies should consider the use of nubs at sites along crowded city sidewalks with high patron volumes, where parking along the curb is permitted. Figure 30 is a plan view example of a typical nub configuration.

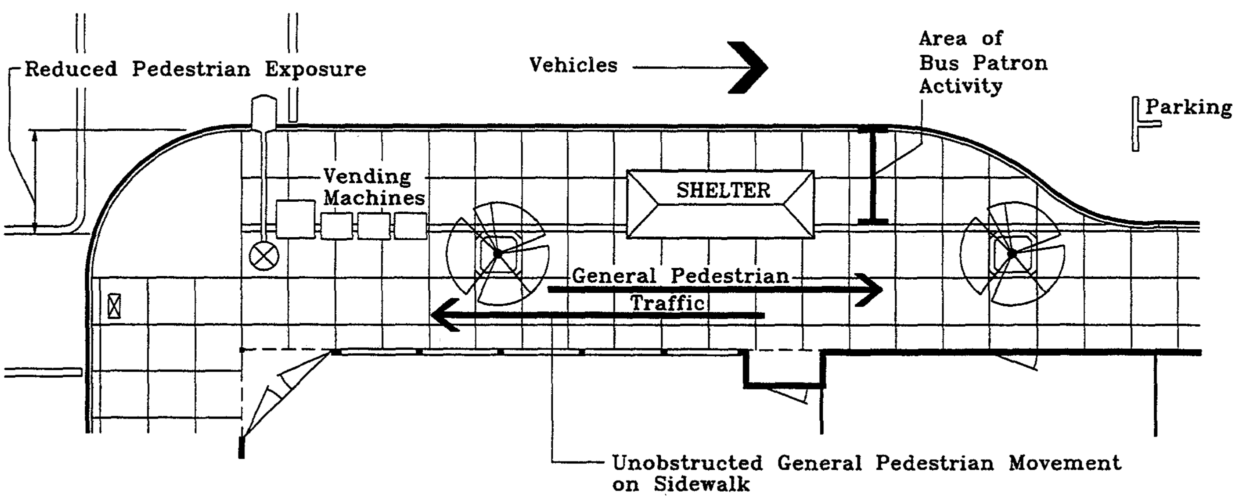


Figure 30. Separating Bus Activities and General Pedestrian Traffic with Nubs.

Chapter 4

CURB-SIDE FACTORS

SHELTERS—Inclusion and Sizing

A bus shelter provides protection from the elements and seating while waiting for a bus. Standardized shelters exist that accommodate various site demands and different passenger volumes. Typically, a shelter is constructed of clear side-panels for clear visibility. Depending on demand and frequency of service, a bus shelter may also have a bench.

The decision to install a shelter is a result of systemwide policy among transit agencies. Many criteria exist to determine shelter installation at a bus stop. In most instances, the estimated number of passenger boardings has the greatest influence. Suggested boarding levels by area type used to decide when to install a shelter are as follows (these values represent a composite of prevailing practices):

Location	Boarding
Rural	10 boardings per day
Suburban	25 boardings per day
Urban	50 to 100 boardings per day

Other criteria used to evaluate the potential for inclusion of a shelter include

- number of transfers at a stop
- availability of space to construct shelters and waiting areas
- number of elderly or physically challenged individuals in the area
- proximity to major activity centers
- frequency of service
- adjacent land use compatibility

Priority may or may not be given to each of these items depending on policy. System equity or funding availability can cause the installation decision to be made on a case-by-case basis. Local priorities and neighborhood requests can also influence the decision to include a shelter at a bus stop.

Other factors that can influence the size of the shelter include availability of right-of-way width, existing street furniture, utility pole locations, landscaping, existing structures, and maintaining proper circulation distances around existing site features.

Ideally, the final location of a bus stop shelter should enhance the circulation patterns of patrons, reduce the amount of pedestrian congestion at a bus stop, and reduce conflict with nearby pedestrian activities. The location of the curb and sidewalk and the amount of available right-of-way can be determining factors for locating a bus stop shelter. The following placement guidelines should be used when placing a bus stop shelter on a site (see also Figure 31):

- Bus stop shelters should not be placed in the 5-foot-by-8-foot wheelchair landing pad.
- General ADA mobility clearance guidelines should be followed around the shelter and between the shelter and other street furniture.
- Locating shelters directly on the sidewalk or overhanging a nearby sidewalk should be avoided because this may block or restrict general pedestrian traffic. A clearance of 3 feet should be maintained around the shelter and an adjacent sidewalk (more is preferred).
- To permit clear passage of the bus and its side mirror, a minimum distance of 2 feet should be maintained between the back-face of the curb and the roof or panels of the shelter. Greater distances are preferred to separate waiting passengers from nearby vehicular traffic.
- The shelter should be located as close as possible to the end of the bus stop zone so it is highly visible to approaching buses and passing traffic. The walking distance from the shelter to the bus is also reduced.
- Locating bus stop shelters in front of store windows should be avoided when possible so as not to interfere with advertisements and displays.
- When shelters are directly adjacent to a building, a 12-inch clear space should be preserved to permit trash removal or cleaning of the shelter.

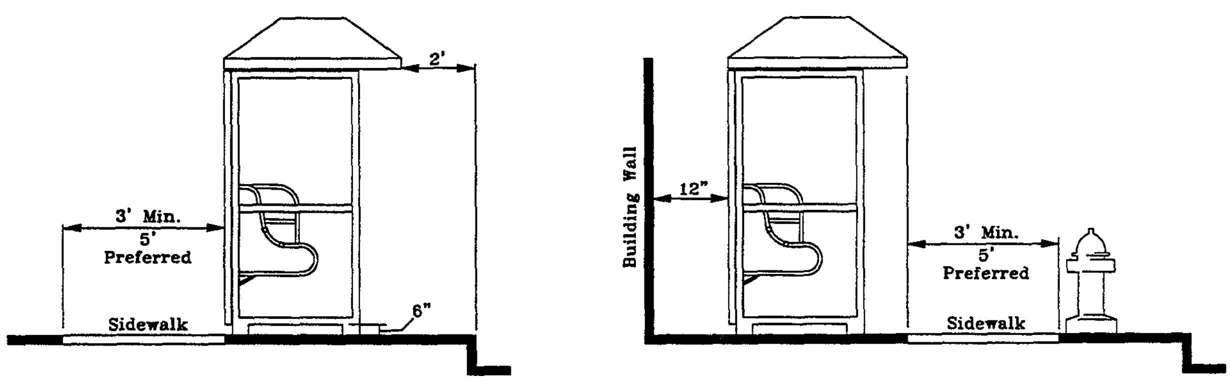


Figure 31. Shelter Clearance Guidelines.

Chapter 4

CURB-SIDE FACTORS

SHELTERS—Configurations and Orientations

In orienting and configuring bus shelters, personnel should consider the environmental characteristics of each site, because placement and design can positively or negatively influence passenger comfort. For example, in very hot climates, particularly in areas with few tall trees, bus shelters may be uncomfortable if they face directly east or west. However, this orientation may be appropriate in cooler climates during the winter months. When shelter interiors are uncomfortable, patrons will seek relief from the elements outside the shelter, appropriating walls or window ledges of nearby private property for their use. Transit agencies should be sensitive to this issue when locating a bus stop shelter.

Different bus shelter configurations can be used to reflect site or regional characteristics (see Figure 32). Shelters can be completely open to permit unlimited movement of air, or panels can be erected to keep the interior of the bus shelter warm. For southern climates, perforated panels can be used to reduce the glare while permitting ventilation. Alternatively, shelters can be fully enclosed by solid panels and the back of the shelter may be rotated to face the street to protect waiting passengers from splashing water or snow build-up. To enhance ventilation and to reduce the clutter that can accumulate inside a shelter, a 6-inch clearance between the ground and the bottom of the panels is standard in fully enclosed shelters. In any case, shelters should be coordinated with landscaping to provide maximum protection from the elements and to enhance the visual quality of the bus stop (see Figure 33). Shade trees reduce heat at a site and provide additional shade for patrons waiting outside the shelter. Technology, such as misters or evapo-cooling towers, can also be used to enhance the interior environment, however, such technology is expensive and maintenance-intensive.

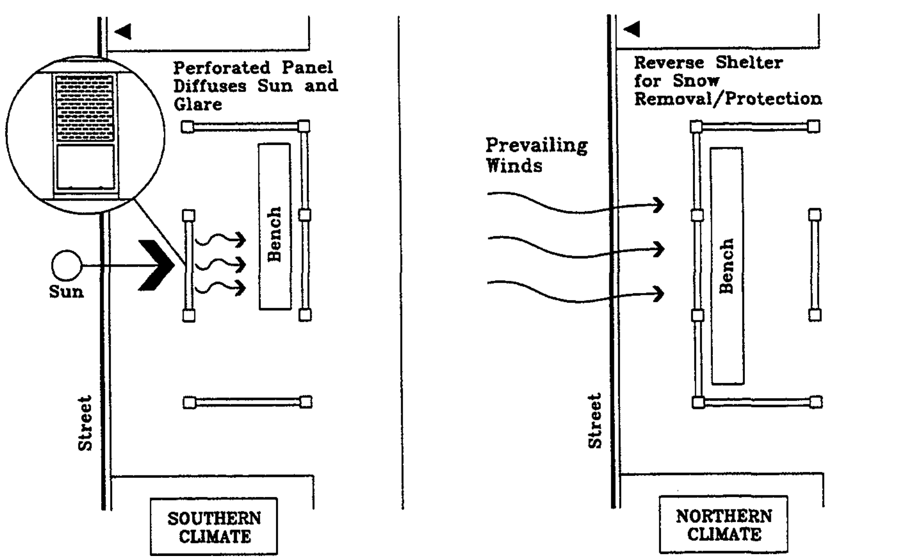


Figure 32. Examples of Orientation and Panel Placement to Improve Interior Comfort.

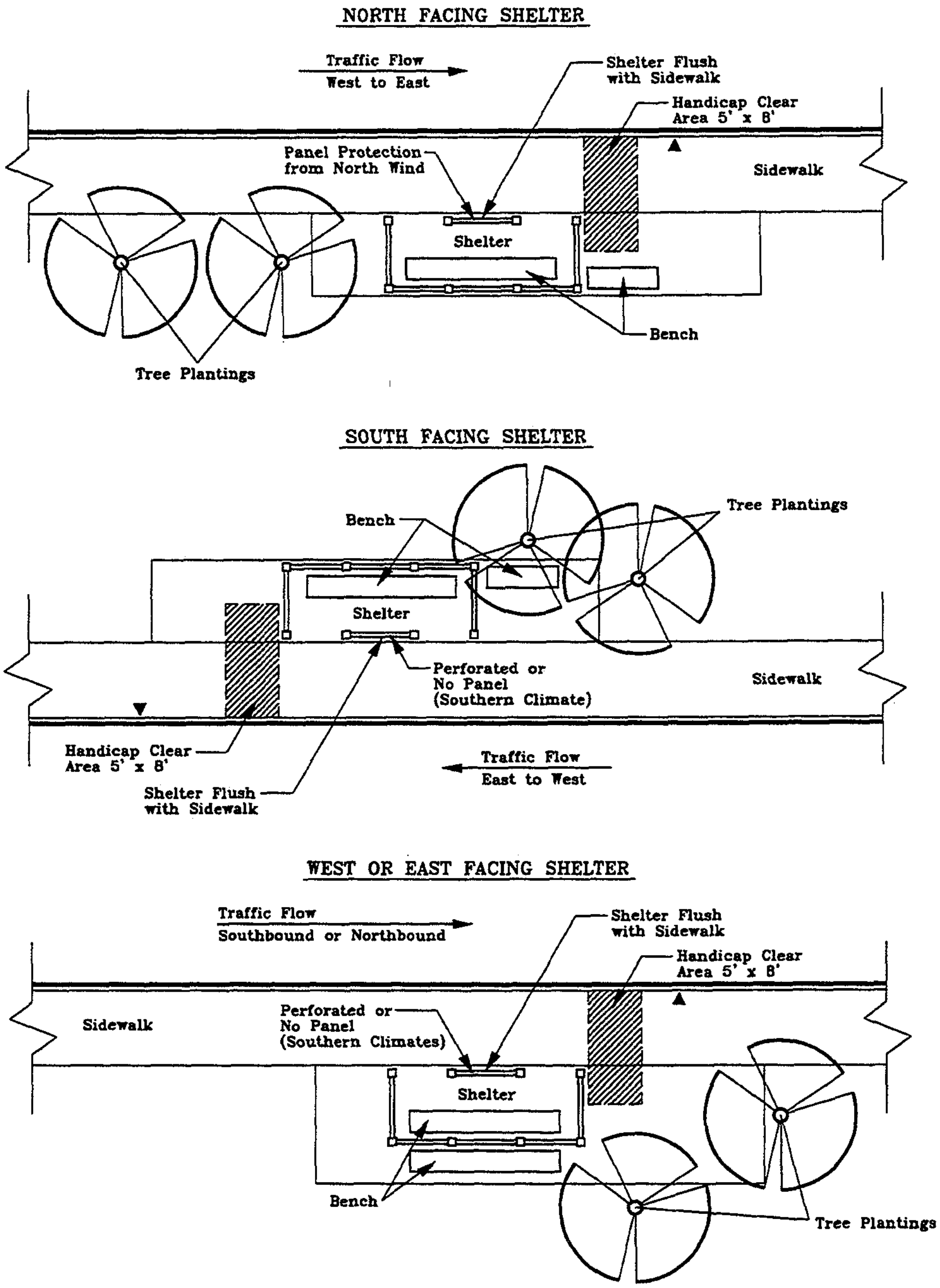


Figure 33. Placement and Orientation Options.

Chapter 4

CURB-SIDE FACTORS

SHELTERS—Advertising

Many transit agencies have paid advertising in bus shelters to supplement funding and to provide other benefits. An advertising-in-shelters program provides the opportunity to install bus shelters at bus stops that otherwise would not receive one. As part of the contract, the advertising company installs the shelter or kiosk. Other benefits of this program include regular maintenance of the bus stop shelters and facilities, including trash removal and installation of interior lighting at selected sites, by the advertising agency.

The advertisements are placed on panels attached to the bus shelter to take advantage of the visibility that the bus stop receives from passing traffic. Backlighting is sometimes used to display the images at night. Advertisements do not necessarily have to be attached to the shelter. In some areas, kiosks are used to display advertisements. Depending on design, the kiosk may provide additional protection from the elements at a bus stop.

Issues associated with advertisements placed on shelters and kiosks include compatibility with local land uses, ordinances, and safety. The signs can conflict with color schemes or limit views of adjacent store fronts. Advertising at bus stops must also comply with local sign ordinances, which may hinder installation in some communities.

Passenger and pedestrian safety and security are of greater concern at shelters with advertising. The advertising panels may limit views in and around a bus stop, making it difficult for bus drivers to see patrons. The panels can also reduce incidental surveillance from passing traffic. To prevent restricted sight lines, advertising panels and kiosks should be placed downstream of the traffic flow. An approaching bus driver should be able to view the interior of the shelter easily. Indirect surveillance from passing traffic should be preserved through proper placement of the panels (see Figure 34).

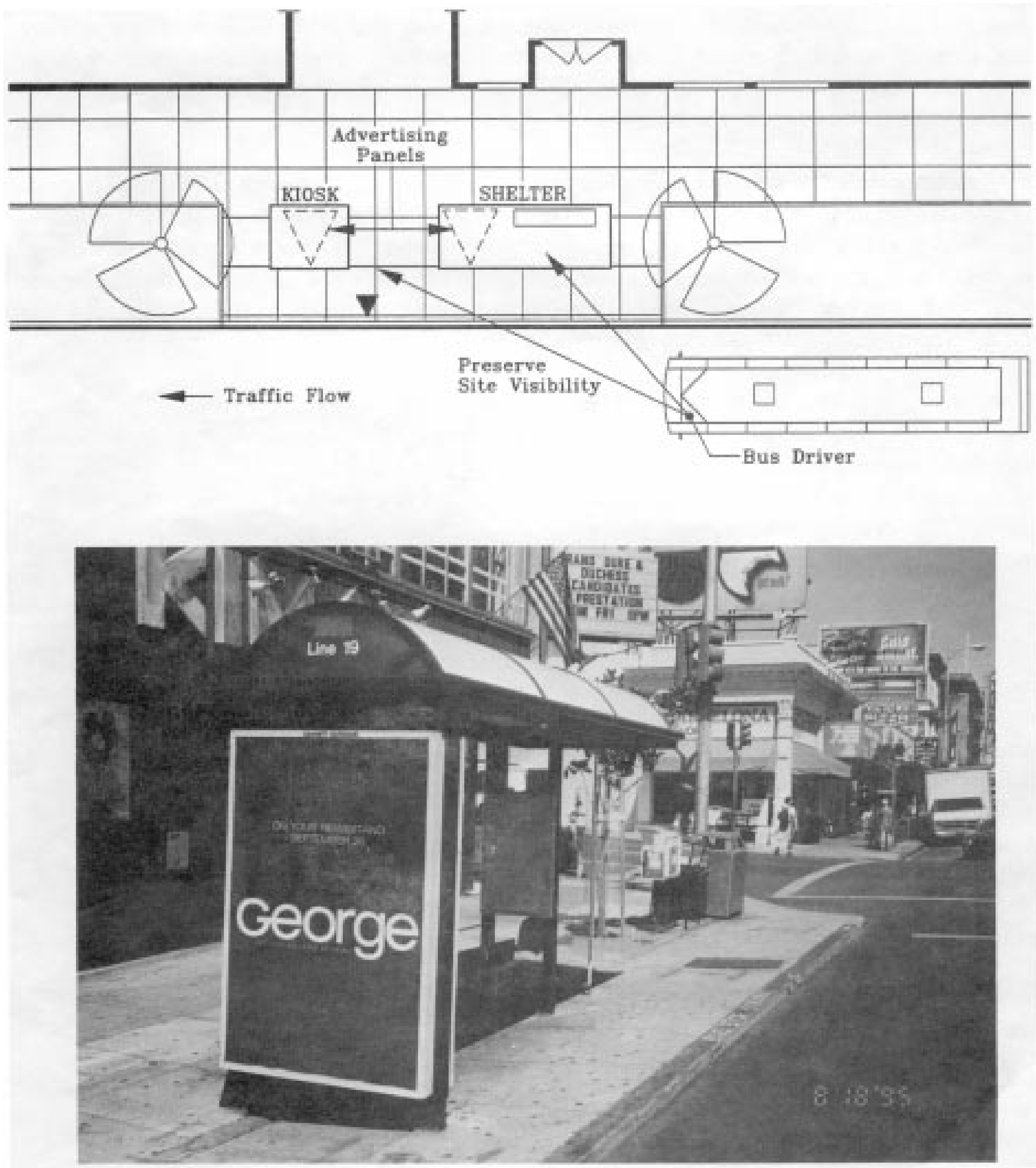


Figure 34. Placement Recommendations for Advertising Panels and Kiosks.

Chapter 4

CURB-SIDE FACTORS

SHELTERS—Developer Provided

Private developers can also provide bus stop shelters. Typically, these shelters are constructed to serve a specific development, neighborhood, complex, or shopping mall. Facilities range in scope from a single stop to a series of coordinated stops serving an entire residential development or office park. The designs are often striking and closely linked visually with the major design features of the central structure, building, or neighborhood.

Bus shelters installed by developers should meet transit agency requirements. These requirements include an acceptable location, safe pedestrian access (i.e., direct sidewalk to the shelter), visibility for vehicles and waiting passengers, access for those with mobility impairments, and signage. Shelter ownership and long-term maintenance responsibilities should be determined before installation. Bus stop location decisions should be made collaboratively by the transit agency and the developer.

When private development and transit service collaborate on shelter installation, the benefits to both are numerous. Transit considerations are factored into the development from the beginning. The development itself may become more transit-friendly through combined transit agency/developer design of routes to provide service to the new development's residents. From the developer's standpoint, designing for transit improves the overall accessibility of the development, may increase the feasible density of the development, may reduce parking requirements, and may increase pedestrian traffic. These factors may have a positive effect on lease (especially retail) value. Improved accessibility can also make recruiting employees easier. Figure 35 is an example of a developer-installed shelter.

Figure 35. Developer-Installed Shelter.

Transit agencies can use artist-designed stops and shelters or other methods to ensure that stops and shelter designs have a theme. One approach is to commission local artists to design or decorate a shelter or waiting area. This requires considerable coordination, the support of the neighborhood, a public relations effort sufficient to generate the interest of local artists, and, ideally, sponsorship by some civic organization. Figure 36 shows an example of a shelter designed by a local artist.

Customized or artistically designed bus stops can make waiting for a bus more pleasant. Innovative designs may also help provide a covered shelter or seating (e.g., flip-seats or awnings) for passengers at locations that do not have sufficient space. However, custom-designed passenger waiting areas should not obscure identification of the bus stop. Transit agency bus stop signs and schedule displays should be available at these types of bus stops. The functionality of the stop should not be compromised in the name of art—the stop should provide as much patron comfort, safety, and security as possible.

Neighborhood or business interests may also want the shelters and bus stop signs to reflect the character of the district. One method is to develop a distinct color or logo for each neighborhood or route group. This can be implemented by the transit agency with appropriate coordination and participation from the neighborhoods.

Figure 36. Artistic Shelter.

Chapter 4

CURB-SIDE FACTORS

AMENITIES—Benches

A bench, even without a bus shelter, provides comfort and convenience at bus stops. As with shelters, benches are usually installed on the basis of existing or projected ridership figures. Ridership figures below those justifying a bus shelter are commonly used. Other factors used in determining bench-only locations include the following:

- The width of the bus stop location.
- Bus stops with long headways and little protection from the weather.
- Locations where the landowner has denied permission to construct a shelter.
- Sites that are frequently used by elderly people or people with disabilities.
- Evidence that transit patrons are sitting or standing on nearby land or structures.

Two factors that greatly influence the use of benches are crowding at a site and the environment at a site. Crowding limits patrons choices about sitting and waiting and forces patrons to wait around, rather than in, the bus stop. Uncomfortable bus stop environmental conditions, such as heat and sun, can also discourage use of the bench.

Preserving minimum circulation guidelines, coordinating with existing landscaping, and providing additional waiting areas can improve bench and site utilization. The following bench placement guidelines are recommended:

- Avoid locating benches in completely exposed locations. Coordinate bench locations with existing shade trees if possible. Otherwise, install landscaping to provide protection from the wind and other elements.
- Coordinate bench locations with existing street lights to increase visibility and enhance security at a stop.
- Locate benches on a non-slip, properly drained, concrete pad. Avoid locating benches in undeveloped areas of the right-of-way.
- Locate benches away from driveways to enhance patron safety and comfort.

- Maintain a minimum separation of 2 feet (preferably 4 feet) between the bench and the back-face of the curb. As the traffic speed of the adjacent road increases, the distance from the bench to the curb should be increased to ensure patron safety and comfort.

- Maintain general ADA mobility clearances between the bench and other street furniture or utilities at a bus stop.

- Do not install the bench on the 5-foot by 8-foot wheelchair landing pad.

- At bench-only stops, additional waiting room near the bench should be provided (preferably protected by landscaping) to encourage bus patrons to wait at the bus stop.

Figure 37 provides an example of the circulation requirements at a bench-only bus stop with additional seating provided.

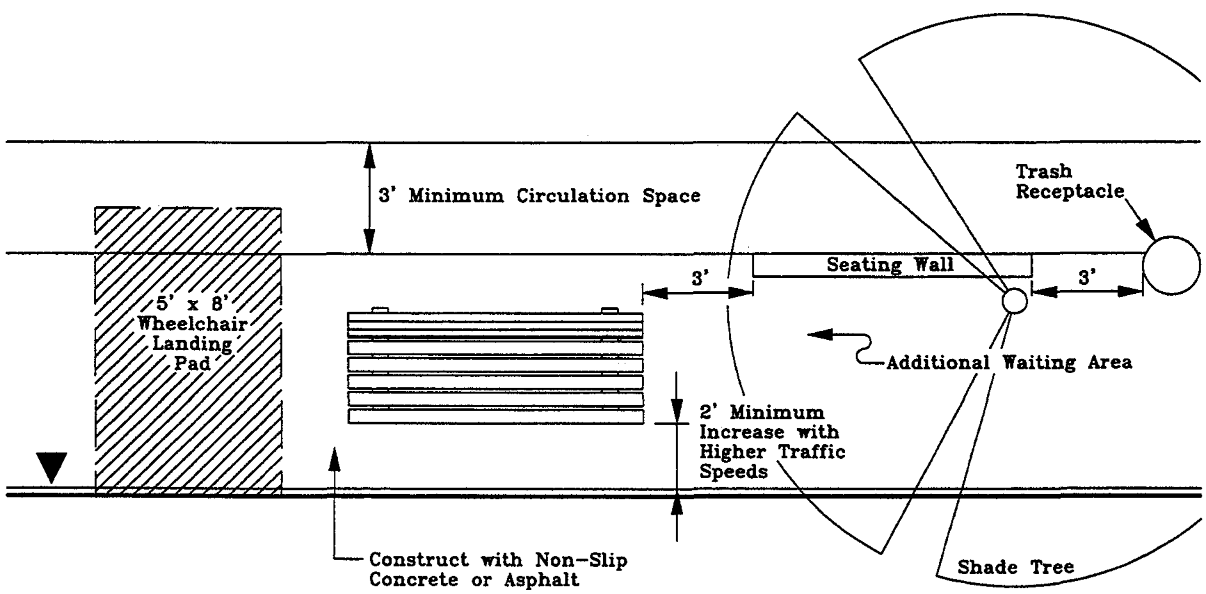


Figure 37. Conceptual Bench and Waiting Pad Design.

Chapter 4

CURB-SIDE FACTORS

AMENITIES—Route or Patron Information

Route and passenger information can be displayed in various ways. A flag sign is the most common method used by transit agencies to display information. Placement and design guidelines for flag signs are discussed in Chapter 3. Installation of schedule holders or schedule and route information on the shelters are also commonly used.

The actual displays mounted on the sign can include the transit agency logo, route numbers available at the stop, type of route (local or express), and destination for a limited number of routes. Detailed guidelines for the design of bus stop signs can be found in *TCRP Report 12,* "Guidelines for Transit Facility Signing and Graphics," and should be referenced for greater detail.

Schedule holders are included at sites with large passenger volumes. The schedule holders can be mounted on the flag sign or inside a shelter. According to "Guidelines for Transit Facility Signing and Graphics," information in Braille can be provided when a four-sided information holder is used. A route plaque and an information holder mounted to a sign post are shown in Figure 38.

Interior panels of shelters also can be used for posting route and schedule information. Side panels may be large enough to display the entire system map and can include backlighting for display at night. Shelters that lack side panels can display route and schedule information on the interior roof of the shelter. Some recommendations for route or patron information display are as follows:

- Provide updated information when changes are made to routes and schedules.
- Consider the quality and appearance of information displays. A visually poor route map conveys a negative impression of the system.
- Make information displays permanent. Temporary methods for displaying information (such as tape-mounting) create a cluttered, unsophisticated appearance at the bus stop.
- Follow ADA clearance, mobility, and visual guidelines for access of information by individuals with impairments.

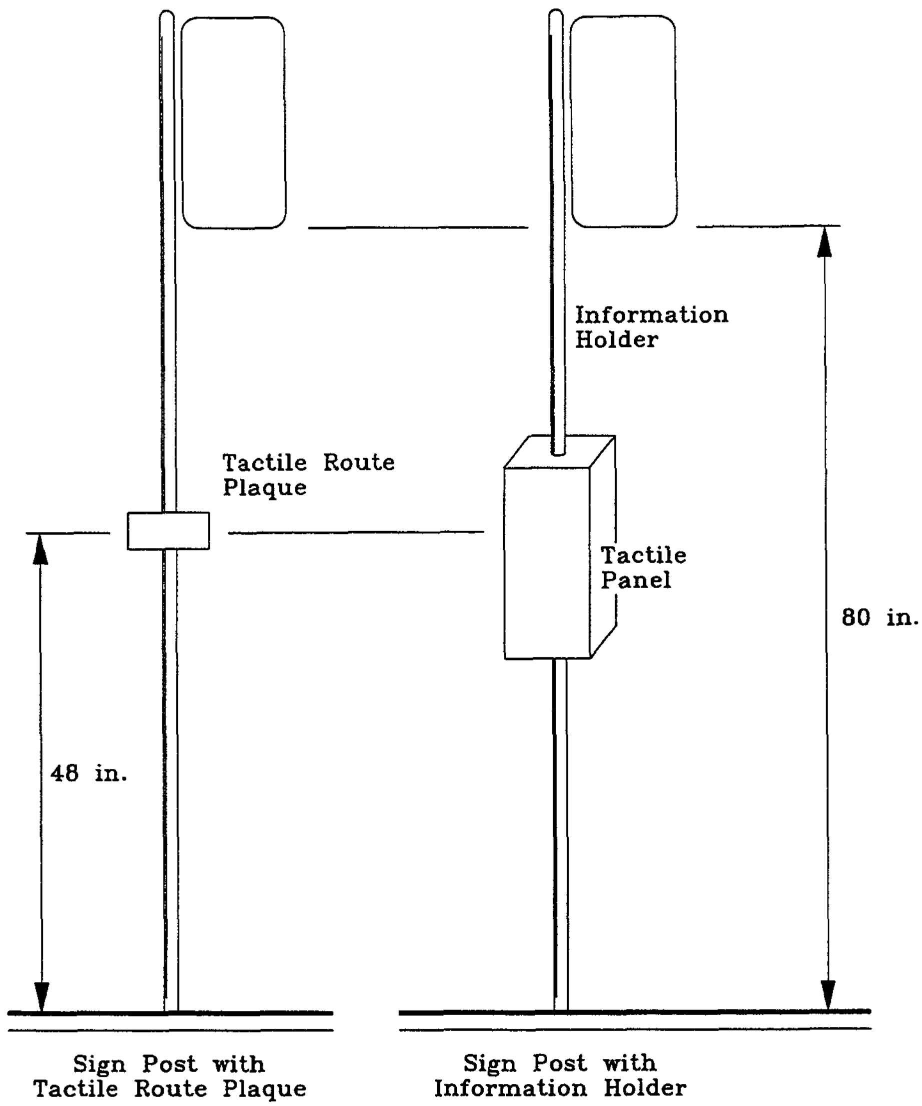


Figure 38. Examples of Passenger Information Holders.

Chapter 4 CURB-SIDE FACTORS

AMENITIES—Vending Machines

Vending machines can provide passengers with reading material while they wait for the bus. However, for local, non-commuter routes, vending machines can be undesirable for many reasons. The machines are often poorly maintained and reduce the amount of room for mobility and waiting (see Figure 39). Perhaps the greatest effect, though, is that trash accumulates at bus stops with vending machines. Trash removal is time-consuming and costly.

The existence of vending machines at or near bus stops does not appear to be the result of transit agency policy. Rather, it is a result of newsprint companies aggressively pursuing a high-profile site. Transit agencies have limited regulatory authority concerning the placement of vending machines.

Transit agencies, if given the opportunity, should review the need for the installation of vending machines at bus stops. The benefits to patrons of having the machines near the stop versus having to maintain trash receptacles and keep the area free of improperly disposed material should be reviewed. Vending machines at a bus stop should be anchored to the ground to reduce vandalism. ADA mobility guidelines should be followed for improved site circulation (e.g., the location of the vending machines should not obstruct the wheelchair landing pad area).

Figure 39. Image of Vending Machines at a Bus Stop.

Bicycle storage facilities, such as bike racks, may be provided at bus stops for the convenience of bicyclists using transit. Designated storage facilities discourage bicycle riders from locking bikes onto the bus facilities or on an adjacent property. Proper storage of bicycles can reduce the amount of visual clutter at a stop by confining bikes to one area. Recommendations regarding bicycle storage facilities are as follows:

- Provide paved access to the bus stop and construct the waiting area with non-slip concrete or asphalt that is properly drained.
- Locate the storage area away from other pedestrian or patron activities to improve safety and reduce congestion.
- Coordinate the location of the storage area with existing on-site lighting.
- Do not locate the storage area where views into the area are restricted by the shelter, landscaping, or existing site elements, such as walls.

Many prefabricated storage methods are available, however, as bicycle prices have escalated in recent years, interest has grown in storing bikes in completely enclosed containers called bike lockers (see Figure 40) or taking bikes on the bus. Although the transit agency can obtain revenue from renting bicycle lockers to patrons, bike lockers are large and awkward to place next to bus stop shelters on sidewalks and present additional surfaces at a bus stop for graffiti. For these reasons, they can be expensive to maintain.

It appears bicycle storage is associated with the commuter market and should be installed when demand warrants, which is primarily at major suburban stops. Where substantial bike activity exists, such as in university towns, on-vehicle bike programs are a major asset. Regional demographics should be carefully reviewed prior to implementing such a program.

Figure 40. Example of a Bike Locker.

Chapter 4

CURB-SIDE FACTORS

AMENITIES—Trash Receptacles

Trash receptacles can improve the appearance of a bus stop by providing a place to dispose of trash. The installation of trash receptacles is typically a systemwide decision and the size, shape, and color reflect transit agency policy. Not all bus stops have trash receptacles. Low patron volumes may not justify the inclusion of this amenity at a bus stop; however, litter at a site may warrant the inclusion of a trash receptacle at an otherwise low-volume location.

Problems can arise when the receptacles are not regularly maintained or when the bus stop is next to a land use that generates considerable trash such as convenience stores and fast food restaurants. In such cases, transit agencies should work with these establishments to define maintenance responsibilities for the bus stop and the area around the businesses. Businesses and community groups typically are reluctant to agree to maintaining trash receptacles at public sites.

Recommendations regarding installing a trash receptacle at a bus stop are as follows:

- Anchor the receptacle securely to the ground to reduce unauthorized movement.
- Locate the receptacle away from wheelchair landing pad areas and allow for at least a 3-foot separation from other street furniture.
- Locate the receptacle at least 2 feet from the back of the curb.
- Ensure that the receptacle, when adjacent to the roadway, does not visually obstruct nearby driveways or land uses.
- Avoid installing receptacles that have ledges or other design features that permit liquids to pool or remain near the receptacle—this may attract insects.
- Avoid locating the receptacle in direct sunlight. The heat may encourage foul odors to develop.

Figure 41 shows the minimum circulation and separation requirements for trash receptacles at bus stops.

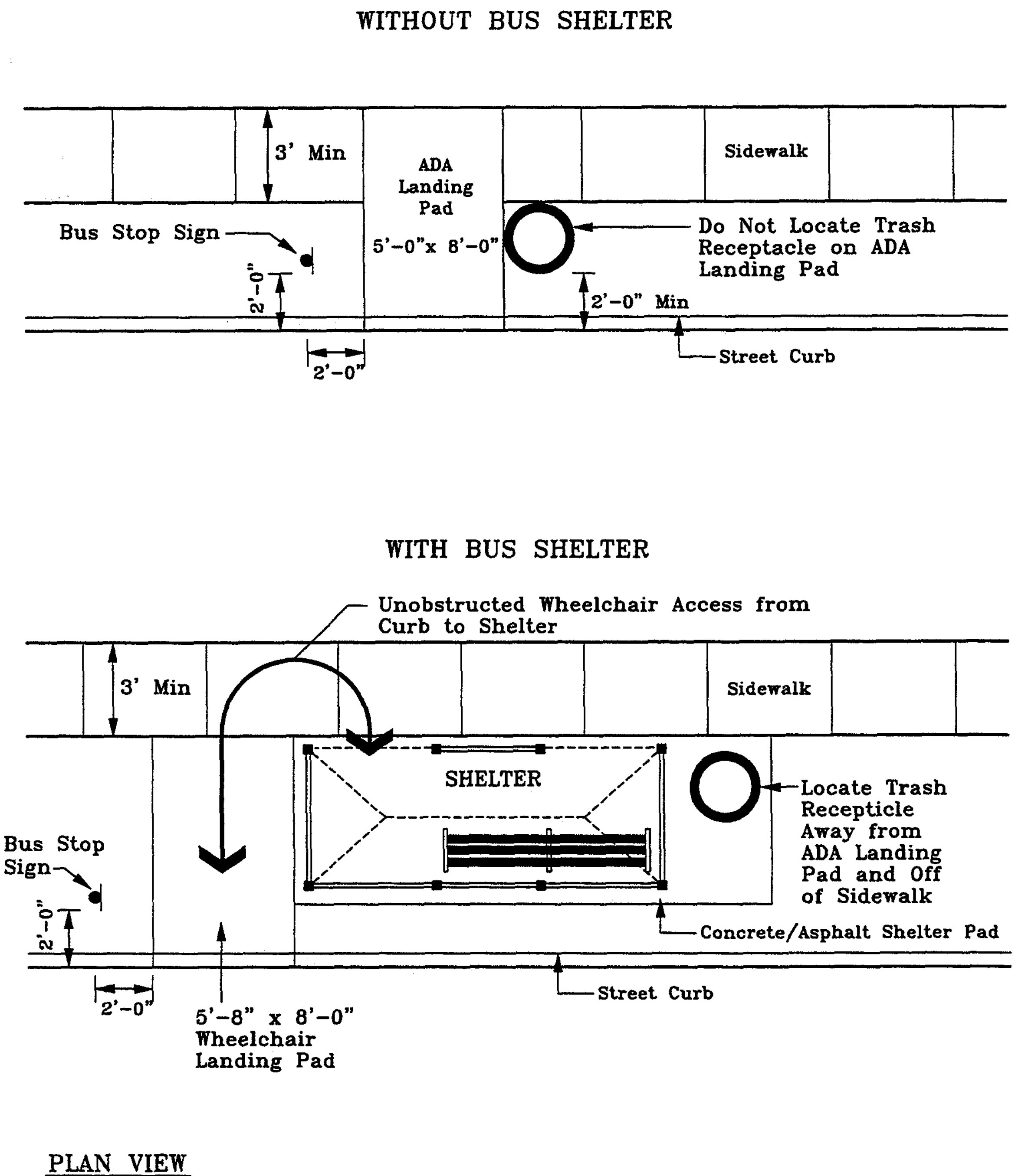


Figure 41. Trash Receptacle Placement Guidelines.

Chapter 4 CURB-SIDE FACTORS

AMENITIES—Phones

Phones at bus stops offer many potential benefits for bus patrons. Patrons can make personal and emergency calls while waiting for the bus. Phones also can provide real-time bus arrival information. Figure 42 shows a phone at a bus stop. Some transit agencies have explicit policies regarding the installation of phones at bus stops. Experience with phones at bus stops has been mixed. For example, inclusion of phones at bus stops can create opportunities for illegal or unintended activities, such as drug dealing and loitering, in and around bus stops. Loitering by non-bus patrons at bus stops appears to increase with the installation of phones; this may discourage bus patrons from using the facility. Transit agencies should review the potential consequences of installing a phone at a bus stop prior to installation.

When locating a phone at a bus stop, the following guidelines should be considered:

- Separate the phone and the bus stop waiting area by distance when possible.
- Follow general ADA site circulation guidelines.
- Remove the return phone number attached to the phone.
- Limit the phone to outward calls only.

Figure 42. Example of a Phone at a Bus Stop.

Proper storage for shopping carts at bus stops adjacent to commercial shopping centers is needed. Because such bus stops normally do not have storage facilities for shopping carts, carts often litter the area around the stop and along the sidewalk accessing the stop. The sight of haphazardly placed shopping carts around a bus stop is visually unappealing and can block sidewalk access. Figure 43 shows shopping carts abandoned at a bus stop.

Because the shopping carts are generated by the shopping center, agreements should be made between the land owner and the transit agency to remove the carts regularly. Frequently, however, the time between removals is too long and shopping carts accumulate at a bus stop. One solution is to install a storage facility near the bus stop to prevent random storage in and around the stop. Factors affecting installation of a storage facility include the location of the sidewalk, available right-of-way, utilities, landscaping, terrain, and cost. Any cart storage facility should follow the general site circulation guidelines and remain clear of the sidewalk and wheelchair landing pad area.

