TCRP
REPORT 65

TRANSIT
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RESEARCH
PROGRAM

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Evaluation of Bus Bulbs

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TRANSIT COOPERATIVE RESEARCH PROGRAM

TCRP REPORT 65

Evaluation of Bus Bulbs

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SUBJECT AREAS
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 Transportation Association (APTA), *Transportation 2000*, also recognized the need for local, problem-solving research. TCRP, modeled after the longstanding and successful National Cooperative Highway Research Program, undertakes research and other technical activities in response to the needs of transit service providers. The scope of TCRP includes a variety of transit research fields including planning, service configuration, equipment, facilities, operations, human resources, maintenance, policy, and administrative practices.

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

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.

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NOTICE

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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 65, "Evaluation of Bus Bulbs," will be of interest to individuals and groups with a stake in the location and design of bus stops. These groups include public transportation organizations, public works departments, local departments of transportation, developers, and public and private organizations along or near bus routes.

This research project was a continuation of TCRP Project A-10, "Location and Design of Bus Stops on Major Streets and Highways," which culminated with *TCRP Report 19*, "Guidelines for the Location and Design of Bus Stops." The project produced guidelines to 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 second phase of this project evaluated bus bulbs, an innovation in the design of bus stops found in several major North American cities.

As part of TCRP Project A-10, data were collected on the use of bus bulbs in North America. Near the conclusion of the project, the researchers informed the panel that the city of San Francisco would be converting several bus bays into bus bulbs. These conversions afforded an important opportunity to examine the changes in bus, automobile, and pedestrian traffic with the implementation of bus bulbs. The objectives of the second phase of Project A-10 were to

- Determine the effect of bus bulbs on transit operations, vehicular traffic, and nearby pedestrian movements at selected sites in San Francisco;
- Collect information on when bus bulbs should be considered and lessons learned from those cities that use the bus bulb configuration;
- Identify vehicular and bus operations for bus bulbs located nearside and farside and along a corridor, using a traffic simulation program; and
- Evaluate the conditions in which the installation and use of bus bulbs is advisable, on the basis of the findings from the above efforts.

Chapter 1 introduces the research objectives, scope, and approach. To observe and report on existing and planned bus bulbs, the research included site visits to San Francisco, California; Portland, Oregon; Seattle, Washington; and Vancouver, British Columbia. These four North American cities each have characteristics considered important to the successful performance of bus bulbs: high development densities, well-developed transit corridors, and a high level of transit patronage. Chapter 2 presents the findings from the site visits, the curbside and roadway before-and-after studies, and the traffic simulation program.

Chapter 3 presents the conditions that support the construction of bus bulbs and the conditions that would not support the use of bus bulbs. Chapter 4 summarizes the

findings from the research and suggests further research. Included are the common reasons for installing bus bulbs, common site design issues, and the effects bus bulbs have on pedestrian movements, traffic, and transit operations. The report has four appendices, which include numerous photographs and schematics relevant to the design and implementation of bus bulbs. Appendix A, which is published with the report, is a review of selected cities' practices. Appendices B through D will be available on CRP's website (www4.nationalacademies.org/trb/crp.nsf) in portable document format (pdf). Appendices B, C, and D elaborate on the curbside before-and-after study, the roadway before-and-after study, and the traffic simulation, respectively.

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The authors gratefully recognize the assistance of individuals who work for the San Francisco Municipal Railway (Muni) and with the City of San Francisco. Duncan J. Watry (Muni) provided initial information on planned bus bulb projects in San Francisco. He also provided extensive assistance with TCRP Project A-10. More importantly, Mr. Watry was the key contact within the transit agency regarding construction schedules and general information regarding bus bulb projects, transit preferential treatments, and general history. John Katz, who is the Capital Projects Planner with Muni, also provided additional assistance and updates regarding the construction schedule and progress update for the south Mission Street renovation project. Other individuals who provided assistance to the research team in San Francisco include the following:

- Bond M. Yee, City Traffic Engineer, Department of Parking and Traffic, City and County of San Francisco;
- Javad Mirabdal, Transportation Planner, Department of Parking and Traffic, City and County of San Francisco; and
- Steve J. Patrinick, Transit Planner, Service Planning, Muni.

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- Young Park, Manager of Capital Projects, Portland Tri-County Metropolitan Transportation District of Oregon (Tri-Met);
- Douglas B. McCollum, Traffic Engineer, City of Portland, Oregon;
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- Lon LaClaire, Neighbourhood Transportation Branch, City of Vancouver, British Columbia; and
- Robert M. Hodgins, Strategic, Transportation Planning Branch, City of Vancouver, British Columbia.

For this research project, unique software programs were developed for use in data collection. Leonard Ruback of the Texas Transportation Institute TransLink was the key individual in developing the software.

EVALUATION OF BUS BULBS

EXECUTIVE SUMMARY

A bus bulb is a section of sidewalk that extends from the curb of a parking lane to the edge of a through lane. Bus bulbs are also known as curb extensions, nubs, and bus bulges. In regard to traffic operations, bus bulbs operate similarly to curbside bus stops. Buses stop in the traffic lane instead of weaving into a parking-lane curbside stop. A major advantage of using bus bulbs is the creation of additional space at bus stops; this space allows for bus patron amenities such as shelters and benches where the inclusion of such amenities would otherwise be limited by lack of space. Other advantages of bulbs are reduced crossing distance for pedestrians (which improves safety, especially for pedestrians who are older or have physical disabilities) and reduced bus stop space requirements because no additional room is necessary to maneuver into or out of the bus stop. The primary motivators for installing bus bulbs are to reduce congestion on sidewalks and to eliminate the bus-weaving maneuver into a parking-lane curbside stop (also called a bus bay stop). Bus bulbs are appropriate at sites that have high patron volumes, are crowded city sidewalks, and permit curbside parking.

Bus bulbs are used in a limited number of cities. Bus bulbs in San Francisco, Portland (Oregon), Seattle, and Vancouver were visited as part of this research project. Characteristics of these cities as compared with other cities in North America are the high development density of the region, well-developed transit corridors, and the high level of transit patronage. Representatives of these cities were interviewed to identify experiences with bus bulbs. Common reasons for installing bus bulbs in these cities included the following:

- High transit ridership in a corridor,
- Re-entry problems for buses during peak vehicular times,
- The need for segregating transit and pedestrian activities on crowded sidewalks, and
- The need for transit amenities at bus stop sites that may be too small to accommodate additional street furniture.

Costs for constructing bus bulbs varied between $15,000 and $55,000 per bulb and were dependent upon drainage needs, utility relocation, construction materials, and patron amenities.

The timing of San Francisco's conversion of several bus bays into bus bulbs provided the opportunity to conduct a direct comparison of the changes in bus, traffic, and pedestrian operations. The evaluation of pedestrian operations used the bus stop at Mission and 30th Streets. The greatest difference between the two designs—bus bays and bus bulbs—is evident during the boarding-and-alighting phase of the bus arrival–departure sequence. The average amount of available space for pedestrians and transit patrons improved from 19 to 44 sq ft/ped (1.8 to 4.1 sq m/ped) after the bulb had been constructed. At 44 sq ft (4.1 sq m), it is far less likely that pedestrians or boarding and alighting transit patrons will need to adjust their walking speeds or path of travel when encountering another person. The greater amount of pavement also eases the difficulties experienced by bus patrons as they cross paths while boarding or alighting from the bus or buses stopped at the bus stop.

The average flow rate of pedestrians traveling along the sidewalk adjacent to the bus stop improved by approximately 11 percent from 4.0 ped/min/ft (13.1 ped/min/m) at the bay configuration to 3.6 ped/min/ft (13.4 ped/min/m) in the bulb configuration during the four highest 15-min increments studied. The data would have shown a greater improvement, but the location of certain street furniture did not change between the two designs. Consequently, the bottlenecks for pedestrians on the sidewalk and boarding and alighting bus patrons still existed. The bulb, however, provided ample space for pedestrians to choose alternative paths around the bottlenecks.

The roadway before-and-after study determined the advantages and disadvantages to traffic and bus operations. Both farside and nearside bus stops were included in the study, with data collected before and after the implementation of the bus bulbs. The replacement of a bus bay with a bus bulb *increased* vehicle and bus speeds on the block and in the corridor (between a 7- and 46-percent increase in speeds for buses and vehicles in the corridor). Reduction in travel speeds are assumed to be the consequence of installing bus bulbs because buses are stopping in the travel lane rather than moving into a bus bay. However, in the before period when the bus bay configuration was present, buses would stop partially or fully in the travel lane. In addition, buses pulling away from the bay would sometimes use both travel lanes to complete the maneuver. After the bulb's installation, the number of buses affecting vehicles in both travel lanes decreased because drivers did not use both travel lanes to leave the bus bulb stop.

The average delay to buses attempting to re-enter the travel stream was similar to the before-to-after period at the farside stop. The nearside stop, which experienced higher delays to buses, saw a reduction in the average delay with the installation of bus bulbs. With a bus bay design, the queues at the signal limited the opportunity for a bus driver to enter the traffic. Queues did occur more frequently with the bus bulb design; however, the queues were generally short—on average, only one- to two-vehicles long.

CHAPTER 1

INTRODUCTION

BUS BULBS

A bus bulb, also known as a nub, curb extension, or bus bulge, is a section of sidewalk that extends from the curb of a parking lane to the edge of a through lane. In regard to traffic operations, bus bulbs operate similarly to curbside bus stops. Buses stop in the traffic lane instead of weaving into a parking-lane curbside stop. A major advantage of using bus bulbs is the creation of additional space at bus stops; this space allows for the inclusion of bus patron amenities such as shelters and benches where the inclusion of such amenities would otherwise be limited by lack of space. The primary motivators for installing bus bulbs are to reduce congestion on sidewalks and to eliminate the bus-weaving maneuver into a parking-lane curbside stop (also called a bus bay stop). Bus bulbs are appropriate at sites that have high patron volumes, are crowded city sidewalks, and permit curbside parking.

Bus bulb configurations were studied as part of a more comprehensive research study of bus stop design and location sponsored by TCRP. The primary objective of the TCRP project was the development of guidelines on locating and designing bus stops (*1*). During the course of the study, U.S. transit agencies were surveyed to determine best practices being applied during bus stop design and location decisions. Only a few transit agencies were identified as having bus bulb configurations: Charlotte, North Carolina; Grand Rapids and Lansing, Michigan; Orlando and West Palm Beach, Florida; Portland, Oregon; San Francisco, California; and Seattle, Washington. The survey and follow-up phone calls demonstrated that little documentation exists on the operation and design of bus bulbs, either in the general literature or within transit agency design manuals.

RESEARCH OBJECTIVES AND SCOPE

The data collected during the previous TCRP project represented current utilization of the bus bulb sites. Needed was information on how bus bulb configurations may change traffic and pedestrian movements, as well as bus operations, at a particular location. The timing of San Francisco's conversion of several bus bays into bus bulbs provided the opportunity to conduct a direct comparison of the changes in bus, traffic, and pedestrian operations. Therefore, the objectives of this research project were to

1. Determine the effect of the installation of bus bulbs on transit operations, vehicular traffic, and nearby pedestrian movements at selected sites in San Francisco;
2. Collect information on when bus bulbs should be considered and lessons learned from those cities that use the bus bulb configuration;
3. Identify vehicle and bus operations for bus bulbs located nearside and farside and along a corridor, using computer simulation; and
4. Evaluate conditions in which the installation and use of bus bulbs is advisable, based on the findings from the above efforts.

RESEARCH APPROACH

The research approach included eight tasks that were split among the four objectives:

- Task A—Site Selection/Refine Data Collection Techniques,
- Task B—Before Data Collection,
- Task C—Survey of Other Transit Agencies Using Bulbs,
- Task D—After Data Collection,
- Task E—Computer Simulation,
- Task F—Draft Final Report,
- Task G—Moving Research Results into Practice, and
- Task H—Final Report.

Task A (Site Selection/Refine Data Collection Techniques) was to select the study sites and determine the data collection techniques to be used at each site (e.g., video or manual, or both). In Task B (Before Data Collection), the before data were collected and reduced; in Task D (After Data Collection), the after data were collected and reduced using similar techniques. The field studies occurred in three general areas: bus, traffic, and pedestrian operations. The primary question of interest was how the installation of the bus bulb affects bus, traffic, and pedestrian operations.

In Task C (Survey of Other Transit Agencies Using Bulbs), the research team conducted a survey of other transit agencies

that use bulbs. To enhance the knowledge base of different bus bulb configurations and designs, select transit agencies were interviewed in greater detail about their policies and designs regarding bus bulbs. On-site visits were made to four cities using bus bulbs (San Francisco; Portland; Seattle; and Vancouver, British Columbia).

In Task E (Computer Simulation), the traffic operation was evaluated for both the bus bay and the bus bulb designs. Traffic simulation models have been used effectively for many operations-related traffic studies and research projects.

Task F (Draft Final Report) involved drafting the final report, which included the conditions for which bus bulbs are appropriate. Revisions to the final report occurred during the final month of the project in Task H (Final Report). In Task G (Moving Research Results into Practice), the research team disseminated the results of the research through written papers and oral presentations.

REPORT ORGANIZATION

This report includes the following chapters and appendix:

- ***Chapter 1: Introduction.*** Chapter 1 presents an introduction to the report and summarizes the research objectives and approach.
- ***Chapter 2: Findings.*** Chapter 2 summarizes the findings from the four major research areas within this study: the review of selected cities' practices, the curbside before-and-after study, the roadway before-and-after study, and the computer simulation.
- ***Chapter 3: Interpretation, Appraisal, and Application.*** Chapter 3 presents the conditions for which bus bulbs are or are not appropriate. The chapter also presents issues to consider regarding the inclusion or construction of a bus bulb at a candidate site.
- ***Chapter 4: Conclusions and Suggested Research.*** Chapter 4 includes the findings from the study and suggests further research.
- ***Appendix A: Review of Selected Cities' Practices.*** Appendix A consolidates the research team's observations about existing and planned bus bulbs in San Francisco, Portland, Seattle, and Vancouver.

In addition to Appendix A, there are three appendices that are not published with this report but that are available in portable document format (pdf) on the Cooperative Research Programs' website (www4.nationalacademies.org/trb/crp.nsf). The three appendices not included in this report are

- *Appendix B: Curbside Before-and-After Study.* Appendix B discusses the pedestrian field studies conducted at the intersection of Mission and 30th Streets in San Francisco;
- *Appendix C: Roadway Before-and-After Study.* Appendix C presents the findings from the roadway field studies that examined travel speeds and traffic and bus operation changes resulting from the conversion of bus bays to bus bulbs in San Francisco; and
- *Appendix D: Computer Simulation.* Appendix D includes information on the computer simulation used to evaluate bus stop designs.

CHAPTER 2

FINDINGS

REVIEW OF SELECTED CITIES' PRACTICES

Bus bulbs were studied as part of a more comprehensive research study of bus stop design and location, which was sponsored by TCRP (*1*). During the course of the study, it was determined that little documentation existed on the operation and design of bus bulbs, either in the general literature or within transit agency design manuals. Several large cities in the Pacific Northwest, however, have begun to explore bus bulbs as one of many strategies used in developing a transit preferential program. Researchers visited four transit agencies on the West Coast that were known to use bus bulbs—San Francisco, Portland, Seattle, and Vancouver—to observe and document existing and planned bus bulbs. The cities were previously identified in the aforementioned TCRP project, and further contact with the transit agencies revealed that bus bulbs are now being given serious consideration at several existing stops. Furthermore, these cities all have high development densities, well-developed transit corridors, and a high level of transit patronage. Each of these cities also has a strong pedestrian and bicycle program to augment transit operations in the regions. The following sections document the findings from the visits.

San Francisco, California

The concept or use of bus bulbs in San Francisco dates back to the early 1970s with the adoption of the Transit Preferential Streets (TPS) program in 1973. Under this program, several "transit-first" strategies were identified; these strategies were designed to create a more "transit-friendly" environment within the city of San Francisco, especially within those corridors in which there was already a large use of transit. Bus bulbs were identified, along with several other measures, as a potential tool for implementing the TPS program. Several older locations of bus bulbs are scattered throughout the city. More recently, nine bus bulbs were added to south Mission Street.

Transit ridership is high throughout the city of San Francisco. Therefore, typical candidate locations are usually identified by the level of transit ridership, the frequency of service, and the presence of existing transit infrastructure. Areas with high auto–bus conflicts are also given high consideration. Two reasons for installing bus bulbs in San Francisco are the (1) bus re-entry problem and (2) congestion on the sidewalks near the bus stop zones.

The typical length of a bus bulb in San Francisco is 140 ft (42.7 m). The standard width is 6 ft (1.8 m), which is nearly equal to the width of the parking lane. As is the case with other cities, maintaining appropriate storm water drainage was the most challenging and costly element of the design. The approximate cost of the nine Mission Street bus bulbs was $500,000 to design and construct. Figures 1 and 2 are examples of bus bulbs being used in San Francisco.

Portland, Oregon

The city of Portland has several existing and pending bus bulb locations. Contrary to the reasons other cities installed bulbs, a majority of the bulbs in Portland are being installed for reasons other than transit. The pedestrian and bicycle program in Portland is very strong and influential. Consequently, a majority of the bulbs are being installed as part of traffic-calming measures or to reduce pedestrian crossing times at intersections. To highlight this pedestrian-to-transit policy, the opposing curb also is reconstructed with a pedestrian bulb to shorten the crossing length of the street for pedestrians (Figure 3).

Currently, the standard width of all bulbs in Portland is 6 ft (1.8 m), which provides a 2-ft (0.6-m) "shy" zone between the bulb and traffic. The 2-ft (0.6-m) shy zone around bus bulbs was selected in consideration of bicyclists who use the curbside parking lane as a travel lane. The interaction of bicycle lanes with bus bulbs is an issue in Portland, where bicycle use is particularly high in some neighborhoods. The bus bulb potentially forces bicyclists to use the general-purposes lanes to pass around the bulb—hence, the 2-ft (0.6-m) zone and the 6-ft (1.8-m) bulb width. However, drivers would prefer that this zone not exist, and Portland is now considering a 7-ft (2.1-m) bulb to accommodate this desire. The city will not stripe a bike lane on streets that have lanes that are less than or equal to 14-ft (4.3-m) wide. Portland will consider striping a bike lane when the lane width is 15 ft (4.6 m) or more. Figure 4 is an example of bicycle lane treatments near bus bulbs in Portland.

Figure 1. Bus at new bus bulb (San Francisco).

The length of the bulbs is highly variable throughout the city and appears to be dependent on the width of the street, the amount of existing parking, and the policy regarding how many doors are used for boarding and alighting the transit vehicle. The preferred location of bus stops in the Portland region is the near side of intersections. (Bus stops are nearside or farside relative to their position to the intersection. Nearside stops are located before the intersection; farside stops are beyond the intersection.) Because of the front-end boarding-and-alighting policy and the retirement of articulated buses, Portland's Tri-County Metropolitan Transportation District of Oregon (Tri-Met) may consider shorter bulbs than other areas of the country will consider. (An articulated bus is usually 55 ft [16.8 m] or longer with two connected passenger compartments that bend at the connecting point when the bus turns corners.) The length of the bus bulbs that were recently installed on Sandy Boulevard is 30 ft (9.2 m). Tri-Met is debating the installation of 20-ft (6.1-m) bulbs in the

Figure 2. Multiple buses at bulb (San Francisco).

Figure 3. Pedestrian bulb used with bus bulb (Portland).

downtown area where boarding and alighting would occur only in the front of the bus. Figure 5 is an example of a newly constructed nearside bus bulb on Sandy Boulevard in Portland. Placing bulbs at farside locations raises concerns of trapping vehicles in the intersection. The city will consider extending a signal's all-red phase if requested; however, no signal extensions were requested as of August 1998.

Retrofitting or rebuilding the street to install a bulb has raised some issues associated with the requirements in the Americans with Disabilities Act (ADA) concerning wheelchair lift deployment. Maintaining the appropriate slope at the bus stop is the primary concern. Where bulbs are short in length, it has been difficult to accommodate the lift. Transit vehicle operators have noted difficulties for patrons navigat-

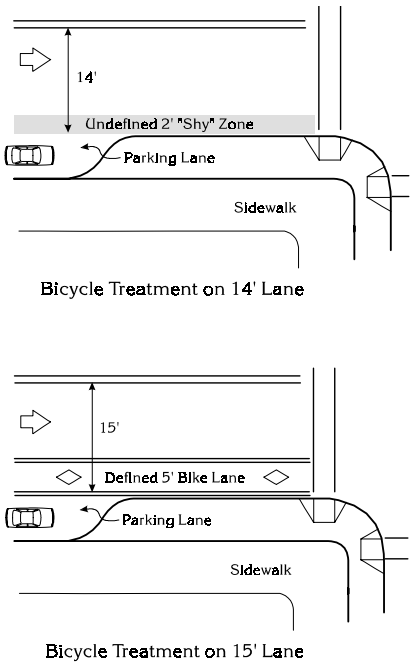


Figure 4. Bike lane treatments with bus bulbs (Portland).

Figure 5. Nearside bus bulb on Portland's north Sandy Boulevard at northeast 67th Avenue (eastbound).

ing wheelchairs around Bus Stop/No Parking signs and vending machines. The city is considering taping or painting pathways at the stops to illustrate where vending machines *cannot* be placed. Retrofitting a site can raise complex design issues associated with storm water drainage and can increase the cost of the project dramatically. The approximate cost for bulbs has been between $15,000 and $30,000 per bulb pair, with slightly higher costs in some instances caused by individual site characteristics.

The northwest 23rd Avenue sites are the oldest examples of bus bulbs in Portland. The bulbs were installed between 1990 and 1991. The project was initially developed as a pedestrian treatment and for traffic calming. A major goal of the project was to provide additional room along the sidewalks to segregate pedestrian and business activities from transit activities (Figure 6). As part of the project, Tri-Met consolidated stops to a three-block spacing. This consolidation strategy increased the amount of parking on northwest 23rd Avenue and improved the speeds of the transit vehicle. The total travel time for the bus, however, remained the same because more people were boarding at fewer stops, which increased the dwell time.

Figure 6. Increased sidewalk space (northwest 23rd Avenue at Irving Street).

Vancouver, British Columbia

The transportation mission statement of Vancouver, British Columbia, is to emphasize transit movement rather than vehicle movement. The City Council, based on a recommendation from an administrative report, has adopted a transit-first policy. Therefore, the city has placed greater emphasis on increased bus service and created a moratorium on additional construction or expansion of freeways. Bus bulges (as bus bulbs are called in Vancouver) have been identified as a potential transit priority measure. Bus bulges, it is assumed, will increase bus travel-time savings by allowing the bus to stop in the travel lane and by eliminating the need for the bus to re-enter the stream of traffic. Interestingly, bus bulges are equally viewed as traffic-calming and pedestrian improvements as well as transit priority improvements.

The city of Vancouver is currently studying the effect of two demonstration bulges near the University of British Columbia at the intersection of Sasamat Street and 10th Avenue. A major reason for installing the bus bulges on 10th Avenue was to eliminate the weaving of buses in and out of the curbside parking lane bus stop.

Currently, no warrants or guidelines have been developed for the installation of bus bulges, but the design on 10th Avenue may yield standards for design. The width of the demonstration bus bulges was constrained by the narrowness of 10th Avenue, which is only 52-ft (15.9-m) wide. The width of the bulge was restricted to 6.5 ft (2.0 m) to minimize the potential of having a stopped bus encroach on the second travel lane. Another concern is having enough room to pass the stopped bus without sideswiping the stopped vehicle or encroaching on the opposing lane.