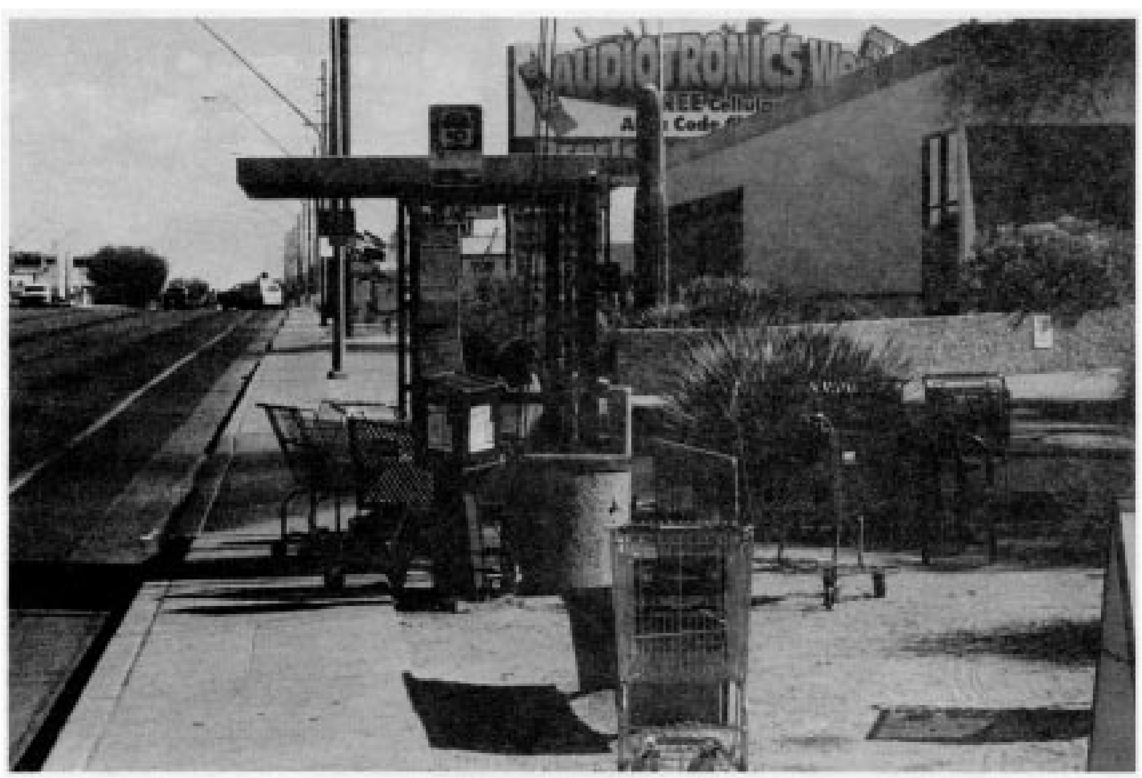


Figure 43. Shopping Carts Abandoned at a Bus Stop.

Chapter 4

CURB-SIDE FACTORS

AMENITIES—Lighting

Lighting affects bus patrons' perception of safety and security at a bus stop, as well as the use of the site by non-bus patrons. Good lighting can enhance a waiting passenger's sense of comfort and security; poor lighting may encourage unintended use of the facility by non-bus patrons, especially after hours. Lighting is particularly important in northern climates where patrons may arrive and return to the stop in darkness during the winter season. Illumination requirements are often a policy of individual transit agencies; however, installing lighting that provides between 2 to 5 footcandles is the general recommendation.

Cost and availability of power influence the decision to install direct lighting at a bus stop. Direct lighting is expensive and difficult to achieve at remote locations. When installing direct lighting at a bus stop, the fixtures should be vandalproof but easily maintained. For example, avoid using exposed bulbs or elements that can be easily tampered with or destroyed.

A cost-effective approach to providing indirect lighting at a site is to locate bus stops near existing street lights. When coordinating bus shelter or bench locations with existing street lights, the minimum clearance guidelines for the wheelchairs should be followed. Figure 44 is an example of coordinating a shelter with an existing street light.

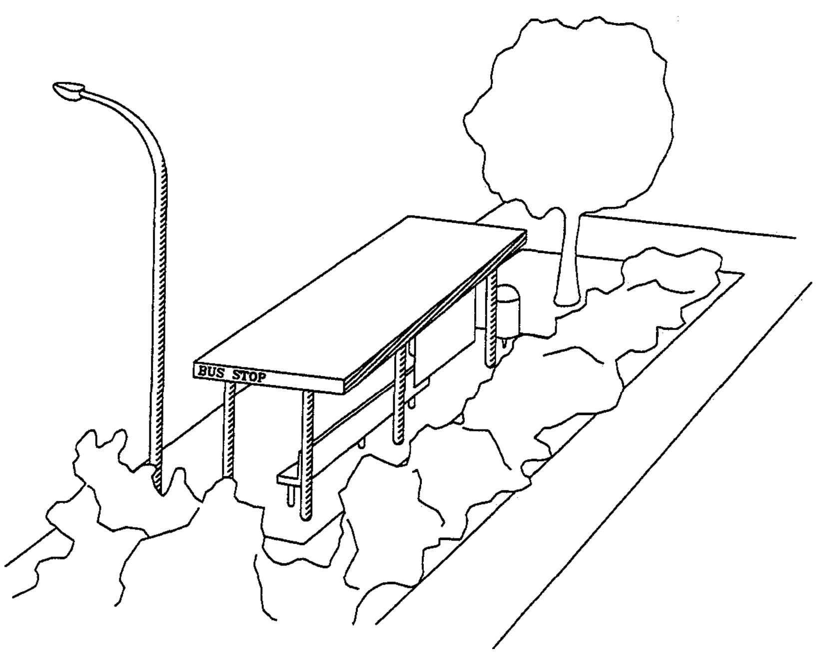


Figure 44. Example of Coordinating Shelter Locations with an Existing Street Light.

Passenger security is a major issue in bus stop design and location, because the design and location of the bus stop can positively or negatively influence a bus patron's perception of that bus stop. From the perspective of security, landscaping, walls, advertising panels, and solid structures can restrict sight lines and provide spaces to hide. Each of these items can be an integral part of the bus stop, either by design or by proximity of existing land uses. Therefore, the transit agency should carefully review which amenities are to be included at a bus stop and consider any factors that may influence security. Other sections of this document have discussed some of these concepts and should be referenced. Some guidelines regarding security at bus stops are as follows:

- Bus stop shelters should be constructed of materials that allow clear, unobstructed visibility of and to patrons waiting inside.

- Bus stops should be at highly visible sites that permit approaching bus drivers and passing vehicular traffic to see the bus stop clearly.

- Landscaping elements that grow to heights that would reduce visibility into and out of the bus stop should be avoided. Low-growing shrubbery and ground cover and deciduous shade trees are preferred at bus stops. Evergreen trees provide a visual barrier and should be avoided.

- Bus stops, whenever possible, should be coordinated with existing street lighting to improve visibility.

- Bus stops should be next to existing land uses, such as stores and businesses, to enhance surveillance of the site.

Chapter 4

CURB-SIDE FACTORS

AMENITIES—Advantages and Disadvantages

Amenity	Advantages	Disadvantages
Shelters	• Provide a place of comfort for waiting passengers • Provide protection from elements (sun, glare, wind, rain, snow) • Help identify the transit system • Can provide a venue for establishing lighting at a site • Can provide a space to install route and schedule information	• Require maintenance, trash collection • May be used by graffiti artists
Shelters (Advertising)	• Can be impetus for installing lighting at stop • Are often maintained by advertising company	• Can reduce sight lines if panels are improperly located • Must be compatible with local sign ordinances and land uses
Benches	• Provide comfort for patrons • Help identify the stop • Are a low-cost amenity when compared to installing a shelter	• Require maintenance • May be used by graffiti artists
Vending Machines	• Provide waiting patrons with reading material	• Increase trash accumulation at a site • May have poor visual appearance • Reduce circulation space • Can be vandalized
Lighting	• Increases visibility • Increases perceptions of comfort and security by patrons • Discourages "after hours" use of bus stop facilities by indigents	• Requires maintenance of lighting elements • Can be costly

CURB-SIDE FACTORS

AMENITIES—Advantages and Disadvantages

Amenity	Advantages	Disadvantages
Trash Receptacles	• Provide place to discard trash • Keep bus stop clean	• May be costly to maintain • May be used by customers of near-by land use (i.e., fast food restaurant) • May smell
Phones	• Are convenient for bus patrons • Provide access to transit information	• May encourage loitering at or near bus stop by non-bus patrons • May encourage illegal activities at bus stop
Route or Schedule Information	• Is useful to first time riders • Helps identify the bus stop • Can communicate general system information	• Must be maintained to provide current route or schedule information • May be popular surface for graffiti

Chapter 4

CURB-SIDE FACTORS

AMENITIES—Materials

Various materials can be used to construct a bus stop. The best materials are those that are weather-resistant, can withstand continual use, and can be easily maintained. The ease with which a particular material can be vandalized can reduce its desirability; easy-to-clean materials are desirable. Primarily, wood, metal, concrete, glass, and plastics are used at bus stops.

Wood, sometimes used for benches, is rarely used to construct other elements because it is easily vandalized and weathers badly.

Metal is frequently used to construct shelters, benches, bike racks, and trash receptacles. Aluminum, although fairly inexpensive and easy to work with, is soft and easily scratched. Its high recyclability makes it a target for theft by unscrupulous recyclers. As with any item or material, objects should be properly affixed to prevent/discourage unauthorized removal. Metal, in combination with a plastic coating, is a good material for benches, especially when a wire mesh design is used. The design resists everyday wear and tear and graffiti.

The best use of concrete at bus stops is in the paving. Concrete, an excellent non-slip surface, can be easily poured on site to construct sidewalks, waiting pads, and connections between the stop and the curb. Concrete is too heavy and cumbersome to use in other elements at a bus stop.

Plastic is used for paneling and roofing on shelters. The material is lightweight and can be installed with minimal effort. Clear plastic permits the interior of the shelter to be visible from a distance, which enhances security. Depending on the desired effect, plastic can be frosted to reduce the amount of sun entering the shelter or left clear to permit sun exposure. A major disadvantage of plastic is that it is easily damaged or destroyed by vandalism—the material can be scratched or kicked out from its holdings. Plastic declines over time by becoming translucent and scratched, and harsh chemical cleaners can expedite the decline.

Tempered glass is primarily used for side panels on shelters. Visually, the material is more pleasing than plastic and withstands environmental demands better than plastic. Unlike plastic, the material is not damaged by repeated cleaning; broken glass, however, can create a hazard for waiting passengers. Improperly anchored objects, such as vending machines and trash receptacles, should be avoided at bus stops with glass because they can be used to destroy glass panels or roofs.

CURB-SIDE FACTORS

AMENITIES—Materials Advantages and Disadvantages

Material	Advantages	Disadvantages
Wood	• Is used to construct benches • Is repaired or replaced easily	• Weathers easily • Can be vandalized easily
Metal (Aluminum)	• Resists weathering • Can be used to construct multiple elements at a bus stop • Can be inexpensive	• Can be scratched easily (vandalism problem)
Concrete	• Can be installed as a non-slip paving surface	• Is too heavy and cumbersome for use other than paving
Plastic	• Is lightweight • Allows unobstructed view into and out of shelter • Can be formed into different shapes	• Declines with exposure to sun and repeated cleaning • Can be scratched easily
Glass (Tempered)	• Withstands environmental demands better than plastic • Can be cleaned easily • Can be perceived as more attractive than plastic • Allows unobstructed view into and out of shelter	• Can be broken, which can present a safety hazard to patrons

Chapter 4 CURB-SIDE FACTORS

CURB-SIDE PLACEMENT CHECKLIST

This section of the guidelines lists topics that should be reviewed to enhance patron comfort, convenience, and security. The topics range from the general (such as locating a bus stop in the community) to the specific (such as preserving sight lines).

- **Location Within the Community:** The location of the bus stop should be coordinated with the business community and neighborhood. Businesses want to preserve clear views of storefronts and maintain open circulation spaces in and around the storefronts. Although improperly located shelters can obstruct business activities, bus stops can enhance both transit and business activities when sited properly.

  Homeowners are another influential voice in the community. Typically, they do not want stops in front of their properties. Efforts to maintain bus stops in residential neighborhoods may reduce the "not-in-my-backyard" attitudes.

  Coordination between governmental agencies can enhance or impede this process. Liability can be a major issue for governmental agencies and businesses. This is especially true when improvements are made to sidewalks at or near bus stops. Transit agencies can create their own regulatory hurdles to avoid liability. However, this action comes at the expense of the transit patron, the ultimate customer. Coordination and cooperation can improve this process.

- **Compatibility:** Bus stops should be located so as to limit conflicts with pedestrians and other activities. Bus stops that create conflict points with pedestrians and bicyclists or reduce the capacity of existing sidewalks should be avoided. Benches, shelters, and other bus-related facilities should be separated from pedestrian or bicycle facilities when space permits. Because bus stops are commonly placed near parking lots, bollards and/or a raised curb would prevent cars from damaging bus facilities (e.g., bus shelters) or interfering with bus activities and patrons.

  Bus stops should be located so as to provide safe separation of passengers and vehicles from nearby land uses. They should not be directly next to the curb, which puts patrons close to passing vehicles. This is especially true for stops on roads with high traffic speeds. The zone of comfort or separation for patrons from high speed traffic may be violated when the shelter or bench is too close to the edge of the roadway. The minimum acceptable offset for benches and shelters from the back face of the curb is 2 feet. This distance should increase with higher speed limits.

CURB-SIDE FACTORS

CURB-SIDE PLACEMENT CHECKLIST

- **Direct Access to Bus Stop:** Landscaping, berms, security walls, large parking lots, and circuitous sidewalks can decrease the convenience of using transit by increasing the walking time between the origin or destination and the bus stop. Direct access to and from the bus stop is critical to the convenience of using transit. The transit agency can work with local jurisdictions or developers to ensure that direct sidewalks are installed near bus stops from the intersection or adjacent land uses. Defined paths or walkways can be installed through parking lots or landscaping to reduce walking times and improve safety.

- **Impervious Ground Surfaces:** Avoid locating bus stops on exposed soil, grass, or uneven ground. For passenger comfort and convenience, a waiting pad constructed of impervious non-slip material should be provided at the bus stop. This should be graded for proper runoff control and meet ADA requirements for cross slopes. The bus stop should be coordinated with existing sidewalks to provide defined and controlled access to the stop. In developing areas, the transit agency can coordinate bus stop location with sidewalk locations and installation through local jurisdictions or developers.

- **Proper Pedestrian Circulation:** Utility poles, fire hydrants, and street furniture can reduce the available space for bus patrons to maneuver. Avoid locating stops near items that may restrict proper movement in and around a bus stop.

  Appropriate spacing of items at a bus stop should also be maintained to allow proper access for wheelchairs and pass-by pedestrian traffic. Shelters, benches, utility poles, and other street furniture should not intrude on the ADA landing pad, which should be at least 5 feet (measured parallel to the curb) by 8 feet (measured perpendicular from the back face of the curb). At least 3 feet of clearance should be maintained to enable wheelchair access to and from the stop and around any transit amenities, posts, poles, fire hydrants, vending machines, or other fixtures that might be present. Ideally, high-volume stops should have clear pedestrian access from both bus doors.

Chapter 4

CURB-SIDE FACTORS

CURB-SIDE PLACEMENT CHECKLIST

- **Existing Street Furniture:** Selecting sites with existing street furniture can save the transit system money while providing patrons with amenities, such as benches, vending machines, and phones. The transit agency should review the condition of the amenities to make sure the items are properly maintained and free of graffiti or other signs of wear. The transit agency should also note the placement of any existing street furniture. When additional improvements are made to the site because of the installation of a bus stop, the location of existing street furniture may reduce circulation space and accessibility.

- **Environmental Treatments:** Existing site conditions can be used to enhance the environmental comfort of a bus stop. Sun/shade patterns provided by existing vegetation or structures can contribute to the comfort of waiting bus patrons. The final design of the bus stop shelter should also respond to the environmental demands of a site (e.g., sun/shade patterns, winds, and precipitation). Panel placement, orientation, and materials should be selected to provide maximum comfort to patrons. The site should also be well drained.

- **Security:** Perception of security at a bus stop can have a significant influence on the comfort level of patrons using that bus stop. To enhance the security of bus stops, regularly remove graffiti and trash (to discourage repeat occurrences), ensure indirect surveillance from nearby land uses and passing traffic, and avoid locating stops where there is opportunity for concealment. When landscaping is involved, use low-growing shrubs that preserve sight lines.

- **Lighting:** Bus stops may include lighting or be located near existing street lights that provide indirect lighting to enhance the security of a stop. Interior shelter lighting can be a critical amenity when patrons arrive and return in the dark. The interior lighting elements should be resistant to vandalism and be maintained regularly. Bus shelters without interior lights should, whenever possible, have translucent roofs.

  Pedestrian-oriented lighting should be encouraged in new developments or when major infrastructure work is being planned. Indirect lighting from nearby businesses can also enhance surveillance of the site from these land uses.

CURB-SIDE FACTORS

Chapter 4

CURB-SIDE PLACEMENT CHECKLIST

- **Sight Line:** The bus stop should be clearly visible for both safety and security reasons. Stops obscured by existing structures or vegetation are difficult for bus drivers to see. Passing vehicles may be unaware of the presence of pedestrians near or on the roadways; this increases the chance that accidents will occur. Right turns on red can increase the likelihood of pedestrian-vehicle conflicts. The bus stop site should be inspected carefully to detect any potential sight-related problems.

  For security reasons, sight lines should be preserved to maintain direct and indirect surveillance of the bus stop. Landscaping, walls, advertising panels, and structures can restrict sight lines and provide spaces to hide. Bus stops should be easily viewed from nearby land uses and passing traffic to enhance the security of the stop. Bus shelters should be constructed of materials that allow clear, unobstructed visibility of patrons waiting inside. Bus patrons also need to be able to observe their surroundings when inside the shelter.

- **Maintenance:** Proper maintenance of bus facilities is crucial to preserving a positive image of a transit system. Trash and graffiti should be removed as soon as possible to prevent further degradation of the facilities. A database containing maintenance schedules can be created to track the condition of the facilities, including pavement surface conditions; age of the facilities; history of damage; and condition of shelter, benches, or other transit amenities.

  Bus stop maintenance can be costly and time-consuming. Working agreements with local businesses or commercial centers can reduce the financial responsibilities of the transit agency. For stops next to convenience stores, the transit agency should try to obtain a working agreement with the local store or businesses to provide trash removal and general maintenance at the bus stop. This should include snow removal.

  Agreements with commercial-strip centers should also be obtained to remove used shopping carts from a bus stop regularly. Shopping carts abandoned around bus stops are visually unappealing and restrict movement through a site.

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GLOSSARY

Chapter 5

TERMS AND DEFINITIONS

accessway - a paved connection, preferably non-slip concrete or asphalt, that connects the bus stop waiting pad with the back face of the curb.

adaptive use - an individual's spontaneous, creative use of a facility or structure in ways that differ from or go beyond the intended use or the formal design.

advertising shelter - a bus shelter that is installed by an advertising agency for the purpose of obtaining a high-visibility location for advertisements. By agreement, the bus shelter conforms to the transit agency specifications but is maintained by the advertising company.

ADA - American's with Disabilities Act of 1990. The Act supplants a patchwork of previous accessibility and barrier-free legislation with a comprehensive set of requirements and guidelines for providing *reasonable* access to and use of building, facilities, and transportation.

amenities - things that provide or increase comfort or convenience.

bollards - a concrete or metal post placed into the ground behind a bus shelter to protect the bus shelter from vehicular damage.

bus bay - a specially constructed area off the normal roadway section for bus loading and unloading.

bus stop spacing - the distance between consecutive stops.

bus stop zone length - the length of a roadway marked or signed as available for use by a bus loading or unloading passengers.

curb-side factors - factors that are located off the roadway that affect patron comfort, convenience, and safety.

curb-side stop - a bus stop in the travel lane immediately adjacent to the curb.

detector - a device that measures the presence of vehicles on a roadway.

discontinuous sidewalk - a sidewalk that is constructed to connect the bus stop with the nearest intersection. The sidewalk does not extend beyond the bus stop.

Chapter 5

GLOSSARY

TERMS AND DEFINITIONS

downstream - in the direction of traffic.

dwell time - the time a bus spends at a stop, measured as the interval between its stopping and starting.

far-side stop - a bus stop located immediately after an intersection.

headway - the interval between the passing of the front ends of successive buses moving along the same lane in the same direction, usually expressed in minutes.

layover - time built into a schedule between arrivals and departures, used for the recovery of delays and preparation for the return trip.

midblock stop - a bus stop within the block.

near-side stop - a bus stop located immediately before an intersection.

nub - a stop where the sidewalk is extended into the parking lane, which allows the bus to pick up passengers without leaving the travel lane, also known as bus bulbs or curb extensions.

open bus bay - a bus bay designed with bay "open" to the upstream intersection.

queue jumper bus bay - a bus bay designed to provide priority treatment for buses, allowing them to use right-turn lanes to bypass queued traffic at congested intersections and access a far-side open bus bay.

queue jumper lane - right-turn lane upstream of an intersection that a bus can use to bypass queue traffic at a signal.

roadway geometry - the proportioning of the physical elements of a roadway, such as vertical and horizontal curves, lane widths, cross sections, and bus bays.

shelter - a curb-side amenity designed to provide protection and relief from the elements and a place to sit while patrons wait for the bus.

sight distance - the portion of the highway environment visible to the driver.

street-side factors - factors associated with the roadway that influence bus operations.

GLOSSARY

Chapter 5

TERMS AND DEFINITIONS

TCRP - Transit Cooperative Research Program of the Transportation Research Board.

upstream - toward the source of traffic.

waiting or accessory pad - a paved area that is provided for bus patrons and may contain a bench or shelter.

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APPENDIXES A-C

Appendixes A through C as submitted by the research agency are not published herein, but are available for loan on request to the TCRP.

Appendix A - Literature Search
Appendix B - Review of Transit Agencies' Manuals
Appendix C - Survey Findings

APPENDIX D

STREET-SIDE STUDIES

A number of alternatives are available when choosing the location, type of facility, and design for a bus stop. These alternatives include near-side, far-side or midblock locations, and curb-side or bus bay designs. None is ideal in all respects, but one design may offer a better balance of benefits to bus patrons and through vehicles given certain conditions. Therefore, the factors influencing the location and type of facility provided need to be analyzed, and a method for selecting the optimum alternative developed.

Appendix D presents the findings from studies that analyzed traffic and bus operations around various bus stop locations and designs. The studies included **regional visits** to agencies involved in transit operations, **field studies** of existing bus stops, and **computer simulation**. How different bus stop designs operate was explored during the regional visits. The objective of the field studies was to learn how different bus stop locations and designs influence traffic operations and driver behavior around a bus stop. The effects of bus stop design on suburban arterial traffic operations were further analyzed with the use of computer simulation.

Appendix D devotes a section to each study approach and concludes with a summary of findings.

REGIONAL VISITS

Both mail and telephone surveys were conducted during this project. (The findings from those surveys are documented in the *Location and Design of Bus Stops*, *Final Report*, Project A-10, available from TCRP.) While phone surveys provided an understanding of different concerns at various agencies, site visits were critical to provide a full appreciation of how different bus stop designs operate. On-site visits also provided the opportunity to photograph examples of bus stop designs for use in the final reports.

Researchers conducted three regional visits that included several transit agencies in each region. The three regions included the southwest, central, and the west coast. Information obtained from the mail surveys was used to identify potential agencies. A broad range of agency types and operational environments were visited. Agency sites were specifically selected based on their responses to the mail survey, the nature of their bus stop design, their bus stop policy, and the extent to which they represent a distinct category of bus stop practice, service area type, or regional category. Selection was also influenced by geographic grouping for efficient travel plans.

Data Collection Methodology

The three key personnel for the project (Fitzpatrick, Perkinson, and Hall) participated on each trip. Each individual was responsible for his or her particular area of expertise. For example, Fitzpatrick made observations on the influence of the street design on bus stop operation, while Hall noted bus patron and pedestrian interaction with the bus stop. Perkinson observed various need-related aspects of each bus stop, such as spacing, placement in relation to adjacent land uses, and so on. All three researchers participated in the interviews with transit agency staff.

The team approach was critical for the site visits. Stop location and design involve many disciplines, as reflected in the expertise of the personnel assembled for this project. However, unification of these perspectives into a single coherent vision of bus stop location and design is critical for the practical application of this research. Consequently, the site visit team integrated their respective observations and insights on a real-time basis during the site visit, as well as immediately following the conclusion of each regional trip.

The mechanics of the site inspection process involved extensive pre-visit planning to identify bus stop locations with certain specified features and to set up interviews with key agency staff. Interviewed agency staff typically had planning and/or operational responsibility. Site-specific survey issues were identified from earlier screening and survey data.

Before interviewing the staff, a typical site survey routine was done with the physical inspection of previously identified key design or location features of the sites. Completion of the inspection before the interview enabled the researcher to prepare for discussion of details during the scheduled interviews. The pre-interview aspect of the field work, however, involved more than interview preparation. This relatively unstructured field work by the team allowed for the application of various unobtrusive research methods. Unobtrusive research in this context means passive observation of the actual use of physical facilities, including the individuals using those facilities and the artifacts of their use. This tactic is appropriate for bus stop location and design because the level and nature of the use of a facility is a critical indicator of the success of the design and placement of that facility.

The relatively unstructured field work was followed by scheduled interviews with appropriate transit agency staff, and others where appropriate. The interviews were guided by a set of interview notes prepared upon completion of the initial site investigations to ensure coverage of predetermined critical issues and questions. The interview was not, however, limited to these questions, allowing for probing and follow up on unanticipated elements in the discussion.

In addition to the largely spontaneous real-time comparisons of observations and impressions between project team members, a more formal "de-briefing" was performed at the end of each regional visit. These sessions consolidated and documented the findings from the site visit, minimizing the loss of data due to the inherently coarse nature of field notes, as well as avoiding confusing the sites and regions.

Overview of Regional Visit Data

Bus stop data were collected for almost 300 bus stops in more than 15 cities, representing more than one dozen transit systems (public and private), during the three regional visits. Table D-1 shows the number of stops examined by region, city, and transit agency. These observations were documented in some 2,000 photographs.

Findings

Several findings emerged from the field observations and the interviews of key agency staff. This appendix presents the findings from the site visits regarding street-side design and location of bus stops. A summary of the findings associated with curb-side issues (such as shelter placement, need for amenities, etc.) is presented in Appendix E.

Table D-1. Summary of Regional Visits by Agency, City, and Number of Stops.

REGION	AGENCY	CITY	STOPS
SOUTH WEST	Phoenix RTA	Phoenix	28
	Phoenix RTA & City of Scottsdale	Scottsdale	14
	Phoenix RTA	Tempe	4
	Mesa Sun Runner	Mesa	2
	Phoenix RTA & City of Chandler	Chandler	17
	SunTran	Tucson	38
			103
CENTRAL	Grand Rapids Area Transit Authority	Grand Rapids	21
	Capital Area Transportation Authority	Lansing	26
	Ann Arbor Transit Authority	Ann Arbor	25
	Detroit Suburban Mobility Authority	Detroit suburbs	17
			89
WEST COAST	San Francisco Municipal Railway	San Francisco	13
	Central Contra Costa Transit Authority	Concord/Walnut Creek	20
	AC Transit	Milpitas	4
	Transportation Agency	San Jose	15
	SamTrans	San Carlos	1
	SamTrans	San Mateo	26
			79

Safety

Pedestrian safety involves both the defined bus stop area and areas used while getting to and from the bus stop. Examples of traffic considerations include traffic control devices with adequate pedestrian cycles, clearly marked crosswalks, adequate setback from the street, good visibility for drivers and pedestrians, positioning of stops and waiting areas away from intersections and driveways, and avoiding mixing stops and vehicle turning movements. While these elements are acknowledged and well known, in practice, compromises such as placing a bus stop near driveways, are often made as shown in Figure D-1.

Figure D-1. Bus Stop Between Driveways.

Vehicle safety relates to the provision of sufficient visibility to other vehicles and to pedestrians. Consideration is needed of the effect that the stopped bus will have on sight distance for parallel traffic and cross traffic. The potential for conflicts in the traffic stream as a bus enters or leaves a stop also needs to be considered. Figure D-2 shows a vehicle passing a stopped bus on a two-lane street. In this situation, adequate sight distance is needed so that the passing vehicle can safely use the opposing traffic's lane to pass the bus. Adequate sight distance for pedestrians in the crosswalk is also needed.

Figure D-2. Example of a Vehicle Passing a Stopped Bus on a Two-Lane Street.

Bus stops are sometimes located between the driveways of gasoline service stations and convenience stores. While this location has several advantages, some disadvantages exist as well. For example, because these facilities are usually on corners, vehicle turning movements abound, and pedestrian access is seldom clearly marked. Since parking is important, sufficient right-of-way to set back the waiting area from the street is rare. Finally, traffic entering and departing the store passes nearby and conflicts with pedestrian access (as illustrated in Figure D-3).

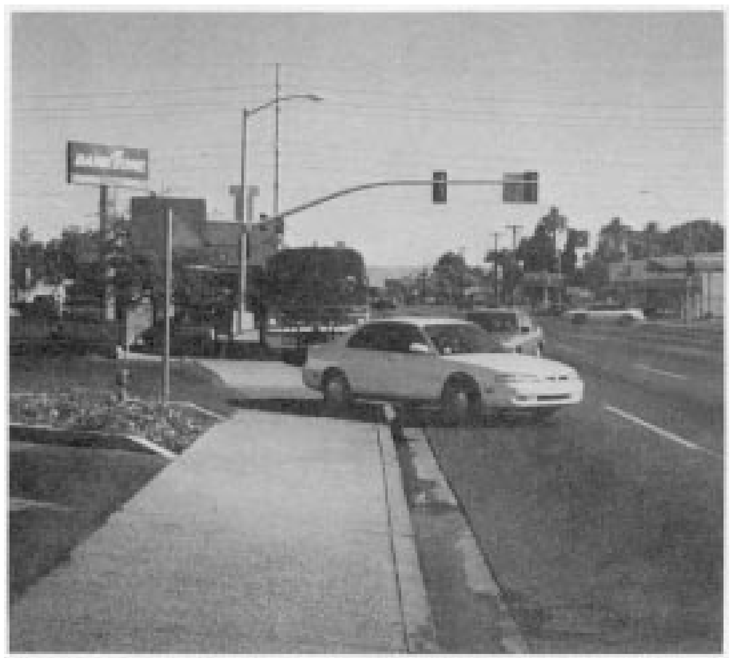


Figure D-3. Vehicle Conflicts with Pedestrian Access.

Roadway Geometry

Two aspects of roadway geometry are critical for good bus operations: 1) turning radius and 2) the contour of the acceleration and deceleration portions of bus bays. While turning radius is not properly a part of the bus stop, the project team observed many buses swinging wide and blocking traffic in the adjacent lane as shown in Figure D-4. In many cases, the adjacent land uses or other factors clearly prevented the use of an adequate turning radius. In others, however, a better design was possible. Good roadway design is well understood and documented in the traffic engineering literature. Interviews and subsequent discussion confirmed that institutional (jurisdictional and coordination) and budget constraints prevented better geometry.

Figure D-4. Bus Using More Than One Lane to Complete a Turn.

Institutional and budget constraints were also identified as preventing the implementation of desirable acceleration and deceleration portions of bus bays. While the performance requirements of buses, in terms of acceleration and deceleration, may be less widely known, they are obtainable. On the other hand, bus operators demonstrated a clear mastery of operating under less than optimal conditions, such as taking advantage of upstream traffic signals that create gaps which allow the bus to re-enter the traffic stream (see Figure D-5).

Figure D-5. Bus Taking Advantage of Upstream Traffic Signal.

Pavement

The project team observed a wide range of pavement conditions at bus stops. Unreinforced pavement at a bus stop will deform and deteriorate in a short time, even with only moderate bus activity. The nature and magnitude of pavement deterioration at bus stops were well documented during the regional visits as shown in Figure D-6.

There are two primary concerns regarding pavements at bus stops: 1) initial design of the pavement and 2) maintenance and repair of existing pavement. Pavement design and management are typically a city or state responsibility; however, the transit agency may provide supplemental funding for the repair of pavements at bus stops. Debate is ongoing concerning how much of the pavement damage near a bus stop is caused by transit buses because other heavy vehicles, such as large trucks and garbage trucks, also contribute to the pavement problems near an intersection. These institutional/organizational conflicts, combined with the difficulties of maintaining a quality roadway pavement (especially at bus stops), point to the value of installing bus pads.

Figure D-6. Poor Pavement Condition at Bus Stop.

Bus Pads

A bus pad is an area of reinforced pavement at a stop. It is designed to handle the additional stresses of the frequent stopping of heavy buses, as illustrated in Figure D-7. (The bus at the stop in this figure would probably make a right turn because of the adjacent right-turn lane.) Bus pads may be installed during street construction or rehabilitation or may be installed as a separate project. Either way, the benefits in reduced maintenance and pavement damage appear to be recognized by both transit and city staff. Unfortunately, the use of bus pads is not as widespread as the recognition of their merit. The primary reasons appear to be the expense involved and the limited constituency they are perceived to benefit. An in-depth analysis of bus pads is beyond the scope of this project; however, it appears that a clear cost/benefit analysis might help clarify this issue.

Bus Stop Location (Far-Side, Near-Side, Midblock)

The team's observations and subsequent interviews confirmed that the advantages and disadvantages of each type of stop placement (far-side, near-side, and midblock) are well understood, although the conclusions drawn and agency preference or policy varies among transit agencies. In practice, bus stop placement is affected by a combination of site-specific considerations, precedent, and transit agency and city policy.

Figure D-7. Reinforced Pavement (Bus Pad) at a Stop.

FIELD STUDIES

To study the operations around existing bus stops, the research team collected data at several field sites. Results from the phone surveys and regional visits were used to select field sites that would be studied. The goal was to include a variety of bus stop designs, including curb-side stops, bus bays, queue jumpers, and nubs. The two major field data collection trips took place in Arizona and California; an additional site in College Station, Texas, was also visited.

Results from the data collection trips were used to study how different bus stop locations and designs influence the traffic operations and driver behaviors around the bus stop. Once the field data were collected, the observed bus stops were divided into two categories: urban stops and suburban stops. Urban stops included stops on low-speed arterials (less than 35 mph) in areas with heavy development and high driveway densities. In contrast, suburban stops were in areas with relatively higher speeds (greater than 35 mph), lighter development, and lower driveway densities.

Objective

The objective of the street-side field studies was to observe the operations at existing field sites to learn how the location and design of bus stops influence traffic and bus operations. To accomplish the objective of these studies, the following tasks were performed:

- Collect field data at bus stops with varying locations and designs in both urban and suburban areas.
- Observe and record traffic operations at each of the field sites for use in the field studies and the computer simulation studies.
- Summarize the information concerning the characteristics and operations at each field site.
- Compare the observations at both urban and suburban bus stop locations.

To learn how different bus stop locations and designs affected the traffic operations around the bus stop area, the bus and traffic operations and erratic maneuvers observed at the sites were analyzed and compared. The findings from the field sites were grouped by bus stop design. By studying the operations and erratic maneuvers occurring at different bus stop designs, certain maneuvers could be associated with a particular design.

Suburban Sites

Data were collected at eight suburban field sites in Tucson, Arizona; Tempe, Arizona; San Jose, California; and College Station, Texas. The sites ranged in location and design. Table D-2 describes each of the suburban sites studied. The following sections describe the study design, discuss each field site, and summarize the findings.

Table D-2. Description of Suburban Study Sites.

Site	City	Location	Bus Stop Location, and Design	Cross Section[a]	Surrounding Development	Speed Limit	Recording Time
S1	Tucson, Arizona	Speedway @ Campbell	Far-Side, Queue Jumper Bus Bay	6 lanes, raised median	hotels, restaurants	35	7am-7pm
S2	Tucson, Arizona	Speedway, Mountain - Cherry	Midblock, Bus Bay	6 lanes, raised median	University of Arizona	35	7am-5pm
S3	Tempe, Arizona	Mill @ University	Far-Side, Curbside	6 lanes, raised median	gas station, restaurants, strip mall	35	7am-1pm
S4	San Jose, California	Bird @ San Carlos	Far-Side, Curbside	6 lanes, raised median	gas stations and strip development	35	12pm-5:30pm
S5	San Jose, California	San Carlos @ Bird	Near-Side, Bus Bay	4 lanes, raised median, parking	gas stations and strip development	35	7am-5:30pm
S6	San Jose, California	San Carlos @Bird	Far-Side, Open Bus Bay	4 lanes, raised median, parking	gas stations and strip development	35	7am-5:30pm
S7	San Jose, California	Santa Clara @ Market	Far-Side, Open Bus Bay	4 lanes, TWLTL, parking	shops and restaurants	35	11am-5pm
S8	College Station, Texas	University @Texas Ave.	Far-Side, Curbside	6 lanes, raised median	apartments, Texas A&M University	40	7am-9am (on two days)

[a] TWLTL = two-way left-turn lane

Study Design

Data Collection. The research team collected data at five sites in Arizona. Data from three of the sites were used for the traffic study in suburban areas. These three sites consisted of two in Tucson and one in Tempe. Portable 8-mm video cameras were used to study the traffic operations around these sites. Typically, from four to five cameras were placed around the bus stop to record traffic volumes, queues behind buses, and bus arrival/departure times. The cameras also recorded erratic or unique behaviors by the bus operators or drivers of other vehicles.

Some of these sites were also used to aid in the traffic simulation study (see following section); therefore, turning movements and travel times were also collected. Travel times were measured from several hundred feet upstream of the bus stop to several hundred feet downstream of the bus stop.

Typically, video cameras taped the following locations: the bus stop; a specific point several hundred feet upstream of the bus stop; a specific point several hundred feet downstream of the bus stop; and the intersection upstream of the bus stop. In some cases, the entire bus stop area could not be captured using only one camera; therefore, an additional camera was used.

The research team collected data at 13 sites in California, four of which were used for the suburban traffic study. The four sites were located in the city of San Jose. While in San Jose, the team collected data with the help of the City of San Jose's Traffic Management Center, which has several high-powered video cameras stationed throughout the downtown area to monitor traffic during special events at the downtown sports arena. Consequently, the data collection team collected data at several different sites using these cameras. Typically, a camera was focused on an area several hundred feet upstream and downstream of the bus stop to record volumes, turning movements, queues behind buses, travel times, bus arrival/departure times, and erratic behaviors.

After the data collection trips to Arizona and California, an additional field site was selected in College Station, Texas to further study the effects that a curb-side stop has on traffic operations. This site was selected because it is known to have high traffic volumes during the a.m. peak period. Traffic operations around this site were recorded using a surveillance camera operated by the Texas Transportation Institute.

Data Reduction and Analysis. The data from the video tapes were reduced by technicians. The technicians recorded information concerning each bus, including the arrival time, departure time, queue behind bus, and delay to bus re-entering traffic. During each bus arrival, any erratic maneuvers observed were also recorded. An erratic maneuver was defined as an unusual action by the bus operator or driver of another vehicle caused by the presence and location of the bus. The erratic maneuvers observed are listed in Table D-3.

Table D-3. Erratic Maneuvers Observed in the Field.

1. Traffic queue occurs due to bus blocking lane while stopped (curb-side stop).
2. Traffic queue occurs due to vehicle stopping in through lane to allow bus to re-enter traffic stream (bus bay).
3. Driver of vehicle changes lanes due to bus (curb-side stop).
4. Bus operator pulls out in front of car causing driver to slow down, change lanes, or stop (bus bay).
5. Conflict occurs between bus and car while bus is re-entering traffic stream causing delay to bus.
6. At a bus bay, bus driver stops in main lanes to board passengers.
7. Conflict occurs between bus and car due to driveway location.