The length of bulge is approximately 105 ft (32.0 m), which accommodates more than one transit vehicle arriving at the stop: Articulated (60 ft [18.3 m]) + Trolley (40 ft [12.2 m]). Unlike the Portland bulbs, the overall length of the Vancouver bulges is not influenced by the number of doors used to board and alight from the transit vehicle. Figure 7 is a picture of one of the bus bulges, and Figure 8 is a detailed plan view of the site with dimensions.

Because the bus stops are located at the far side of the intersection, there is concern regarding the potential for queuing of traffic in the intersection and for increased weaving movements at these locations. There is also concern regarding vehicular traffic experiencing delays caused by buses stopping in the traffic lanes.

The potential exists for bulges being perceived as traffic-calming devices. Vancouver has several traffic-calming strategies already in place, and the bus bulges may be seen as another strategy to decrease traffic. Drivers may see the bulges

Figure 7. Bus bulge in Vancouver.

and switch to a parallel route, which raises concerns for incidentally increasing traffic volumes on neighboring streets.

The city is planning to install additional bus bulges at locations with high bus volumes to improve transit service and to improve the pedestrian environment. More than Can$650,000 has been set aside in the city budget for future bus bulges. The estimated cost for the two bus bulges already built is Can$48,000 for the pair.

Seattle, Washington

The city of Seattle is actively considering the use of bus bulbs. Currently, there are three locations of bus bulbs within Seattle proper—northwest Market Street, northeast Lake City Way, and University Way. The University Way location is serving as a test case for bus bulbs in the region. The city is awaiting the outcome of the demonstration project on University Way before installing bulbs at other locations. Several suburban communities surrounding Seattle are also considering bus bulbs; however, these sites have concerns about van services that have very slow lift deployment (which can block traffic for extended periods of time), longer bus headways, and lower passenger volumes.

Northwest Market Street and northeast Lake City Way each have a pair of bus bulbs that have been in place for a number of years. Neither location was planned or built as a bus bulb, and both sets were built prior to the advent of any bus bulb design standard. The bulbs were originally designed as pedestrian improvements and accordingly vary in size. Because of the age of these sites, a majority of the institutional experience in the region associated with the design and construction of bus bulbs will be fostered from the University Way Demonstration Project. It is visibly apparent in the region that pedestrian movement receives strong attention. A common sight at each of these locations is the large, well-defined pedestrian crosswalk at the intersecting street.

The bus bulb demonstration project on University Way was created to demonstrate the following improvements (*2*):

- An increase in the pedestrian-carrying capacity of the sidewalks;
- An improvement in transit travel times in the corridor by consolidating stops and eliminating the bus re-entry problem;
- A reduction in or an elimination of adaptive use of storefronts by providing a defined space for waiting bus patrons;
- The provision of a potential location for bus patron amenities (e.g., bus shelters); and
- A demonstration and/or development of "reasonable criteria" for installing bus bulbs at bus stops.

Prior to the installation of the bulbs on University Way, transit vehicles were encountering bus re-entry problems. The bulbs allow buses to stop in the travel lane, eliminating the need for the buses to weave in and out of traffic.

As is the case in other cities, parking or the availability of parking can be a controversial issue. The length of the bus stop zone prior to the installation of the demonstration bulbs was 120 ft (36.6 m). The length of the bulbs after installation

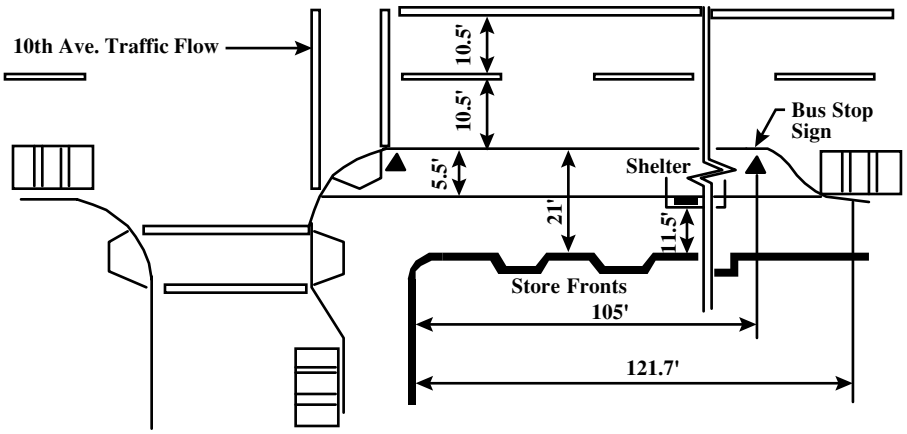


Figure 8. Bus bulge details (Vancouver).

was approximately 80 ft (24.4 m), with additional space for the curb returns. The 80-ft (24.4-m) length was determined by considering several factors: the desire to consolidate bus stops and to add parking, the potential for having two articulated buses arrive at the same time, and the ability to have all doors on an articulated bus be used for boarding and alighting. The University Way sites are retrofit designs; therefore, it is unclear whether the lengths used at those locations would be applied to new locations in the future.

The curb return radii of 20 ft/20 ft (6.1 m/6.1 m) were selected to permit street sweeping and to consume fewer parking spaces. With the 80-ft (24.4-m) length and 20 ft/20 ft (6.1 m/6.1 m) curb return configuration, an additional parking space was added to each side of the street. The consolidation of stops also provided additional room for parking because two curbside stops have been temporarily removed for the demonstration project.

Complying with design standards as set forth by the ADA guidelines was a challenge. In the process of retrofitting the University Way demonstration sites, the city had to grind the street lower to achieve minimum slope standards.

Another problem associated with a retrofit design, such as the design of the University Way location, was drainage. Standing water on the sidewalk could freeze and pose a potential danger to pedestrians and waiting passengers. This problem is particularly acute where the bulb joins the sidewalk. Designers are wary of creating joints that would allow water to accumulate rather than to drain (Figure 9). Figure 10 is a plan view of one of the demonstration bulbs.

The demonstration project achieved some transit travel-time savings in the corridor by increasing the speed of the transit vehicle from 4.5 to 5.7 mph (7.2 to 9.2 km/h) in the corridor (*2*). Total delay to general-purpose vehicles was minimal. Pedestrian congestion points were also removed from the sidewalk because of the additional space afforded by the bulb. Five additional parking spaces were added because of the bus stop consolidation and construction of the bulbs. The cost to construct the two demonstration bulbs was $35,000. A majority of the expenses were related to drainage and to accommodating wheelchair lift deployment.

Placement and Use of Bulbs

Table 1 summarizes the lessons learned about the placement and use of bus bulbs from the regional visits to the transit agencies.

CURBSIDE BEFORE-AND-AFTER STUDY

Sidewalks can be crowded with pedestrians, street furniture, storefront displays, transit shelters, and bus boarding and alighting activities. Bus stops can become unintended bottlenecks or points of congestion on crowded urban sidewalks. With the bus bay configuration, there is limited space to segregate transit activities (e.g., patron boarding and alighting or waiting) from pedestrian movement on a sidewalk. Bus bulbs are a logical strategy for reducing pedestrian congestion in narrow or small areas. By extending the curb toward the outside travel lane, a defined waiting area can be provided for bus patrons that is away from the flow of pedestrian traffic on the sidewalk. Also, amenities such as bus shelters can be stored off the sidewalk altogether.

Study Design

The objectives of the curbside before-and-after study were to

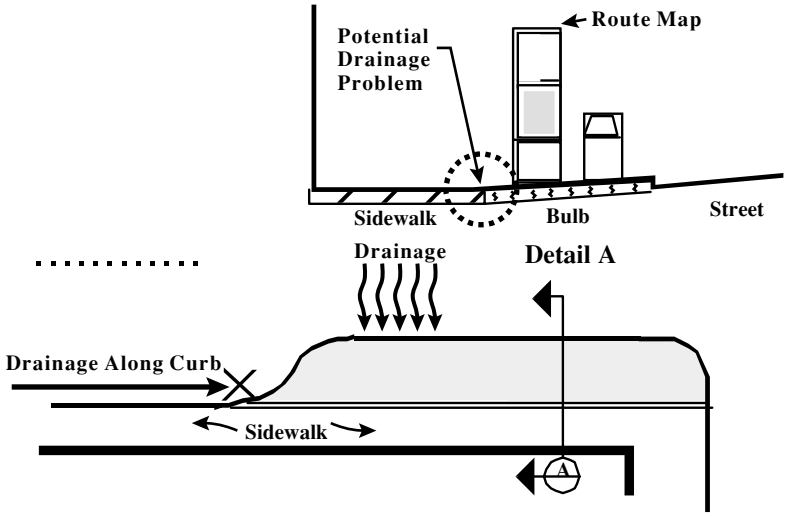


Figure 9. Potential drainage issues with bus bulbs (Seattle).

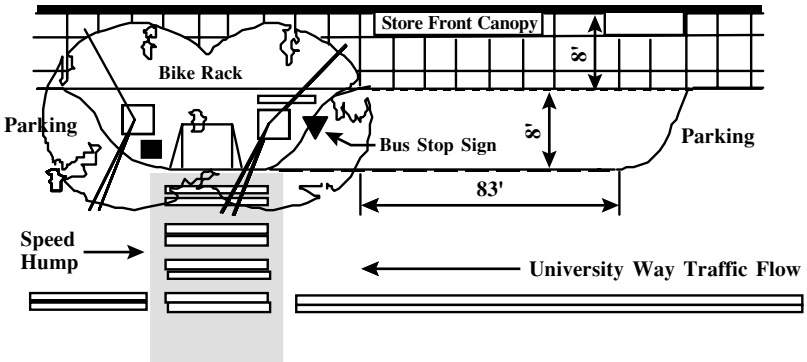


Figure 10. Detail of northbound demonstration bulb (Seattle).

- Determine whether the space available per pedestrian increases with the construction of the bus bulb, thereby improving walking speeds, reducing conflict points, and increasing waiting area for patrons;
- Calculate the sidewalk level-of-service (LOS) values and determine whether they change with the addition of the bus bulb;
- Determine whether the corner operates at a higher LOS with the additional room created by the bus bulb; and
- Identify boarding and alighting characteristics on the available sidewalk space.

The intersection of Mission and 30th Streets was chosen because it had the highest pedestrian and boarding and alighting volumes of any of the sites on south Mission Street where the bus bulbs were being constructed. The high pedestrian volumes are created by a Safeway grocery store and Walgreens pharmacy directly adjacent to the bus stop zone, a variety of restaurants and retail establishments close to the bus stop, and the high volume of children who ride the bus to and from school. Further adding to the pedestrian traffic at the site is the location of two bus stops on 30th Street, which serve as transfer points from the Mission Street bus routes

TABLE 1 General comments from regional visits on locating bus bulbs

City	Where to Locate Bulbs	Where Not to Locate Bulbs
San Francisco, California	• High bus patronage • High pedestrian activity on sidewalk • Bus re-entry problems	• High-speed facilities • Lack of community commitment • Concerns with queues forming behind stopped buses
Portland, Oregon	• Reduce pedestrian exposure at the crosswalk • Traffic calming • Attract riders	• Two-lane streets intersecting with two-lane streets • Locations with significant boarding activity • Layover locations • Signalized intersections with capacity concerns • Locations with speeds greater than 45 mph (72.5 km/h) • Locations where the bus would turn right after the bulb
Seattle, Washington	• Isolated streets • High pedestrian volumes • Neighborhood in which street is perceived to be pedestrian-oriented • Sites with neighborhood "feel" • Areas in which bus stop consolidation is desired	• Low transit ridership • High vehicular volumes • Two-lane streets • Narrow streets (sideswipe potential)
Vancouver, British Columbia	• High pedestrian demand • Traffic calming • Communities in which transit is given high priority	• Where 24-hr parking is not available • Locations with striped parking (on one side only during peak periods)

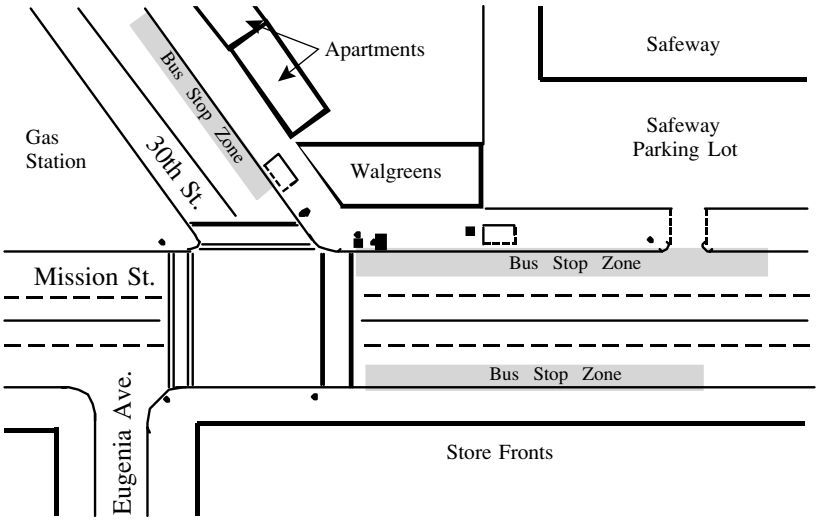


Figure 11. San Francisco's Mission and 30th Streets intersection (bus bay configuration).

onto the Divisadero bus route. Data were collected, primarily using palmtop computers, video, still photography, and general observations made in the field about pedestrian congregation areas and common travel paths. Figures 11 and 12 show the layout of the entire intersection before and after the construction of the bus bulb.

Results

The following sections contain a comparison of the before-and-after curbside study findings conducted at Mission and 30th Streets in San Francisco.

Available Pedestrian Space

A significant indicator of change for the benefit of pedestrians and transit patrons is available pedestrian space at the bus stop. Available space is determined by measuring the space per pedestrian in a defined area. Measurements were taken of the number of people in the bus stop area for the following three time intervals:

- 1 min prior to a bus arriving in the bus stop zone (*prior to* bus stopping);
- While the bus was present in the stop zone with patrons boarding and alighting (bus is *present*); and

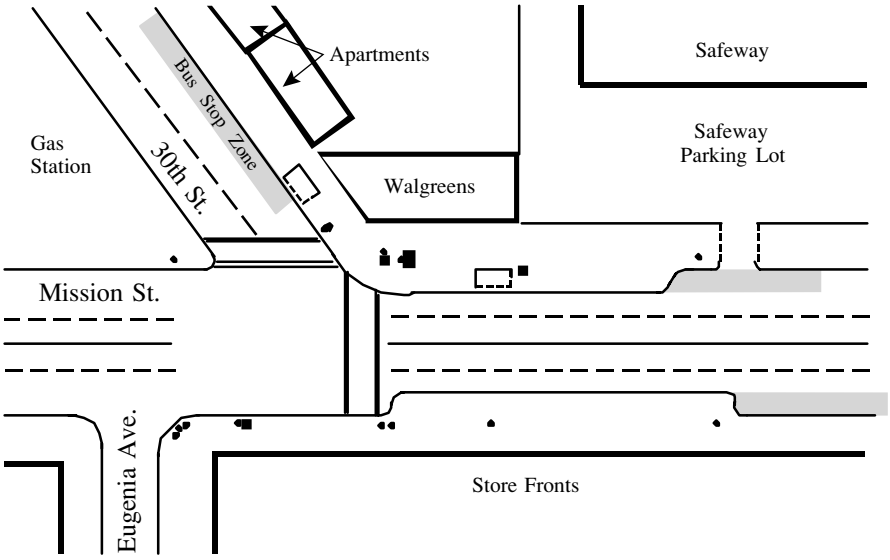


Figure 12. San Francisco's Mission and 30th Streets intersection (bus bulb configuration).

- 1 min after the bus had left the bus stop zone (*following* the bus departure).

The three time intervals were adopted in order to analyze the effect of a bus loading and alighting.

The available area in and around the bus shelter increased from 173 to 284 sq ft (16.1 to 26.4 sq m) after the bulb was constructed. This increase represents an improvement of nearly 64 percent in available waiting space at the bus stop. Figures 13 and 14 show the dimensions of the study area for the bus bay and bus bulb configurations. These figures illustrate the space available for pedestrians moving through the bus stop. Space available is determined by removing the space occupied by street furniture and the area typically used by standing pedestrians from the paved area present at the bus stop.

The results of the space study show that the construction of the bus bulb dramatically improved the available space and LOS for the bus stop at Mission and 30th Streets. The most dramatic differences occurred during the boarding-and-alighting phase when patrons and pedestrians are most likely to encounter the greatest mix of multiple streams of pedestrians, queuing areas, and walking speeds. The average available space increased from 19 sq ft (1.8 sq m) per pedestrian in the bay configuration to 44 sq ft (4.1 sq m) in the bus bulb configuration. This amounts to a difference of 132 percent, or a factor greater than 2 when comparing available square footage. At approximately 19 sq ft (1.8 sq m), which is the average condition at the bay, walking speeds and paths need to be adjusted because of crowding; the difficulty in crossing bidirectional traffic; and the tight pedestrian passing space, which is close to the minimum comfort threshold of 18 sq ft (1.7 sq m) per pedestrian. Conversely, at 44 sq ft (4.1 sq m), passing slower pedestrian traffic is easier, crossing bidirectional traffic is nearly unhindered, and traveling through the zone is dramatically less affected by other walking or standing pedestrians.

In nearly 26 percent of the total observations made at the bus bulb when a bus was boarding and alighting, the bus bulb

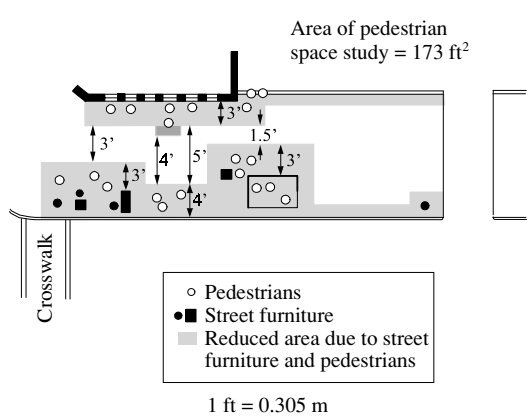


Figure 13. Common pedestrian waiting areas at bus bay.

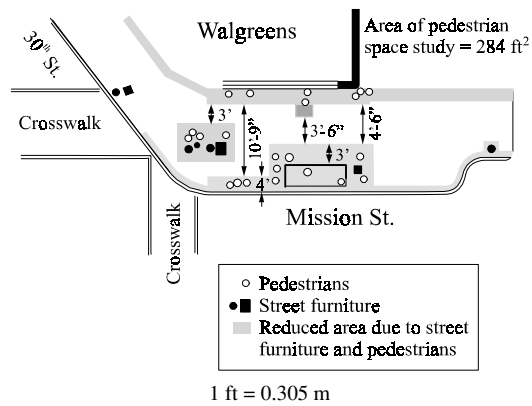


Figure 14. Common pedestrian waiting areas at bus bulb.

bus stop operated at an LOS greater than or equal to B (see Table 2 for definitions of LOS values). In comparison, only 4 percent of the observations made at the bus bay during the boarding-and-alighting period revealed the bus bay bus stop operating at this level. Nearly 40 percent of the boarding and alighting activities that were observed at the bus bay configuration had densities that were significant enough to affect pedestrian behavior, comfort, and travel patterns. However, the percentage of times that crowding would be encountered when a bus was at the bus bulb was reduced to nearly 28 percent, which represents a notable difference between the bus bay and the bus bulb designs. Figure 15 compares the available pedestrian space measured during the boarding and alighting activities between the two bus stop designs. In more than 50 percent of the observations, it was found that the bus bulb had notably more space available per pedestrian than was observed at the bus bay bus stop.

Sidewalk LOS

Pedestrian flow rates were collected at the southern end of the bus stop zone between the corner of the Walgreens pharmacy and a light post approximately 10 ft (3.1 m) south of the shelter. This area represented the greatest level of pedestrian flow for the entire bus stop area. The flow rate for four 15-min peak time periods was determined for both the bus bay and bulb configurations using the technique presented in Chapter 13 of the *Highway Capacity Manual* (*HCM*) (*3*). The data were also divided into 1-min intervals and for two scenarios—when buses are and are not present during the 1-min time period. The average flow rate for the four highest 15-min peak time periods for the bay configuration was 4.0 ped/min/ft (13.1 ped/min/m), while the average for the bus bulb was 3.6 ped/min/ft (11.8 ped/min/m). This represents an 11-percent improvement in the sidewalk flow level after the bulb was constructed.

Figure 16 shows the cumulative frequency of all measured flow rates for the two bus stop configurations. The figure also

TABLE 2 Pedestrian levels of service

Level of Service (LOS)	Characteristics
A	Pedestrian Space: ≥ 130 sq ft / ped Flow Rate: ≤ 2 ped / min / ft At walkway LOS A, pedestrians move in desired paths without altering their movements in reaction to other pedestrians. Walking speeds are freely selected, and conflicts between pedestrians are unlikely.
B	Pedestrian Space: ≥ 40 sq ft / ped Flow Rate: ≤ 7 ped / min / ft At walkway LOS B, sufficient area is provided to allow pedestrians to freely select walking speeds, to bypass other pedestrians, and to avoid crossing conflicts with others. At this level, pedestrians begin to be aware of other pedestrians and to respond to their presence in the selection of walking space.
C	Pedestrian Space: ≥ 24 sq ft / ped Flow Rate: ≤10 ped / min / ft At LOS C, sufficient space is available to select normal walking speeds and to bypass other pedestrians in primarily unidirectional streams. Where reverse-direction or crossing movements exist, minor conflicts will occur, and speeds and volume will be somewhat lower.
D	Pedestrian Space: ≥ 15 sq ft / ped Flow Rate: ≤15 ped / min / ft At LOS D, freedom to select individual walking speed and to bypass other pedestrians is restricted. Where crossing or reverse-flow movements exist, the probability of conflict is high, and its avoidance requires frequent changes in speed and position. LOS D provides reasonably fluid flow; however, considerable friction and interaction among pedestrians is likely to occur.
E	Pedestrian Space: ≥ 6 sq ft / ped Flow Rate: ≤ 25 ped / min / ft At LOS E, virtually all pedestrians would have their normal walking speed restricted, requiring frequent adjustment of gait. At the lower range of this LOS, forward movement is possible only by "shuffling." Insufficient space is provided for passing of slower pedestrians. Cross or reverse-flow movements are possible only with extreme difficulties. Design volumes approach the limit of walkway capacity, with resulting stoppages and interruptions to flow.
F	Pedestrian Space: ≤ 6 sq ft / ped Flow Rate: variable At LOS F, all walking speeds are severely restricted, and forward progress is made only by "shuffling." There is frequent, unavoidable contact with other pedestrians. Cross and reverse-flow movements are virtually impossible. Flow is sporadic and unstable. Space is more characteristic of queued pedestrians than of moving-pedestrian streams.

SOURCE: *Special Report 209: The Highway Capacity Manual*. 3rd Edition. Transportation Research Board, National Research Council, Washington, D.C. (1994).

shows the two scenarios (when a bus is and is not present) and provides the resulting LOS ranges. Table 2 summarizes the characteristics of the walkway for the different level of services as defined by the *HCM* (*3*). As shown in Figure 16, the sidewalk adjacent to the bus stop typically functions at a high LOS (more than 90 percent of the 1-min periods were LOS B or better). The average flow rate when buses were not present improved in the bulb configuration, decreasing from an average of 2.8 to 2.4 ped/min/ft (10.2 to 9.2 ped/min/m). This decrease equals an improvement of nearly 17 percent. When buses were present, the average flow rate showed a small increase (from an average of 4.0 to 4.1 ped/min/ft [13.1 to 13.4 ped/min/m]).