Travel time and traffic volume data from selected sites (sites S1, S2, and S4) were also used to calibrate a computer simulation model for the traffic simulation study. Because these sites were used for calibration, more detailed information was obtained (i.e., intersection turning movements, average speeds, and traffic signal timings). Traffic volume and travel time data were reduced in five-minute intervals around each bus arrival (for example, two minutes before a bus arrived to three minutes after the arrival).

To measure travel times during a five-minute increment, the technicians would record the time a vehicle entered the system, track the vehicle through the system, and record the time that the vehicle left the system. The system was typically defined as either a set distance upstream and downstream of the bus stop or the intersection upstream and the intersection downstream of the bus stop. Once the data were reduced from the video tapes, they were put into a spreadsheet for data manipulation.

After the field data were collected and reduced, the results were summarized for each site. Included in the summary are descriptions of each of the study sites and descriptions of the bus and vehicular operations observed. After analyzing each site separately, the operations at all suburban sites were compared.

Study Sites

This section describes the eight suburban sites studied. Included are discussions of the findings at each site.

Site S1: Tucson, Arizona; Speedway at Campbell. Site S1 is a queue jumper bus bay located in the central part of Tucson, Arizona. Figure D-8 presents the plan view of the site. For the 12 hours that site S1 was video taped, 68 bus arrivals were observed. During the study time, very few erratic maneuvers occurred. Conflicts between the bus and other vehicles occurred only twice when drivers of vehicles changed lanes to avoid a bus. Also, the delay to traffic caused by the bus was minimal because the bus stop was located off the main lanes. The delay to the bus re-entering traffic was also minimal. The 200-foot acceleration lane permitted the bus to merge with traffic smoothly.

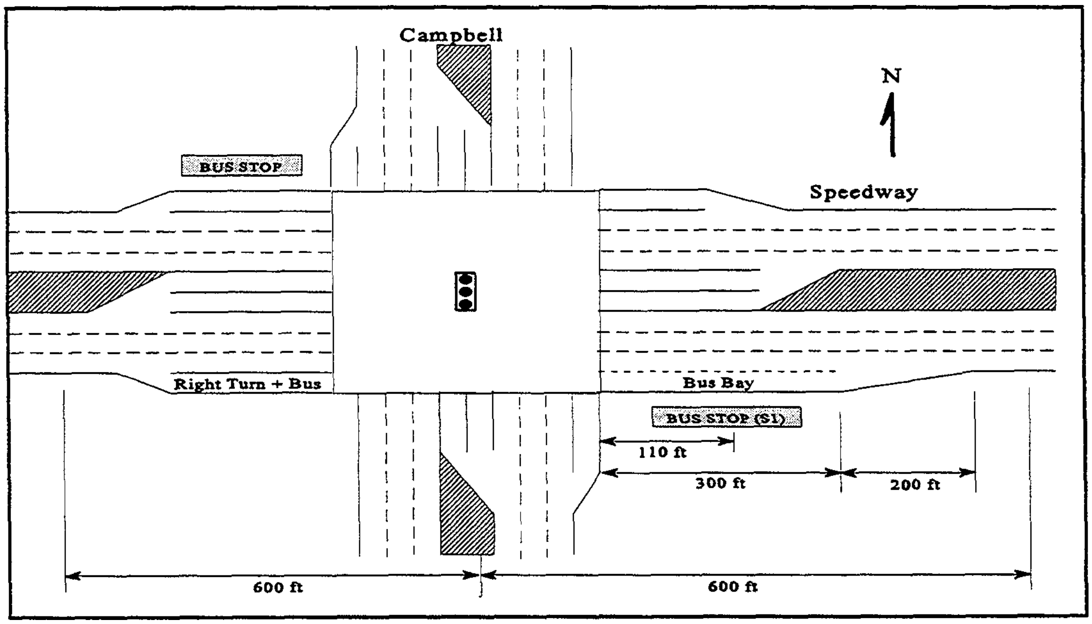


Figure D-8. Site S1: Speedway at Campbell.

Site S2: Tucson, Arizona; Speedway between Mountain and Cherry. Site S2 is a midblock stop with a bus bay located in Tucson, Arizona. Figure D-9 presents the plan view for Site S2. Most of the conflicts observed at Site S2 occurred between buses leaving the stop and through traffic. However, out of 35 bus arrivals, conflicts only occurred seven times. The conflicts occurred when a bus using the acceleration lane trying to re-enter the traffic stream had to slow and wait for an adequate gap in the through traffic before merging. For the seven conflicts observed, the delay ranged from two seconds to five seconds with an average delay of three seconds.

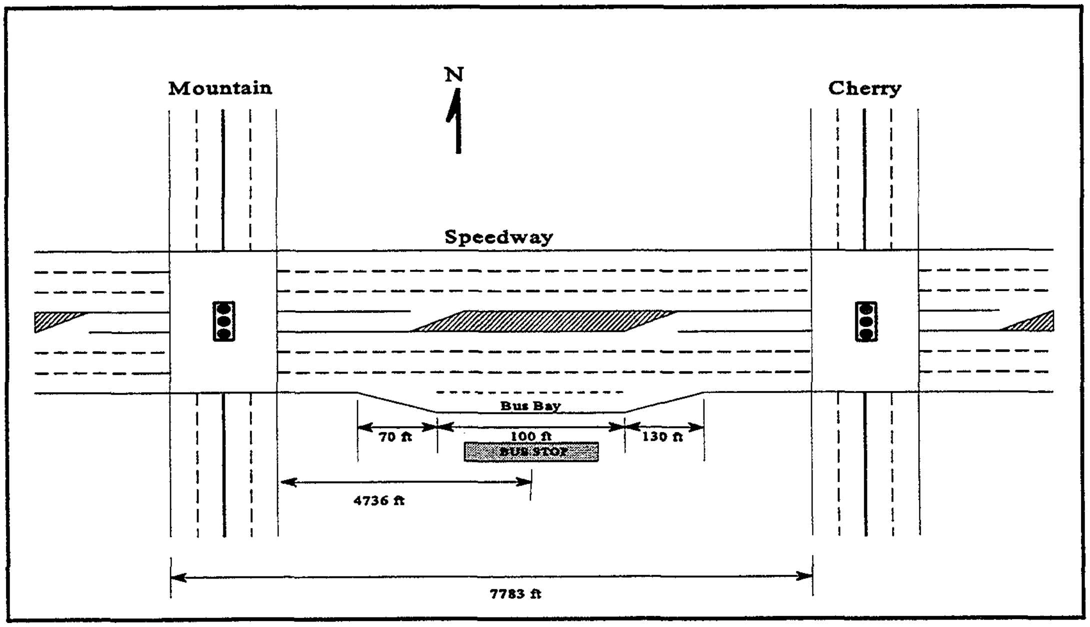


Figure D-9. Site S2: Speedway between Mountain and Cherry

Site S3: Tempe, Arizona; Mill at University. Site S3 is a far-side curbside bus stop located in the central area of Tempe, Arizona. The stop is positioned between two driveways leading into a gas station. Two southbound lanes are on Mill until approximately 220 feet north of University. At this point, an additional through lane is added (see Figure D-10).

For the time that Site S3 was studied, very few erratic maneuvers occurred. Conflicts between the bus and other through vehicles were minimal. Also, queues and delay to the traffic caused by the bus were minimal. This was due in part to the lane configuration at this site. As stated above, an additional outside lane is added to Mill approximately 220 feet upstream of the bus stop. Buses traveling along Mill, approaching the bus stop, were observed moving into the additional lane before reaching the stop; however, the majority of through vehicles did not move into this lane if a bus was present. Therefore, stopped buses typically did not interfere with the through vehicles; thus, delay to through vehicles was minimized.

Conflicts were observed between stopped buses and vehicles entering and exiting the driveways because the bus stop was located between two driveways, leading to a gas station. Drivers wanting to enter or exit the driveways experienced conflicts when a bus blocked one of the driveways. In these situations, the drivers of the vehicles either waited for the bus to move or went to the next driveway. Conflicts for exiting vehicles also occurred when the view of oncoming traffic along Mill was blocked by the bus.

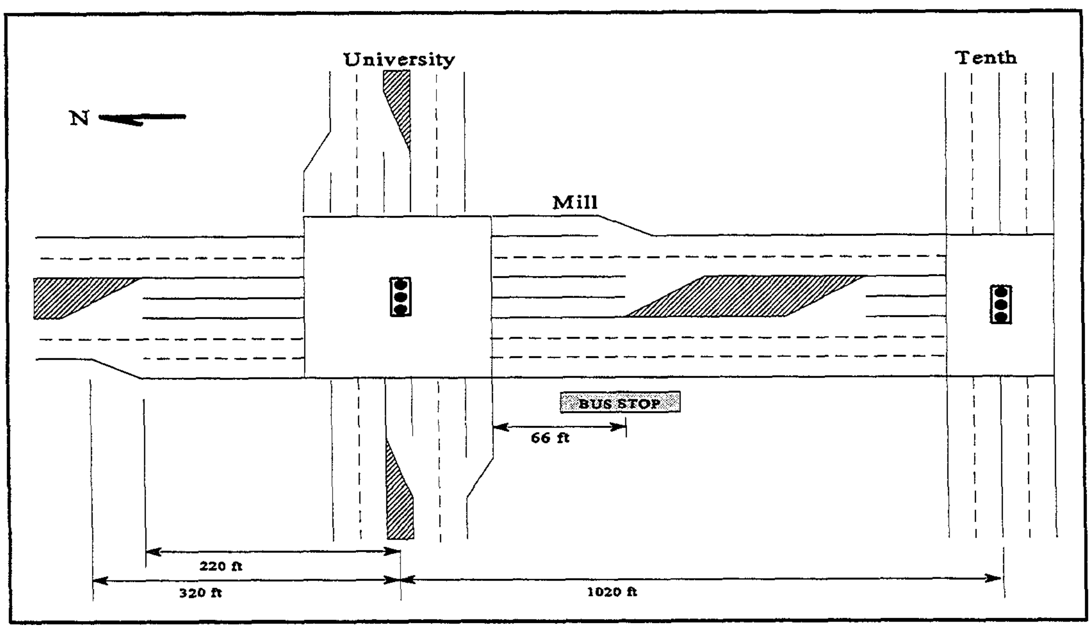


Figure D-10. Site S3: Mill at University.

Site S4: San Jose, California; Bird at San Carlos. Site S4 is a far-side curbside bus stop located in the southern part of San Jose. Figure D-11 presents the plan view of the site. At Site S4, 30 bus arrivals were observed. Eighteen conflicts occurred between stopped buses and through traffic in which the drivers of through vehicles changed lanes to avoid the bus. However, because of the relatively low volumes observed, vehicles never queued behind the stopped buses and, therefore, the delay to through traffic was minimal.

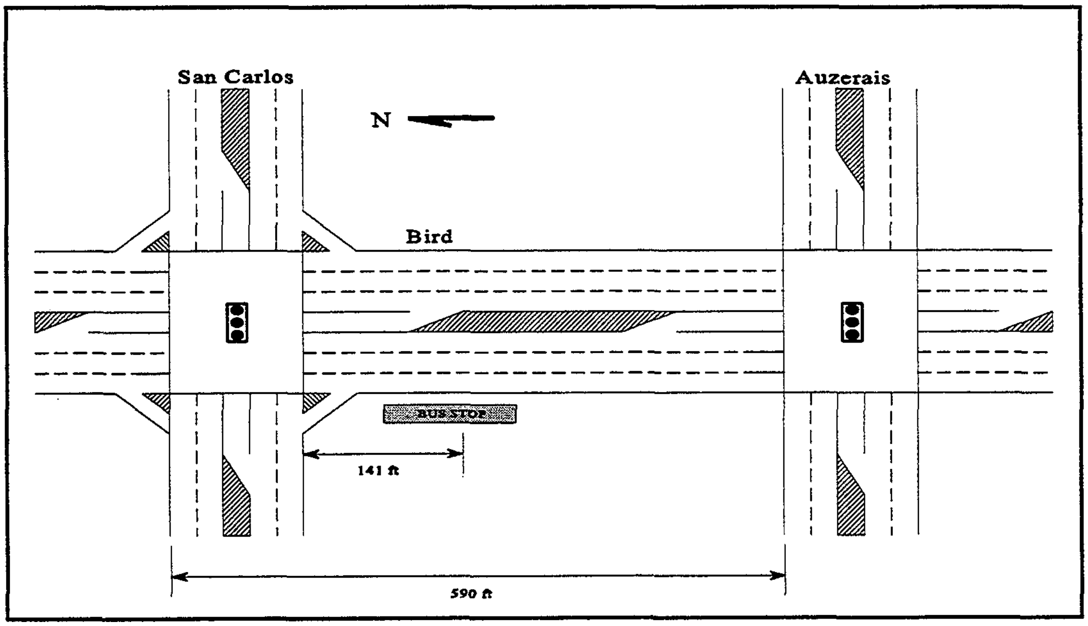


Figure D-11. Site S4: Bird at San Carlos.

Sites S5 and S6: San Jose, California; San Carlos at Bird. Sites S5 and S6 were both located at the intersection of San Carlos at Bird (just north of Site S4). Parking is discontinued where the bus stops are located so that the buses can stop next to the curb. Since the buses pull off the main lanes to drop off and pick up passengers, the bus stops function as bus bays (i.e., while stopped, buses have minimal effects on through traffic). Figure D-12 presents of the plan view for sites S5 and S6.

For the time that Site S5 was studied, 47 bus arrivals were observed. During these arrivals few conflicts occurred between the buses and other traffic. Those erratic maneuvers observed typically occurred when buses were leaving the stop and re-entering the traffic stream. These erratic maneuvers included the following: bus operators pulling out in front of other traffic causing the drivers to slow, stop, or change lanes (three times); and drivers of vehicles stopping to allow the bus to re-enter traffic (three times). Also, twice during the day, buses were observed stopping in the through lanes to board passengers instead of pulling up to the curb. During the study of this stop, a bus re-entering traffic was only delayed once for only for five seconds.

At Site S6, 45 bus arrivals were observed. The conflicts that occurred included drivers of vehicles changing lanes to avoid a bus (four times). This typically occurred when a bus was slowing down in the through lanes before making a stop. Delay to buses re-entering the traffic stream occurred four times ranging from two to four seconds.

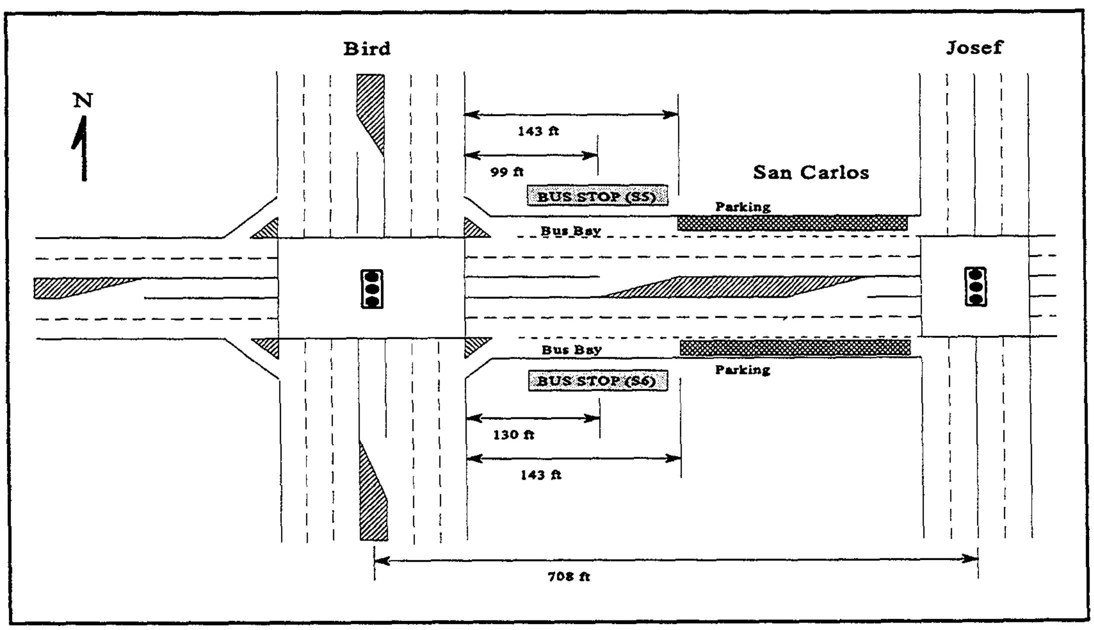


Figure D-12. Sites S5 and S6: San Carlos at Bird.

Site S7: San Jose, California; Santa Clara at Market. Site S7 is a far-side bus stop located in the central part of San Jose (see Figure D-13). Parking is discontinued where the bus stop is located so that the buses can stop next to the curb; therefore, the bus stop functions as an open bus bay. For the time that this site was studied, no erratic maneuvers were observed.

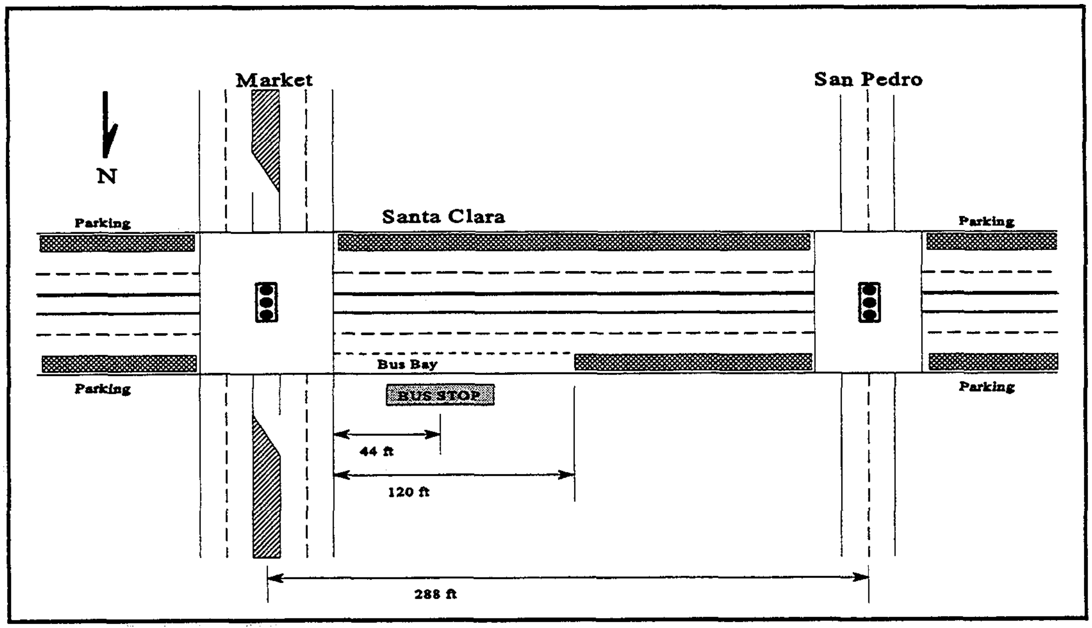


Figure D-13. Site S7: Santa Clara at Market.

Site S8: College Station, Texas; University at Texas. To further study the effects that a curbside stop has on traffic operations, an additional field site was selected in College Station, Texas. Site S8 is a far-side curbside bus stop located in the central part of College Station near Texas A&M University and the Texas Transportation Institute. The buses accessing this stop are university shuttle buses serving university students. This site was selected because it is known to have high traffic volumes during the a.m. peak periods. Figure D-14 presents the plan view for site S8.

The erratic maneuvers observed at Site S8 included vehicles changing lanes to avoid stopped buses and vehicles queuing behind stopped buses. At this site, vehicles were observed changing lanes to avoid a bus 46 times and queuing behind stopped buses 14 times. The maximum queue length ranged from one vehicle to seven vehicles.

Observing the operations at this site, for lower traffic volumes drivers would change lanes to avoid a stopped bus. As traffic volumes increased, the opportunity for through vehicles to change lanes decreased and more queues were observed. Figure D-15 illustrates the relationship between maximum queue and volume for Site S8. Observing this figure, queues began forming at volumes above 300 vphpl. Queues greater than three vehicles in length formed at volumes above 900 vphpl.

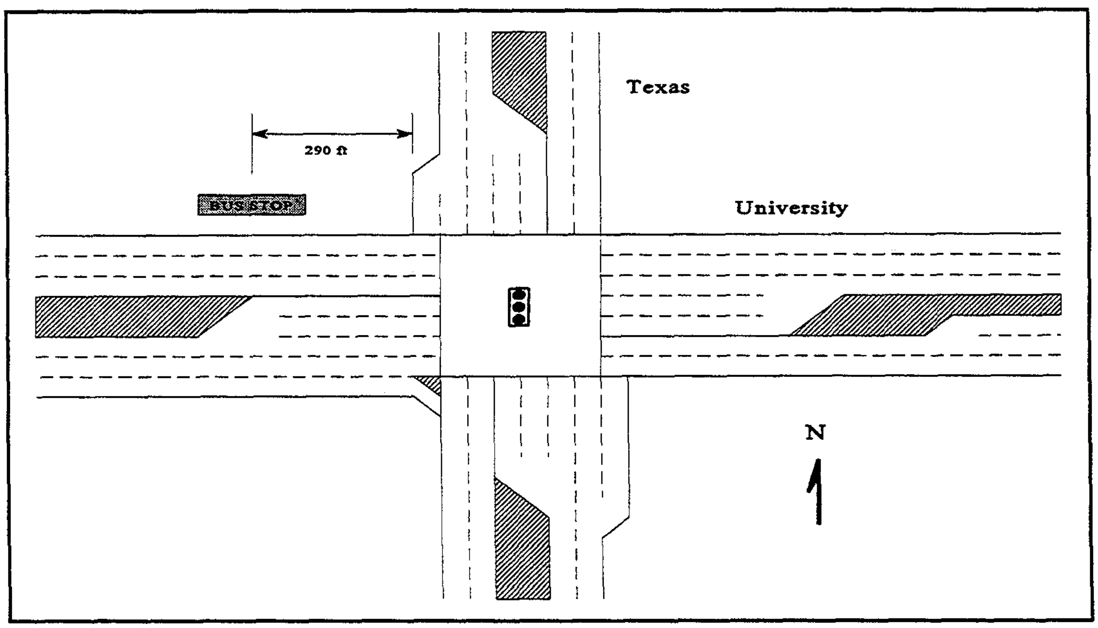


Figure D-14. Site S8: University at Texas.

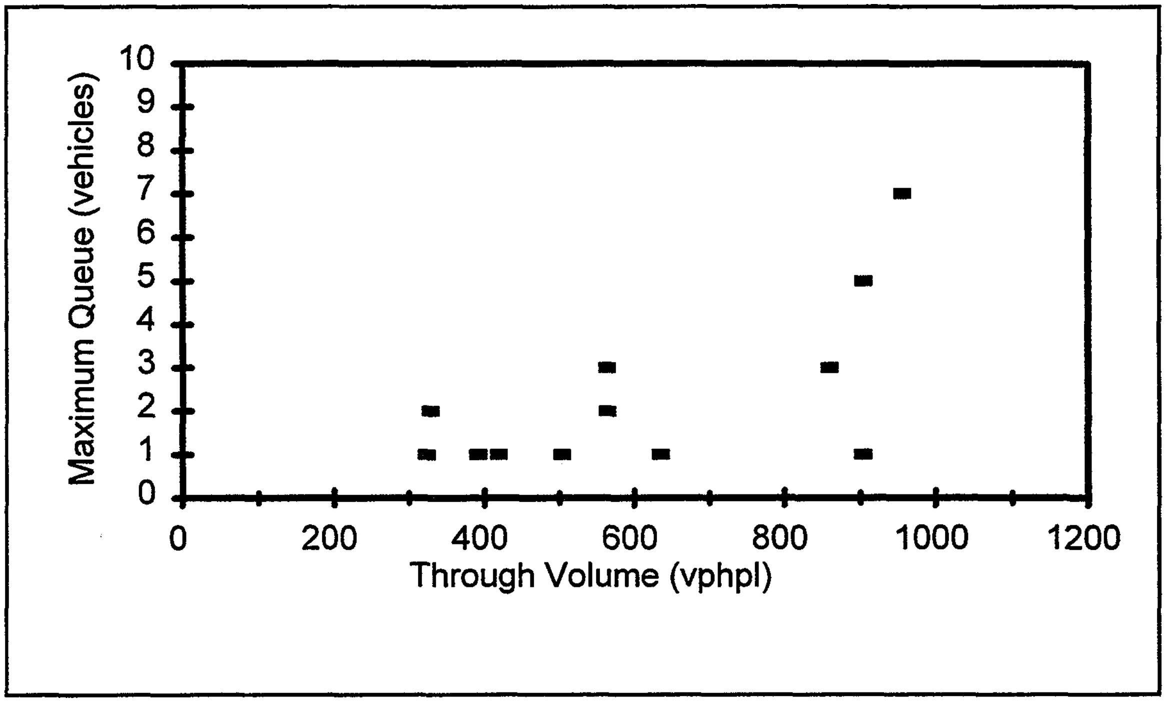


Figure D-15. Relationship between Maximum Queue and Volume for Site S8.

Findings

Tables D-4 and D-5 summarize the research findings for the suburban sites. Table D-4 includes the operational characteristics measured from the field and Table D-5 summarizes the erratic maneuvers observed. The operational characteristics include the following: speed (either measured or posted speed limit); maximum through volume observed; minimum, maximum, and average dwell time for the buses; minimum and maximum number of vehicles in queue behind a stopped bus; and minimum and maximum delay to buses re-entering the traffic stream. In Table D-5, the erratic maneuvers observed in the field (see Table D-3) were combined into three categories: those that involved traffic queuing near a bus stop because of the presence of bus, those that involved a vehicle changing lanes because of the presence of a bus, and those that involved delay to a bus reentering the traffic stream. The erratic maneuvers are summarized by number (total number observed) and rate (number of erratic maneuvers / number of bus arrivals).

Table D-4. Observational Characteristics for Suburban Sites.

Site	Location[a]	Design[b]	Speed (mph)[c]	Max. Through Volume (vphpl)	Dwell Time (sec)			Number of Vehicles in Queue[d]		Delay to Bus (sec)[d]	
					Minimum	Maximum	Average	Minimum	Maximum	Minimum	Maximum
S1	FS	OBB QJ	43 (m)	830	7	180	33	--	--	--	--
S2	MB	BB	43 (m)	670	8	35	15	--	--	2	5
S3	FS	CS	35 (p)	330	11	150	53	--	--	--	--
S4	FS	CS	36 (m)	500	9	110	28	--	--	--	--
S5	FS	OBB	35 (p)	300	7	140	26	1	2	0	5
S6	NS	BB	35 (p)	420	11	195	54	--	--	2	4
S7	FS	OBB	35 (p)	280	7	34	14	--	--	--	--
S8	FS	CS	40 (p)	910	12	90	35	1	7	--	--

[a] FS=Far-Side, NS=Near-Side, MB=Midblock
[b] BB=Bus Bay, OBB=Open Bus Bay, QJ=Queue Jumper, CS=Curbside
[c] m=85th percentile speed measured in field; p=posted speed limit
[d] — signifies that no queues or delays were observed

Table D-5. Erratic Maneuvers for Suburban Sites.

Site	Location and Design[a]	Number of Bus Arrivals Observed	Traffic Queue[b]		Lane Changes[c]		Delay to Bus[d]	
			Number[e]	Rate[f]	Number	Rate	Number	Rate
S1	FS, QJ	68			2	1 / 34.0		
S2	MB, BB	35					7	1 / 5.0
S3	FS, CS	27						
S4	FS, CS	30			18	1 / 1.7		
S5	FS, OBB	47	4	1 / 11.8	3	1 / 15.7	1	1 / 47.0
S6	NS, BB	45			4	1 / 11.3	4	1 / 11.3
S7	FS, OBB	13						
S8	FS, CS	28	14	1 / 2.0	46	2 / 1.0		

[a] FS=Far-Side, NS=Near-Side, MB=Midblock, BB=Bus Bay, OBB=Open Bus Bay, QJ=Queue Jumper, CS=Curbside
[b] Traffic queue occurs near bus stop because of the presence of a bus.
[c] Driver of vehicle changes lanes because of the presence of a bus.
[d] Bus experiences delay while re-entering traffic stream.
[e] Total number of erratic maneuvers for the number of bus arrivals observed.
[f] Number of erratic maneuvers / number of bus arrivals.

Bus Stop Design. After data from each of the suburban field sites were analyzed and the results summarized, the next step was to investigate the effects that different bus stop locations and designs had on the traffic operations near a bus stop. This was accomplished by grouping the study findings by bus stop design. The bus stop designs analyzed in this study included curbside, bus bay, open bus bay, and queue jumper. Following is a discussion on the findings for each suburban bus stop design and a comparison of the results.

Curbside. A curbside bus stop is located on the outside main lane along the curb. Because the stop is located in the travel lane, conflicts may occur between through traffic and stopped buses. While the delay to through vehicles may increase with a curbside design, the delay to buses is decreased because bus operators do not have to re-enter the traffic stream (as with bus bay designs). An example of a curbside bus stop is illustrated in Figure D-16.

From the suburban field sites studied, three sites (Sites S3, S4, and S8) included curbside designs. Observations at the suburban sites included recording the number of queued vehicles behind a stopped bus and erratic maneuvers of through traffic drivers due to the presence of a bus.

Figure D-16. Example of a Curb-side Bus Stop.

For the three suburban sites studied with curb-side designs, queues behind stopped buses were only observed for one site, Site S8.

The probable reason that queues were not observed at Site S3 was due to the lane configuration at this site. This road has a lane added approximately 220 feet upstream of the far-side bus stop. Bus operators traveling in the through lane approaching the bus stop were observed moving into the additional lane before reaching the intersection preceding the stop; however, the drivers of through vehicles typically did not move into this lane if a bus was present. For this reason, and because of the relatively low through volumes observed (approximately 330 vphpl maximum), queues were basically nonexistent.

Queues were minimal at Site S4 because drivers of through vehicles were able to change lanes before reaching the stopped bus. Drivers easily changed lanes to avoid the stopped bus because of the number of through lanes (three) and the relatively low traffic volumes (approximately 500 vphpl maximum).

As traffic volumes increase, drivers have less opportunities to change lanes before reaching the stopped bus. This was the primary reason for the number of queues observed at Site S8. At this site, vehicles were observed queuing behind a stopped bus for eight different bus arrivals. The maximum queue length ranged from one vehicle to seven vehicles. Observation of the operations at this site indicate that, for lower traffic volumes, drivers would change lanes to avoid a stopped bus. Queues began forming at volumes above 300 vphpl. Queues greater than three vehicles in length formed at volumes above 900 vphpl.

Site S3 included a bus stop located between two driveways leading to a gas station. This allowed the research team to study conflicts between buses and vehicles entering and exiting the driveways. As anticipated, for drivers wanting to enter or exit the driveways, conflicts occurred when a bus was blocking one of the driveways. Conflicts for exiting vehicles also occurred when the view of oncoming traffic on the main lanes was blocked by the bus.

Bus Bay/Open Bus Bay. A bus bay or an open bus bay is a specially constructed section off the normal roadway to provide for bus loading and unloading in an area separated from the main lanes. This separation allows through traffic to flow freely without being impeded by stopped buses. Bus bays are provided primarily on high-volume or high-speed roadways. Additionally, bus bays are frequently constructed in heavily congested downtown and shopping areas where large numbers of passengers may board or disembark. Although the delay to through traffic is minimized with the use of a bus bay, the delay to the bus may increase due to the difficulty in re-entering the traffic stream. The delay to the bus re-entering traffic is dependent upon the traffic volume and whether an acceleration lane is provided on the bus bay. While bus bays may be positioned at far-side, near-side or midblock locations, open bus bays are typically located at far-side locations. Figures D-17 and D-18 illustrate examples of a bus bay and an open bus bay, respectively.

Note in Figure D-18 that the bus is changing lanes while in the intersection to access the open bus bay. This illustrates one of the benefits associated with an open bus bay. The bus operator has the width of the intersection available for decelerating and accessing the bay. Because the open bus bay design does not need to include a deceleration lane or an entrance taper, less right-of-way is needed.

For the eight suburban sites studied, sites S2 and S6 contained bus bays and sites S1, S5, and S7 contained open bus bays. The majority of bus delays observed occurred at Site S2 (midblock stop) and Site S6 (near-side stop). Seven buses were delayed in 10 hours of observations at S2, while four buses were delayed in 10.5 hours of observations at S6. For sites S1, S5, and S7 (far-side stops), the delays to buses re-entering the traffic stream were minimal. These findings reveal that for the sites studied, far-side, bus bay stops resulted in less delay than near-side or midblock bus bay stops.

One reason for the minimal delays at the far-side stops was due to the breaks in traffic caused by the upstream signalized intersection. Another reason was the acceleration lanes provided. For those sites with acceleration lanes, bus operators were observed merging smoothly with the through traffic with minimal conflicts. Site S1 had an acceleration lane, and Site S7 had a continuous shoulder to be used for acceleration.

Figure D-17. Example of a Bus Bay.

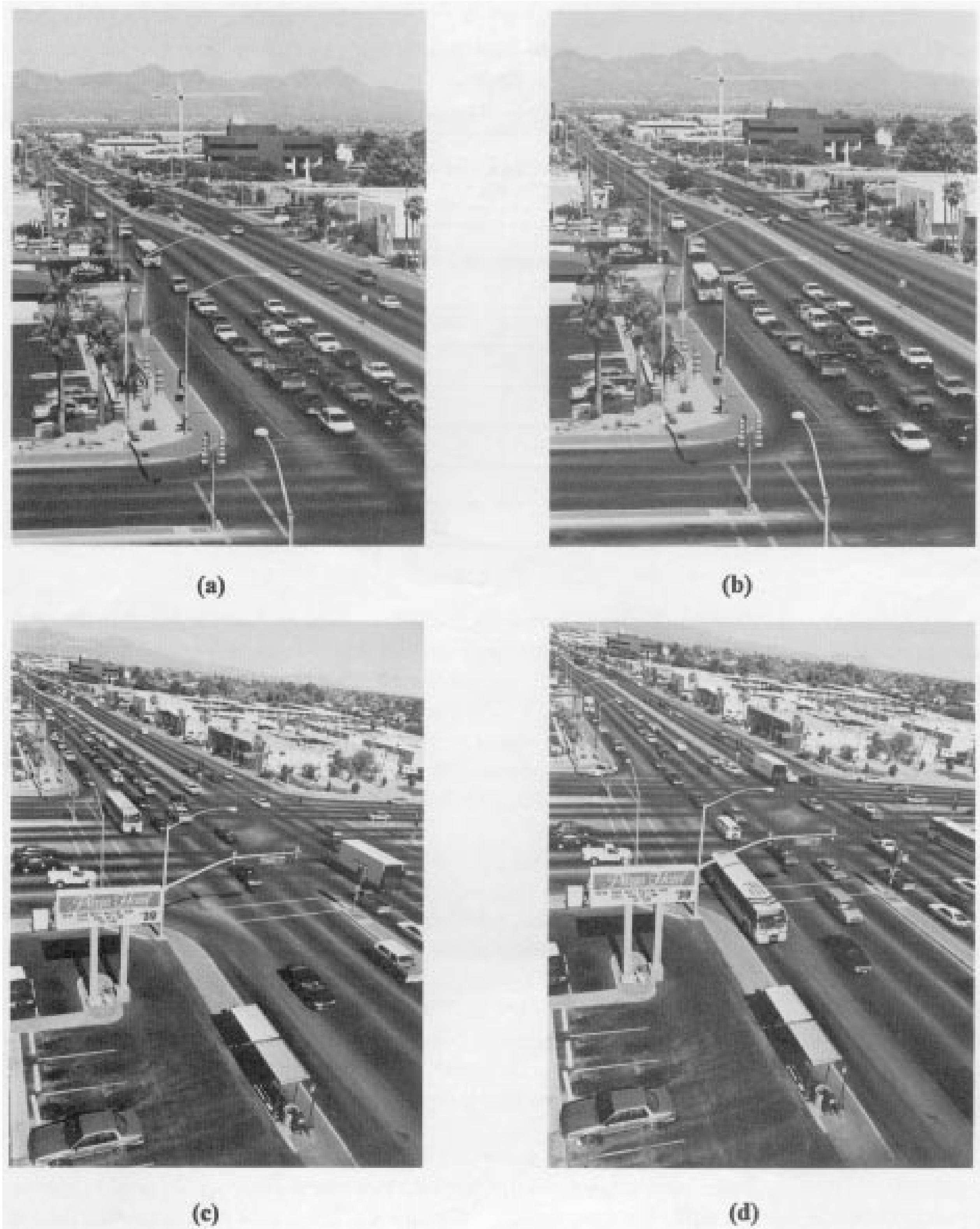
Figure D-18. Example of an Open Bus Bay.

Queue Jumper. When buses can use a right-turn lane to by-pass traffic queued at congested intersections to access a far-side open bus bay, a substantial amount of time savings may result for the bus passengers. When this situation is allowed, the right-turn lane may be defined as a "queue jumper". The effects on average delay to right-turning traffic would be based upon several factors such as the number of buses expected; however, the average delay to right-turning traffic is generally assumed to be minimal. The right-turn lane is typically signed as "Right Turns Only—Buses Excepted" or with the sign shown in Figure D-19.

Figure D-19. Example of Sign Used at Queue Jumper.

Figure D-20 illustrates the travel time savings to a bus using a queue jumper. In part (a) of Figure D-20, the bus is approaching the queue jumper and the vehicles queued at the intersection. In part (b) the bus is entering the queue jumper to bypass the queue. The bus then proceeds through the intersection in (c) and arrives at the stop in (d).

At Site S1, the travel time savings to buses using the queue jumper was estimated for a select number of buses. To estimate travel time savings, the travel time of each selected bus using the queue jumper was measured and compared to that of a through vehicle entering the system at the same time as the bus. Travel times were measured from 600 feet upstream of the intersection preceding the bus stop to the stop bar at the intersection. Travel time savings for each selected bus was estimated by subtracting the travel time of the bus from the travel time of the through vehicle entering the system at the same time as the bus.



(a) (b) (c) (d)

Figure D-20. Example of a Queue Jumper.

Travel time savings were estimated for six buses during high volume periods. Table D-6 contains the results from this study. The travel time savings to buses ranged from 0 to 14 seconds with an average of 6.5 seconds. The travel time savings was dependent upon the queue length at the intersection and the number of right turning vehicles.

Table D-6. Travel Time Savings of Bus Using Queue Jumper.

Volume (vph)	Travel Time (sec)		Travel Time Savings to Bus (sec)
	Bus	Through Vehicle	
1460	10	13	3
2150	56	66	10
2350	11	25	14
1500	10	10	0
1300	48	58	10
1800	8	10	2
		Average:	6.5

Comparison of Design Types. Comparing the results from each of the bus stop designs studied revealed that the majority of conflicts between through vehicles and buses occur at bus stops with curbside designs. The predominate conflicts observed included drivers changing lanes to avoid a stopped bus or queuing behind a stopped bus. The queue length behind a bus is dependent upon traffic volume. For lower traffic volumes, vehicles are able to change lanes to avoid the bus; however, as traffic volumes increase the opportunity for drivers to change lanes decreases. Therefore, as traffic volumes increase, the delay to through traffic due to the presence of a bus increases.