With the addition of the bus bulb, the width of the sidewalk at the location of the LOS study did not change. However, the available sidewalk width between the shelter and the store

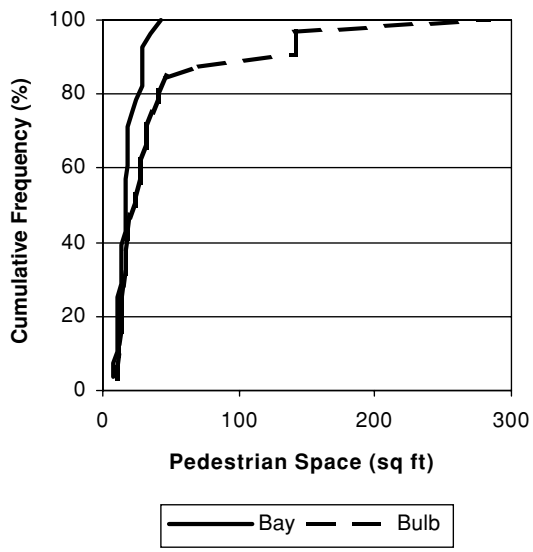


Figure 15. Available pedestrian space measurements when bus is present.

changed from 3 to 7.5 ft (0.9 to 2.3 m), and the width of the sidewalk increased from 14 to 20.25 ft (4.3 to 6.2 m), which equates to an improved cross section of approximately 45 percent. More importantly, the space directly behind the bus shelter would no longer be considered a point of congestion. In summary, the addition of the bulb increased, and thus dramatically improved, the sidewalk width around the shelter; the increased sidewalk width improved pedestrian movement.

Corner LOS

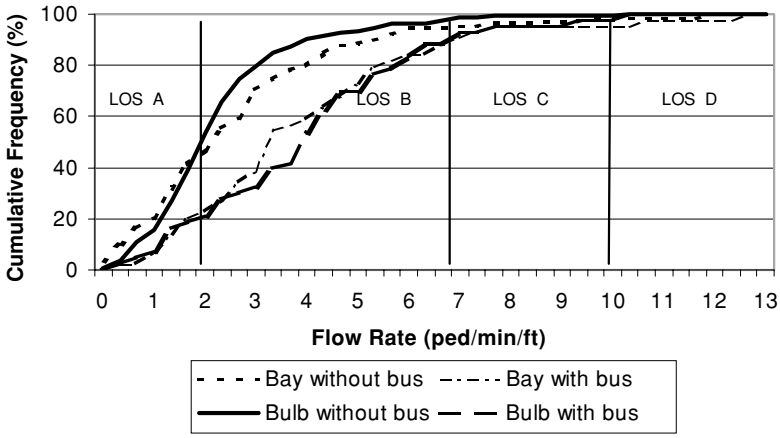
Pedestrian counts and traffic signal–timing information were used in the *HCM* (*3*) procedure to evaluate the performance of the corner near the bus stop. There was an increase in the percentage of readings that were LOS A as a result of the improvements made at the site. The bus bay configuration with limited storage space had 79 percent of the readings at LOS A. After the bulb was constructed and the additional 6 ft of sidewalk extended at the curb, the percentage of LOS A readings increased to 86 percent.

Although a majority of the LOS readings with the bus bay and bulb were either A or B, there were other improvements observed as a result of the reconfiguration. With a bus bay, there were noticeable conflicts between pedestrians crossing the street in an inbound direction (toward the study site) and pedestrians waiting to traverse the cross street in an outbound direction. This conflict was especially true for pedestrians crossing Mission Street in the inbound direction. The location of street furniture and the pedestrian queues at the corner reduced the area available to pedestrians. However, after the construction, there was a noticeable increase in the area available for pedestrians to queue while waiting to cross the street. This additional space resulted in conflicts between pedestrians waiting to cross one street and pedestrians approaching the corner area on the other street.

Figure 17 is a view upstream toward the bus bay at Mission and 30th Streets. The bus stop operations are constrained by the narrow sidewalk and the presence of street furniture. Figure 18 is a plan view of the curbside corner study area. Figure 19 is a picture of the corner after the bulb was constructed. The corner is noticeably larger with the addition of the bus bulb, which extends 6 ft (1.8 m) beyond the old curbside location (Figure 20). The actual increase in corner area is 32 percent, increasing from 100 sq ft (9.3 sq m) in the bay configuration to 132 sq ft (12.3 sq m) in the bulb configuration.

Boarding and Alighting Characteristics

The length of time for a bus at a bus stop is increased by pedestrian crowding that affects boarding and alighting activ-



1 ft = 0.305 m

Figure 16. Pedestrian flow rates.

Figure 17. Corner of Mission Street at 30th Street (bus bay configuration).

Figure 19. Corner of Mission Street at 30th Street (bus bulb configuration).

ities. Data were collected at two sites: Mission and 30th Streets (nearside stop) in the southbound direction and Mission and 30th Streets (farside stop) in the northbound direction. Dwell times less than 40 s were used in the analysis because longer dwell times were associated with drivers meeting San Francisco Municipal Railway (Muni) supervisors, which was a fairly common event.

The average dwell time (in seconds) per passenger boarding and alighting decreased by nearly 1 s in the off-peak period in the northbound direction at Mission and 30th Streets (3.2 s to 2.3 s). The remaining analysis groups all showed a slight increase in average dwell time per passenger boarding and alighting (either a 0.2-s or a 0.7-s increase).

Observations of pedestrian behavior in the bus stop zone when buses were boarding and alighting were also made. Figures 21 and 22 provide an overview of common walkway paths made by pedestrians during the boarding-and-alighting process. The boarding passengers are represented by thick gray arrows, and the area in which high conflicts occurred are shown as crosshatched boxes. In the after study, improvements were observed at the front door of the bus where patrons alighted and boarded. In both the before and after data collection trips, high levels of congestion were noted in and around the front door of the bus. With a bus bay, the congested areas consumed a large portion of the sidewalk space; however, with a bus bulb, the primary congestion occurred on the bus bulb. This shifting of congestion allowed for less disruption of pedestrian movement on the sidewalk.

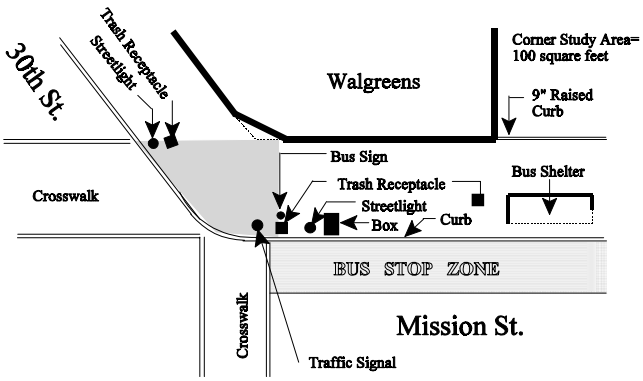


Figure 18. Corner LOS study area for bus bay.

ROADWAY BEFORE-AND-AFTER STUDY

The benefits to pedestrians and bus patrons are numerous when a bus bay is replaced with a bus bulb. Theoretically, buses should operate more efficiently at the stop when they are not required to weave into and out of a bus bay. The bus bulb also provides additional room near the sidewalk to increase walking speed or comfort and waiting areas. However, these benefits may be offset by the disadvantage to motorists and other buses. In the bus bulb design, passengers board and alight while the bus is stopped in the travel lane. The bus being stopped in the travel lane could result in queues forming behind the bus and longer travel times for both vehicles and buses.

Study Design

San Francisco planned to convert several bus bays to bus bulbs during the late 1990s. As part of a 1999 pavement rehabilitation project, stops located on Mission Street from Cesar Chavez Street to Santa Marina Street were converted. The timing of this TCRP project and the construction schedule for the nine stops on Mission Street allowed the inclusion of the stops in a before-and-after study. The before-and-after study would examine the effects of converting a bus stop from a bus bay design to bus bulb design. The goal was to analyze the operations at both farside and nearside bus stops and to determine effects on buses and other vehicles in the traffic stream. Specific objectives of the roadside study included determining whether the following changed from the before period (bus bay) to the after period (bus bulb):

Figure 20. Corner LOS study area for bus bulb configuration.

- Bus and vehicle speeds near a bus stop (peak and nonpeak time periods),
- Bus and vehicle speeds for the corridor (peak time period),
- Length of queue behind a bus and driver behavior near the bus stop, and
- Bus operations.

Bus speeds represent the speed of buses stopping at a bus stop of interest. Vehicle speeds represent the speeds of all vehicles in the traffic stream. Mission Street is a low-speed arterial (less than 30 mph [48.3 km/h]) with heavy commercial development. The surrounding development is primarily shops and restaurants. The corridor has four lanes without a median and is posted with a 25-mph (40.3-km/h) speed limit. Traffic and bus data were collected for six of the nine bus stops that were converted as part of the construction project and for the corridor. Data were collected using travel-time software, palmtop computers, video, photographs, and general observations made in the field. Figure 23 shows the distances over which the travel times were collected and the six bus stops studied. Sites 1 and 2 are nearside stops, and Sites 3 through 6 are farside stops.

Results

The following sections contain a comparison of the before-and-after roadway studies conducted in San Francisco.

Bus and Vehicle Speeds Near a Bus Stop

Travel speed data were available for two blocks (Figure 23). The results show that the installation of a bus bulb improved traffic operations. The block with the farside stop (Site 5) saw a statistically significant increase in vehicle speeds from 11.4 to 20.9 mph (18.4 to 33.6 km/h) in the peak period and from 9.5 to 15.7 mph (15.3 to 25.3 km/h) in the nonpeak period. Buses also traveled faster along this block after the bus bulb was installed (an increase of 0.2 to 2.2 mph [0.3 to 3.5 km/h]). Improvements in operating speed also occurred for both buses and vehicles on the block with the nearside stop (Site 1) (an increase of 4.5 mph [7.2 km/h] for vehicles and of 0.9 mph (1.4 km/h) for buses). Changes in traffic volumes were checked to determine whether they had an influence on the change in travel speeds. Both blocks experienced a slight increase (between 2 and 4 percent) in traffic volumes, which would have a marginal effect, if any, on travel speeds.

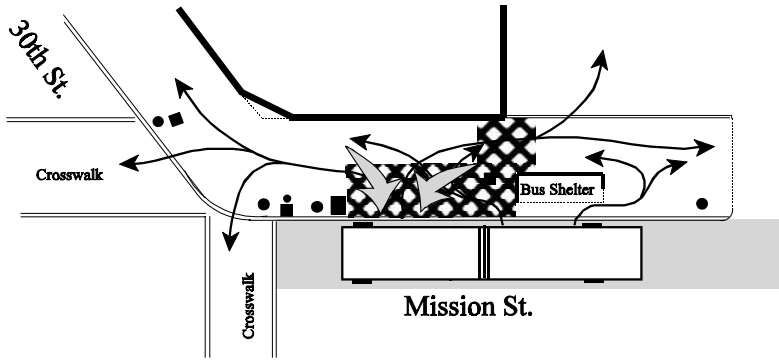


Figure 21. Pedestrian walking paths (bay configuration).

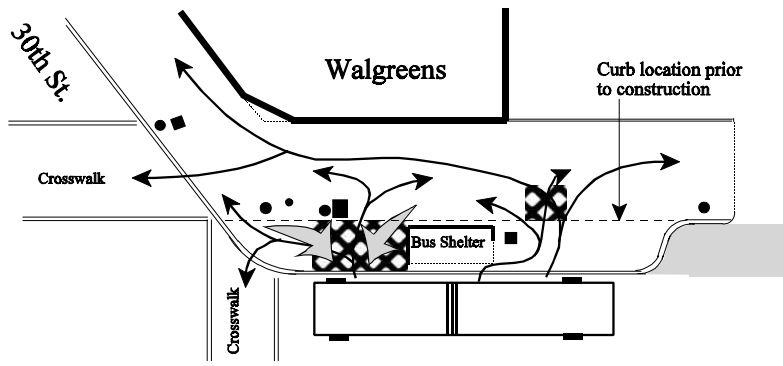


Figure 22. Pedestrian walking paths (bulb configuration).

Bus and Vehicle Speeds for the Corridor

The travel time and speeds of vehicles and buses were recorded between Cortland and Precita Avenues (Figure 23). In this section of the corridor, there were six intersections and seven bus stops, and the distance was approximately 2,400 ft (732 m). Table 3 lists the findings for both the southbound and northbound direction within the corridor. In the northbound and southbound directions, the average speed for vehicles increased approximately 3 mph (4.8 km/h) and 7 mph (11.3 km/h), respectively. Figure 24 is a plot of the individual vehicle speeds collected in both directions for both bus stop designs. The figure demonstrates that much higher speeds are present with the bulb design. Approximately 40 percent of the vehicles observed when the bulbs were present were driving at speeds greater than 19 mph, which was the highest speed measured in the before (bus bay) condition.

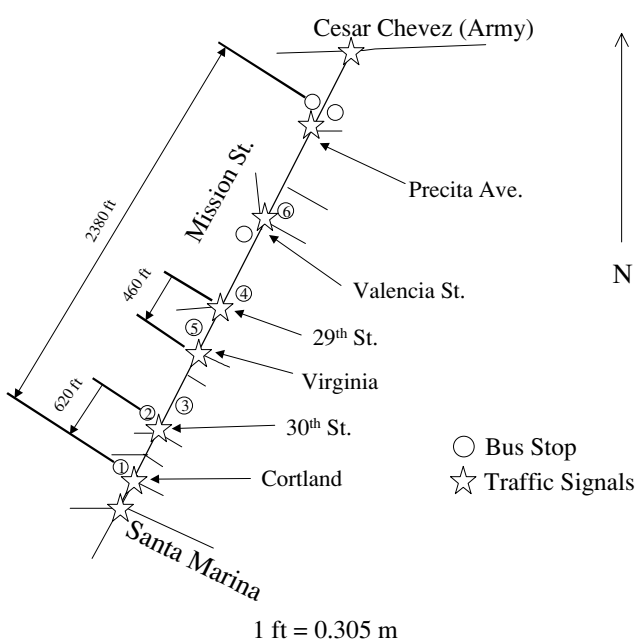


Figure 23. Travel time collection locations.

The average speed for buses in both directions improved slightly (an increase of about 0.5 mph [0.8 km/h]). Eliminating the need for the bus to re-enter the traffic stream should have contributed to the slight improvement observed. Table 3 lists the average speed, and Figure 25 is a plot of the individual bus speeds. The closeness of the curves in Figure 25 demonstrates that the speed distribution for bays and bulbs in both directions is similar.

Length of Queue Behind a Bus and Driver Behavior Near the Bus Stop

The number of vehicles queued and the number of lane changes that occurred behind a stopped bus were counted at four sites during the nonpeak period and at three sites during the peak period. The nonpeak period represents operations between 9:00 A.M. and 3:00 P.M. Lower traffic volumes and higher speeds are present during this period. The average number of vehicles in a queue was only one vehicle with a maximum of two vehicles. Buses would frequently stop in the traffic lane with a bus bay design. A traffic queue would form behind these buses for every 7 to 17 bus arrivals. After the installation of the bus bulb, a queue would form for every three to five bus arrivals. Therefore, queues were forming more frequently during the nonpeak period with bus bulbs. However, the queue lengths were still fairly short, typically between one- to four-vehicles long, and averaged less than one vehicle for each queue. In most cases drivers would attempt to change lanes rather than queue behind a stopped bus. For both the bus bay and the bus bulb design, on average, one lane change occurred for each bus arrival. Slightly more lane changes occurred when the bus bulb design was present.

Vehicle queues behind stopped buses were longer during the peak period (after 3:00 P.M.) than during the nonpeak period. When a bay was present, the queues were one- to six-vehicles long and averaged between one and three vehicles. After the bus bulbs were installed, the observed number of vehicles in queue was slightly less, with a maximum length of four vehicles. At the nearside stop (Site 1), queues formed

TABLE 3 Speed for corridor between Cortland and Precita Avenues (evening peak)

Site	Type	Measure	Bay	Bulb	Change in Speed
Northbound Corridor	Vehicle	Average time Average speed Observations	114 s 14.5 mph 21	116 s 17.0 mph 29	17 %
	Bus	Average time Average speed Observations	219 s 7.8 mph 33	212 s 8.4 mph 20	8 %
Southbound Corridor	Vehicle	Average time Average speed Observations	114 s 14.9 mph 9	89 s 21.7 mph 45	46 %*
	Bus	Average time Average speed Observations	252 s 7.0 mph 19	238 s 7.5 mph 33	7 %

* Change in speeds from the bay to bulb condition was significantly different at alpha = 0.05; 1 ft = 0.305; 1 mph = 1.61 km/h.

less frequently after the bulb was installed; however, the number of lane changes increased. At the farside stops, queues formed more frequently with the bus bulb design. The frequency of lane changes, however, was generally constant.

In summary, queues occur more frequently with the bus bulb designs; however, the queues are generally short—on average, only one- to two-vehicles long. During the peak period, the number of lane changes is similar for both designs at the farside stops. The nearside stop had a greater number of lane changes with the bulb design than with the bay design.

Bus Operations

During the before study, more than 500 bus arrivals at the bus bay were observed. A majority of these buses completely or partially stopped in the outside lane instead of pulling into the bus bay (Figures 26 and 27, respectively). Site 3 had the highest incidence of buses stopping in the lane, with more than 72 percent of the buses in the peak period stopping in the lane. Other sites had between 48 and 70 percent of the buses at a bus bay stopping in the travel lane. Muni representatives acknowledged this observation and concluded this behavior was due to two reasons: (1) bus drivers are wary of the bus re-entry problem and want to avoid this maneuver; and (2) the overhead electrical wires had already been moved for the reconstruction of the bus stops, which could cause the catenary poles from the buses to dislodge from the electrical wire (the data collection team observed both of these scenarios several times). However, bus patrons are asked to step off the curb and onto the street whenever buses stop in the travel lane.

At the sites where the palmtop computers were used, the amount of delay to buses attempting to re-enter the traffic stream was observable. The average delay to the bus was slightly longer in the peak period, and buses at the nearside stop experienced longer delays than buses at the farside stop. Drivers at the farside stop could pull into traffic during the gaps created by a traffic signal; however, the queues at the signal at the nearside stop limited the opportunity for a bus driver to re-enter traffic. Figures 28 and 29 are plots of the bus delay data collected for both bus stop designs for non-peak and for peak time periods, respectively.

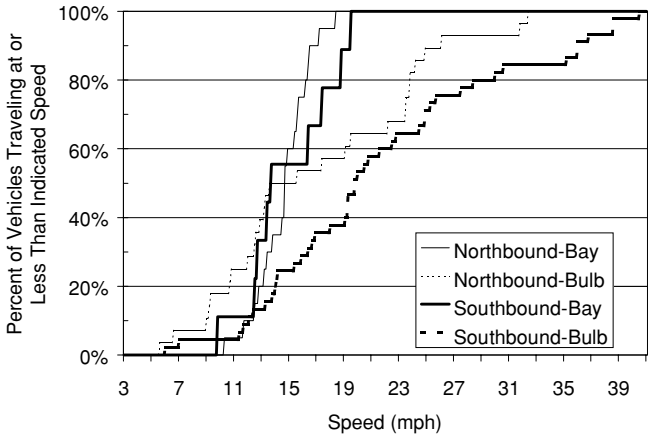


Figure 24. Vehicle speeds in corridor between Cortland and Precita Avenues.

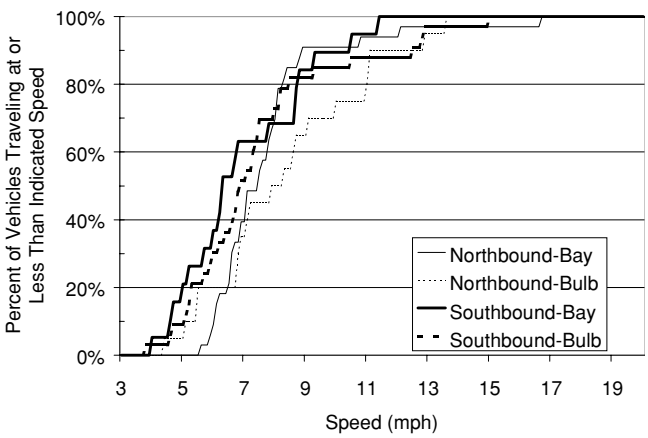


Figure 25. Bus speeds in corridor between Cortland and Precita Avenues.

Figure 26. Bus completely stopped in lane.

Figure 27. Bus partially stopped in lane.

COMPUTER SIMULATION

Traffic simulation programs are frequently used to analyze traffic operations for various conditions. The benefit of using computer simulation is that operations are analyzed over a wide range of variables in a relatively short period of time as compared with collecting data in the field. The two bus stop designs analyzed using computer simulation were bus bay and bus bulb. Farside and nearside locations were used in the simulation. The evaluation of the bus stop designs used two approaches: (1) the effect on speeds within a *corridor* containing a series of bus stops, and (2) performance at an *isolated intersection*. The results from the computer simulation are intended to be used in selecting a preferred bus stop design for a given location and traffic volume.

Traffic Simulation Program

NETSIM, the traffic simulation program, was selected for this study because of its national acceptance and its capability to allow the user to modify text files for multiple runs. The two bus stop designs studied were bus bay and bus bulb. NETSIM was used to compare the two bus stop designs at both farside and nearside locations.

The analysis used multiple simulation runs on a corridor (which included farside and nearside locations) and on two isolated intersections (one with farside locations and one with nearside locations). Figure 30 shows the bus stops included in the corridor analysis. The isolated intersection models consisted of a single signalized intersection with four approaches. The main street approach consisted of two through-lanes in each direction. The bus stop under investigation was located on a main street approach either at the farside or at the nearside of the intersection.

After each simulation run, the necessary data were retrieved from the NETSIM output and graphical interface. The data retrieved included vehicle and bus speeds, the number of vehicles in the outside lane that passed by a stopped bus (bus bay design only), and the number of vehicles in the outside lane that were delayed by a stopped bus (bus bulb design only).

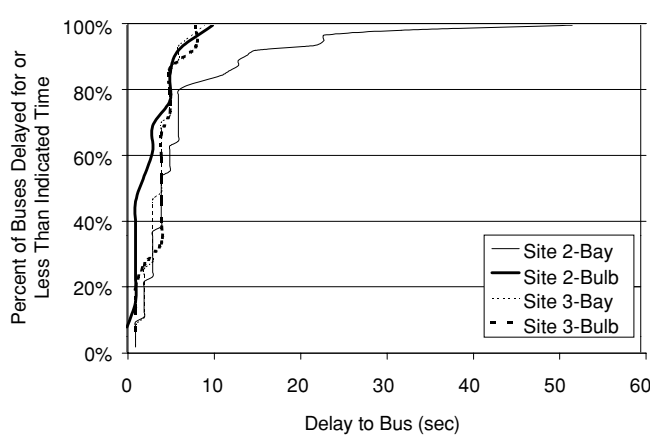


Figure 28. Nonpeak bus delay.

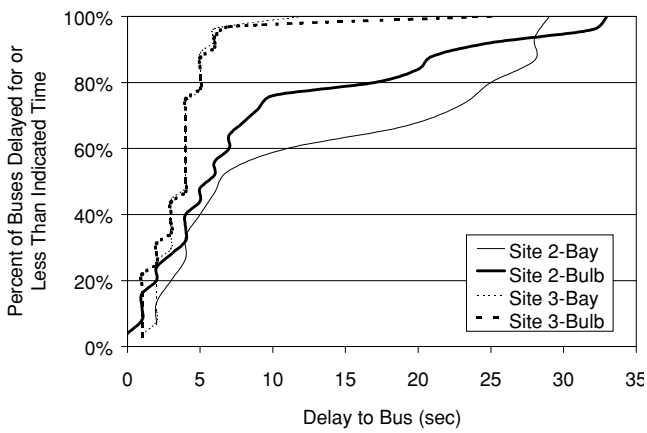


Figure 29. Peak bus delay.