The research also reveals that buses may experience more delay at stops with bus bays; however, for the sites studied the delay was only on the order of five seconds. With the bus bay design, bus operators desiring to safely re-enter the traffic stream are required to wait for an adequate gap in the through traffic. When volumes are low, adequate gaps are frequent. When volumes are high, the presence of adequate gaps decrease and also are influenced by the platooning effects of signals. For the sites studied, far-side stops resulted in less delay to buses when compared to near-side or midblock stops. One of the reasons for the minimal delays at the far-side stops is due to the breaks in traffic caused by the upstream signalized intersection.

In addition, for the bus bay sites studied, delay was minimized for those sites with acceleration lanes. Acceleration lanes typically provide bus operators with an area to merge smoothly with the through traffic resulting in minimal conflicts. The use of an acceleration lane is demonstrated in Figure D-21.

Figure D-21. Example of a Bus Bay with an Acceleration Lane.

The findings from this study also revealed that travel time savings may result for bus passengers when buses can use a queue jumper to access a far-side open bus bay. The travel time savings to buses are dependent upon the queue length at the intersection and the number of right turning vehicles.

Urban Sites

Data were collected at six sites in San Francisco and San Jose, California to study the operations around bus stops in urban areas. The sites varied in locations and designs. Table D-7 describes each of the urban sites studied. Following is a description of the study design, discussions for each of the field sites studied, and a summary of the findings.

Study Design

Data Collection. During the field data collection trip to San Francisco, California, data were collected at three urban sites. Because San Francisco is a dense urban center, data could not be collected using portable video cameras. Traffic data were collected manually because the use of video equipment in this environment would draw the immediate attention of both general pedestrian traffic and bus patrons.

Table D-7. Description of Urban Study Sites.

Site	City	Location	Bus Stop Location and Design	Cross Section[a]	Surrounding Development	Speed Limit (mph)	Collection Technique (time)
U1	San Francisco, California	Polk Clay-Sacramento	Midblock, Nub	4 lane, undivided	hotels, restaurants, shops	30	manual (11am-2pm)
U2	San Francisco, California	Polk @ Sutter	Near-Side, Nub	4 lane, undivided	hotels, restaurants, shops	30	manual (7am-9am)
U3	San Francisco, California	Polk @Pine	Far-Side, Nub	4 lane, undivided	hotels, restaurants, shops	30	manual (11am-12:30 pm)
U4	San Francisco, California	Alameda @ Montgomery	Midblock, Bus Bay	4 lane, raised median	sports arena	30	video (9am-12pm)
U5	San Francisco, California	San Carlos @ Market	Near-Side, Curbside	4 lane, light rail	shops, restaurants	30	video (8:30 am-5:30 pm)
U6	San Francisco, California	Santa Clara @ Almaden Ave.	Far-Side, Bus Bay	4 lane, TWLTL	shops, restaurants	30	video (7am-5:30pm)

[a]TWLTL = two way left-turn lane

Travel times were collected using a license plate matching software program (LP Match) developed by TTI. Two members of the data collection team were positioned at set locations upstream and downstream of the bus stop being studied. Each member loaded and entered the license plate numbers of vehicles on a laptop computer as they passed by. The time that a vehicle entered or exited the study zone was automatically recorded in the laptop computer when a license plate number was entered. After the data collection was complete, the upstream and downstream files were combined. The software matched the license plate numbers for each vehicle passing through the system and computed a travel time.

Volumes and turning movements were collected manually by positioning a team member at the intersection upstream of the bus stop. Also recorded manually were bus arrival and departure times, and queues behind the bus. The team did not attempt to record erratic maneuvers at the San Francisco sites.

Three of the nine field sites studied in San Jose were included in the urban traffic study. As with the suburban field sites studied, the team was able to collect data at urban sites with the aid of the City of San Jose's Traffic Management Center. A description of this effort is given in the summary of the data collection efforts for suburban sites.

Data Reduction and Analysis. The effort required to reduce the data collected from the license plate match technique in San Francisco was minimized because most of the field data were collected in a usable format. The software used to collect the travel times produced output in a format that could be easily imported into a spreadsheet. Therefore, reducing the data involved entering the traffic volume and bus arrival information into a spreadsheet and importing the travel time data. Since data at these sites were not collected using video cameras, erratic maneuvers could not be observed during the data reduction efforts.

The data from the video tapes collected in San Jose were reduced with the same techniques used on the suburban sites. Data were again reduced in five minute intervals around each bus arrival. The data reduced included bus arrival time, bus departure time, queue behind bus, and delay to bus re-entering traffic. The team studied the operational behaviors occurring in the field at or near the bus stops by viewing the video tapes of each site. During each bus arrival, any erratic maneuvers observed were recorded. The erratic maneuvers studied for the suburban sites (see Table D-3) were also studied for the urban sites.

Once the field data were collected and reduced, the results were summarized for each field site. The summary contains a description of each of the study sites and the bus and vehicular operations observed. After analyzing each site separately, the operations at all urban sites were compared. The findings from the field sites were grouped by bus stop design. The goal was to determine how different bus stop locations and designs affected the traffic operations around the bus stop area.

Study Sites

To study the operations around bus stops in urban areas, data from six field sites in San Francisco and San Jose, California were studied. The stops in San Francisco all contained nub designs while those in San Jose contained bus bay and curb-side designs. Nubs are an extension of a sidewalk from the curb of a parking lane to the edge of the through lane. A bus bay is a specially constructed area off the normal section of a roadway that provides for the pick up and discharge of passengers in an area separated from the travel lane. At a curb-side design, buses stop in the travel lane. Following are discussions on each of the urban sites studied.

Site U1: San Francisco, California; Polk between Clay and Sacramento. Site U1 is a midblock stop with a nub design. Figure D-22 presents the plan view of the site. To estimate the delay to through traffic caused by the bus, the travel times were separated into the following two categories: travel times when a bus was not in the system, and travel times when a bus was in the system. The travel times for each category were then averaged and compared. For Site U1, the average travel time of vehicles when a bus was not in the system was 24 seconds, compared with an average travel time of 30 seconds when a bus was in the system. Therefore, the average delay to vehicles when a bus was in the system was approximately 6 seconds. For the 16 bus arrivals observed at Site U1, traffic queued behind a stopped bus 6 times. The queue lengths ranged from one to four vehicles.

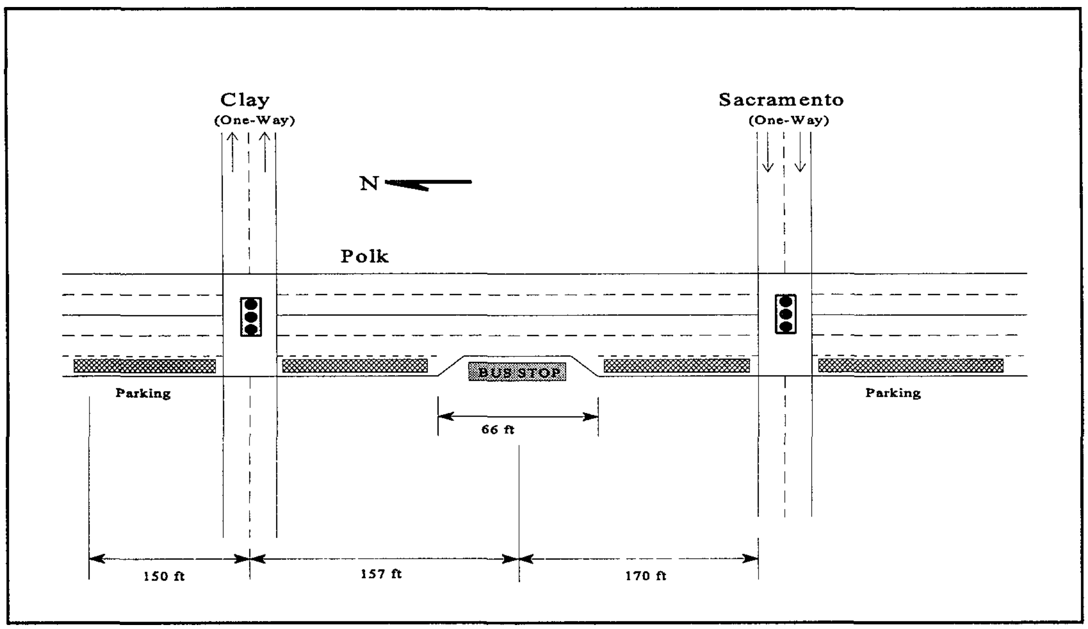


Figure D-22. Site U1: Polk between Clay and Sacramento.

Site U2: San Francisco, California; Polk at Sutter. Site U2 is a near-side stop with a nub design (see Figure D-23). To estimate the delay to through traffic caused by the bus, the travel times were again separated into travel times when a bus was not in the system, and travel times when a bus was in the system. For site U2, the average travel time of vehicles when a bus was not in the system was 60 seconds, compared to an average travel time of 67 seconds when a bus was in the system. Therefore, the average delay to vehicles when a bus was in the system was approximately 7 seconds. For the time period observed (12 bus arrivals), queues did not form behind the stopped buses.

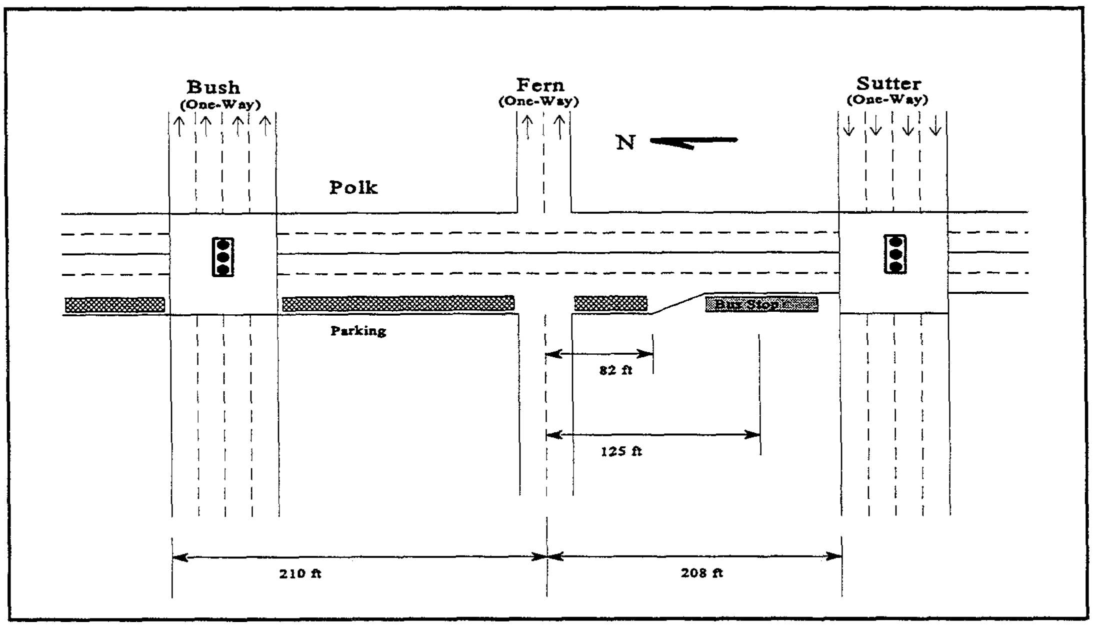


Figure D-23. Site U2: Polk at Sutter.

Site U3: San Francisco, California; Polk at Pine. Site U3 is a far-side stop with a nub design (see Figure D-24). The average travel time of vehicles when a bus was not in the system was 65 seconds, compared to an average travel time of 85 seconds when a bus was in the system. Therefore, the average delay to vehicles when a bus was in the system was approximately 20 seconds. For the time period observed (11 bus arrivals), queues behind the stopped buses formed twice with maximum queues of one and three vehicles.

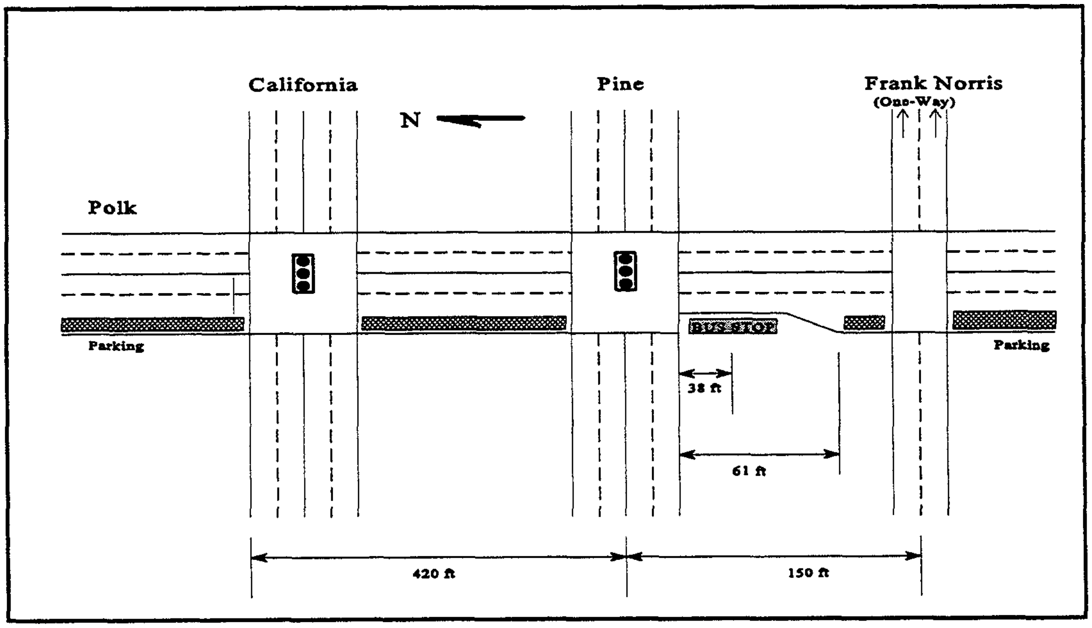


Figure D-24. Site U3: Polk at Pine.

Site U4: San Jose, California; Alameda at Montgomery. Site U4 is a midblock bus stop located in the central part of San Jose at Alameda and Montgomery. Since the buses pull onto the shoulder to drop off and pick up passengers, the bus stop functions as a bus bay. Figure D-25 presents the plan view for site U4.

Few conflicts occurred between the buses and other traffic at Site U4. Those erratic maneuvers that were observed occurred when buses were leaving the stop and re-entering the traffic stream. For the 26 bus arrivals studied at Site U4, drivers of vehicles were observed stopping to allow the bus to re-enter the traffic stream three times. While this minimized the delay to the bus, it increased the delay to the through traffic. Buses re-entering the traffic stream were only delayed twice for four and six seconds, respectively.

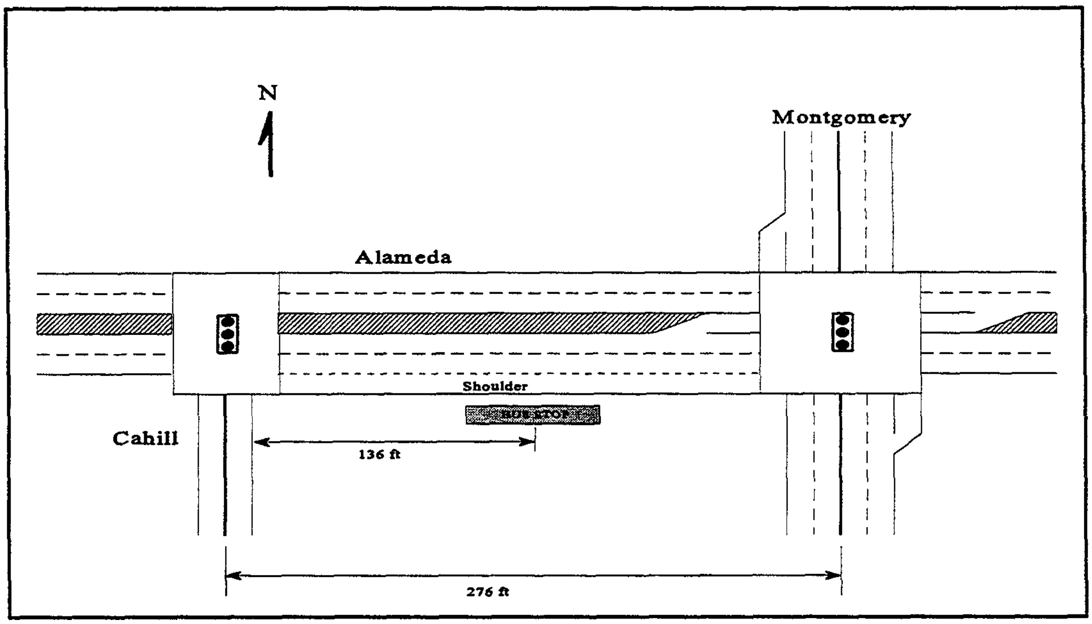


Figure D-25. Site U4: Alameda at Montgomery.

Site U5: San Jose, California; San Carlos at Market. Site U5 is a near-side, curb-side bus stop located in the central part of San Jose (see Figure D-26). For the time that Site U5 was studied, very few erratic maneuvers were observed. Out of the 30 bus arrivals, only five drivers changed lanes to avoid a bus. Queues behind the stopped buses were observed 6 times with a maximum queue of one vehicle each time.

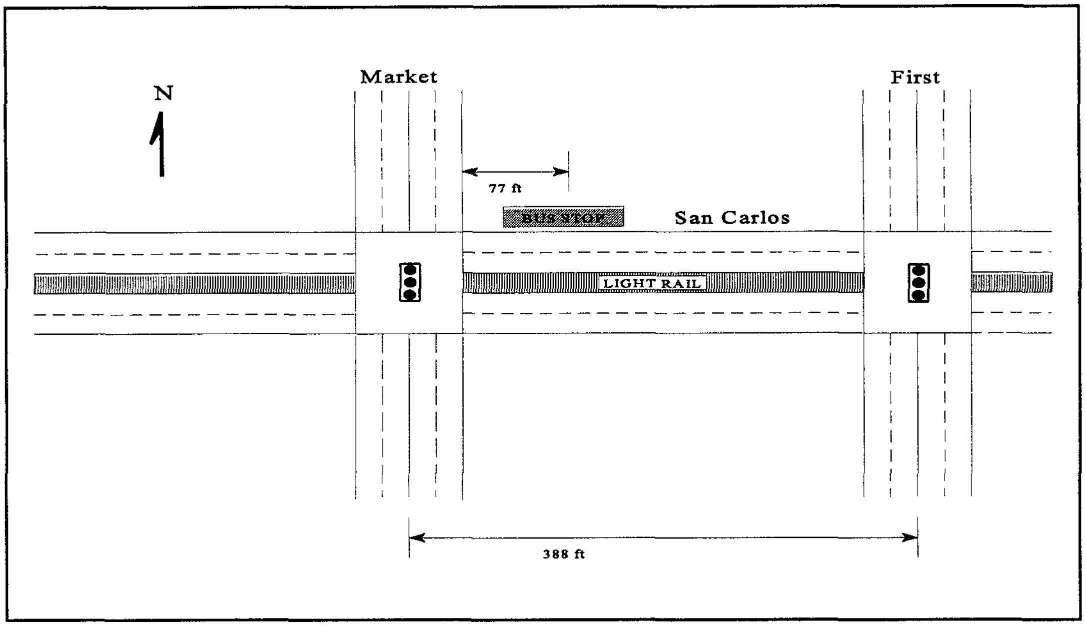


Figure D-26. Site U5: San Carlos at Market.

Travel time and volume data were collected for a total of nine 5-minute periods. For site U5, the average travel time of vehicles when a bus was not in the system was 30 seconds, compared to an average travel time of 28 seconds when a bus was in the system. Therefore, the average travel time of vehicles when a bus was in the system was very close to the average travel times when a bus was not in the system. In other words, the overall delay to through vehicles caused by the presence of a bus was minimal. For the time period observed, queues behind the stopped buses formed 6 times; however, the maximum queue each time was one vehicle.

Site U6: San Jose, California; Santa Clara at Almaden. Site U6 is a far-side bus stop located in the central part of San Jose at Santa Clara and Almaden. Since the buses pull off on the shoulder to drop off and pick up passengers, the bus stop functions as a bus bay with an acceleration lane. Figure D-27 shows the plan view for this site. The erratic maneuvers observed at this site were again few. For the 37 bus arrivals observed, drivers changed lanes to avoid a bus only twice. Also, a bus was only delayed once trying to re-enter traffic and the delay was 4 seconds.

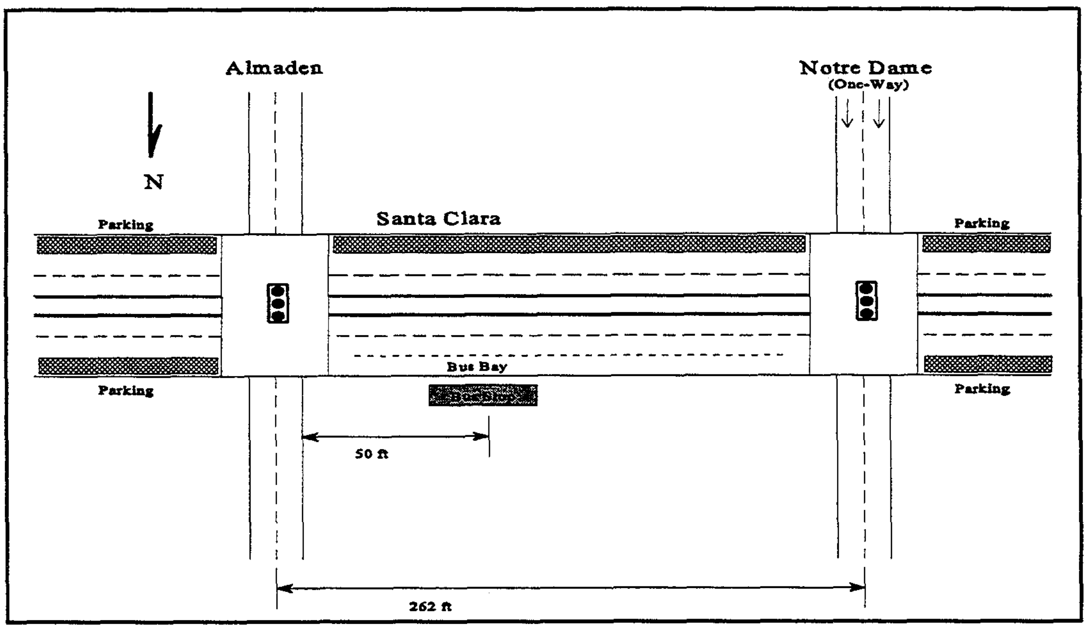


Figure D-27. Site U6: Santa Clara at Almaden.

Findings

Tables D-8 and D-9 summarize the findings for the urban sites. Table D-8 includes the operational characteristics measured from the field and Table D-9 summarizes the erratic maneuvers observed. The operational characteristics include the following: posted speed limit; maximum through volume observed; minimum, maximum, and average dwell time for the buses; minimum and maximum number of vehicles in queue behind a stopped bus; minimum and maximum delay to buses re-entering the traffic stream; and estimated delay to through vehicles.

Table D-8. Observational Characteristics for Urban Sites.

Site	Location	Design[b]	Posted Speed Limit (mph)	Max. Through Volume (vphpl)	Dwell Time (sec)			Number of Vehicles in Queue[c]		Delay to Bus (sec)[c]		Vehicle Delay (sec)[d]
					Minimum	Maximum	Average	Minimum	Maximum	Minimum	Maximum	
U1	MB	NB	30	350	10	45	23	1	4	--	--	6
U2	NS	NB	30	350	10	44	31	--	--	--	--	7
U3	FS	NB	30	350	10	35	19	1	3	--	--	20
U4	MB	BB	30	325	8	56	20	--	--	4	6	x
U5	NS	CS	30	200	5	25	13	0	1	--	--	0
U6	FS	BB	30	450	8	32	16	--	--	0	4	x

[a] FS=Far-Side, NS=Near-Side, MB=Midblock
[b] NB =Nub, BB=Bus Bay, CS=Curbside
[c] — signifies that no queues or delays were observed
[d] x signifies that delays were not measured

Table D-9. Erratic Maneuvers for Urban Sites.

Site	Location and Design[a]	Number of Bus Arrivals Observed	Traffic Queue[b]		Lane Changes[c]		Delay to Bus[d]	
			Number[e]	Rate[f]	Number	Rate	Number	Rate
U1	MB, NB	16	6	1 / 2.7	--	--		
U2	NS, NB	12			--	--		
U3	FS, NB	11	2	1 / 5.5	--	--		
U4	MB, BB	26					2	1 / 13.0
U5	NS, CS	30	6	1 / 5.0	5	1 / 6.0		
U6	FS, BB	37			2	1 / 18.5	1	1 / 37.0

[a] FS=Far-Side, NS=Near-Side, MB=Midblock, NB=Nub, BB=Bus Bay, CS=Curb-side
[b] Traffic queue occurs near bus stop because of the presence of a bus.
[c] Driver of vehicle changes lanes because of the presence of a bus. (Note: Lane change behavior was not collected for Sites U1, U2, and U3.)
[d] Bus experiences delay while re-entering traffic stream.
[e] Total number of erratic maneuvers for the number of bus arrivals observed.
[f] Number of erratic maneuvers / number of bus arrivals.

Bus Stop Design. To summarize the results from urban field sites studied, the findings were grouped by bus stop design. The bus stop designs analyzed in this study included nub, curb-side, and bus bay. Following is a discussion on the findings for each bus stop design and a comparison of the designs.

Nub. Nubs are a section of sidewalk that extends from the curb of a parking lane to the edge of the through lane. They permit buses to make a stop in a traffic lane without weaving around parked cars. Nubs are typically located in urban areas and operate similarly to curb-side stops, except they offer additional area for patrons to wait. Nubs are also referred to as "curb extensions" or "bus bulbs." An example of a nub is illustrated in Figure D-28.

From the six urban sites studied, three included nubs (sites U1, U2, and U3). For these sites, the effects that buses had on the operations of through vehicles was estimated by dividing the travel times measured in the field into two categories: travel times when a bus was not in the system and travel times when a bus was in the system. By averaging the travel times for each of these categories and comparing the averages, delays due to the presence of a bus could be estimated. The estimated delays to through traffic are included in Table D-8. Because of other factors influencing vehicle delay, the values in Table D-8 are not meant to represent actual delays to through vehicles due to the presence of a bus; however, comparing the delays measured at separate sites should provide some insight into how bus stop location affected delay.

Figure D-28. Example of a Nub.

The resulting delays to through vehicles for Site U1 (midblock stop) and Site U2 (near-side stop) were very similar (see Table 8); however, the delays measured for Site U3 (far-side stop) were somewhat higher. Although the magnitude in the differences in delay may not be accurate, the results signify that higher delays for traffic existed at the far-side location.

Curb-Side. From the urban sites studied, only Site U5 contained a curb-side design. Similar to the sites with nubs, travel times were measured at Site U5 and were divided into two categories: travel times when a bus was in the system and travel times when a bus was not in the system. Comparing the average travel times for these two categories revealed that the overall delay to through vehicles due to the presence of a bus was minimal.

The minimal delays to through traffic were most likely due to the relatively low traffic volumes observed at Site U5 (200 vphpl). For the low traffic volumes, drivers of through vehicles had little difficulty in changing lanes to avoid a stopped bus, resulting in low delays. Even though a queue behind the bus was observed 6 times for the period that Site U5 was studied, the maximum queue each time was only one vehicle. In addition, the drivers in queue behind a stopped bus were observed changing lanes quickly because of the low traffic volumes, again resulting in low delays.

Bus Bay. For the urban sites studied, delays to buses due to through traffic occurred at bus stops with bus bays. Out of the six urban sites studied, sites U4 and U6 operated as bus bays. At Site U4 (midblock stop), buses were delayed twice for 4 and 6 seconds. A bus at Site U6 (far-side stop) was delayed only once for 4 seconds. Therefore, even though the volumes at the far-side stop were higher than the volumes at the midblock stop (450 vphpl compared to 325 vphpl), the buses were delayed less at the far-side stop (corresponding to the results from the suburban sites).

Because of the limited number of sites, the relatively low traffic volumes, and the limited number of delays observed, additional data are needed to develop a definable relationship between volume, delay, and stop location for urban bus bay designs. The traffic volume level that has significant influence on urban bus bay operations cannot be determined from the data collected in this study. Based on the data, that point appears to be above 450 vphpl. Additional field data at high volume locations or computer simulation would provide more insight into the relationship.

Comparison of Design Types. Similar to the results from the suburban sites, the results from the urban bus stop designs studied revealed that conflicts between through vehicles and buses were more likely to occur at bus stops with curb-side (or nub) designs. For the sites studied, the nub design located at the far-side of an intersection resulted in more delay to through vehicles when compared to nubs at near-side or midblock locations. At near-side stops, delay to through traffic due to a bus loading/unloading passengers and delay due to a signalized intersection overlap, resulting in less delay.

Also corresponding to the results from the suburban sites, results from the urban sites studied revealed that buses experience slightly more delay at stops with bus bays when compared to curb-side (or nub) stops; however, whether the amount of delay is significant is debatable. Also, the far-side stop resulted in less delay to buses when compared to the near-side or midblock stops. Again, the reason for the minimal delays at the far-side stops is due to the breaks in traffic caused by the upstream signalized intersection.

COMPUTER SIMULATION

This study involved using computer simulation to study the effects of bus stop design on traffic operations. Traffic simulation programs have been used for years to analyze traffic operations under various conditions. The benefit of using computer simulation is that operations can be analyzed over a wide range of variables in a relatively short period of time (compared to collecting data in the field).

Objective

Other studies have been conducted to determine the optimum location of a bus stop (i.e., near-side, far-side, or midblock) for given situations; however, few have investigated the effects of bus stop design. The objective of this study was to use computer simulation to determine how specific factors influence traffic operations near a bus stop. Bus stop designs analyzed in this study included curb-side, bus bay/open bus bay, and queue jumper. Far-side and midblock locations were used in the simulation. The results can be used to aid in the selection of a preferred bus stop design for a given location and traffic volume. To accomplish the objective of this study, the following tasks were performed:

- Select a traffic simulation program to be used.
- Use field data to aid in calibrating the traffic simulation program.

- Perform the simulation for various traffic volumes and bus dwell times.
- Analyze the data from the simulation runs.
- Develop conclusions from the study that can aid in the selection of a preferred bus stop design for given bus stop locations and traffic characteristics.

Study Design

To investigate how various bus stop designs and locations influence traffic operations, field data and computer simulation were used. The intent was to use the field data to calibrate the traffic simulation program and to use the simulation program to study traffic and bus operations under various conditions. The results from computer simulation could then be used to identify the preferred bus stop design for a given situation.

Field Data

Field data from three of the suburban sites studied during the field studies were used to calibrate the traffic simulation program. Two of the sites were located in Tucson, Arizona, and one of the sites was located in San Jose, California. The three bus stop designs studied were a queue jumper, a bus bay, and a curb-side stop. Table D-10 provides a description of the calibration sites.

Table D-10. Description of Field Sites Selected for Calibration.

Site	City	Location	Bus Stop Location and Design	Cross Section[a]	85th Percentile Speed (mph)
1	Tucson, Arizona	Speedway @ Campbell	Far-Side, Queue Jumper Bus Bay	6 lanes, raised median	43
2	Tucson, Arizona	Speedway, Mountain - Cherry	Midblock, Bus Bay	6 lanes, raised median	43
3	San Jose, California	Bird @ San Carlos	Far-Side, Curb-Side	6 lanes, TWLTL	36

[a] TWLTL = Two-Way Left-Turn Lane

Data at each site were collected in the form of video tapes. For calibration purposes, technicians reduced the following data from the video tapes: traffic volumes, turning movements, travel times, speeds, bus arrival time, bus dwell time, and maximum queue behind bus. In some cases, because of the camera locations, the turning volumes could not be obtained; therefore, in these situations, the turning percentages were estimated. Signal timing information for the intersections was obtained from the respective cities. A summary of the data collection and data reduction efforts is presented in the second section of this appendix entitled *Field Studies.*

Traffic volume and travel time data were reduced in 5-minute intervals around each bus arrival. Travel times were measured from a set location upstream of the bus stop to a set location downstream of the bus stop. Since it would be difficult to measure the travel times of all vehicles, technicians only measured the travel times of selected vehicles which were believed to be traveling at speeds representative of other traffic. Travel times of selected vehicles were calculated by recording the time that a vehicle entered the system and the time that the vehicle left the system.

For each site, the free-flow speeds of approximately 100 vehicles were measured. Speeds were measured by recording the time that it took a vehicle to travel a known distance. The speed was then calculated by dividing the distance traveled by the travel time.

Computer Simulation Programs

Traffic simulation programs have been used effectively for many operations-related traffic studies and research projects. These programs can be used to analyze the effects that a wide range of roadway, traffic and bus characteristics have on the operations of a system. This wide range of data is very difficult to collect in the field; however, it can be easily studied using computer simulation. The two traffic simulation programs investigated for use in this study were TRAF NETSIM and TexSIM.

TRAF-NETSIM. TRAF is a software system which consists of several macroscopic and microscopic simulation programs which can be used to analyze traffic operations in large urban areas containing surface street networks and freeways. NETSIM is one of the modules in the TRAF package and is a microscopic model of urban street traffic. For NETSIM, each vehicle is a distinct object which is moved every second, and every event is updated every second. Vehicles are moved according to car-following logic, response to traffic control, and response to other demands. Outcome in NETSIM is stochastic (i.e., a similar set of input data can generate different output data for different runs).

NETSIM has the capabilities of simulating bus operations including routing, stops, number of buses at each stop at any one time, dwell times, and bus headways (flow rates). Each bus is identified by bus path, route, and bus flow rate. The bus path is the geometric path which the bus follows as it travels through the network. The bus route is the sequence of bus stops which the bus services. The bus flow rate is the mean headway for buses which service a particular route. Bus stops can be placed anywhere on a link, and "protected" or "unprotected" stops can be coded. This would be synonymous to bus bays and curbside stops, respectively.

TexSIM. The microscopic traffic network simulation program TexSIM is currently being developed by the Texas Transportation Institute. TexSIM runs under the Microsoft Windows environment and is being developed using C++ language. The system is built on a completely object-oriented architecture. The initial purpose for developing TexSIM was to evaluate the response of signal systems to new types of control strategies. TexSIM is an extremely flexible program. The users are allowed to dynamically interact and examine the network system during and after the simulation. Options are also provided to directly interact with real-time traffic controllers. TexSIM also simulates vehicles using a car following model. Vehicle movement and response occur in increments of one tenth of a second. Outcome in TexSIM is also stochastic.

TexSIM uses a system involving routes and links to determine the movement of a bus during simulation. Coding for buses and bus routes is split into three sections: routes, buses, and bus stops. The number of routes that are to be simulated are identified initially. A route system is determined by the links that the bus is to follow. A link is defined by the intersection number and the approach to that intersection. The route logic within TexSIM was developed so that bus routes must have adjoining links. Links within the route that have bus stops on them are assigned to a number specific to that bus stop. This allows for several stops within the system.

The buses are coded next. The route that the bus is to follow is coded along with the start time at which the bus enters the system. This allows for multiple buses to follow one route at different start times.

The bus stop information is the final coding requirement for bus operations within TexSIM. The bus stop number is coded and it corresponds with the route information given above. Next the location of a bus stop is defined by the intersection ID, link ID, and the lane ID along with the length of the bus stop. The set back length from the start of the link is coded to allow for the movement of the bus stop to different locations on the link. The set back length is the length from the start of the link to the upstream end of the bus stop. The bus dwell time is the final coding requirement for the bus stop. This is the time in seconds that a bus would typically spend at a bus stop loading passengers. This time is coded as an average and a variance around that average.

Selection of Program. TexSIM was selected as the traffic simulation program to be used for this study because of its flexibility and its capability to simulate unique bus stop designs such as queue jumpers. Most importantly, output from TexSIM can be given for each individual vehicle passing through the system. This feature allowed the researchers to monitor the traffic operations only when a bus was in the system (opposed to average travel times over a set period of time which might include times in which a bus was in the system and times that no bus was in the system). In addition, TexSIM can generate output which separates queues associated with the bus from queues caused by other factors such as an intersection. Because members of the research team were in close contact with the developers of TexSIM, there was a greater opportunity to customize TexSIM for research team use and to receive any needed assistance during the simulation process.

Development and Calibration of Models. Once TexSIM was selected as the program to be used for simulation, the first step was to develop models for each bus stop design to be studied (i.e., curb-side, bus bay/open bus bay, and queue jumper). Three TexSIM models were developed based upon the three field sites. After the models were developed, the next step was to calibrate TexSIM. This was accomplished by comparing output from TexSIM (i.e., average travel times and maximum number of vehicles in queue behind bus) to the operations observed in the field. TexSIM coding was then modified so that the models produced results similar to that expected in the field. This procedure helped the researchers determine how closely the computer simulation models represented what was actually happening in the field.

Figure D-29 presents schematics of the three field sites studied. For calibration purposes, data at each field site were collected for approximately 3 hours. Site information and operational data collected at the field sites are provided in Table D-11.

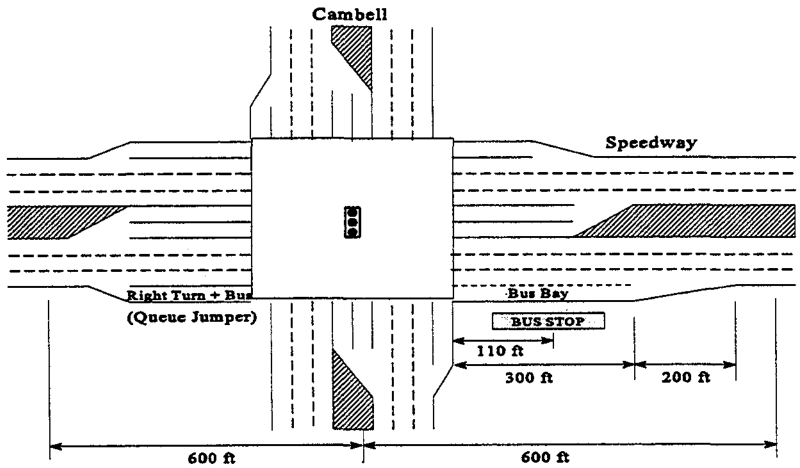
Table D-11. Operational Data Collected at Field Sites.

Site	Time of Study	No. of Bus Arrivals	Length of Study Section (ft)	Maximum Through Volume (vph)	85th Percentile Speed (mph)
1	7:00 am - 10:00 am	9	1200	2500	43
2	2:00 pm - 5:00 pm	9	7783	2000	43
3	2:00 pm - 5:00 pm	7	590	1500	36

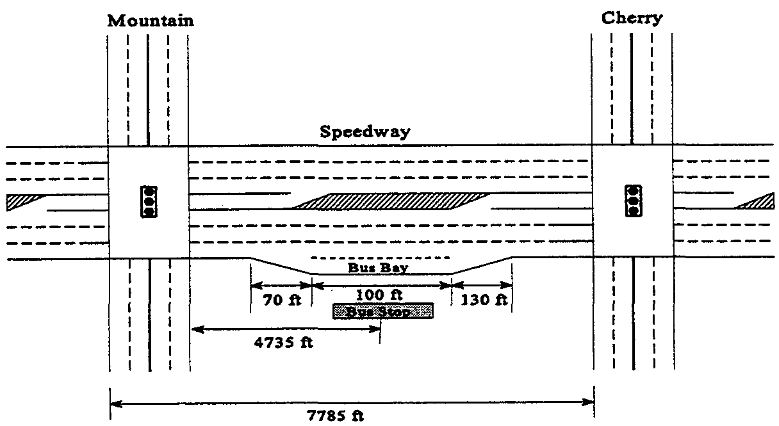
For each of the three sites, a TexSIM run was made for each bus arrival observed. Therefore, for Sites 1, 2, and 3, the number of TexSIM runs made was 9, 9, and 7, respectively, for a total of 25 runs. For each run, the 5-minute traffic volumes and turning movements, as well as the traffic speeds (85th percentile), bus arrival time, and bus dwell time observed in the field were coded.