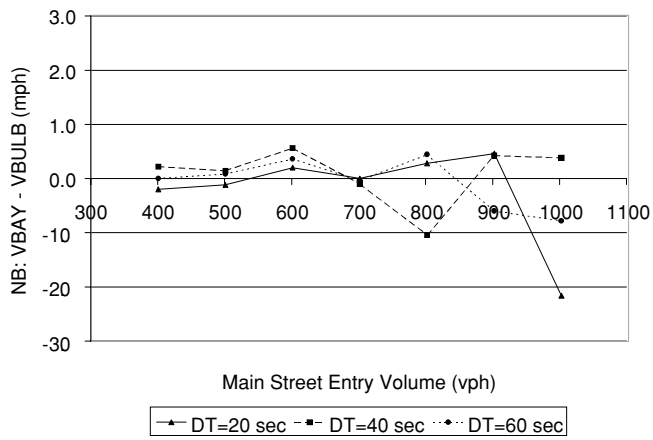


Figure 31. Northbound average vehicle speed difference between bus bay and bus bulb design.

Corridor Results

The intent of the corridor computer simulation was to evaluate the effect of bus stop design (i.e., bus bay and bus bulb) on traffic and bus operations (i.e., vehicle and bus speeds) within a corridor. The variables adjusted included main street entry volume (400 to 1,000 vehicles per hr [vph]) and bus dwell time (20 to 60 s). The maximum main street entry volume was determined to be 1,000 vph, because volumes higher than 1,000 vph caused the corridor to become too congested to collect accurate data.

Northbound Corridor

The northbound direction (from Cortland Avenue to Precita Avenue) contained three farside bus stops and six signalized intersections (Figure 23). The average vehicle speeds within the corridor for both designs range from 12 to 17 mph [19.3 to 27.4 km/h]. Figure 31 shows the difference in the average vehicle speeds for the bus bay and bus bulb designs (i.e., the average vehicle speed for bus bay design minus the average vehicle speed for bus bulb design). For almost all of the dwell times (20, 40, and 60 s), the difference in the average vehicle speed is relatively constant (less than a 1-mph [1.61-km/h] difference). The one exception is for the 20-s dwell time at 1,000 vph—the difference in the average vehicle speed decreases (≥ –2 mph [–3.2 km/h]). Thus, the average vehicle speed for the bus bay design (11.9 mph [19.2 km/h]) is lower than the average vehicle speed for the bus bulb design (14.1 mph [22.7 km/h]). This indicates that the bus bulb design does not negatively affect traffic operations (i.e., vehicle speed) compared with the bus bay design.

The average bus speeds within the corridor for both designs range from 6 to 12 mph (9.7 to 19.3 km/h). Figure 32 shows the difference in the average bus speeds for the bus bay and bus bulb designs (i.e., the average bus speed for bus bay design minus the average bus speed for bus bulb design). For the 20-s

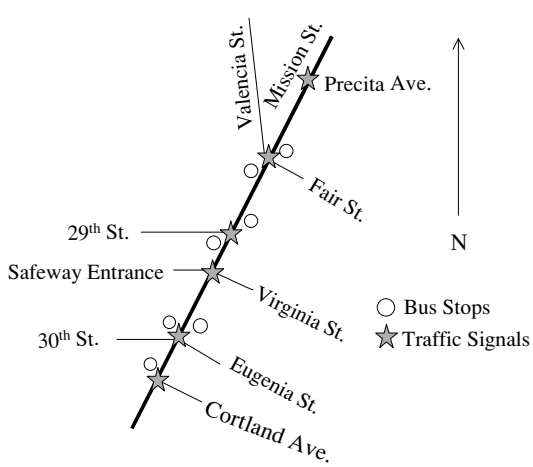


Figure 30. Bus stops included in the corridor simulation.

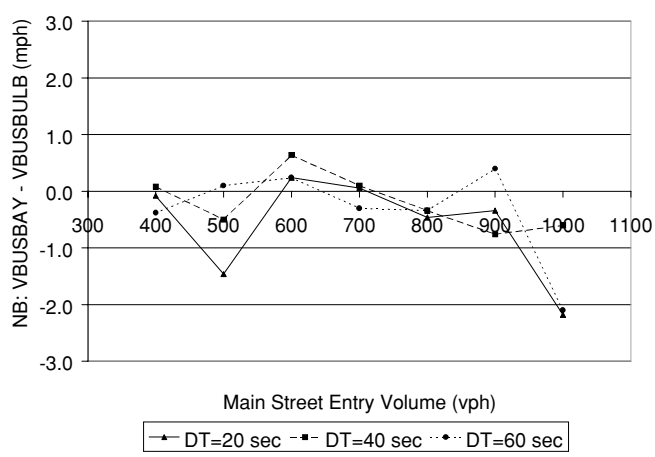


Figure 32. Northbound average bus speed difference between bus bay and bus bulb design.

dwell time, the difference in the average bus speed at 500 vph and 1,000 vph is greater than 1 mph and 2 mph (1.6 km/h and 3.2 km/h), respectively. Thus, the average bus speeds for the bus bay design (10.4 and 8.0 mph [16.7 and 12.9 km/h], respectively) are lower than the average bus speeds for the bus bulb design (11.9 and 10.1 mph [19.2 and 16.3 km/h], respectively). The difference in the average bus speed for the 60-s dwell time at 1,000 vph was also greater than 2 mph (3.2 km/h), with the average bus speed for the bus bay design (6.5 mph [10.5 km/h]) being less than the average bus speed for the bus bulb design (8.6 mph [13.8 km/h]). These results reveal that the bus bulb design may provide the greatest benefit to bus operations at higher volumes (>900 vph).

Southbound Corridor

The southbound direction (from Precita Avenue to Cortland Avenue) contained two farside bus stops, two nearside bus stops, and six signalized intersections (Figure 23). The average vehicle speeds within the corridor ranged from 14 to 18 mph (22.5 to 29.0 km/h). In almost all cases, the difference in vehicle speed between the two designs was less than 1 mph (1.6 km/h). The data indicate that the bus stop design may affect vehicle speed (more than a 1-mph [1.6-km/h] difference) only at higher volumes.

The average bus speeds within the corridor for both designs range from 7 to 11 mph (11.3 to 17.7 km/h). For all of the dwell times and main street entry volumes, the difference in the average bus speed is relatively constant (less than a 1-mph [1.6-km/h] difference). These results reveal that there is no difference between the bus bay and bus bulb designs with respect to bus operating speed within the corridor.

Comparison of NETSIM and Field Results

To determine how well NETSIM was simulating the actual conditions in the corridor, the simulation results were compared with the data collected in the field for each of the bus stop designs. Table 4 contains the average vehicle and bus speeds in both directions that were collected in the field during peak periods and were computed using simulation for the bus bay and bus bulb designs. For both the before and the after data (i.e., bay and bulb) in the northbound direction, the difference between the simulation results and the field results is less than 3 mph [4.8 km/h]; in the southbound direction, the difference was less than 4 mph (6.4 km/h).

The field results indicate that the installation of the bus bulbs improves the travel speed for vehicles and slightly improves the travel speed for buses. (Appendix C, which is posted on CRP's website [www4.nationalacademies.org/trb/crp.nsf], provides additional information on these findings.) The computer simulation program, however, did not show such improvements in travel speeds. The subroutines within NETSIM to evaluate buses were added to the program in recent years. The large difference in travel speed between the simulation and the field data indicates that the subroutines may not be sensitive enough to the nuances of how the bus stop design affects operations. Therefore, the design of the bus stop may have greater effect on travel speed than was found in the computer simulation study.

Isolated Intersections Results

In addition to the corridor study, simulation was used to study the operations around an isolated intersection. This approach allowed for the counting of the number of vehicles in the outside lane that passed by a stopped bus (bus bay design only) and the number of vehicles in the outside lane that were delayed by a stopped bus (bus bulb design only).

Farside Location

The variables adjusted included main street entry volume (1,000 to 1,700 vph) and dwell time (20 to 60 s). The aver-

TABLE 4 Comparison of NETSIM* and field results

Direction	Bus Stop Design	Method	Average Vehicle Speed (mph)	Average Bus Sped (mph)
Northbound	Bay	Field	14.5	7.8
		NETSIM	17.0	10.6
	Bulb	Field	17.0	8.4
		NETSIM	16.8	10.4
Southbound	Bay	Field	14.9	7.0
		NETSIM	17.9	10.4
	Bulb	Field	21.7	7.5
		NETSIM	17.8	10.8

* Data for 600 vehicles per hour and 20-s dwell time used in comparison; 1 mph = 1.6 km/h

age vehicle speeds on the link that contained the bus stop for both designs range from 24 to 26 mph (38.6 to 41.8 km/h); the average bus speeds range from 4 to 10 mph (6.4 to 16.1 km/h). The difference in the average vehicle and bus speeds between a bay and a bulb design was relatively constant (about or less than a 1-mph [1.6-km/h] difference) over all of the main street entry volumes.

To further study the effects of the bus stop design on traffic operations, the average number of vehicles in the outside lane that passed a stopped bus (bus bay design only) and the average number of vehicles in the outside lane that were delayed by a stopped bus (bus bulb design only) were counted. In general, both factors increased as the main street entry volume increased, as was expected. However, the average number of vehicles that were delayed by a stopped bus (2 to 14) was consistently lower than the average number of vehicles that passed a stopped bus (6 to 16) for a given dwell time.

Nearside Location

The operations at a bus stop sited on the nearside location of an intersection were also studied. The variables adjusted included main street entry volume (1,000 to 1,600 vph) and dwell time (20 to 60 s). The average vehicle speeds on the link that contained the bus stop for both designs range from 10 to 21 mph (16.1 to 33.8 km/h). Figure 33 shows the difference in the average vehicle speeds for the bus bay and bus bulb designs (i.e., the average vehicle speed for bus bay design minus the average vehicle speed for bus bulb design). For all of the dwell times, the trend is that the difference in the average vehicle speed increases as the main street entry volume increases. This increase in the difference in the average vehicle speed is greatest for the 60-s dwell time. These results reveal that for a nearside location, the bus bay design provides the greater benefit to traffic operations. The average bus speeds for both designs range from 5 to 10 mph (8.1 to 16.1 km/h). However, the difference in the average bus speed is, in general, relatively constant (less than a 1-mph [1.6-km/h] difference for most combinations).

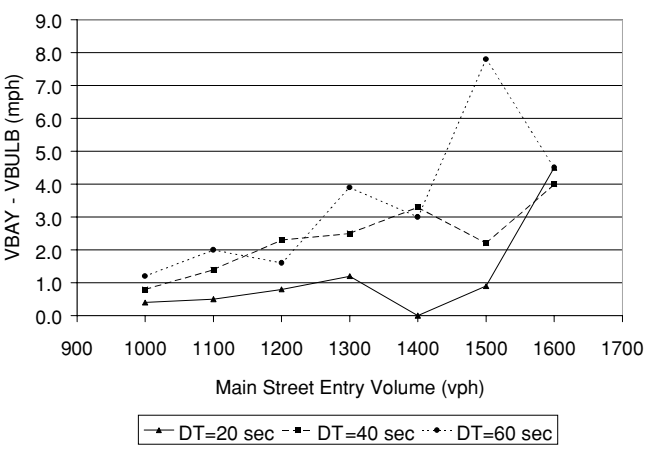


Figure 33. Average vehicle speed difference between bus bay and bus bulb design for a nearside location.

As with the farside data, to further study the effects of the bus stop design on traffic operations, the average number of vehicles in the outside lane that passed a stopped bus (bus bay design only) and the average number of vehicles in the outside lane that were delayed by a stopped bus (bus bulb design only) were counted. In general, both factors increased as the main street entry volume increased, as was expected. But as with the farside data, the average number of vehicles that were delayed by a stopped bus (2 to 9) was consistently lower than the average number of vehicles that passed a stopped bus (3 to 13) for a given dwell time.