Because outcome from TexSIM is stochastic, the output may not be the same for given input. For this reason, each run was simulated for 1 hour with a bus arriving every 10 minutes. Therefore, for each run a total of six bus arrivals were included. Travel times and maximum queues behind bus were then averaged for each run and compared to the observations made in the field. If the output from TexSIM was drastically different from the field observations, then the necessary coding in TexSIM was modified until the researchers believed that the output from TexSIM was representative of the field observations.

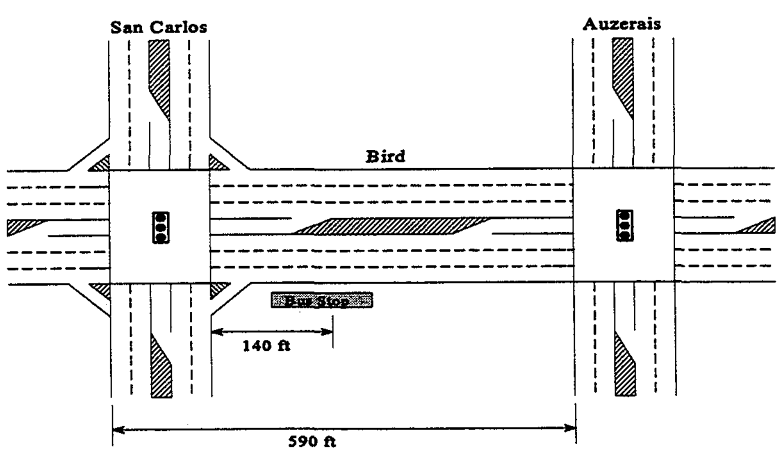
Table D-12 shows a comparison between field observations and output from the TexSIM models developed for each field site. The travel times and maximum queue lengths shown were averaged for the number of bus arrivals studied. Although there was some variance between the travel times measured in the field and the travel times predicted by TexSIM, the majority of the differences were caused by the traffic signals. As mentioned earlier, some of the turning movements at each intersection could not be obtained and had to be estimated. Because the signals were semiactuated, it was difficult to replicate the actual signal operations observed in the field, therefore affecting the overall travel times.



(a) Site 1



(b) Site 2



(c) Site 3

Figure D-29. Field Sites Used for Calibration of TexSIM.

Table D-12. Comparison of TexSIM Output to Field Data.

Site	Bus Stop Design	Average Travel Time (sec)		Average Maximum Queue (vehicles)[a]	
		Field	TexSIM	Field	TexSIM
1	Queue Jumper Bus Bay	53	49	N.A.	N.A.
2	Midblock, Bus Bay	31	30	N.A.	N.A.
3	Far-Side, Curb-Side	32	39	1.2	1.5

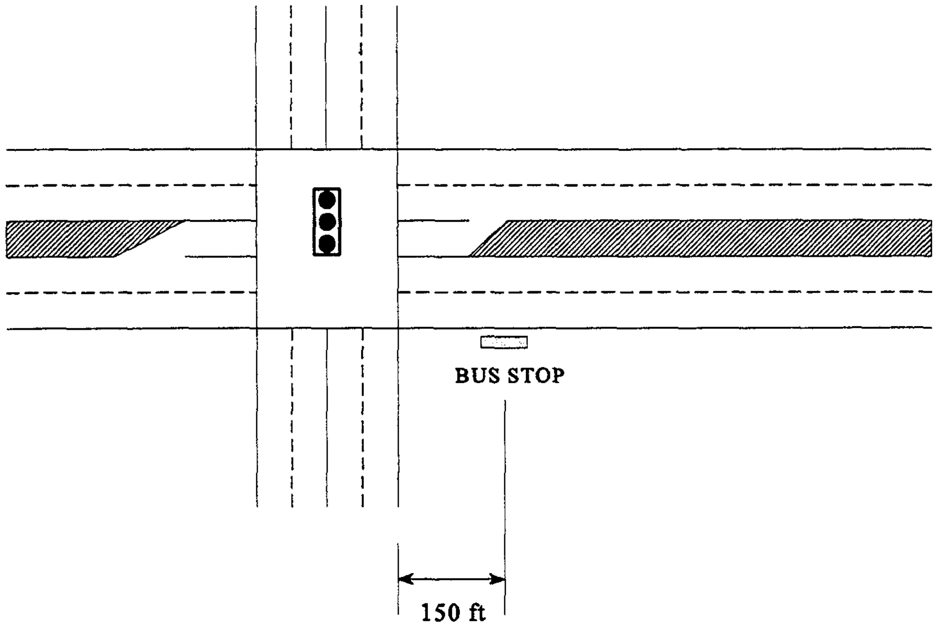
[a] N.A. - Bus bay present resulting in no queue.

To further calibrate TexSIM, the on-line graphical interface was used to compare the operations of buses and other traffic around the bus stop area to field observations. Maneuvers observed from TexSIM that were compared to field observations included vehicles changing lanes to avoid a stopped bus, vehicles queuing behind a stopped bus, and buses re-entering the traffic stream after completing a stop. The researchers agreed that the final TexSIM models provided a good representation of the actual field operations.

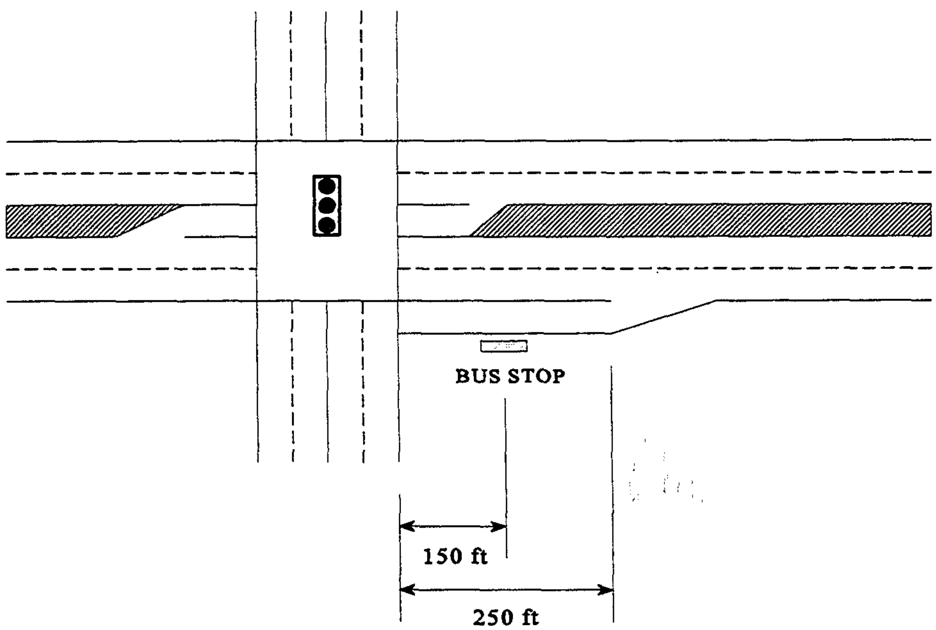
Performing the Simulation. The first two bus stop designs studied were curb-side and bus bay/open bus bay. The goal was to develop recommendations as to when a curb-side stop should be converted into a bus bay/open bus bay. TexSIM was used to compare different bus stop designs at both far-side (curb-side versus open bus bay) and midblock (curb-side versus bus bay) locations.

Schematics of the models used to study curb-side and bus bay designs for both far-side and midblock locations are shown in Figures D-30 and D-31, respectively. The models consisted of a single signalized intersection with four approaches. The main street approach consisted of two through lanes with left turn bays at the intersection. The bus stop under investigation was located either at the far-side of the intersection or at a midblock location downstream of the intersection on the main street. To remove the effects of the downstream intersection on vehicle travel time, a downstream intersection was not included in the model. This allowed the researchers to investigate only the effects that the bus stop design had on traffic operations for various traffic volumes.

The queue jumper design was also studied to determine the effects of a queue jumper on bus operations. The goal was to determine the situations in which a queue jumper would provide the greatest benefit. The models studied included a far-side open bus bay with a queue jumper and a far-side open bus bay without a queue jumper (see Figure D-32).

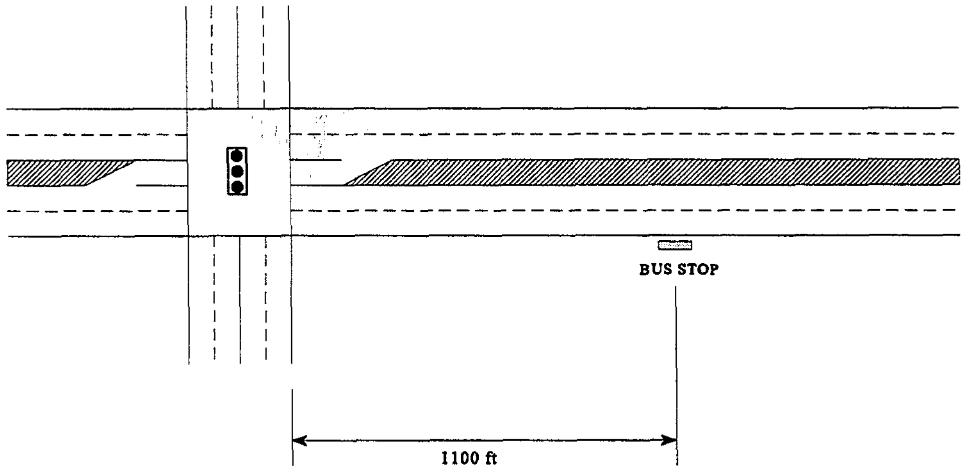


(a) Far-Side, Curbside

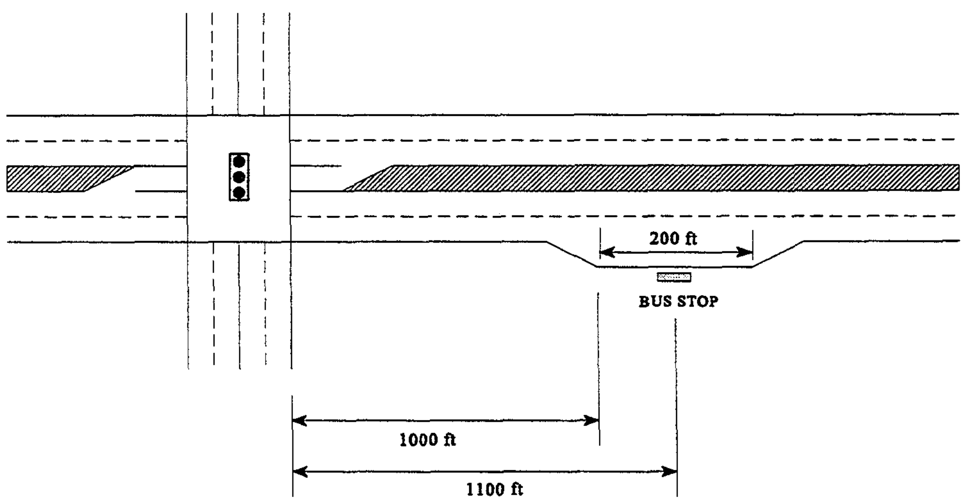


(b) Far-Side, Open Bus Bay

Figure D-30. Far-Side Bus Stop Designs.

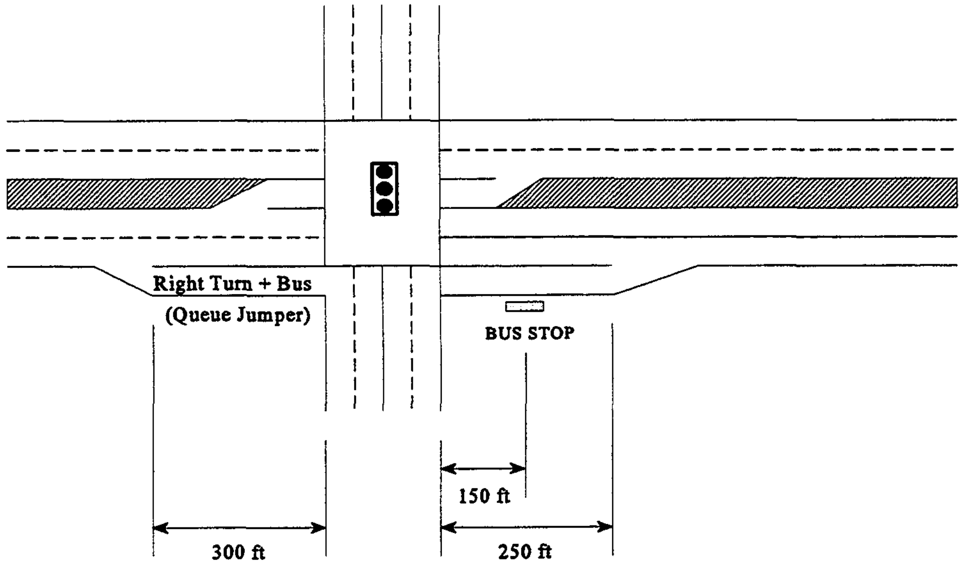


(a) Midblock, Curbside

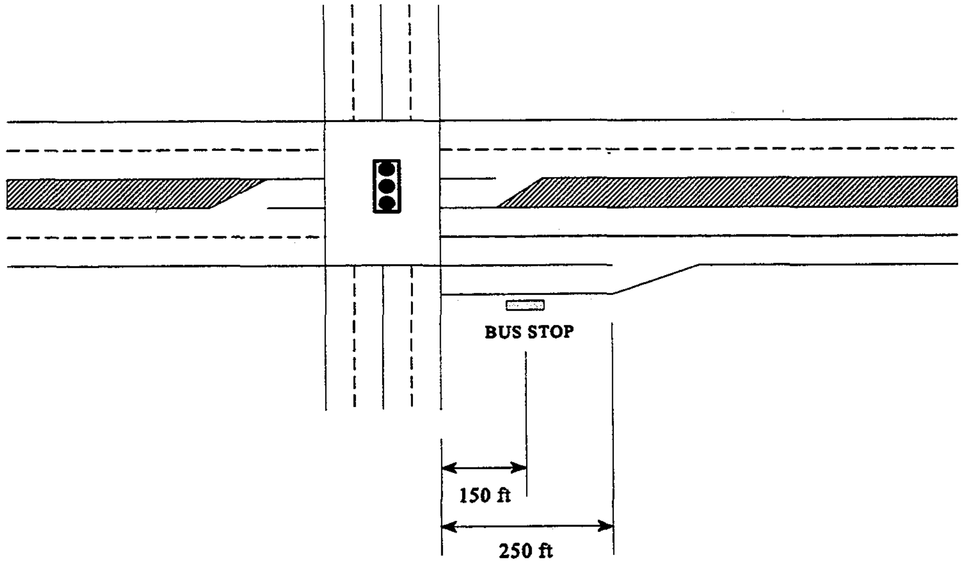


(b) Midblock, Bus Bay

Figure D-31. Midblock Bus Stop Designs.



(a) Queue Jumper



(b) No Queue Jumper

Figure D-32. Queue Jumper Bus Stop Designs.

To perform the simulations, variables to be adjusted and their increment size were selected. Specific inputs required by TexSIM included traffic volumes, turning percentages, speed, bus headways, bus dwell times, and signal timings. The values used for each of the above variables are shown in Table D-13. Optimum signal timings were computed using the signal optimization package, PASSER II. The variables adjusted included main street through traffic volume (100 to 3000 vph) and bus dwell time (20 to 60 seconds). For the queue jumper study, right turn percentages of 10% and 25% were used, and only a dwell time of 20 seconds was studied. Again, because outcome from TexSIM is stochastic, each run was simulated for 1 hour with a bus arriving every 10 minutes. Therefore, a total of six bus arrivals was included for each run.

Table D-13. TexSIM Model Variables.

Variables	Values
Desired Speed	45 mph
Main Street Through Volumes	100, 300, 500, 1000, 1500, 2000, 2500, 3000 vph
Main Street Turning Percentages: Left Through Right[a]	 10 % 80 % 10 %
Cross Street Through Volume	750 vph
Cross Street Turning Percentages: Left Through Right	 20 % 60 % 20 %
Bus Headway	10 min
Bus Dwell Time[b]	20, 40, 60 sec

[a] Right turn percentages of 10% and 25% were used for queue jumper study.
[b] A dwell time of 20 seconds was used for queue jumper study.

Data Reduction. After each simulation run, the necessary data were retrieved from the TexSIM output. The data reduced included vehicle travel times and the number of vehicles queued behind a stopped bus (for curb-side design). Output from TexSIM was given for each vehicle which traveled through the system; therefore, the researchers were allowed to record the travel time of vehicles only when a bus was in the system.

Travel times were measured from a set point upstream of the bus stop to a set point downstream of the bus stop. The output generated from TexSIM included the time that each vehicle entered the link containing the bus stop and the time that the vehicle left the link. From the entry and exit times, the actual travel time was computed.

Table D-14 contains an example of the output generated by TexSIM for a midblock curb-side bus stop with a dwell time of 60 seconds. The first column contains the vehicle ID which is assigned to each vehicle as it enters the system. The vehicle type, shown in the second column, specifies whether the vehicle is a passenger car (C) or a bus (B). The third and fourth columns include the time (in milliseconds) that each vehicle entered and exited the bus stop link. The travel time was computed by subtracting the entry time from the exit time. By noting the times that the bus entered and exited the link, the vehicle travel times when a bus was on the link could be identified (shown as the shaded area in Table D-14. In this example, the vehicles traveling through the system when the bus was present took, on average, 20.1 seconds to travel the link. In comparison, the bus took 78.4 seconds (18.4 seconds travel time and 60 seconds dwell time).

For the curb-side bus stops, TexSIM recorded the number of vehicles queued behind a stopped bus. The number of vehicles in queue was recorded for each second that the bus was stopped. Table D-15 shows an example of the output from TexSIM for a midblock curb-side stop with a dwell time of 20 seconds. As shown in this table, the amount of dwell time remaining is recorded each second along with the number of vehicles in queue. Observing the output, a queue only exists for the last 5 seconds that the bus is stopped, and the maximum number of vehicles in queue is two.

Data Analysis. After the TexSIM data were reduced, they were analyzed. Output from TexSIM recorded for the curb-side versus bus bay/open bus bay study included vehicle travel times when a bus was in the system and number of vehicles queued behind the stopped bus. For the far-side stops, travel times were measured from the intersection to a point 1000 ft downstream of the intersection. For the midblock stops, travel times were measured from 100 ft upstream of the bus stop to a point 900 ft downstream of the bus stop. The travel times were used to compute average speeds. Then, the speeds for the curb-side designs were compared to the speeds for the bus bay designs for various volumes.

Output recorded for the queue jumper study included travel times for the bus both upstream of the queue jumper and through the queue jumper. Travel times were measured from a point 3300 ft upstream of the intersection to the intersection. This information helped to determine the travel time savings to a bus when a queue jumper was present. Again, average speeds were computed from the travel times, and the travel times and speeds for the queue jumper designs were compared to those for bus stops without a queue jumper.

Results

The calibrated TexSIM models for curb-side, bus bay, open bus bay, and queue jumper designs were run for various combinations of traffic volumes and bus dwell times. Following is a discussion of the results from the curb-side versus bus bay/open bus bay study and the queue jumper study.

Table D-14. Example of TexSIM Output — Travel Time Data.[a]

Vehicle ID	Vehicle Type	Entry Time (millisec)	Exit Time (millisec)	Travel Time (sec)
960	C	1001800	1017600	15.8
997	C	1008600	1025900	17.3
1040	C	1023100	1036500	13.4
1045	C	1025100	1039900	14.8
898	C	1040800	1057400	16.6
794	C	1042900	1059500	16.6
824	C	1046300	1063500	17.2
856	C	1050200	1066600	16.4
1018	C	1053500	1069500	16.0
1010	C	1051400	1077200	25.8
852	C	1056100	1081200	25.1
905	C	1063700	1084000	20.3
860	C	1059500	1085900	26.4
887	C	1063000	1089100	26.1
993	**B**	**1023500**	**1101900**	**78.4**
1031	C	1084300	1102700	18.4
1029	C	1085900	1109200	23.3

[a] Shaded area represents vehicles which traveled through the system when a bus was present.

Curb-Side Versus Bus Bay/Open Bus Bay

An objective of the computer simulation was to develop criteria as to when a curb-side stop should be converted to a bus bay/open bus bay for midblock and far-side locations. Factors investigated included vehicle speeds and maximum queue length behind stopped buses. To study the trends between these factors and varying traffic volume and bus dwell times, several figures were generated.

Using the travel time data collected from TexSIM, the average speeds of vehicles were computed for the curb-side and bus bay/open bus bay designs. Figure D-33 illustrates the relationship between the speed of vehicles (when a bus was in the system) and through traffic volume (vehicles per hour per lane) for curb-side and bus bay designs at a midblock location. This figure shows that the speeds for the bus bay design are consistently higher than the speeds for the curb-side design, as was expected. Also, for the bus bay design, dwell time did not have an influence on speed because the bus bay minimized the effects of the bus on traffic operations.

Table D-15. Example of TexSIM Output — Queue Data.

Bus ID	Dwell Time Left (sec)	Number of Vehicles in Queue	Bus ID	Dwell Time Left (sec)	Number of Vehicles in Queue
1519	20	0	1519	9	0
1519	19	0	1519	8	0
1519	18	0	1519	7	0
1519	17	0	1519	6	0
1519	16	0	1519	5	0
1519	15	0	1519	4	1
1519	14	0	1519	3	1
1519	13	0	1519	2	1
1519	12	0	1519	1	2
1519	11	0	1519	0	2
1519	10	0			

For the curb-side design, however, dwell time did have an effect on speed. The speeds for the 20-second dwell time were relatively higher than the speeds for the 40- and 60-second dwell times. The speeds for the 40- and 60-second dwell times were very similar. This similarity is most likely due to the timing of the upstream traffic signal, which controls the release of the main street through-traffic volume.

Figure D-33 also shows that for traffic volumes below approximately 350 vphpl, the speeds for the curb-side design decrease at a relatively higher rate for increasing traffic volume than do the speeds for the bus bay design. Above 350 vphpl, the rate of decrease in speed becomes less for the curb-side design.

Figure D-34 was plotted to illustrate the benefits of a bus bay over a curb-side design. This figure shows the difference in vehicle speeds for the bus bay and curb-side designs (i.e., speeds for bus bay design minus speeds for curb-side design). For volumes below 350 vphpl, the difference in speeds increases at a relatively high rate for increasing traffic volume. Above 350 vphpl, the difference in speeds becomes relatively constant.

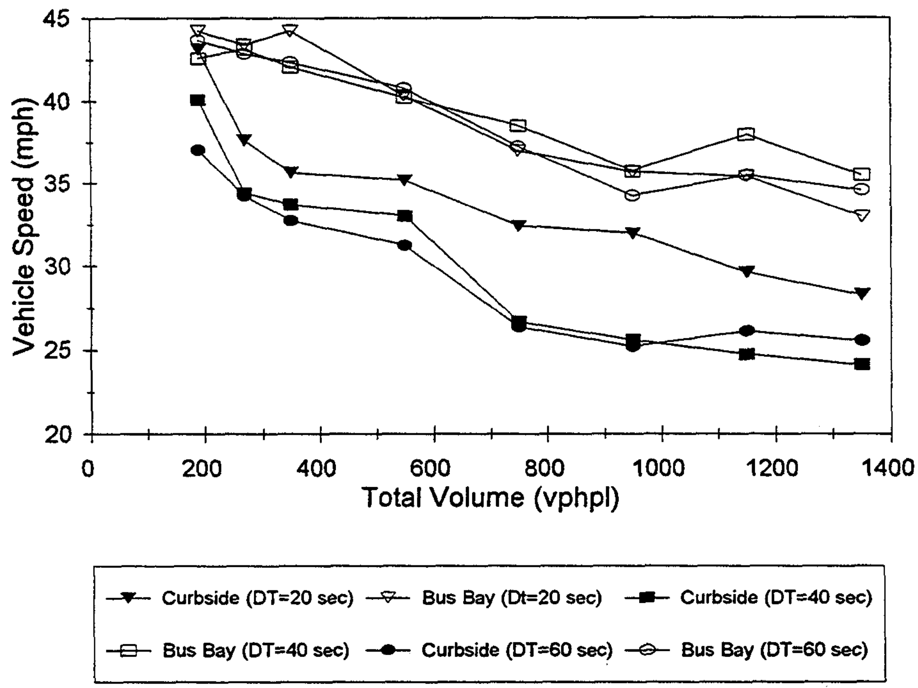


Figure D-33. Relationship Between Speed and Volume for Midblock Location.

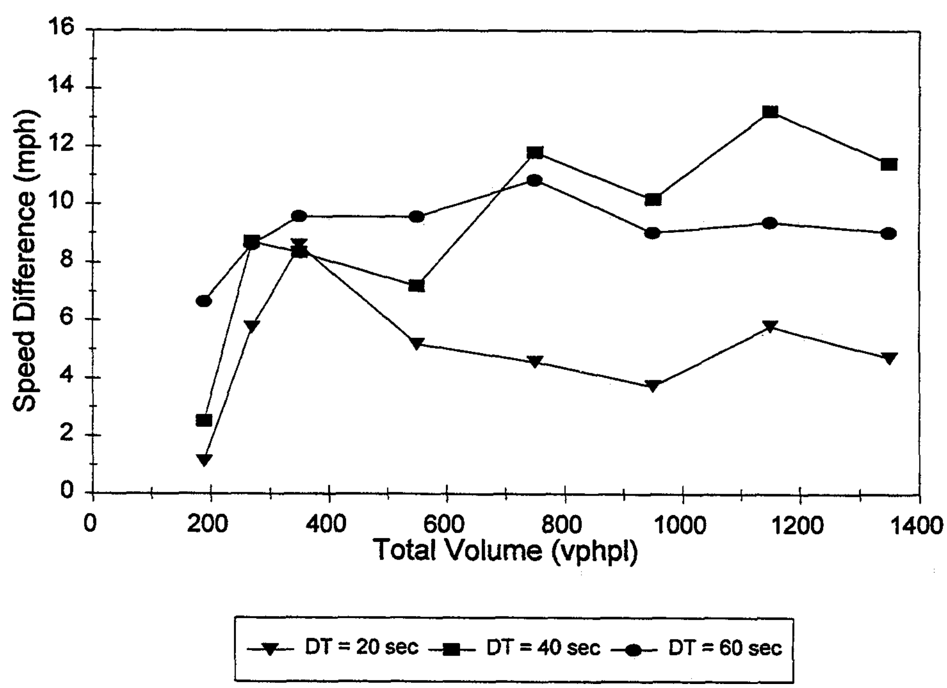


Figure D-34. Speed Difference Between Bus Bay and Curbside Design for Midblock Location.

Figure D-35 illustrates the relationship between vehicle speed and through volume for the far-side location, and Figure D-36 shows the benefits in speed due to a far-side bus bay design as compared to a far-side curb-side design. Similar to the results for the midblock location, Figure D-35 reveals that the rate of decrease in vehicle speed for the curb-side design was greatest for traffic volumes below 350 vphpl. Also, Figure D-36 shows that the difference in speeds between bus bay and curb-side designs reaches a maximum at approximately 350 vphpl. Therefore, these results reveal that the bus bay design provides the greatest benefits to traffic operations at volumes above 350 vphpl.

To further study the effects of the curb-side design on traffic operations, the maximum number of vehicles in queue behind a stopped bus were obtained from the TexSIM output. Figures D-37 and D-38 illustrate the relationship between maximum queue and traffic volume for midblock and far-side locations, respectively. As mentioned earlier, for each combination of traffic volume and bus dwell time, TexSIM was run for 1 hour with a bus headway of 10 minutes (for a total of six bus arrivals). Therefore, the maximum queues illustrated in Figures D-37 and D-38 are the average maximum queues for the six bus arrivals.

Observing Figures D-37 and D-38, for both midblock and far-side locations, the average maximum queue increases at a linear rate for increasing traffic volume for volumes below approximately 950 vphpl. Above 950 vphpl, the rate of increase becomes smaller for the far-side location and is relatively constant for the midblock location. The maximum queues for the observed traffic volumes were approximately four and five vehicles for the midblock and far-side locations, respectively.

From the field studies, the highest number of vehicles in queue was observed at Site S8, which contained a far-side curb-side bus stop (see Table D-2). In the bus stop area at Site S8, there were three through lanes, and the maximum volume observed was approximately 910 vphpl. Figure D-39 shows the maximum queues observed at Site S8 along with the maximum queues predicted by TexSIM for the far-side curb-side design over a range of traffic volumes. Although the field data contain a much higher variation in the maximum queues observed relative to the TexSIM data, there are some similarities between the two data sets. Both the TexSIM output and the field data queues of at least one vehicle occur at approximately 300 vphpl. In addition, queue lengths of three vehicles or more form at traffic volumes of approximately 600 vphpl and above for both the TexSIM data and the field data.

Queue Jumper

The intent of the simulation of the queue jumper bus bay design was to develop recommendations for when to consider a queue jumper bus bay design at a far-side bus stop. Benefits of a queue jumper bus bay were measured in terms of travel time savings and speed increases to the bus when a queue jumper bus bay was present. Factors adjusted during the computer simulation runs included traffic volume (100 to 3000 vph) and right turn percentage (10% and 25%).

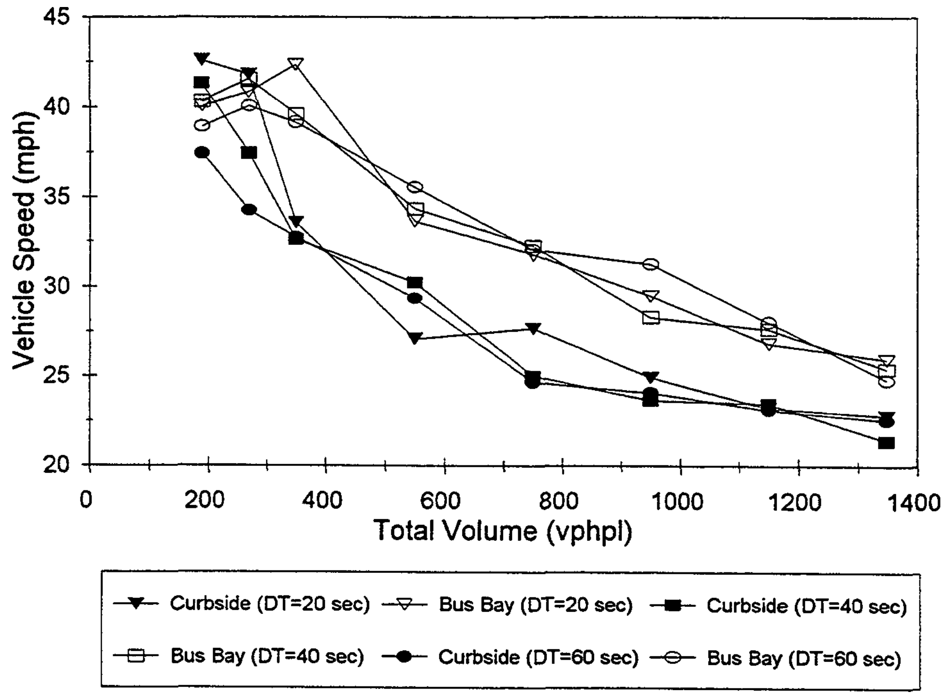


Figure D-35. Relationship Between Speed and Volume for Far-Side Location.

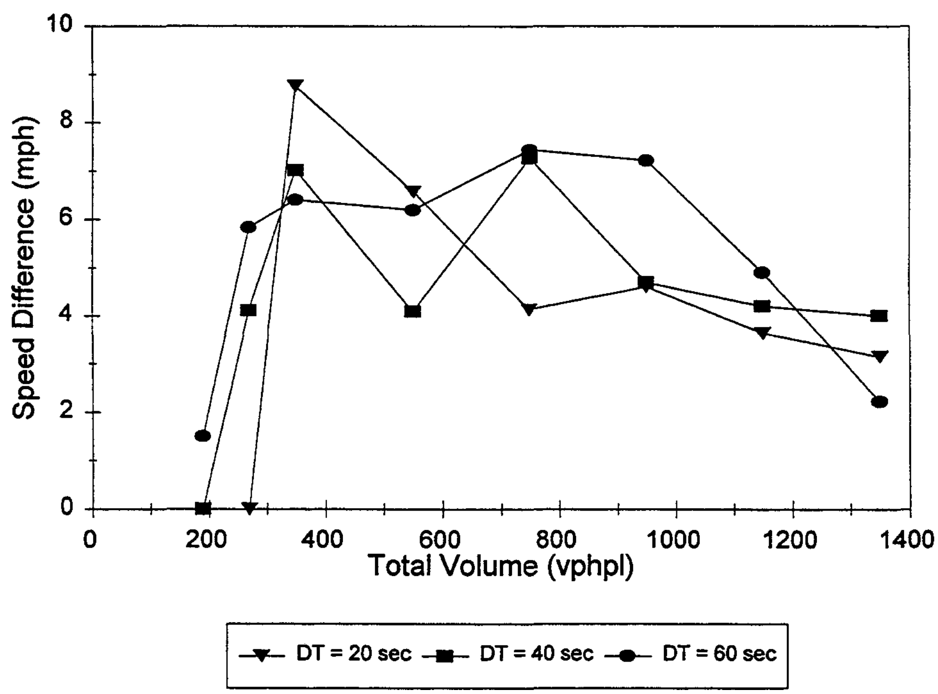


Figure D-36. Speed Difference Between Bus Bay and Curbside Design for Far-Side Location.

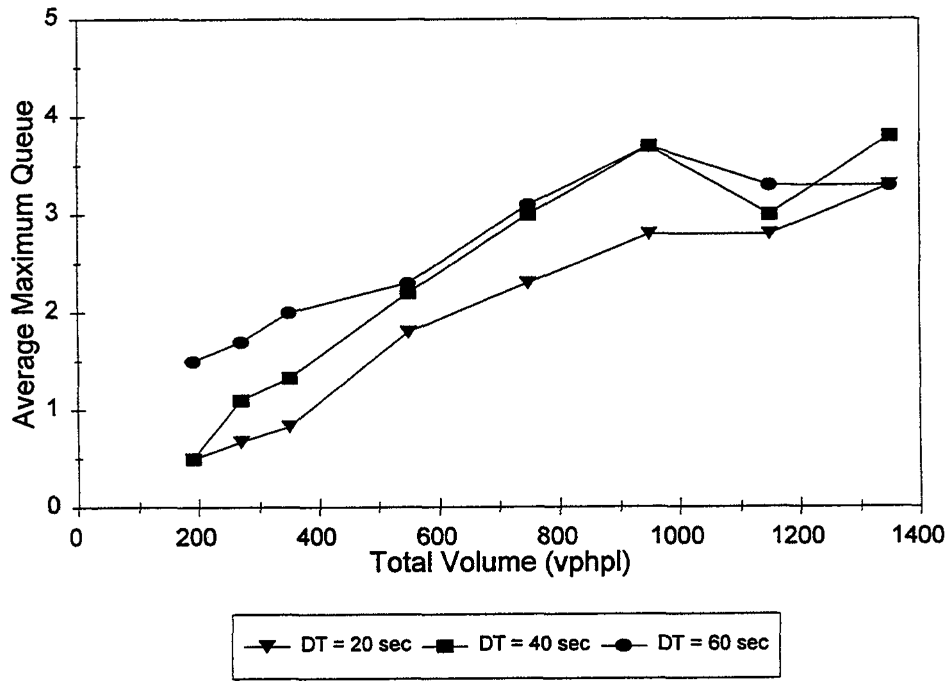


Figure D-37. Relationship Between Maximum Queue and Volume for Midblock Location.

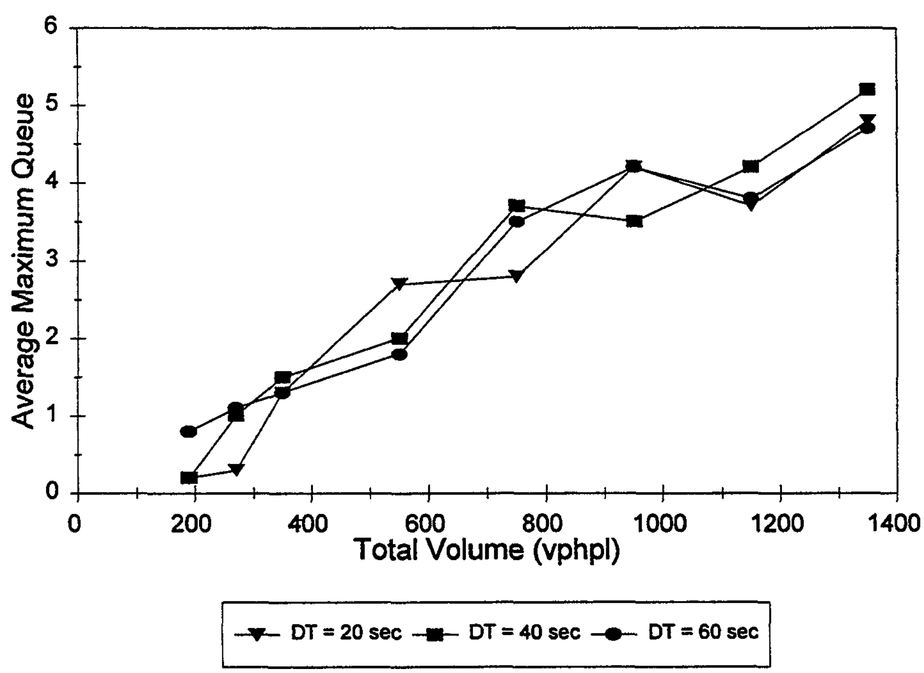


Figure D-38. Relationship Between Maximum Queue and Volume for Far-Side Location

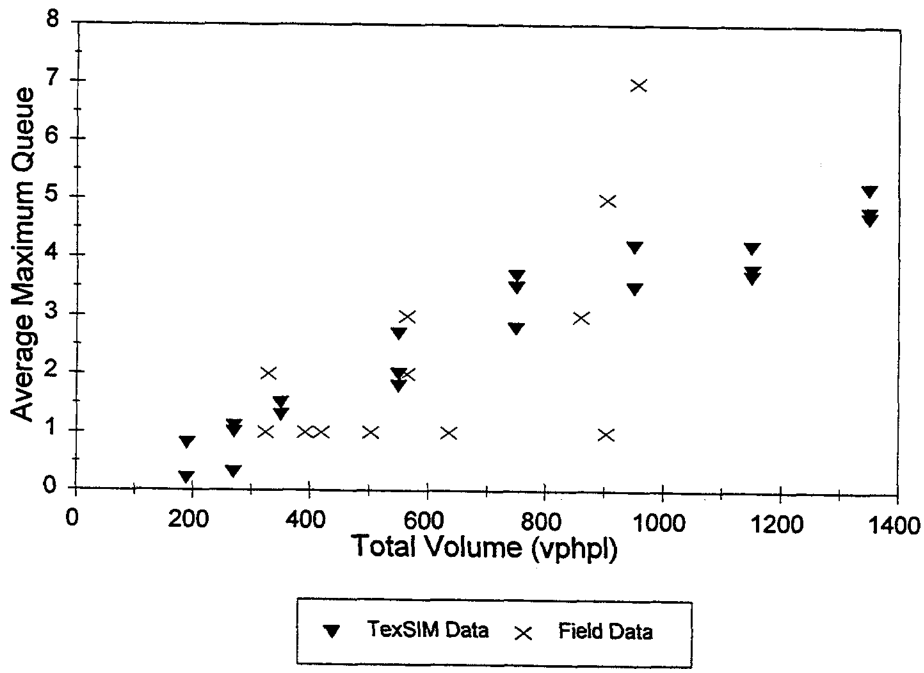


Figure D-39. Relationship Between Maximum Queue and Volume for TexSIM Data and Field Data.

The bus travel times predicted by TexSIM were measured from a point 3300 feet upstream of the intersection to the intersection. This distance included the right turn/queue jumper lane (300 feet in length) and 3000 feet upstream of the queue jumper. Figure D-40 illustrates the relationship between bus travel time and through traffic volume for a far-side open bus bay with and without a queue jumper. As shown in this figure, as the traffic volume increases the bus travel time increases. At traffic volumes above 1000 vphpl, the bus travel time increases significantly for all situations except for a queue jumper with 25% right turns. Above 1000 vphpl, the capacity of the arterial controls the traffic operations and the addition of a right turn bay increases the capacity of the arterial (especially when a heavily-used right turn bay is present, which is the case when right turns = 25%). Increasing the right turn percentage increased the throughput of the arterial because right-turn-on-red was allowed.

Figure D-41 was generated to examine the travel time savings to a bus using a queue jumper bus bay. This figure shows the relationship between travel time savings and through volume for traffic volumes below 1000 vphpl (so that a better view of the operations at lower traffic volumes is available). Observing this figure, the travel time savings were relatively independent of right turn percentage for traffic volumes below 1000 vphpl. For this volume range, the travel time savings varied from approximately 5 seconds to approximately 33 seconds. The travel time savings are relatively constant to approximately 250 vphpl. After 250 vphpl, the travel time savings increase notably.

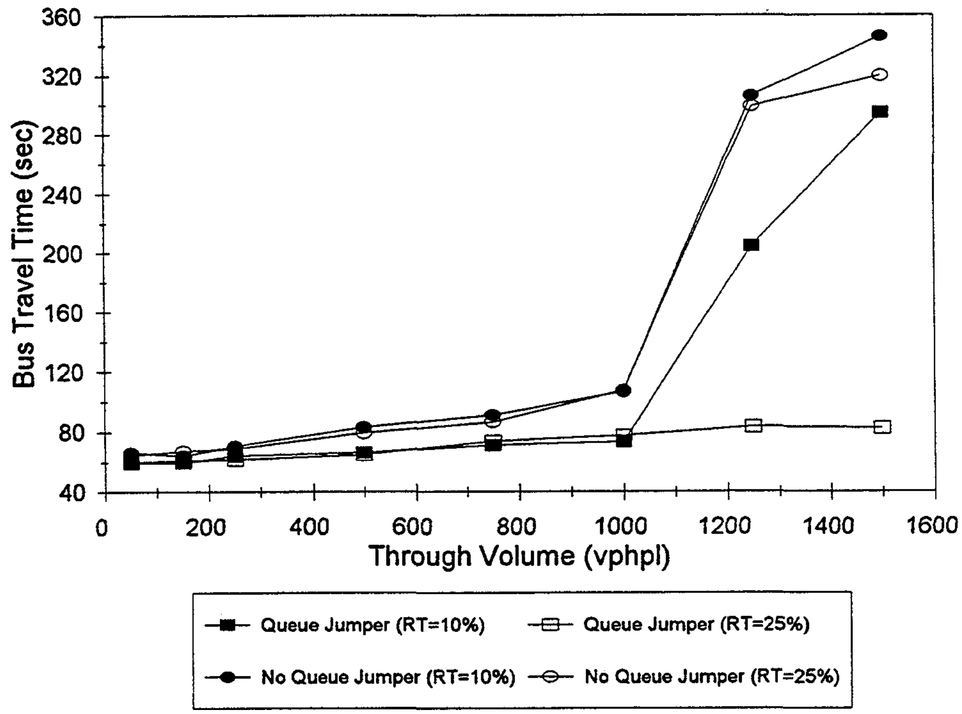


Figure D-40. Relationship Between Bus Travel Time and Volume for Queue Jumper Design.

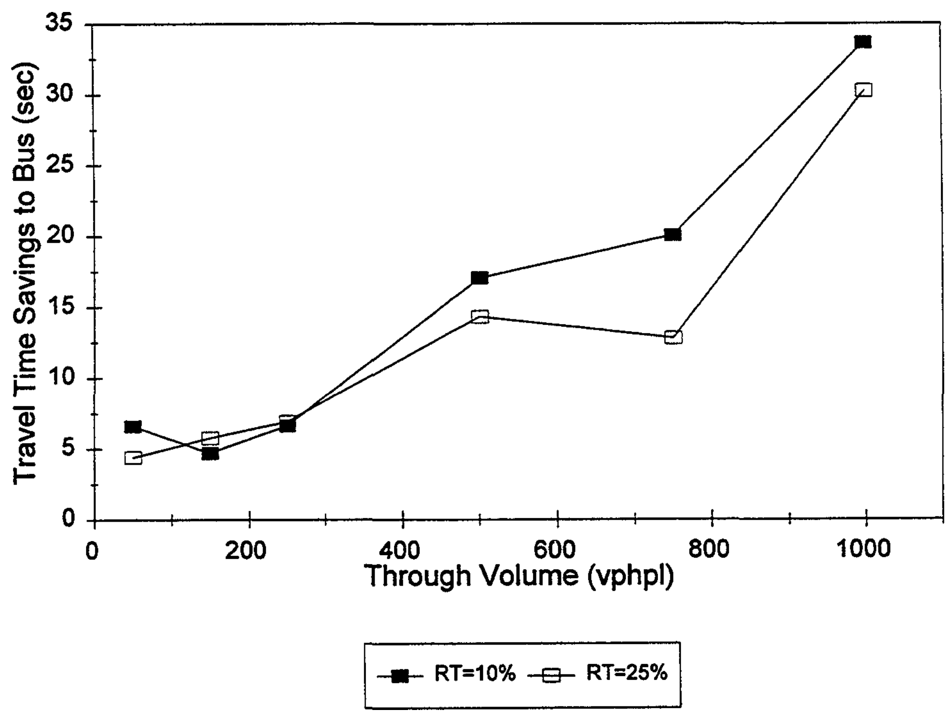


Figure D-41. Relationship Between Travel Time Savings and Volume for Queue Jumper Design.

To further illustrate the benefits of a queue jumper bus bay, the travel time savings were converted to speed. Figure D-42 shows the relationship between traffic volume and the difference in bus speed for bus stops with and without a queue jumper (i.e., bus speeds with queue jumper minus bus speeds without queue jumper). For traffic volumes below 1000 vphpl, the advantages in average speed when a queue jumper was present ranged from approximately 3 mph to 8 mph.

Conclusions

The objective of the computer simulation study was to determine how specific factors, such as volume and bus stop location, influence traffic operations around a bus stop. The conclusions that were made are presented below.

Curb-Side Versus Bus Bay/Open Bus Bay

- For the midblock curb-side and bus bay designs studied, the advantages in average vehicle speed of a bus bay design compared to a curb-side design ranged from approximately 2 mph to approximately 10 mph over the 1000-foot study area (based on traffic volume).

- For the far-side designs studied, the advantages in average vehicle speed of an open bus bay design compared to a curb-side design ranged from approximately 1 mph to 7 mph over the 1000-foot study area.

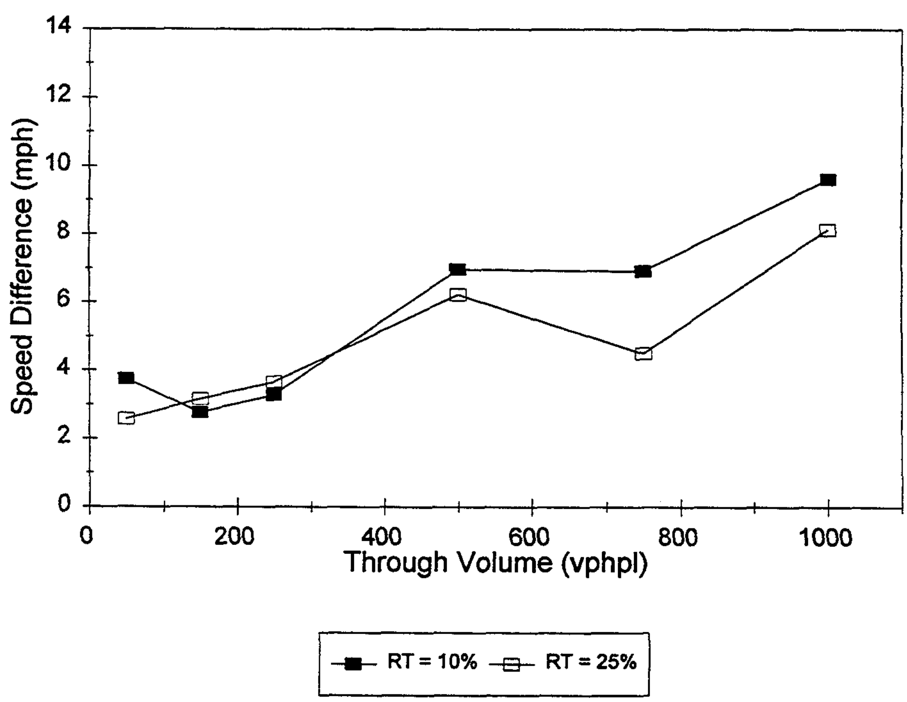


Figure D-42. Speed Difference Between Queue Jumper and No Queue Jumper.

- For the midblock curb-side design, the dwell time of the stopped bus affected traffic operations. The predicted speeds for a 20-second dwell time were from 2 mph to 7 mph higher than the predicted speeds for the 40-second and 60-second dwell times. Speeds for the 40-second and 60-second dwell times were relatively similar.

- For the far-side curb-side design, dwell time had minimal effect on the traffic operations. The relationship between vehicle speed and volume was similar for the 20-, 40-, and 60-second dwell times.

- For both the midblock and far-side bus stop locations, 350 vphpl was the volume at which the advantages in average vehicle speeds due to a bus bay either increased significantly or were near maximum. Notable travel time savings were also observed at 250 vphpl.

Queue Jumper

- For the queue jumper study, the results revealed that traffic operations began to diminish significantly at volumes above 1000 vphpl because of the limited capacity of the arterial (which is to be expected).

- For traffic volumes below 1000 vphpl, the travel time savings to a bus using a queue jumper bus stop ranged from approximately 5 seconds to 33 seconds over the 3300-ft study area (based on traffic volume). The advantages in average bus speed when a queue jumper bus stop was present ranged from 3 mph to 8 mph.

- The queue jumper bus stop design provided notable travel time savings and speed advantages above approximately 250 vphpl.

SUMMARY OF FINDINGS

This appendix documents research that focused on street-side factors affecting the location and design of bus stops. The research included regional visits, field studies, and computer simulation. The findings from each of these studies are summarized below.

Regional Visits

The objective of the regional visits was to explore how different bus stop designs operate. The states visited during the trips included Arizona, Michigan, and California. The efforts during the regional trips included interviewing transit agency staff, visiting several bus stops with different designs and locations, and observing how the stops operated. The findings from the regional visits were as follows:

- Successful design and placement of a bus stop requires coordination between transit agencies and other government agencies (primarily cities but also including neighborhood organizations, etc.).

- Safety considerations include providing adequate sight distances for pedestrians, vehicle drivers, and bus operators and minimizing the number of bus stops near driveways.

- Reinforced bus pads result in reduced pavement deterioration and minimal maintenance costs. Further research is needed to analyze the benefits of bus pads by comparing stops using reinforced bus pads with stops that do not have bus pads.

Field Studies

The objective of the field studies was to observe the operations at existing sites to determine how the location and design of bus stops influence traffic and bus operations. The study sites were divided into suburban sites (traffic speeds greater than 35 mph), and urban sites (traffic speeds less than 35 mph). The locations investigated included near-side, far-side, and midblock. The suburban bus stop designs included curb-side, bus bay, and queue jumper. The urban bus stop designs included curb-side, bus bay, and nub. Following are the findings from these studies:

- For bus bay stops, far-side locations may result in less delay to buses when compared to near-side or midblock locations. One reason for the minimal delays to buses at the far-side stops is due to the breaks in traffic created by the upstream signalized intersection.

- For bus bay stops, delay to buses is minimized for those sites with acceleration lanes. Acceleration lanes provide bus operators with an area to merge smoothly with the through traffic resulting in minimal conflicts.

- For far-side open bus bay stops, a queue jumper can provide significant travel time savings to bus passengers. The travel time savings to buses are dependent upon the queue length at the intersection and the number of right-turning vehicles. The effects on average delay to right-turning traffic due to a bus using a queue jumper is generally assumed to be minimal.

- For nub or curb-side designs, near-side locations may result in less delay to through vehicles when compared to far-side locations. At near-side stops, delay to through traffic due to a bus loading/unloading passengers and delay to a signalized intersection overlap, resulting in less overall delay.

Computer Simulation

The objective of this study was to use computer simulation to determine how different bus stop designs affect traffic and bus operations. Bus stop designs analyzed included curb-side, bus bay, open bus bay, and queue jumper. Both midblock and far-side locations were used in the simulation. Factors varied during the computer simulation included traffic volume and bus dwell time. For the queue jumper design, the percent of right-turning vehicles was also varied. Following are the findings from the computer simulation study:

- For the curb-side design, the dwell time of the stopped bus at the midblock location had an effect on traffic operations; however, dwell time did not affect traffic operations for the farside location.

- For both midblock and far-side locations, 350 vphpl was the volume at which the advantages in average vehicle speeds due to a bus bay either increased significantly or were near maximum. Notable travel time savings were also observed at 250 vphpl.

- The queue jumper bus bay design provided notable travel time savings and speed advantages above approximately 250 vphpl.

APPENDIX E

CURB-SIDE STUDIES

This appendix presents a review of the curb-side studies findings and observations. The information has been integrated and organized to reflect the experiences and amenities that might be encountered at a bus stop by patrons.

The objective of the curb-side studies was to determine how placement and design of curb-side amenities impact patron and pedestrian utilization of bus stops. To accomplish this objective, the following tasks were completed:

- Collect information on a wide variety of bus stop designs, configurations, and placements.
- Collect field data on pedestrian and patron behavior at bus stops at a number of different locations with high bus patron volumes.
- Observe actual utilization of bus stop sites for extended periods to determine site utilization patterns and external influences on site utilization.
- Analyze the environmental characteristics of an individual site and how they may impact site utilization and adaptive use of the nearby land use.
- Analyze the placement of the bus stop and how it influences pedestrian- and bus-patron-related activities (conflicts with boardings/alightings and waiting areas and changes in general pedestrian traffic).
- Summarize and integrate the observations from both the regional and field study locations.

STUDY DESIGN

The data collected for the curb-side field studies were categorized into two general areas: (1) site-specific information and (2) behavior of bus patrons and general pedestrian traffic. Table E-1 shows the type of information gathered within these two broad categories.

Table E-1. Field Study Data Collected.

Patron and Pedestrian Behavior	Site-Specific Information
• Popular Congregating Areas	• Existing Amenities and Location
• Integration with Neighboring Pedestrian Traffic	• Sun/Shade Patterns
• Boarding/Alighting Patterns	• Orientation of Stop (E, W, N, S)
• Adaptive Use of Site and Off-Site Elements (Ledges, Curbs, and Store Fronts)	• Placement of Stop with Respect to Land Use, Sidewalk, and Curb
• Queuing Areas/Informal Staging Areas	• Evidence of Use - Mud or Worn Areas
• Jaywalking	• Landscaping
• Unintended Use of Bus Facilities by Non-Bus Riders	
• Seating/Standing Patterns as a Result of Crowding and Environmental Conditions	

Pedestrian information was collected using video cameras, field notes, sketches, checklists, and still photography. The video camera was useful for recording congregation areas, pedestrian movement information, sun/shade patterns, and seating patterns. Still photography was utilized to record individual characteristics of a site, adaptive behavior, and pedestrian movement patterns. While using still and video photography at these sites, researchers were very careful not to influence the behavior of individuals sensitive to having their pictures taken.

Site-specific information was recorded on checklists and by measuring each site. Field notes and sketches were useful for recording behavioral observations and physical elements found at the site. Table E-2 describes each bus stop site studied in greater detail and which data collection methods were utilized. Following are discussions on the findings from the field studies.

Table E-2. Description of Field Study Sites.

State	Location & (City)	Shelter Location	Method of Data Collection					
			Video	Site Measurements	Notes	Sketches	Still Photo	Check-lists
AZ	Speedway @ Campbell (Tucson)	On Sidewalk	✓	✓	✓	✓	✓	✓
	Campbell @ Speedway (Tucson)	Behind Sidewalk	✓	✓		✓	✓	✓
	Speedway @ Mountain/Cherry (Tucson)	Behind Sidewalk	✓	✓	✓	✓	✓	✓
	Mill @ University (Tempe)	Behind Sidewalk	✓	✓		✓	✓	✓
	Washington @ N. First/Central (Phoenix)	On Sidewalk	✓	✓	✓	✓	✓	✓
CA	Polk @ Clay/Sacramento (San Francisco)	On Nub		✓	✓	✓	✓	✓
	Polk @ Jackson/Pacific (San Francisco)	On Nub		✓	✓	✓	✓	✓
	Polk @ Sutter (San Francisco)	On Nub		✓	✓	✓	✓	✓
	Polk @ Pine (San Francisco)	On Nub		✓	✓	✓	✓	✓
	Santa Clara @ First (San Jose)	On Sidewalk		✓	✓	✓	✓	✓

APPROACH TO BUS STOP

The walk to the bus stop affects the comfort, convenience, and safety of the bus patron. This section documents common treatments used to enhance patron access.

Integration of Bus Stop with Streetscape and Adjacent Land Use

The best pedestrian access to bus stops are locations with sidewalks that are direct and comprehensive in approach (see Figure E-1). The waiting area is a concrete pad and access from the curb to the sidewalk or waiting area is concrete or another impervious material. In Phoenix, the transit agency (RPTA) coordinates bus stop installation or improvements with street reconstruction activities. Waiting pads are defined with brick pavers, and additional space is provided at the waiting pad to install a bench or shelter depending on need. Landscaping is also installed during construction to provide shade trees for waiting pedestrians. The Phoenix example illustrates the need to coordinate bus stop locations and improvements with other street projects. By coordinating with other street projects, RPTA has the opportunity to update and improve an existing bus stop or install a new bus stop at developing locations. The bus stop is considered an important element of the overall "streetscape."

Figure E-1. Example of Good Pedestrian Access.

Sidewalk Location

In rural or developing suburban areas, sidewalks may or may not be installed along major roadways due to continuing development in the area or lack of justification for them. Sidewalks along the roadways may or may not exist. Typically, the only passenger amenity at the bus stops is a transit agency sign. The bus stop sign is located on the soft shoulder or placed in the dirt, which makes reaching the stop inconvenient during inclement weather (see Figure E-2). Patrons either stand on the undeveloped right-of-way (ROW) or seek relief from the elements by standing beneath nearby trees. Depending upon familiarity with the schedule, the patron may or may not have a long wait at these unsophisticated bus stops.

As areas become more developed, sidewalks become more commonplace. ADA compliance can be an impetus for installing sidewalks. At some locations, a discontinuous sidewalk has been installed to give bus patrons greater access to the bus stop from the intersection. The sidewalk begins at the intersection and ends at the bus stop (see Figure E-3). Although the sidewalk may not continue toward the next land use or along the roadway, this is the first step toward providing complete access to the stop.

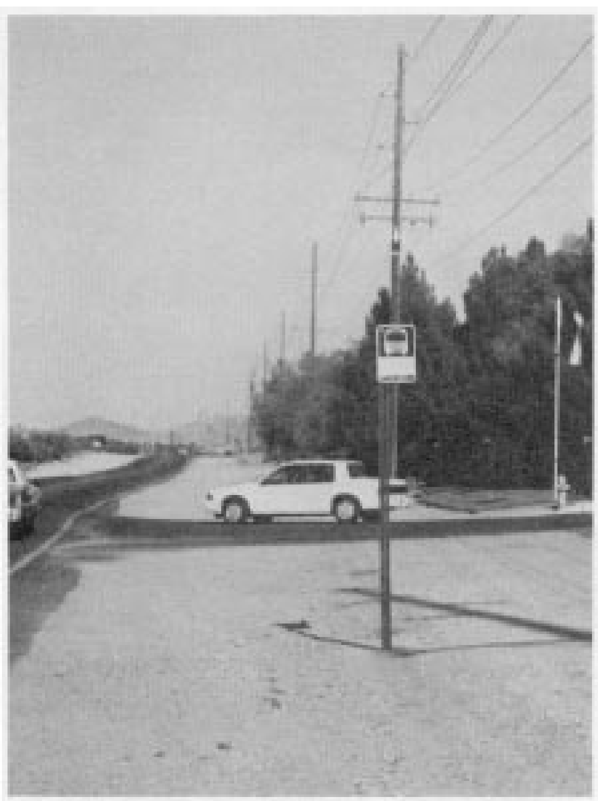


Figure E-2. Bus Stop on Soft Shoulder.

Figure E-3. Discontinous Sidewalk to Bus Stop

Sidewalks located far away from the curb can create large distances between the edge of the curb, sidewalk and bus stop. Suburban bus stops with wide right-of-ways are characteristically developed in this manner to permit further roadway expansion. The sidewalk is parallel to the curb but several feet from it. The sidewalk, bus stop, and curb may or may not be connected by impervious material. The bus stop is often located directly on the grass and is marked with a bus stop sign. A bench or bus shelter may or may not be present, depending upon demand. Over time, the site where the shelter or stop is placed becomes worn (see Figure E-4). Footpaths also develop in these areas showing common circulation paths. During inclement weather, the worn areas become muddy, creating the need for patrons to reach the bus from another location, such as a nearby driveway.

Commonly, bus stops are positioned between the sidewalk and the curb (see Figure E-5) or behind the sidewalk away from the curb (see Figure E-6). In both scenarios, the bus stop or bus shelter is away from the general pedestrian traffic on the nearby sidewalk. Some transit agencies prefer to have the sidewalk in front of the bus stop so bus patrons can see the general vehicular traffic and the surrounding pedestrian activity. The additional space also provides waiting patrons a zone of comfort away from the nearby traffic flow. At some suburban sites observed, speeds were over 45 mph near the bus stops, which further justifies the need to separate waiting passengers from high-speed vehicles.

Figure E-4. Bus Stop on Grass.

Figure E-5. Bus Stop Positioned Between Sidewalk and Curb.

Figure E-6. Bus Stop Positioned Behind Sidewalk.

Different bus stop configurations can also impact the relationship of the sidewalk to the bus stop. For example, in Phoenix, the shelters are located at the taper of either the acceleration or deceleration lanes of the bus bay. The shelters are parallel to the sidewalk and the taper. By angling the shelters in a linear area, additional room is created for the amenity. Depending upon where the bus ultimately stops, patrons may or may not have a long walk from the shelter to the vehicle when the shelter is sited in this manner (see Figure E-7).

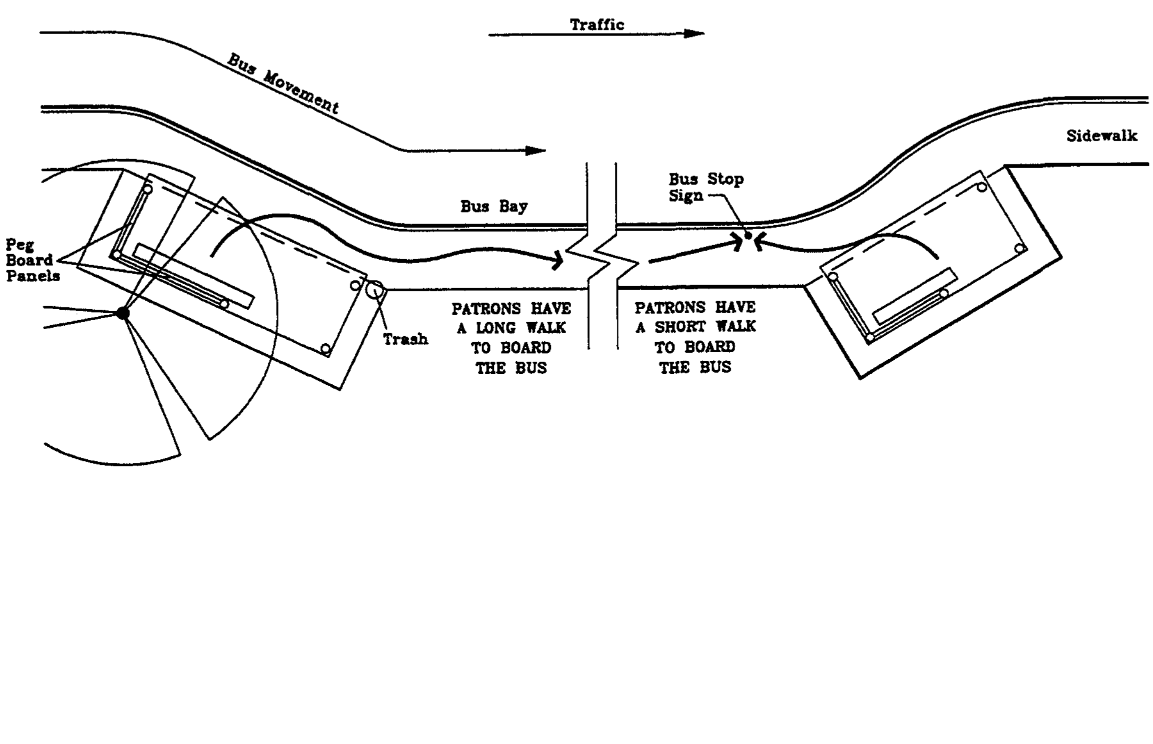


Figure E-7. Examples of Angled Shelters at a Bus Bay.

Access Between the Curb, Bus Stop, Sidewalk, and Land Use

Indirect or inconvenient access between the land use and the bus stop can detract from the experience of using transit by increasing walking time. Items such as walls, landscaping berms, fences, and circuitous sidewalks can limit direct access from the land use to the stop. Walls and fences are common along the perimeter of housing and apartment complexes. Smaller walls also exist along commercial developments in suburban settings. The walls are used to define and separate the edge of the parking lot from the nearby roadway and sidewalk (see Figure E-8).

Pedestrians can have direct access to and from the land use and the bus stop by providing an opening through the wall. An additional pedestrian improvement is defined or designated walkways through parking lots. Walkways can be as elaborate as a landscaped sidewalk through the parking lot or as subtle as painted walkways that warn vehicles and direct pedestrians (see Figure E-9).

Figure E-8. Wall Separating Parking Lot from Sidewalk.

Figure E-9. Painted Walkway.

Another land use interaction issue is circuitous sidewalks and landscaping berms. These elements are commonly associated with business parks and along suburban roadway systems. The circuitous sidewalks can create difficulties for transit agencies when determining the final stop location. The curvilinear sidewalks may not align with the final stop destination and can create access problems through grass and landscaping (see Figure E-10). Transit agencies will often request that sidewalks run parallel with the curb until the sidewalk meets the stop. By doing so, patrons will have direct access from the bus onto impervious cover when boarding and alighting the vehicle. Early involvement in the development approval process can help insure coordination between bus stop placement and sidewalk location. As evident in these examples, the location of the sidewalk and access to the curb can significantly influence the comfort and convenience of patrons.

Figure E-10. Curvilinear Sidewalk at Stop.

ADA ACCESS

The influence of ADA access mandates was clearly visible in the field. A direct and impervious path should be installed between the curb, sidewalk, and stop for both general bus patrons and for the physically impaired. Mobility impediments include cluttered sites that have an abundance of vending machines, bike stalls, trash receptacles and undeveloped ROW that lack sidewalks. Figure E-11 is an example of ADA improvements observed at many sites.

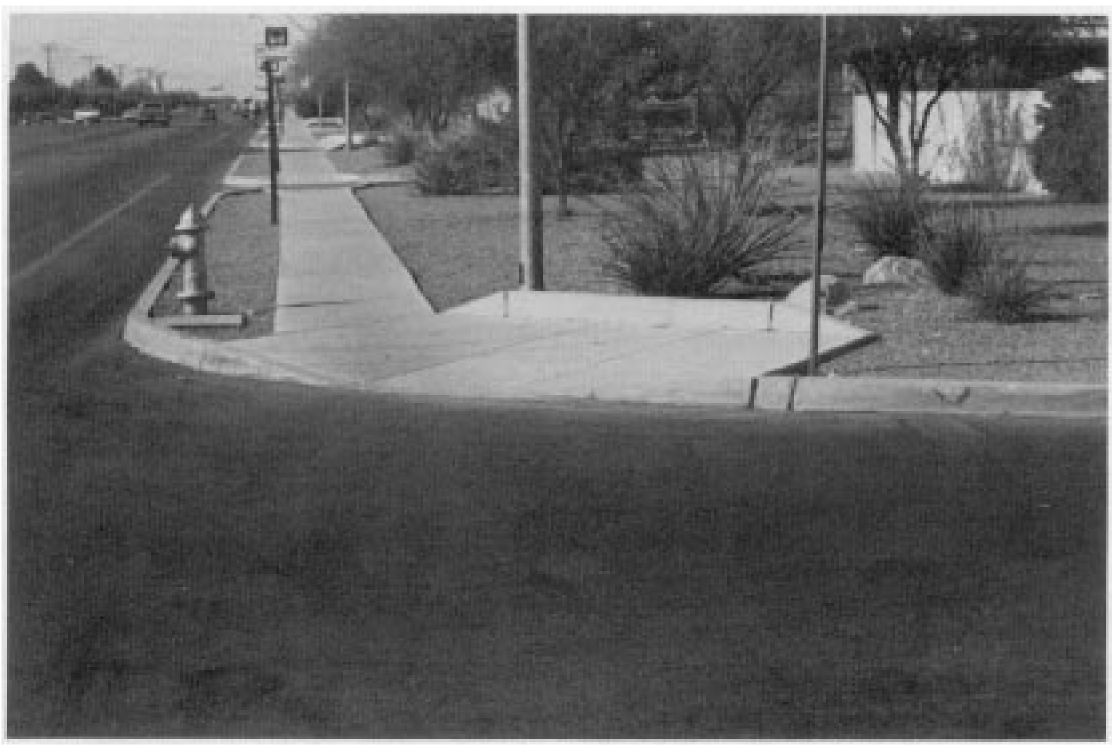


Figure E-11. Sidewalks for ADA Mandates.

PLACEMENT WITHIN RIGHT-OF-WAY (ROW)

Available ROW can significantly influence the location and number of pedestrian amenities that can be constructed at a site. Items commonly found in the ROW, such as the edge of the curb, sidewalk, landscaping, and utility poles can influence the size and positioning of a bus stop and the number of amenities that can be placed at the site for patrons. Different street-side stop designs, such as bus bays, can also place additional constraints on space availability. Many of the sites observed are compromises between needed amenities and the space available in the right-of-way.

Bus Stops Located Directly on Sidewalk

Where right-of-way is limited, bus stop shelters are sometimes placed directly on the sidewalk or overhang the sidewalk. Several examples of shelters located directly on the sidewalk or impinging on the sidewalk were observed on the regional visits (see Figure E-12). One benefit of having the shelter or stop located directly on the sidewalk is that it ensures that patrons will have a paved surface to await the next bus. However, locating the stop or shelter on or close to the sidewalk can affect the flow of general pedestrian traffic.

To gain a better understanding of the influence of shelter placement on pedestrian movement, video and still photography were used at the field study site in Tucson on Speedway at Campbell. The site has two shelters that slightly overhang the sidewalk (see Figure E-13). Pedestrians and bus patrons must share this space between the curb and the overhanging shelters.

Figure E-12. Shelter Located on the Sidewalk.

Figure E-13. Shelters Overhanging Sidewalk.

From the video and observations made at the site, a majority of pedestrians chose to walk around the shelter into the nearby parking lot rather than share the sidewalk in front of the bus shelters. Of the 189 pedestrians observed in a 12-hour period, 143 pedestrians walked around the shelters (see Figures E-14 and E-15). This behavior could be due to a number of different elements associated with the site:

- People may have previous experiences of walking through the site when a bus was boarding or alighting and the area became too crowded.
- The width of the sidewalk with respect to the shelter overhang may "infringe" on the personal comfort zone of people causing them to choose another route.
- Ample space to walk around the shelters is available in the hotel parking lot.

A potentially hazardous situation exists when pedestrians walk behind a structure rather than on the sidewalk in front of the shelter. The bus shelter blocks the view of pedestrians walking behind the shelter from the traffic turning into the hotel. The proximity of the driveway to the shelter could create conflicts between pedestrians and turning vehicles. Although this situation was not directly observed, the opportunity exists because of the large numbers of bus patrons and general pedestrian traffic using the sidewalk.

Site observations made at other locations during the regional visits reinforce this observation. Worn paths in grass and dirt suggest that general pedestrian traffic prefers to walk behind the shelters instead of through the shelter. Based on these observations, shelters located directly on the sidewalk should be avoided because of their impact on general pedestrian traffic.

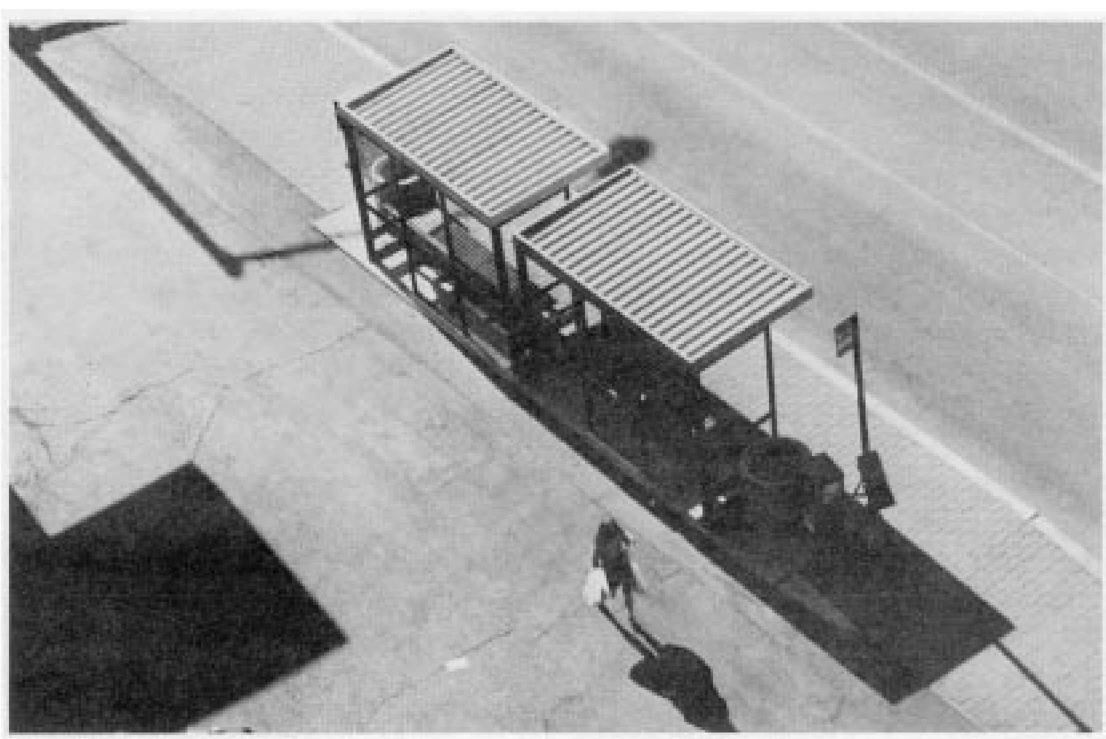
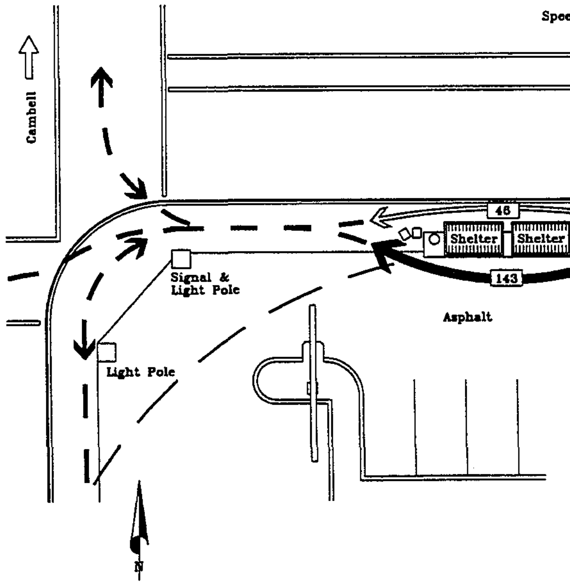


Figure E-14. Pedestrian Walking around Shelter.



Bus Patrons Inside Shelter	# of Pedestrians Who Chose To:	
	Walk in Front of Shelter	Walk Behind Shelter
Yes	28	95
No	18	48
Total	46	143

Figure E-15. Pedestrian Movement Study (Speedway at Cambell Street).

Nubs

In San Francisco, limitations on sidewalk space near bus stops have been overcome with the addition of bus nubs. Bus nubs create additional space for shelters, benches, and phones in dense urban settings. Nubs are also known as bus bulbs and curb extensions. The nubs provide enough space for bus patrons to comfortably board and alight the bus with little or no conflict with nearby general pedestrian traffic.

As part of the field studies, four nub sites in San Francisco were studied in greater detail to determine the advantages of this type of configuration. A far-side, near-side, and two midblock stops were studied. Three of the sites are along Polk Street, which is an established shopping and residential neighborhood. The Polk Street sites experience higher bus patron volumes on the weekend because of shopping opportunities in the area. Each site includes a standard agency design shelter, while only one site, Polk Street between Sacramento and Clay Streets, has additional seating outside the shelter (see Figures E-16 through E-19).

The fourth study site is located in the Chinatown district along Stockton Street between Jackson and Pacific Streets. The site is a midblock stop in a thriving shopping area punctuated by neighborhood grocery stores and restaurants. The sidewalks experience high general pedestrian volumes throughout the week. The midblock nub does not have any pedestrian or bus patron amenities to note. It is essentially a concrete curb extension which could be due to the high bus patron volumes at this site during the weekend. The Stockton Street site, similar to the Polk Street sites, has a dramatic increase in bus patron volumes on the weekend.

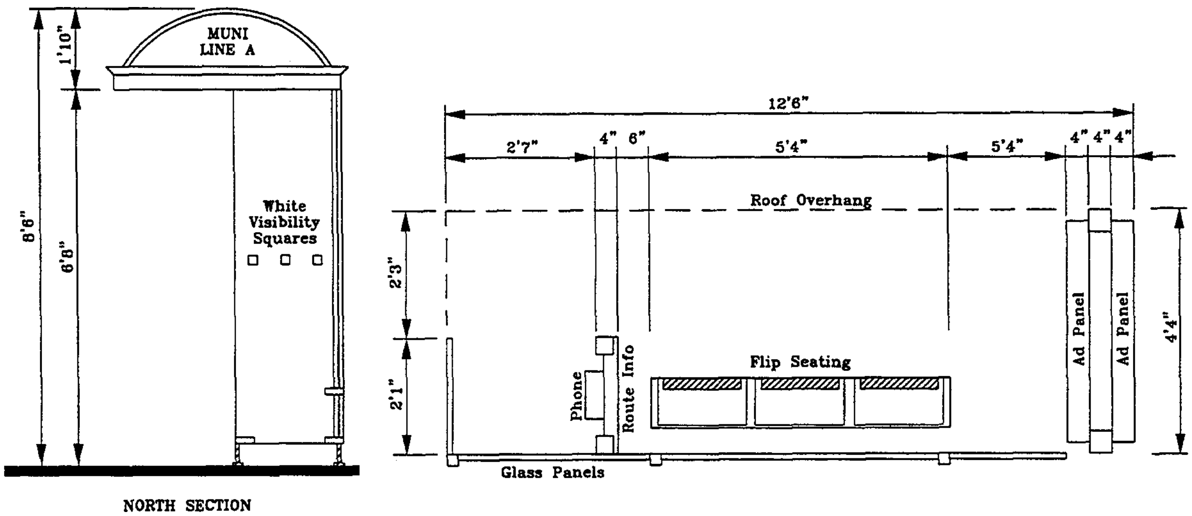


Figure E-16. Example of Shelter Detail at Polk Street Bus Stops.

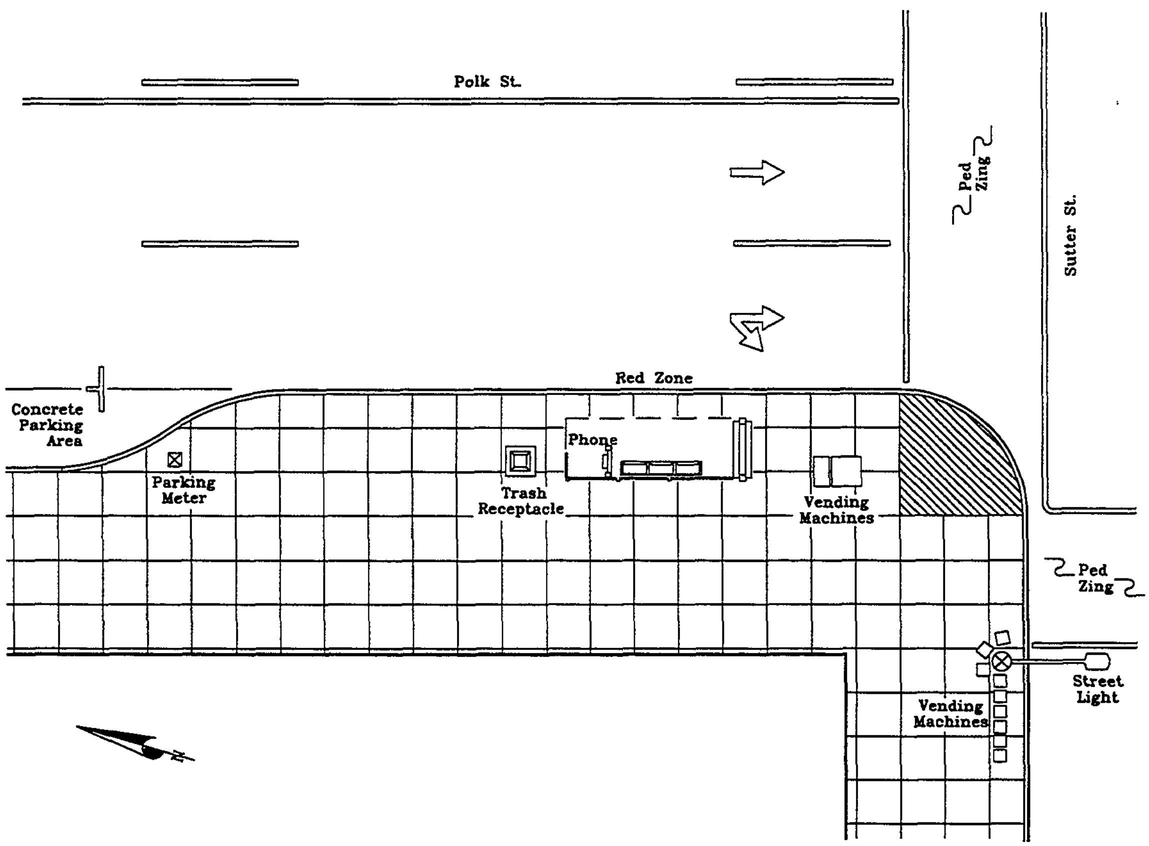


Figure E-17. Near-Side Nub (Polk Street at Sutter Street).

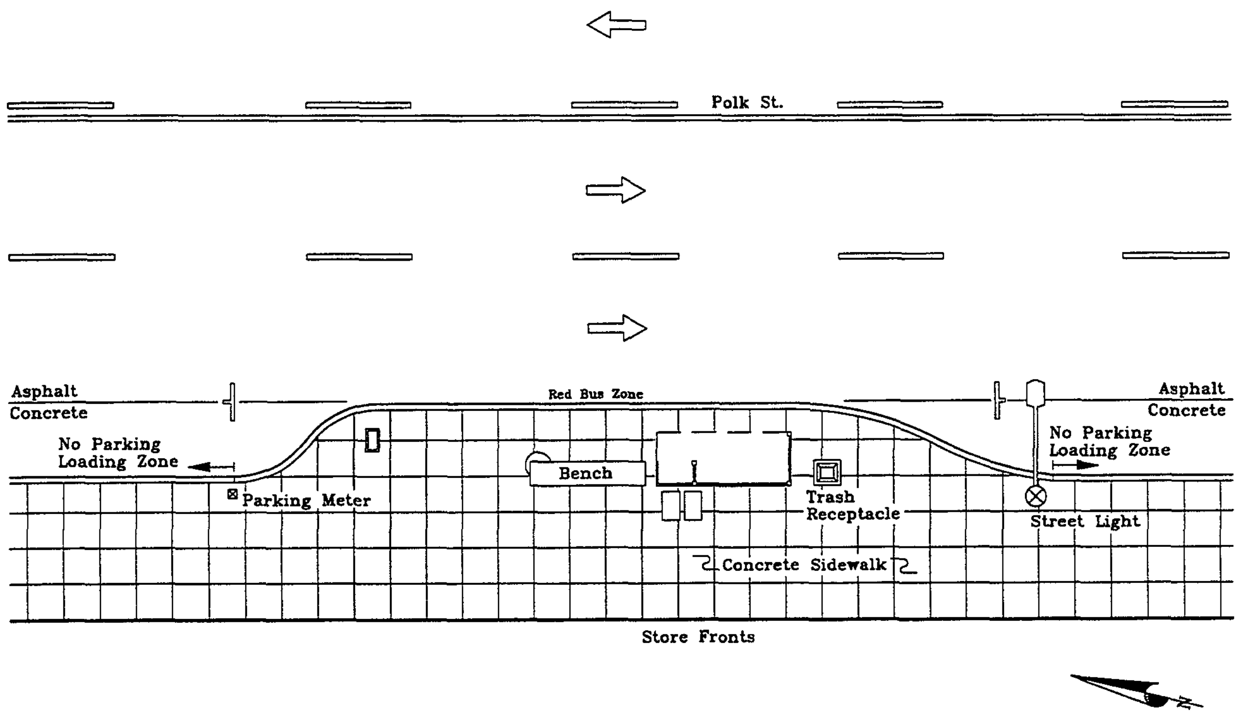


Figure E-18. Midblock Nub (Between Sacramento and Clay Street).

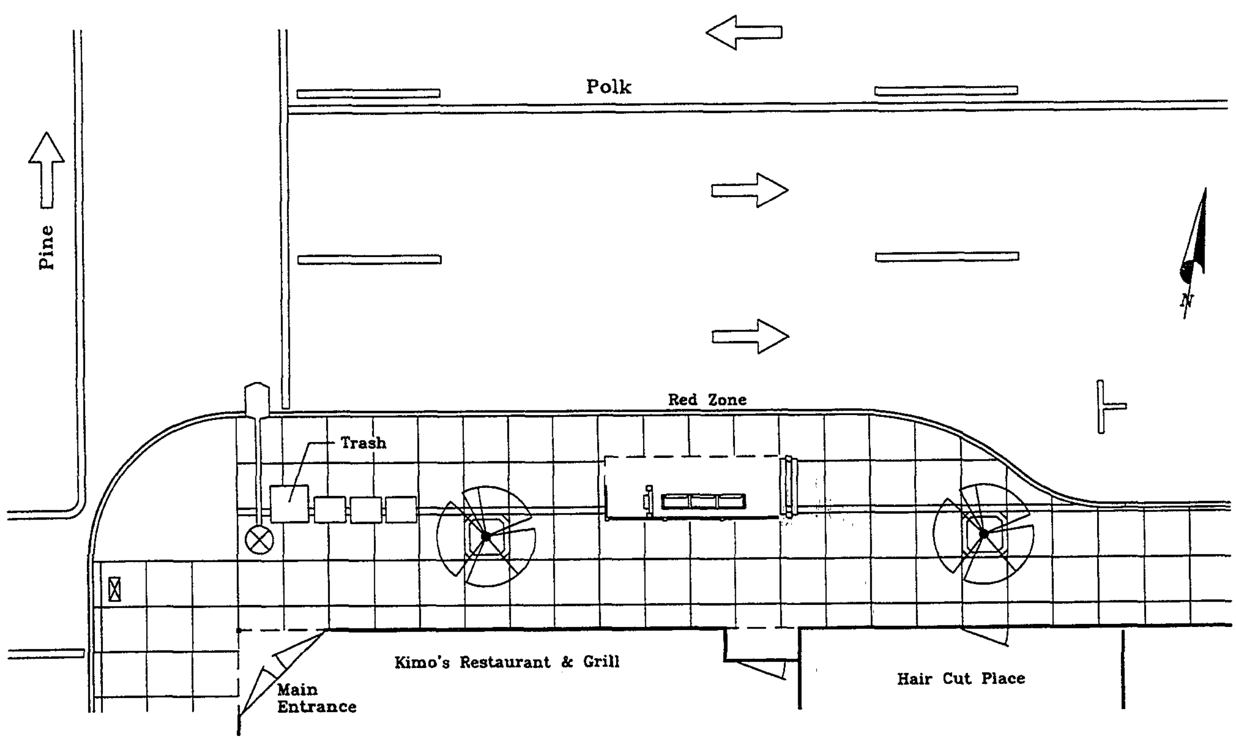


Figure E-19. Far-Side Nub (Polk Street at Pine Street).

The following general observations were made about nubs:

- The general pedestrian and bus patron conflicts are reduced when nubs are used.
- The number of amenities that can be included at a dense downtown setting can be increased.
- The amount of adaptive use of store ledges or awnings because of the separation between the bus stop and the store fronts and the increased waiting area is reduced. Bus patrons, with the exception of the Chinatown site, were observed to be using only those amenities located at the site.
- Without the additional space provided by the nub, the site and adjacent sidewalk would probably reach an uncomfortable level of saturation. Figure E-20 is an example of bus patrons standing on the nub at the Stockton Street field study site away from the pedestrians using the nearby sidewalk.
- The amount of jaywalking may increase. Although no bus patrons were seen illegally crossing the street, several pedestrians were seen taking advantage of the reduced width between opposing curbs. Midblock nubs appear to have the greatest impact on encouraging jaywalking. The near-side and far-side nubs do not appear to encourage any type of jaywalking because of the proximity to the intersection. With near-side and far-side nubs, pedestrians "shortcut" the walk through the intersection when approaching the curb (see Figure E-21).
- The telephone provided inside the shelter was never used by people waiting for the bus. The additional pedestrian traffic caused by the telephone created minor conflicts between bus patrons and pedestrians, especially during bus boardings and alightings.
- From a pedestrian and bus patron point of view, nub configurations enhance the comfort and convenience of transit in dense urban settings.

Figure E-20. Bus Patrons Standing on Nub Design.

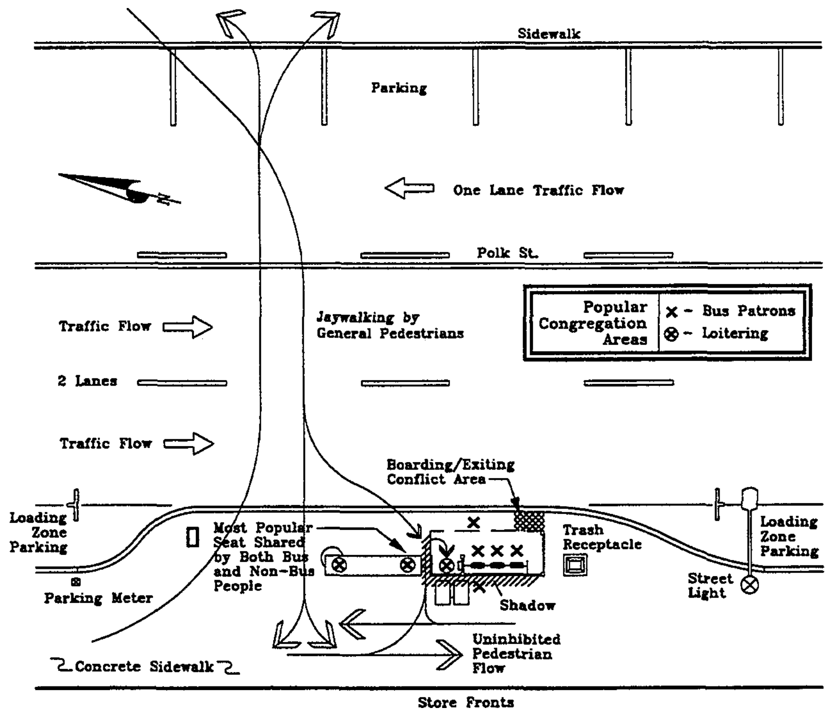


Figure E-21. Pedestrian Movement Study (Midblock: Polk Street).

AMENITIES

Amenities are considered to be those elements at a bus stop that enhance the comfort and convenience of using transit. Amenities can also influence a patron's real or perceived sense of security at a bus stop. It is unclear which amenities attract new riders and which amenities, when removed, may cause reductions in existing riders because of reductions in security, comfort, and convenience.

Amenities found at most bus stops are placed at the site in response to a human need or a need to address an environmental condition association with that specific site or region. This section summarizes the observations of bus stop amenities made during the regional visits and includes detailed findings from the field study sites.

Shelter

A number of bus shelter configurations and designs were observed during the project. Multiple conditions, constraints, and opportunities exist on a site-by-site basis, which can determine the final placement, configuration, and appearance of a shelter. With some exceptions, such as developer-constructed and -installed or artist-designed shelters, there was little variation in size, shape, and color of shelters observed by the research team.

The primary site-specific factor affecting shelter placement is available right-of-way. In virtually every case where there was adequate right-of-way, shelters were set away from vehicle traffic and out of the flow of pedestrian traffic. Many of the shelter installations observed were visible compromises in response to unique site-specific conditions.

An important issue for transit agencies regarding bus shelters is maintenance and safety. Several transit agencies visited during the regional visits noted the importance of proper bus shelter maintenance and providing safe, secure bus shelters.

Shelter Configurations

Panel placement and type is the most common treatment used to make the bus shelter as comfortable as possible. In southern climates with mild winter temperatures and extreme summer temperatures, shelters can be designed to be completely open to air circulation from all four sides. At sites with wind, rain, or glare problems, standardized shelters can be retrofitted with panels to provide protection and shade. The panels can be solid pieces of glass, metal, or plastic. The panels observed in southern climates typically have openings to permit air movement through the shelter. On some occasions, panels are properly placed to diffuse direct sunlight and glare. Figure E-22 is an example of a shelter in Tucson, Arizona, that uses a perforated panel to protect waiting patrons from the heat and glare of the setting sun.

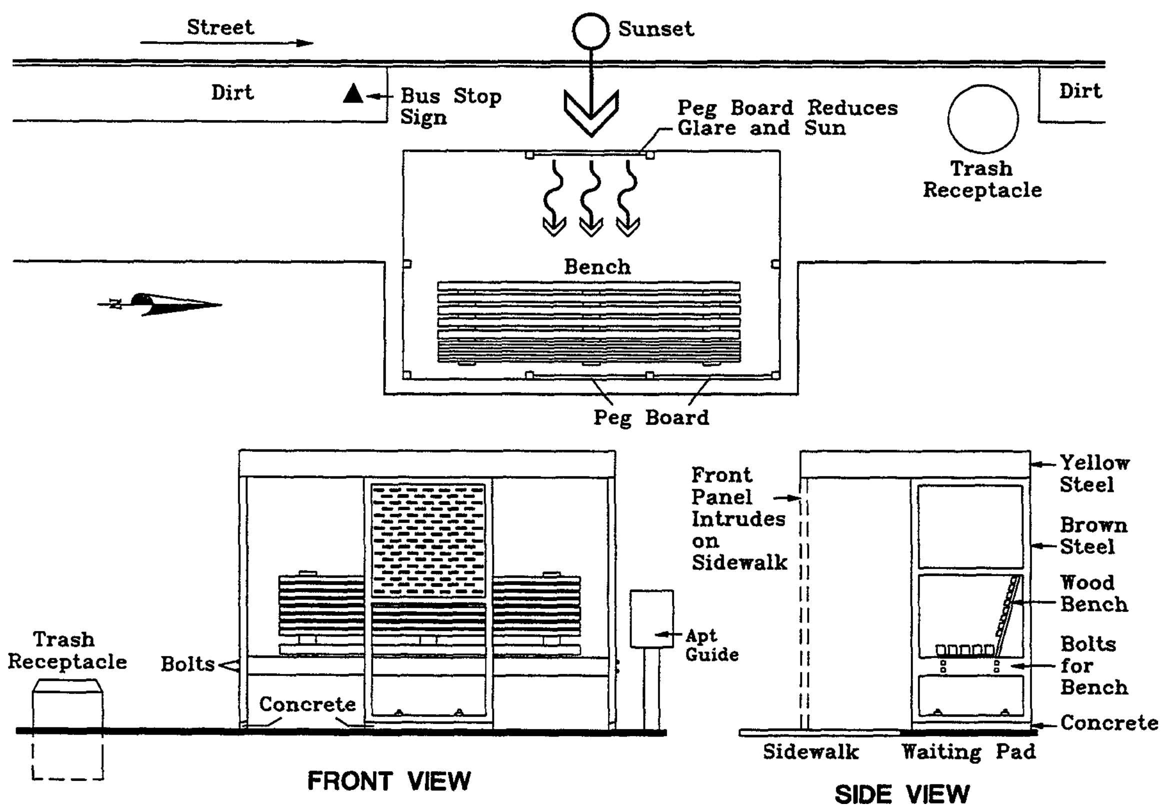


Figure E-22. Bus Stop Treatment in a Southern Climate.

In northern climates, four-sided shelters with solid paneling is common. The panels help reduce exposure to wind and precipitation. Four-sided shelters usually have two openings for entry and exiting (see Figure E-23). One opening for entry and exiting is avoided because of safety concerns rather than enhancing ventilation conditions.

Figure E-23. Shelter in Northern Climate with Two Openings for Entering and Exiting.

Orientation of Bus Shelter

An important consideration when determining the final location of a stop or shelter is the orientation of the stop or shelter with respect to the environmental conditions of a site. Proper orientation of the stop or shelter can offer patrons protection from the elements. Bus stops that are improperly placed can accentuate the negative environmental factors at a site and make transit an uncomfortable and inconvenient experience. Improper bus shelter orientation may also encourage waiting bus patrons to seek relief at locations other than inside the bus shelter (see Figure 24).

In southern climates, shelters should be oriented to take advantage of cross ventilation or to reduce the amount of afternoon sun entering the shelter. In northern climates, shelters are typically oriented to block cold winter winds and to protect patrons from snow and rain. A unique feature associated with northern climates is that some shelters are oriented with the rear of the shelter facing the street instead of the entrance and exit facing the street. By having the rear of the shelter adjacent to the street, it protects patrons from snow that can be moved or blown by snow removal machines on the street (see Figure E-25).

In urban areas, shade and glare can be created by adjacent buildings and materials. Attention to the climate created by adjacent structures should be made when determining the location and orientation of a bus stop.

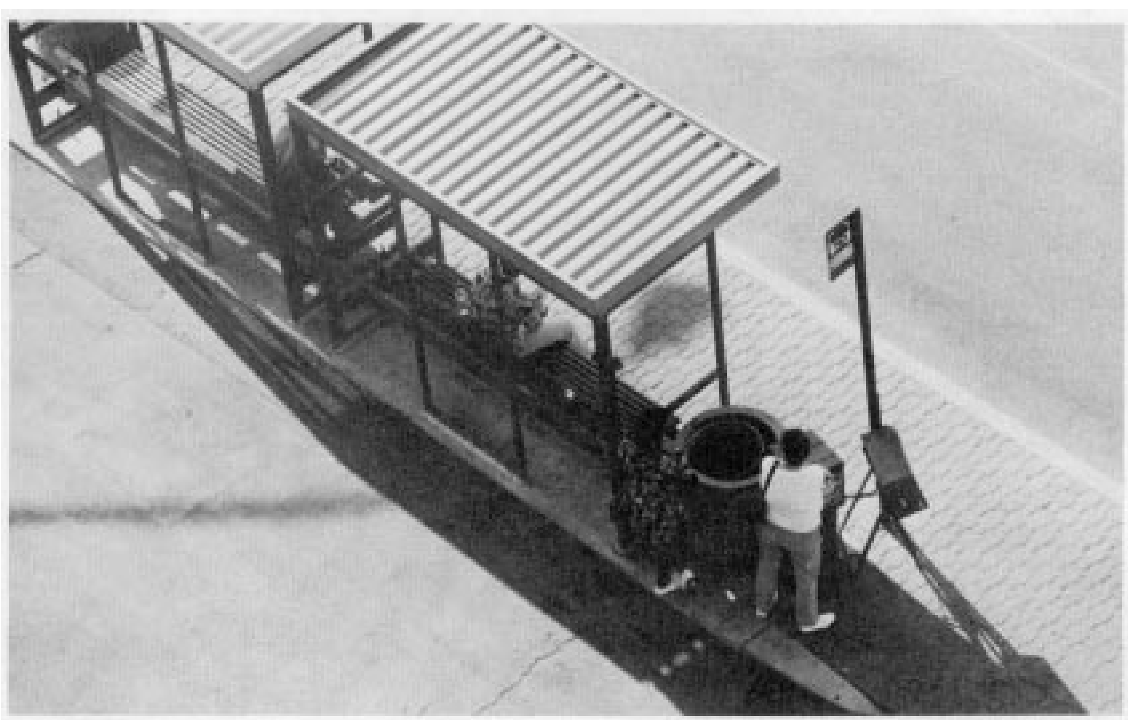


Figure E-24. Patrons Using Shadows Cast by Shelter as Shade.

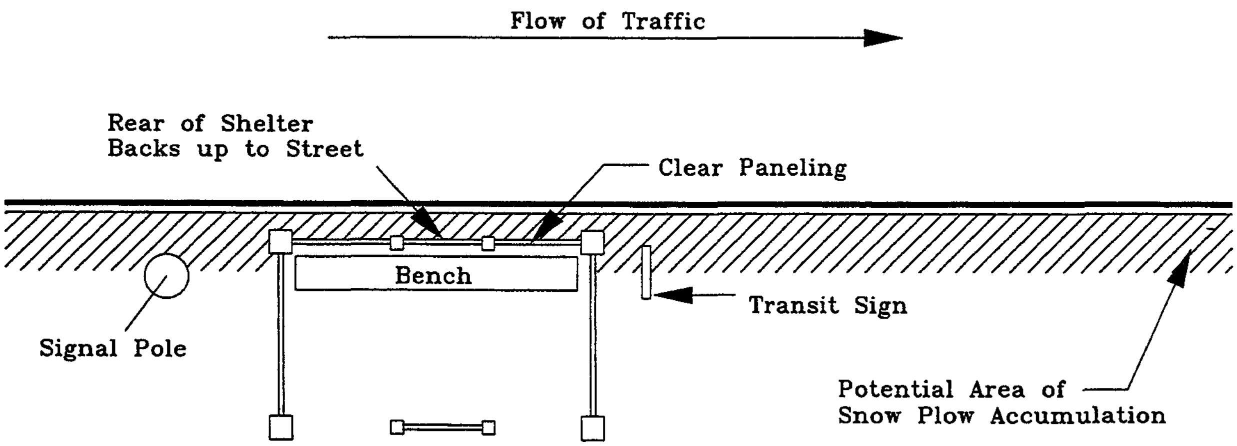


Figure E-25. Example of Rotated Shelter in Northern Climate.

The climatic conditions of a bus stop site can influence the utilization of the shelter. The shelter in Figure 26 is an example of a poorly oriented bus stop. During the morning hours, the site is in complete shade because of an adjacent building. In the afternoon hours, the site is in full sun. Patrons are generally comfortable in the morning hours because of the mild climate and shade. However, in the afternoon, the site would become quite warm and the shelter will be unused. Because the front of the shelter is completely exposed to the setting sun, patrons will stand behind the shelter for shade or linger in adjacent store fronts. Re-orienting the shelter with the back toward the street could overcome this situation. As the example currently exists, the waiting passengers standing behind the shelter would block the sidewalk during the afternoon hours.

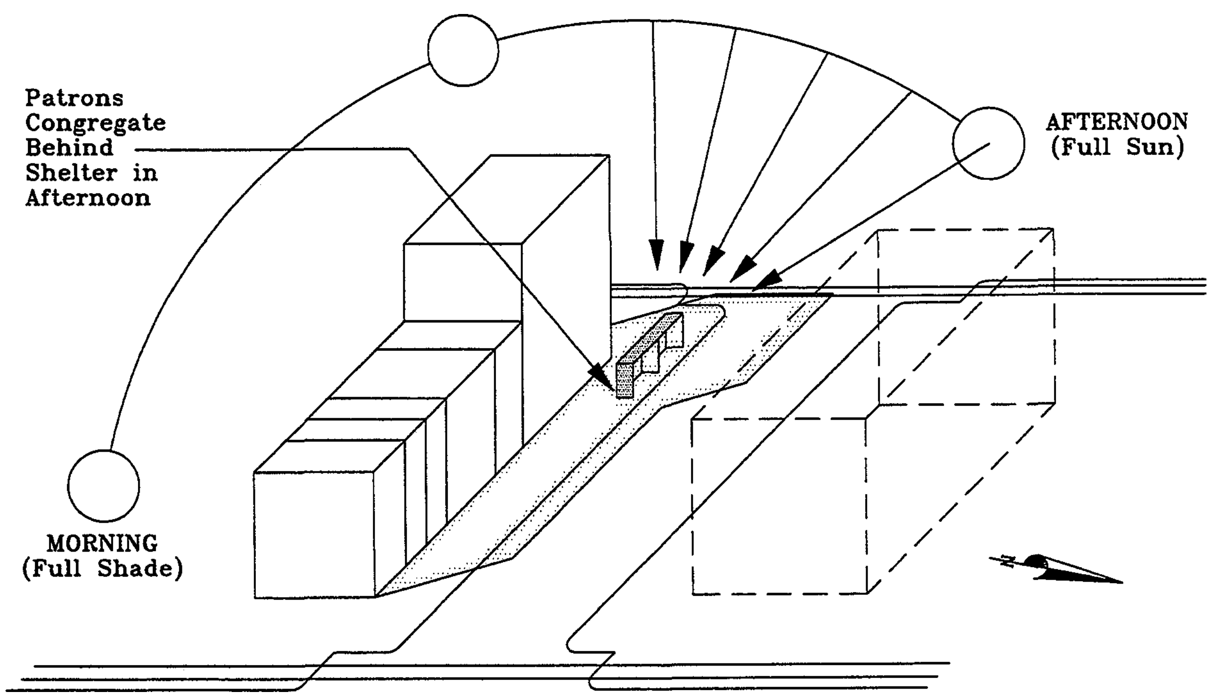


Figure E-26. Morning Shade Patterns and Afternoon Sun Angles.

Unique Shelter Designs to Compensate for Environmental Extremes

To overcome extremes in local weather conditions, a few select sites throughout the United States have been outfitted with features to give waiting patrons climatic comfort within the shelter. In the Southwestern region of the United States, air temperatures can reach above 110 degrees Fahrenheit on a regular basis during the summer. Asphalt and concrete increase the air temperature by several degrees because of the heat the materials retain and reflect. Because of the proximity of the shelter to roadways, temperatures at a bus stop can exceed the air temperature by several degrees. The areas where bus stops are typically located can be an extremely uncomfortable microclimate. Unique designs observed included a cool air mister and evaporation cooling towers.

In Tempe, Arizona, a misting system has been installed along the edges of the roof at one bus stop along a major arterial (see Figure E-27). Patrons activate the system by pushing a red button inside the shelter. Small particles of water are then sprayed around the edges of the roof of the shelter and the interior environment is cooled. While in Tempe, the mister worked as designed.

In Phoenix and Tucson, Arizona, cooling tower technology is being tested at a few designated transit malls (see Figure E-28). At the top of the tower, approximately 25 feet high, water is evaporated by wind. As the air cools, it sinks to the lower portions of the shelter and exits the shelter as a cool breeze.

No special cold weather treatment were observed during the regional visits. Any type of technological treatment applied to bus shelters to improve environmental comfort appears to be maintenance-intensive and costly.

Figure E-27. Bus Stop Misting System.

Figure E-28. Bus Stop with Cooling Tower.

Developer-Built Shelters

Developers will often differentiate their development from surrounding developments by using themes, color schemes, and repetition of forms and materials. By doing so, the developer can establish an identity that can be easily marketed. A number of outstanding examples of developer-designed shelters were observed during the regional visits. Three examples (an apartment complex in Concord, California; a residential community [Orindawoods] near Concord, California; and a commercial shopping center in Phoenix, Arizona) each coordinated the bus stop design with elements from the development.

In all three examples, the developer repeated common forms, colors, and materials from the development into the design of the shelter to create unity and similarity between the shelters and elements in the development. The shelter at the apartment complex in Concord, California, is the same form, shape, material, and color of the entry awning (see Figure E-29). In Orindawoods, the neighborhood association constructed shelters throughout the community that are similar to the design form of the entry sign (see Figure E-30). The landscaping in and around the shelters is also similar to the plant material used around the entry sign. At the commercial shopping site in Phoenix, Arizona, the developer-constructed shelter repeats the forms of the adjacent entry sign and buildings in the development (see Figures E-31 and E-32). The shelter is essentially a smaller scale representation of the buildings in the commercial center. Aesthetically, the shelters are significant changes from the standard prefabricated shelter.

Developer-designed shelters should be recognized for their merits in achieving aesthetic coordination with nearby land uses. This highlights the need and potential for coordinating transit with future development. Developer-designed and -constructed shelters can be a cost-effective way of providing an aesthetically unique shelter at a development.

Figure E-29. Shelter in Concord.

Figure E-30. Shelter in Orindawoods.

Figure E-31. Entry Sign at Commercial Center.

Figure E-32. Shelter at Commercial Center.

Artist-Designed Bus Stop Shelters

Under flexible funding provisions available from the Federal Transit Administration, funds can be allocated for designing and installing non-traditional shelters and related amenities. Artist-designed bus stops add festivity, color, and beauty. Four bus stops in Tempe, Arizona, have been designed by local artists (see Figure E-33). The sites are close to the Arizona State University campus and downtown Tempe. The sites experience high volumes of bus patrons and are located at highly visible intersections. Each design is uniquely identifiable. In addition to creating new shelters, the local artists have created new benches, trash receptacles, and bike racks at each site (see Figure E-34).

The functionality of the bus stop should not be sacrificed for aesthetics. An artist-designed bus stop should adequately provide protection from the elements. In one such case, it was obvious that the artist-designed bus shelter did not protect waiting patrons from the sun. Consequently, the patrons looked uncomfortable at this stop.

Figure E-33. Artistic Bus Stops in Tempe, Arizona.

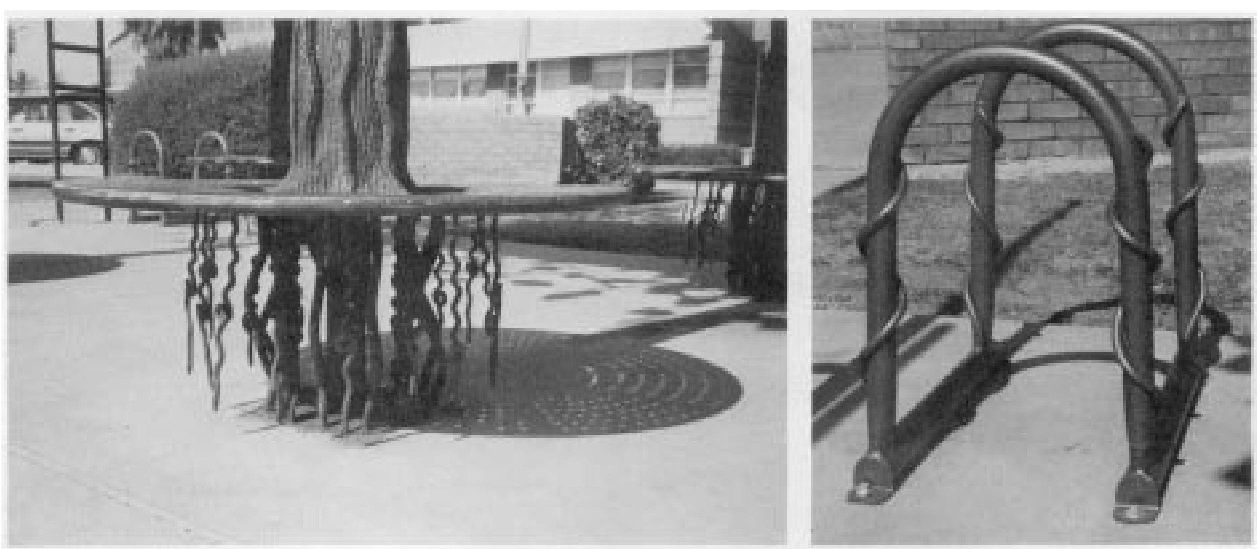


Figure E-34. Bench and Bike Rack Created by Local Artists in Tempe, Arizona.

Advertising Bus Shelters.

Advertising bus shelters are bus shelters installed by advertising companies in exchange for the right to place advertising panels on the bus shelter. For more information regarding advertising bus shelter design and placement, please refer to Chapter 4 of the *Guidelines.*

Advertising Kiosks. An alternative to advertising panels placed directly on bus shelters is advertising kiosks in close proximity to the shelter. Advertising kiosks were observed in Phoenix, Arizona, at some stops in downtown. The form, color, and material are similar to the adjacent shelter (see Figure E-35). An advantage of kiosks is that the advertising is located elsewhere, which permits greater surveillance of the shelter interior. The kiosks also create additional shade during the morning and evening hours (see Figure E-36). In Phoenix, the advertising kiosks are located downstream of the traffic flow to permit full view of the bus stop from passing traffic and bus drivers (see Figure E-37).

Figure 35. Advertising Kiosks.

Figure 36. Using Shade Created by Kiosks.

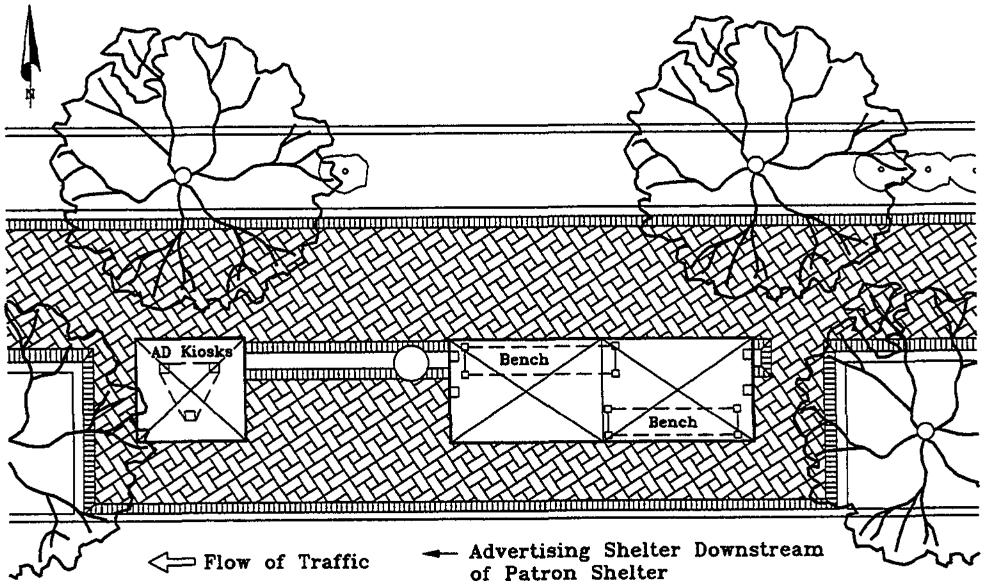


Figure E-37. Example of Locating Advertising Kiosk Downstream of Bus Stop.

Seating/Benches

As part of the field studies, benches were studied to determine what items (e.g. placement, crowding, and comfort) might impact their utilization. Benches at bus stops can be a stand-alone amenity inside a bus shelter or additional seating outside a bus shelter. The following paragraphs are a review of the observations and findings from the field studies of benches.

Interior Seating. Interior seating is standard among many manufactured shelter designs. The seats or benches are typically linear and are parallel and adjacent with the rear of the shelter. In some instances, the bench did not extend along the entire length of the shelter. The additional space may accommodate standing patrons inside the bus shelter or passengers in wheelchairs (see Figure E-38).

In some instances, multiple benches are used inside a bus shelter to accommodate large numbers of waiting bus patrons. Based on observations, when benches are staggered, patrons moved easily through the shelter (see Figure E-39). The bus stopped directly in front of the shelter and the "walk through" space helped relieve any potential congestion in front of the shelter. Other shelters have variations of the two-bench configuration. Depending on placement of the benches, movement through the shelter was either simple or challenging.

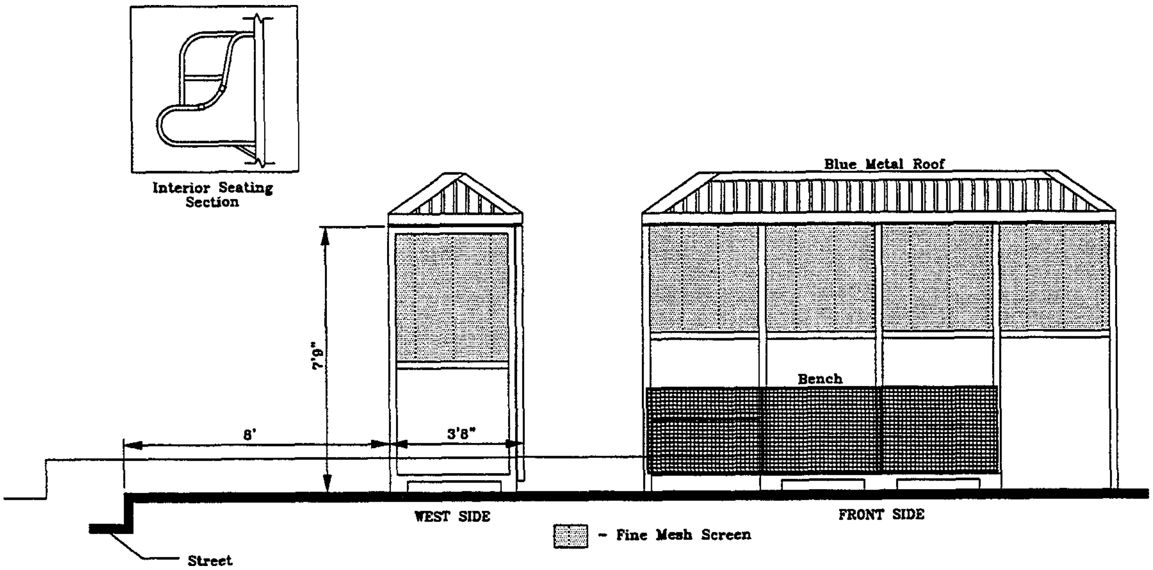


Figure E-38. Bus Shelter Section With Bench That Does Not Extend Along the Entire Length.

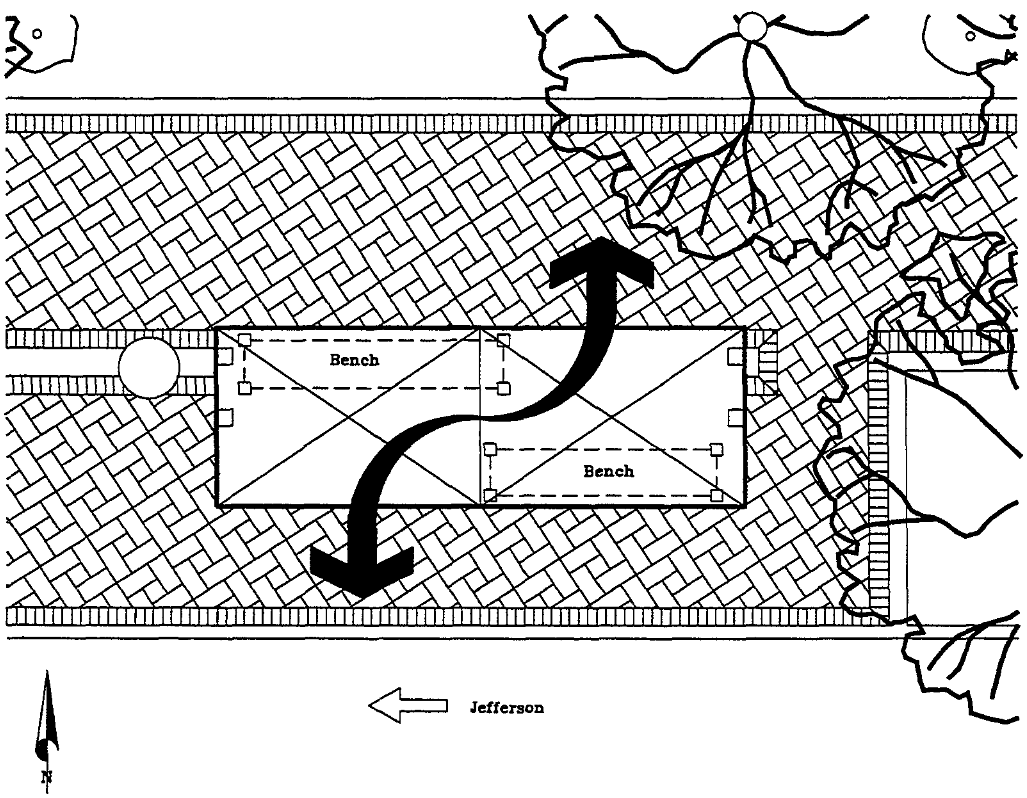


Figure E-39. Offset Linear Seating in Phoenix.

Other unique seating configurations exist in San Francisco where the bus shelters are equipped with three chairs that pivot on a common rod. The chairs are somewhat uncomfortable and awkward to use. According to local transit agencies, the chairs are designed to discourage unintended use of the bus shelters after operating hours. A benefit of the pivoting chairs is that additional standing space is created inside the bus shelter when the chairs are unused (see Figure E-40).

One factor that can greatly influence utilization of interior benches is crowding at the site. Crowding can limit the amount of available choices to sit or wait and creates situations where patrons must wait elsewhere than in intended areas in and around the shelter. Discouraging all amenities that may encourage non-bus riders to loiter in and around a bus stop can assist in preventing overcrowding at a bus stop.

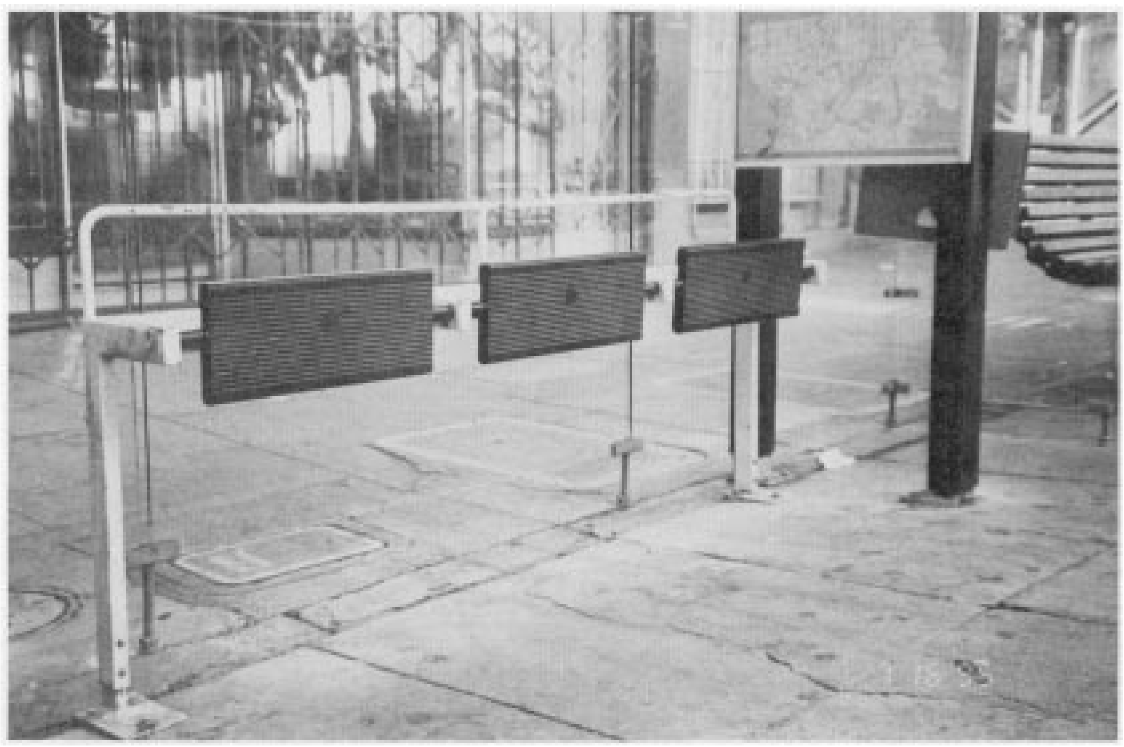


Figure E-40. Pivoting Chairs in San Francisco.

As noted in the sections on bus shelter configurations and orientation, interior bus shelter comfort can influence how the shelters are used by bus patrons. Despite the availability of seating within the shelter, patrons will seek relief elsewhere if the climate of the bus shelter is harsh (see Figure E-41). A detailed evaluation of seating patterns with respect to sun/shade patterns was conducted at the Speedway at Campbell site in Tucson, Arizona. Figure E-42 details theses findings. As previously believed, the preferred seats are those in the shade and those seats in the sun were left largely unused throughout the day.

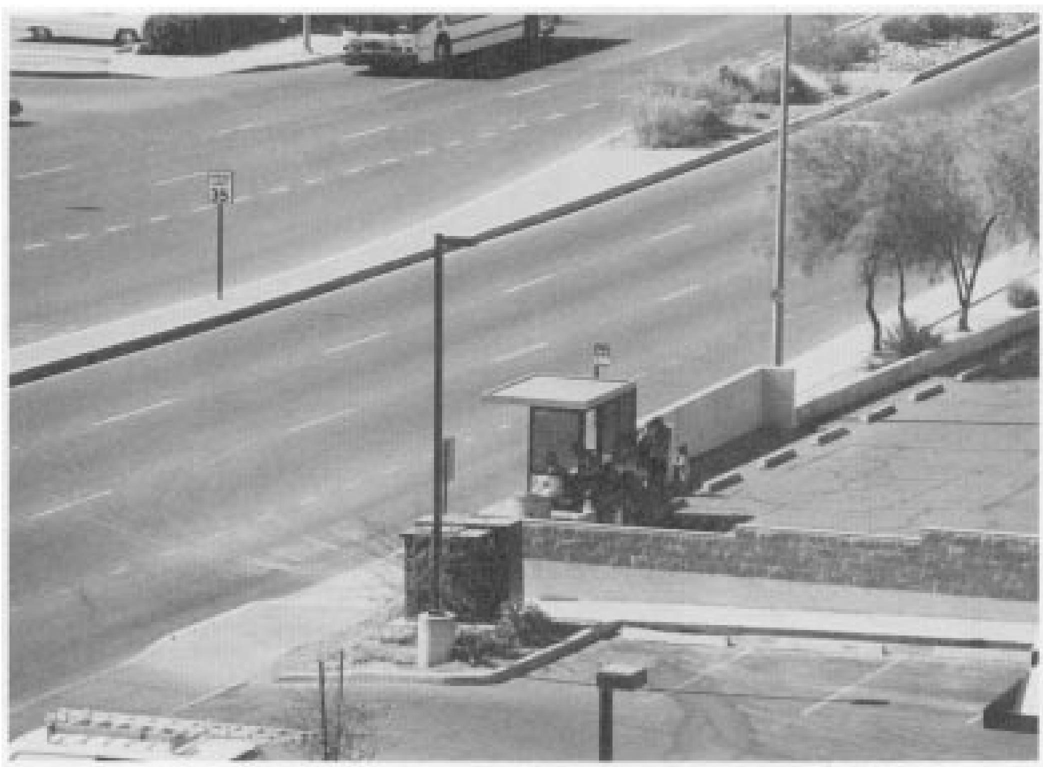


Figure E-41. Seating Patterns at Speedway at Campbell.

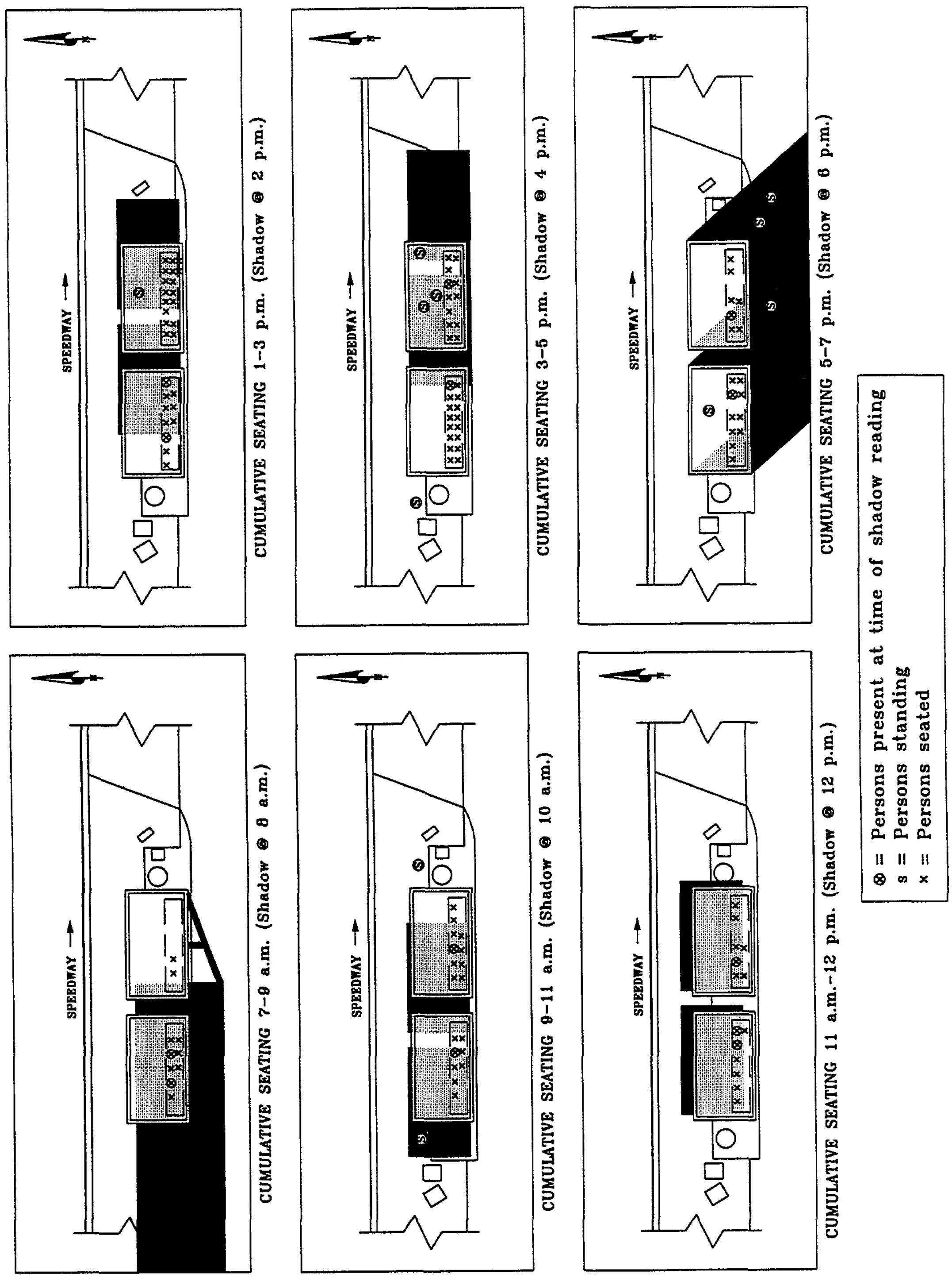


Figure E-42. Seating Pattern Study (Speedway at Campbell).

Exterior Seating with Shelter. Additional seating outside a shelter is necessary at sites with large passenger volumes or to accommodate increased demand during peak periods. Typically, the additional seating is placed to either side of the shelter and may vary in length, depending upon space availability, demand, or system policy. Crowding, environmental conditions, and claims to personal space affect utilization of benches and surrounding features.

Three study sites (San Francisco, San Jose, and Phoenix) yielded interesting information concerning exterior bench utilization. In San Francisco, the exterior bench is only 9 inches from the shelter, but is a comfortable 4.5 feet from the curb. The distance between the shelter and the bench is too small for most patrons to move through. However, the placement of the bench with respect to the curb allows for unobstructed movement between the bench and the curb (this is especially important when a bus is boarding and alighting) and the space provides patrons with an acceptable zone of comfort from the nearby traffic.

The bus stop in San Jose, California, has two shelters and four additional benches. The closest bench is only 4 feet away from a shelter. The other three benches are more than 30 feet away from the shelter (see Figure E-43). Each bench is 4 feet away from the curb and approximately 9.5 feet away from the edge of the building, providing a large area for general pedestrian traffic between the stop and the building. The additional sidewalk space is useful during peak periods of the day to limit pedestrian congestion in and around the bus stop. Similar to the San Francisco bus stop, the 4 feet of space between the benches and the curb provides a much-needed circulation space when the buses are boarding and alighting at this bus stop. Observations at this site are illustrated on Figure E-43.

The downtown Phoenix, Arizona, field study site reinforced previous observations about the influence of crowding and environment on bench utilization (see Figure E-44). The site has a large shelter with two interior benches. An advertising kiosk is downstream of the shelter and two exterior benches are upstream of the shelter. The sidewalk is landscaped with several shade trees. The landscaping is utilized well at this bus stop. The additional shade provided by the trees served as informal waiting areas for bus patrons when the shelter or exterior benches were exposed to the sun.

From the field study sites, observations include:

- The distance between the shelter and the exterior bench needs to be large enough to permit unobstructed movement.
- Minimal conflict between general pedestrian traffic and bus patrons waiting on the bench occurs at nub sites because the bench and the bus shelter are separated from the sidewalk.
- Crowding and environmental extremes encourage patrons to seek cover other than the bus stop.
- Rarely will people sit next to each other during non-congested periods. People would rather lean against the wall of a nearby building or sit on a ledge.
- The exterior benches are more popular than the seating inside a shelter (see Figure E-45). People may feel safer waiting on an exterior bench than on benches in a semienclosed space (bus shelter), when weather permits.

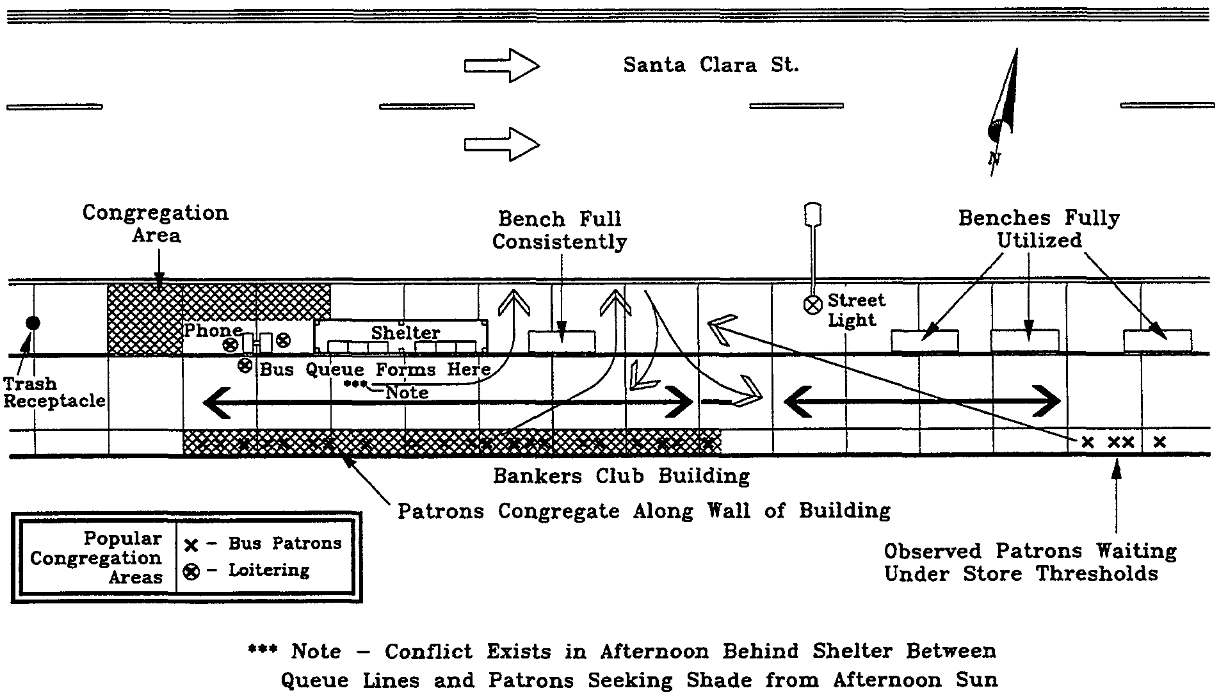


Figure E-43. Pedestrian Observations (San Jose).

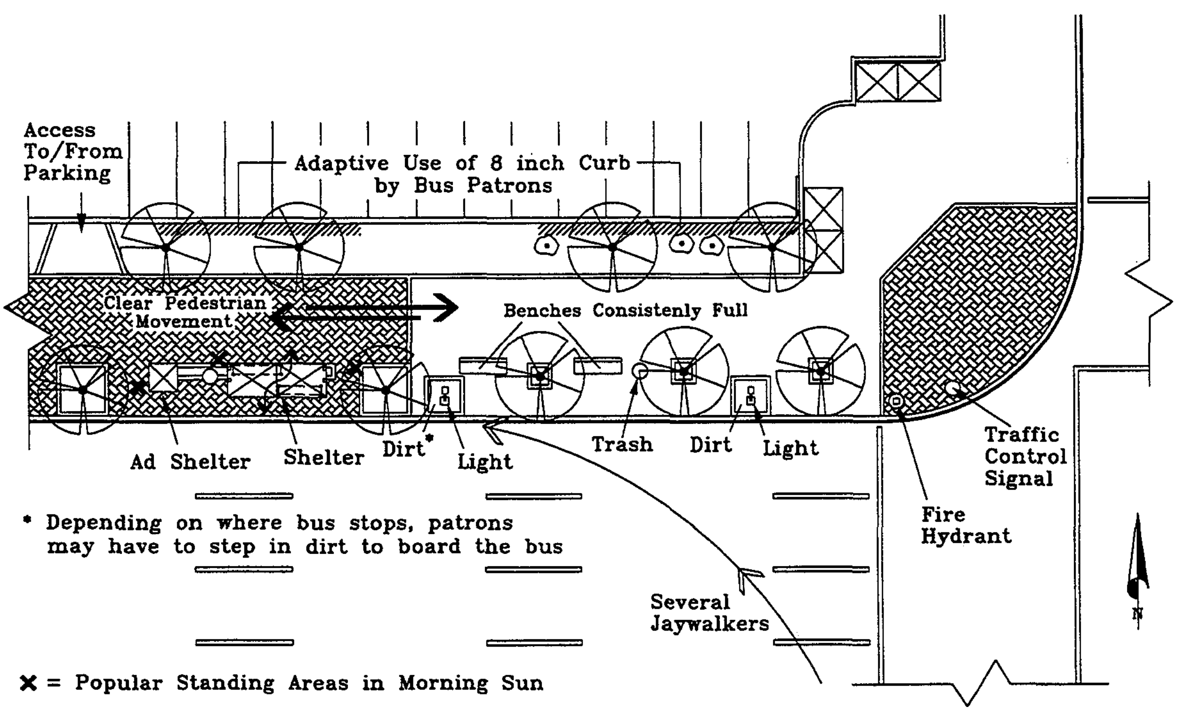


Figure E-44. Pedestrian Observations (Phoenix).

Figure E-45. Exterior Bench Close to Shelter.

Each of these factors can be addressed with proper site evaluation by the transit agency. One factor that the transit agency has little control over, though, is the patron's zone of public domain or personal space. When patrons place objects to separate or claim space on the bench, other patrons may be forced to stand or look elsewhere for seating. The need to produce or protect individual space may be a result of perceptions of security.

Bench-Only Sites. Benches are a means of providing a convenient and comfortable amenity at bus stops that do not warrant a bus shelter. A bench and a sign post can be the sole amenities provided at a stop that has few riders or infrequent service. During the regional visits, a number of benches were observed in various conditions and locations.

The location of a bus stop bench can influence a bus patron's comfort and convenience. Figures E-46 and E-47 show two different examples of bench placement. In northern climates, snow can create significant access problems for bus stops with benches. Snow plowed from the adjacent street can be pushed onto the bench or onto the space between the sidewalk and the bench, creating hazardous conditions for patrons. Because of liability problems, transit agencies sometimes do not clear foot paths for patrons at bench-only sites. Bus drivers, out of courtesy, will typically board and alight the vehicle at cleared driveways to avoid having patrons walk through slush or snow.

Figure E-46. Benches Close to Sidewalk.

Figure E-47. Bench Near Street.

In Phoenix, Arizona, benches for bus patrons are coordinated with streetscaping projects that are currently taking place on many arterial streets. Benches are automatically installed at sites that have less than 10 feet of right-of-way on a 40-foot-by-10-foot brick-paver waiting pad. At a minimum, a 4-foot-wide sidewalk is installed to either side of the waiting pad, which is contiguous with the street. Furthermore, the benches are placed on the backside of the waiting pad and are coordinated with landscaping to provide shade for waiting passengers (see Figures E-48 and E-49).

Figure E-48. Bus Stop Coordinated with Streetscaping Project.

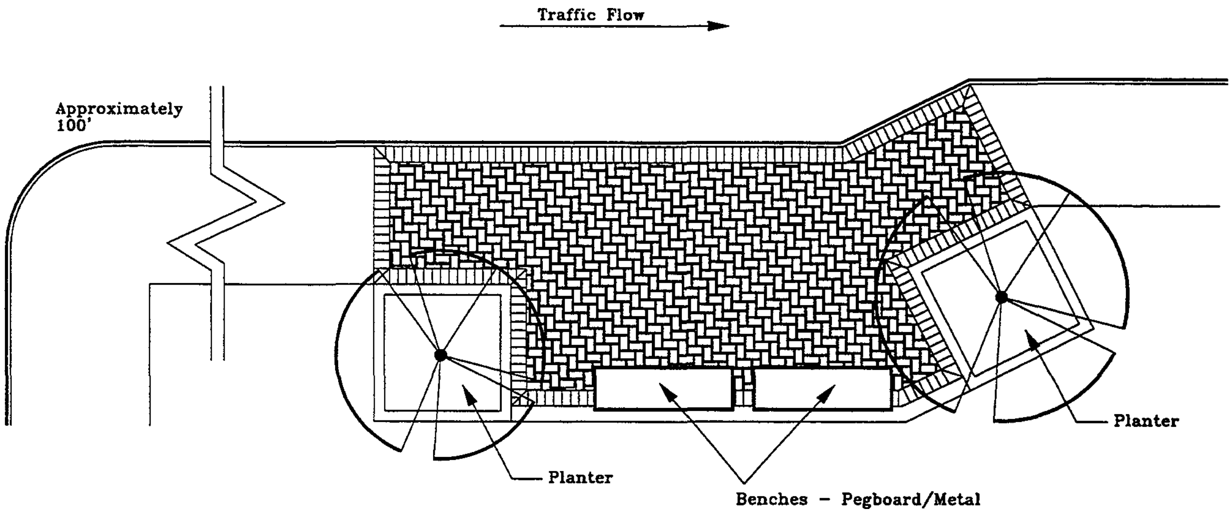


Figure E-49. Example of Integrating Bus Stop with Sidewalk and Landscaping.

Advertising Benches. Another element of benches is the prevalence of privately provided benches with advertising (see Figure E-50). This has allowed more benches to be provided than might otherwise be the case. Advertisers are primarily concerned with drive-by visibility, rather than transit ridership. In situations where good coordination exists between the private bench providers and the transit agency, this does not appear to be a problem. While in other situations, transit agencies noted a loss of control and influence. Finally, some agencies have decided not to allow advertising benches at all.

Figure E-50. Example of Advertising.

Lighting

Lighting is an important amenity at bus stops, in particular during the winter when daylight is limited. Lighting significantly influences the passenger's perception of safety and security at a bus stop. Lighting at a bus stop can provide a waiting passenger comfort because of the increased surveillance afforded by the light. It can also discourage loitering or unintended uses of transit facilities by non-bus riders.

Only a few of the transit agencies visited maintained lighting within a shelter or at a bus stop. For some transit agencies, service ceases at dusk or shortly afterwards. Therefore, interior lighting is considered an unnecessary expenditure. The transit agencies, though, did acknowledge the need for interior lighting when daylight-savings time is in effect since passengers may arrive and return in the dark. Cost, availability of power, and vandalism usually influence the decision to install lighting at a site.

Direct lighting is expensive and can be difficult to achieve with limited access to a power source. In San Francisco, interior bus shelter lighting is provided at most urban stops. Figure E-51 details the design and location of the lighting elements in the San Francisco bus shelters. In Tucson, Arizona, SunTran has installed lighting at some sheltered stops using solar power (see Figure E-52). The energy collected from the sun during the day is stored in power cells and is used after sunset. All new shelters in Phoenix, Arizona, will be equipped with lighting powered by solar panel electricity.

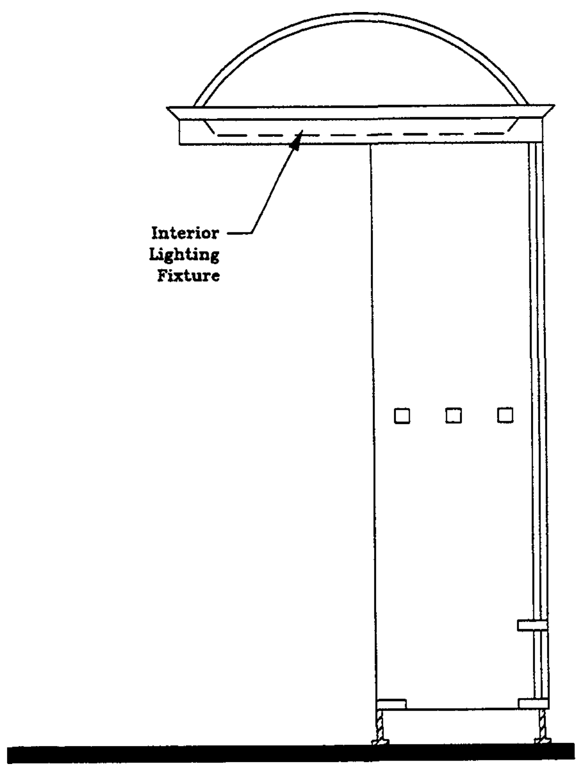


Figure E-51. Location of Interior Lighting.

Figure E-52. Lighted Shelter Using Solar Power.

An option that is being implemented by some transit agencies is to include installation of lighting as a part of the agreement with advertising shelter companies. This is viewed as a costeffective approach to providing lighting at sites that would otherwise be uneconomical for the transit agency to install. The advertising company maintains the lighting as well.

A cost-effective approach to providing indirect lighting is coordinating stops with existing street lights. Among the transit agencies visited, coordinating the bus stop locations with a street light is a system policy when interior lighting cannot be provided. It is an inexpensive method of achieving lighting at a bus stop. A majority of shelters and stops observed during the regional visits were located within 30 feet of an existing street light.

Vending Machines

Some transit agencies encourage the installation of vending machines (primarily newspaper) at or near their stops, typically on the grounds that they are convenient for the passengers. Others actively discourage such installations on the grounds that they clutter the area and contribute to the trash problem (see Figure E-53).

Figure E-53. Vending Machines at Stop.

Trash Receptacles

Trash receptacles are common at bus stops, especially at stops with benches or shelters. The decision whether to install trash receptacles or not seems to be a general policy matter, though not a very high-profile one. Experience with trash receptacles is varied. Some find wide public acceptance and appreciation with limited vandalism or abuse. Others find maintenance difficult and expensive, abuse and clutter high, and public acceptance correspondingly poor. This is especially evident at sites near convenience stores, fast food restaurants, or gas stations. General pedestrian traffic generated by the convenience stores also uses receptacles that are conveniently located along sidewalks near bus stops. Companies installing advertising shelters or benches, though, offer a solution to this problem. As part of the agreement to install shelters or benches at a site, the company must maintain and clean the sites regularly, thereby relieving the transit agency of this duty.

Trash receptacle designs may be artistic (see Figure E-54) but should be functional. Bus patrons are concerned with the appearance, placement, and smell of the receptacle. Trash receptacles that are overflowing and in full sun are unpleasant in a number of ways. The negative impacts of uncontained trash can be unintentionally enhanced with some receptacle designs. For example, trash receptacles with ledges create spaces for liquids to remain, rather than be contained inside the trash receptacle or drain away. Designs that allow the contents of the container to be exposed also attract insects, which can be hazardous to some bus patrons. In Arizona, some of the trash receptacles are partially installed below grade; whether it is to reduce exposure to sun or permanently affix the receptacle to the site is unclear.

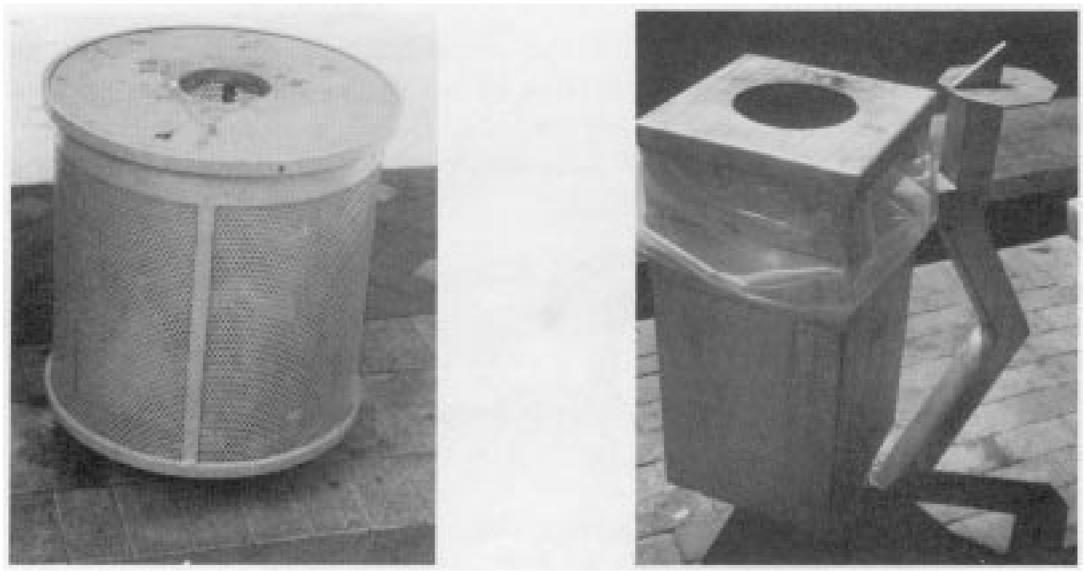


Figure E-54. Trash Receptacle Designs.

Phones

Phones at bus stops, like trash receptacles, are a result of a systemwide policy, rather than random placement. Some transit agencies have explicit policies regarding the installation of phones—such as that phones offer patrons the potential convenience of receiving real-time bus arrival information (if available) and quick access to emergency services and allow patrons to make personal calls (see Figure E-55). Conversely, some agencies strongly feel phones at bus stops create opportunities for illegal or unintended activities.

Figure E-55. Exterior Phone at Bus Stop.

In San Francisco, phones are included at several bus stops because of a city ordinance restricting the amount of phones on a per block basis. At the Polk Street study sites in San Francisco, phones are installed in each shelter (see Figure E-56). The phones added to the number of people at the bus stops, which increased congestion levels during boardings and alightings.

Figure E-56. Interior Phone at Bus Stop.

Route Information

Route information, such as system maps and schedules, is an amenity that is quite valuable to transit customers. Including route or schedule information at a bus stop is a system policy at many transit agencies. Most shelters and stops visited have the mechanism for including route schedules and maps. Mechanisms include panels specifically designed to hold this type of information, frames inside the shelter, and panels on signposts (see Figure E-57).

Several transit agencies, though, ceased updating the route and schedule information at the stop because of the number of changes that occur during the year. Instead of replacing old schedules with updated schedules, the information is removed from the shelter completely or is quickly taped to the side of the shelter (see Figure E-58).

Figure E-57. Panel on Post.

Figure E-58. Schedules Taped to Shelter.

Bicycle Storage Facilities

Bicycle storage facilities, such as bike racks, are provided at bus stops as a matter of convenience for bike riders using transit. The storage facilities also discourage bicycle riders from locking their bikes on the shelter or bench or on an adjacent piece of property. Proper storage of bicycles can reduce the amount of visual clutter at a stop by confining the bikes to one area. Several designs were observed on the regional visits (see Figure E-59).

To encourage greater multimodalism, transit agencies are pursuing greater numbers of bicycle riders on buses. Bicycle riders can, in some cities, either take the bike on the bus or store the bike on a bike rack installed on the front of the bus. From conversations with transit agencies, it is believed that bicycle riders would rather take the bike with them on the bus rather then store the bike at a bus stop for extended periods. The increased purchasing costs and popularity of bicycles probably play a significant role in the preference of bicycle riders to take the bikes with them on the bus. On-vehicle bicycle programs are extremely successful in university towns, such as Tempe, Arizona.

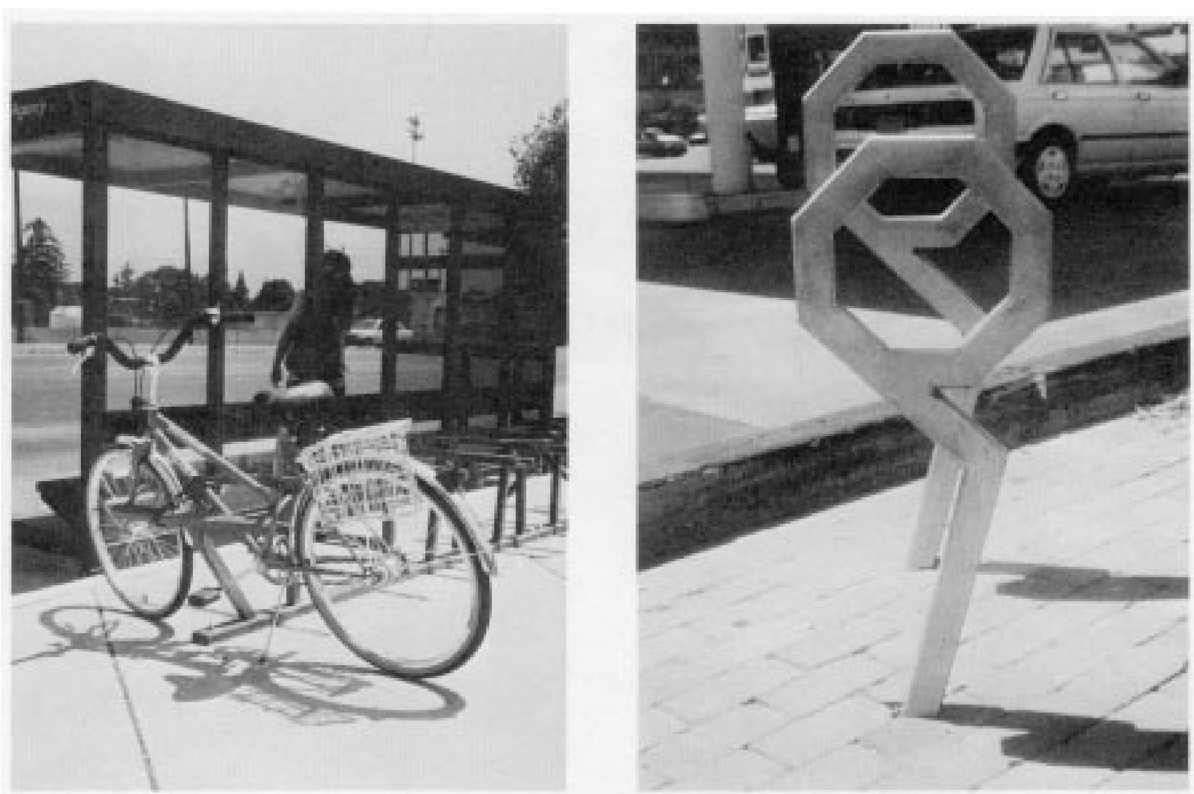


Figure E-59. Bicycle Rack Designs.

Shopping Cart Storage Areas

A phenomenon observed on a frequent basis that does not receive attention in the literature is the presence of shopping carts at bus stops. Shopping carts were observed at multiple bus stops. The carts are haphazardly stored in and around the bus stop, creating an eyesore and blocking the sidewalk (see Figure E-60). Typically, sites with shopping carts are suburban strip commercial centers where patrons have long distances to walk between the store entrance and the bus stop. The bus stop is too far from the store to return the carts and the bus stop lacks a place to store the carts. A need exists to install a storage facility near the stop to accommodate shopping carts and to prevent random storage in and around the stop.

Figure E-60. Shopping Cart Left at Bus Stop.

Landscaping

Installation of trees at a bus stop can enhance environmental comfort regardless of region. The shade is welcome in southern climates and trees provide wind protection in northern climates. In Phoenix, Arizona, a number of bench-only and bus shelter sites are coordinated with "streetscaping" projects. The landscaping provides additional aesthetic value and the shade provided by the trees serves a necessary function in a warm climate (see Figure E-61). Sites with limited natural protection from the elements, as evident in Figure E-62, should be avoided or improved to enhance patron comfort. Landscaping (trees and shrubs) that block visual access to/from a bus stop should also be avoided. The location of trees and the height of shrubs are important to preserving visual access.

Figure E-61. Bus Stop Shaded by Trees.

Figure E-62. Bus Stop with Little Vegetation.

MATERIALS

Several materials are used at bus stops. The primary determinants for selecting materials are resistance to weather, continual use, vandalism, and how easily the materials are maintained. A balance must be made between aesthetics and functionality when selecting materials.

Resistance to weather is highly variable among the regions visited. In Arizona, the materials are subjected to extreme heat and sun, while in Michigan, materials must withstand rain and snow. The San Francisco Bay area remains mild throughout the year except in San Jose where summer temperatures can be very warm.

Vandalism is increasingly becoming a major problem at bus stops and greatly influences materials chosen. Graffiti "artists" select bus stops because of the visibility the stop receives from drive-by traffic. Depending on the material selected, evidence of vandalism or graffiti may or may not remain after removal. Graffiti removal is costly and time-consuming.

A review of materials used at bus stops, including advantages and disadvantages, is provided in Chapter 4 of the *Guidelines.*

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Abbreviations used without definitions in TRB publications:

AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
APTA	American Public Transit Association
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
IEEE	Institute of Electrical and Electronics Engineers
ITE	Institute of Transportation Engineers
NCHRP	National Cooperative Highway Research Program
NCTRP	National Cooperative Transit Research and Development Program
NHTSA	National Highway Traffic Safety Administration
SAE	Society of Automotive Engineers
TCRP	Transit Cooperative Research Program
TRB	Transportation Research Board
U.S.DOT	United States Department of Transportation