Simulation Summary

The intent of the computer simulation for the corridor was to evaluate the effect bus stop design has on traffic and bus operations for a series of intersections that closely represent a real-world environment. The computer simulation runs show that at lower volumes (≤900 vph), there is no practical difference between the bus bay and bus bulb designs with respect to traffic operations. However, at higher traffic volumes (>900 vph) a difference between the two designs was found.

The simulation results were compared with data collected in the field during the peak period to determine how well NETSIM was simulating the actual conditions in the corridor. The field results indicate that the installation of the bus bulbs notably improves the travel speed for vehicles and slightly improves the travel speed for buses. The findings from the computer simulation comparison indicate that NETSIM may not be sensitive enough to the nuances of how the bus stop design affects operations. Therefore, the design of the bus stop may have greater effect on travel speed than was found in the computer simulation study.

The objective of the computer simulation for the isolated intersections was to develop recommendations that could aid in the selection of a preferred bus stop design for a single bus stop location. Based on the vehicle and bus speed data, it was determined that there is no practical difference between the bus bay and bus bulb designs when the bus stop is located on the far side of the intersection. Based on the traffic data, it was determined that the bus bay design is beneficial over the bus bulb design with respect to traffic operations at higher volumes (above 1,000 vph), regardless of the dwell time when the bus stop was located on the near side of the intersection. Based on the bus data, it was concluded that only at very high volumes is there a potential difference between the two designs when the bus stop is located on the near side of the intersection.

CHAPTER 3

INTERPRETATION, APPRAISAL, AND APPLICATION

INTERPRETATION AND APPRAISAL

Bus bulbs are appropriate in areas with high-density developments and in which the percentage of people moving through the corridor as pedestrians or in transit vehicles is relatively high in comparison with the percentage of people moving in automobiles. Examples of bulbs are shown in Figures 34 and 35. Well-developed, mixed-use downtown or urban settings are typically the most viable areas in which bus bulb designs are considered. Conditions that support the construction of bus bulbs include

- Communities in which transit is given high priority;
- High levels of pedestrian activity on the sidewalk;
- High levels of bus patronage at the bus stop or within the corridor;
- Lower operating speeds on the roadway;
- Interest in the bulbs of local business owners;
- Presence of on-street parking;
- Two travel lanes per direction (to allow passing of stopped buses); and
- Difficulties for buses in re-entering the traffic stream, usually because of high traffic volumes.

The extension of the curb into a parking lane creates additional area for pedestrians to walk and for patrons to wait for a bus. The bulb can also provide space for bus patron amenities, such as shelters and benches (Figure 36), and for additional landscaping to improve the visual environment. Bulbs reduce pedestrian crossing distances and provide pedestrians with a more comfortable position for determining the location of oncoming traffic at the start of a crossing. Pedestrians can stay on the curb rather than step into a parking lane to see beyond the parked cars when looking at upstream traffic. The replacement of a bus bay in a parking lane with a bus bulb can result in additional parking spaces because the bulb does not require the inclusion of weaving space for a bus to enter the bay. The bulb can be the length of the bus or the minimum length required for boarding and alighting activities. If the bulb is too short to accommodate both bus doors, drivers can announce that patrons must alight at the front door. Figure 37 is a schematic of typical bus bulb dimensions.

Not all locations are good candidates for bus bulbs. A list of conditions or site characteristics that would not support the use of bus bulbs includes

- Facilities with high operating speeds (e.g., 40 to 45 mph [64.4 to 72.5 km/h]),
- Facilities with very high traffic volumes,
- Facilities that are served by vans that deploy wheelchair lifts or where the majority of buses are lift-equipped (e.g., where wheelchair lift operation can take up to 10 min),
- Sites where 24-hr curbside parking is not available,
- Sites with low transit ridership,
- Sites with low pedestrian activity, and
- Layover locations.

Other conditions that may limit the use of a bulb include

- Two-lane streets (i.e., traffic cannot pass a stopped bus),
- Complex drainage patterns,
- High bicycle traffic on roadway, and
- Citizens' and businesses' concerns about changes in traffic patterns.

APPLICATION

Seattle, Washington, and Vancouver, British Columbia, reinforced the concept of urban form and design as a leading indicator for placement of bus bulbs. Both cities highlighted neighborhood characteristics and pedestrian-oriented development as ideal settings for bus bulbs. A key element in the adopted transit-first policy in San Francisco, California, was the promotion of pedestrian-oriented development to improve transit accessibility. Bus bulbs were identified as one of many strategies to improve pedestrian mobility on the sidewalk, to increase waiting areas in and around bus stops, and, ultimately, to improve transit accessibility. In coordination with other transit priority projects such as signal preemption and automobile turn restrictions, bus bulbs may have a significant effect on the end-to-end route travel time and on the operating efficiency of the bus (e.g., elimination of the bus re-entry problem). The benefits for improved pedestrian movement and increased transit waiting areas are undeniable. There are also benefits for transit vehicles.

Table 5 provides a list of common questions and concerns regarding the inclusion or construction of a bus bulb at a candidate site. The list of issues and concerns were developed from meetings with transit officials in cities that currently have bus bulbs and through site observations.

Figure 34. Example of a bus bulb.

Figure 35. Example of boardings at a bus bulb.

Figure 36. Sidewalk clearance created by bulb.

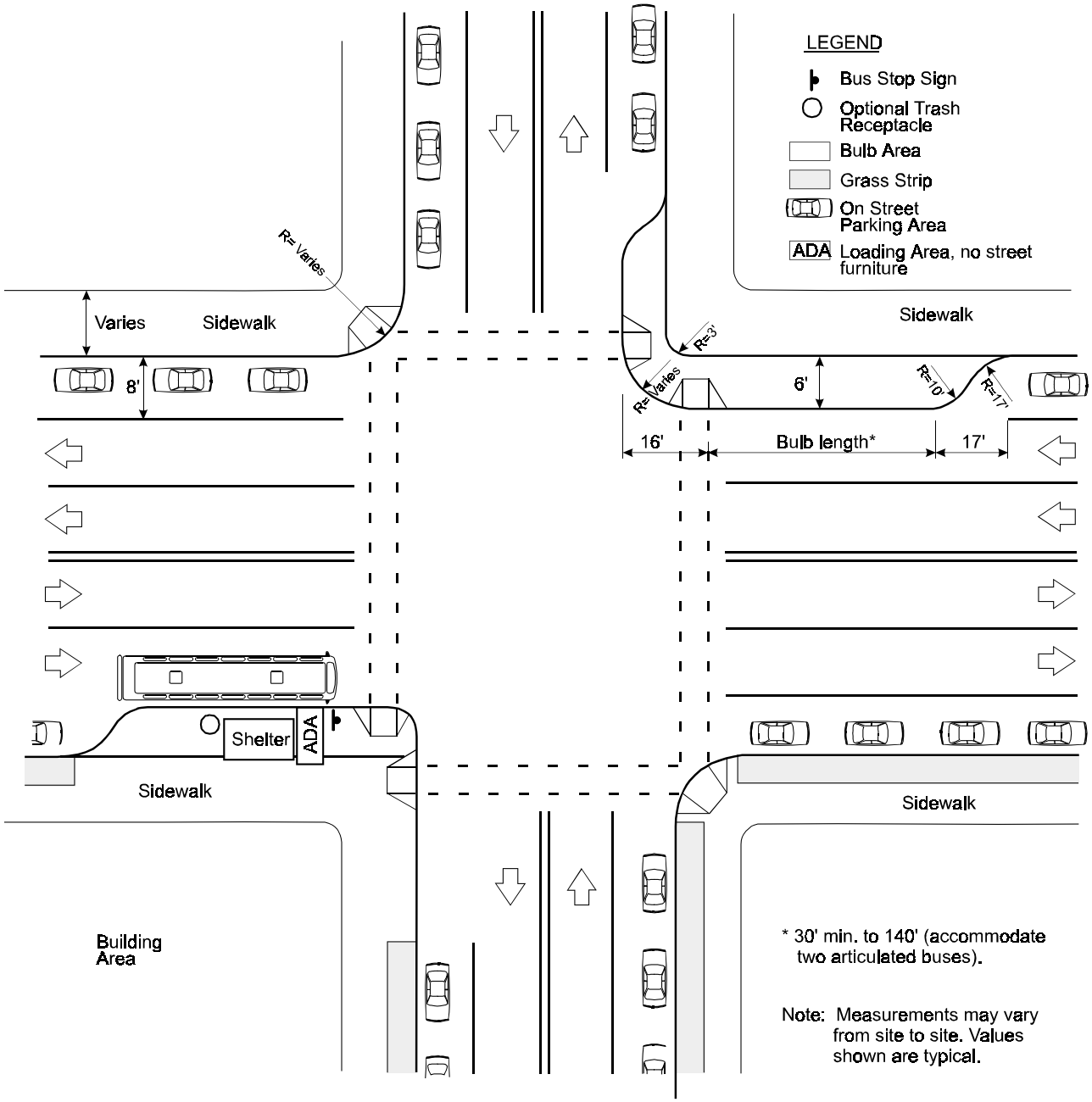


Figure 37. Typical dimensions for a bus bulb.

TABLE 5 Issues with and concerns about the installation of bus bulbs

Community / Neighborhood	• Does the area have a neighborhood feel? • How involved will the citizens be in the project? • Will the bulbs help pedestrian accessibility? • Will the presence of bulbs on one street cause cut-through traffic on a parallel street (i.e., traffic calming)? • Is transit an acceptable means of transportation within the community?
Business Owners	• Will business owners support construction in front of their stores? • Will business owners perceive that the bulbs are removing parking spaces?
Pedestrians	• Does the area have high pedestrian demand? • Is the sidewalk congested at or near the bus stops? • Is there a need to add amenities at the bus stops? • Is there a need to reduce pedestrian exposure in crosswalks and to improve pedestrian safety? Consider curb extensions on two approaches at the same corner—nearside on one corner and a farside on the other corner. • Will a midblock bulb encourage jaywalking? • Is there a need to place a greater emphasis on nonmotorized transportation in the corridor or region?
Bicyclists	• Do bicyclists currently use the parking lane as a travel lane? • How will bicyclists interact with buses that are stopped at the bus bulbs if there is no defined bicycle lane? • Are there defined bicycle facilities on parallel streets (e.g., bike lanes)?
ADA Wheelchair Lift Deployment	• Will vans serve the bus stop (e.g., it is acceptable for the van to be present for up to 10 min while the wheelchair lift deploys)? • Where will the bus shelter, benches, and signs be placed with respect to the ADA landing pad? • How will placement of vending machines be controlled to avoid machines being placed near the pad?
Transit Operations	• Are there high transit ridership numbers in the corridor? • Are there a high number of boardings and alightings at a stop? • Is the site a transfer point? • Will more than one bus be arriving at the site at the same time? Will articulated buses be stopping at the site? • What is the preferred location of bus stops—nearside, farside, or midblock? • What is the frequency of stops? • Will the presence of bulbs provide an opportunity for consolidation of stops?
Traffic	• Are there high traffic volumes on the roadway? • Are the speeds on the street too fast for bus bulbs? • Is the posted speed 45 mph or higher? • Is there a concern for the speed differentials between stopped or slower transit vehicles and faster-moving, general-purpose traffic? • Is the bus having re-entry difficulties at the bus bay stop? • Are buses currently stopping in the travel lane to avoid the re-entry problem? • Will bus bulbs be perceived as traffic-calming measures? • Are erratic maneuvers frequent in and around the bus stop to avoid the stopped bus? • Does the potential exist for conflict between right-turning vehicles and the stopped buses? • Will the all-red phase be extended to avoid having cars trapped in the intersection at farside stops? • Will the back-end of the bus extend into the intersection and block the intersection at a farside stop? • Are there signalized intersections with general-capacity concerns? • How frequently will the bus stop in the travel lane? • Will a stopped bus in the travel lane create unacceptable traffic queues behind the bus? • Are the streets too narrow to have a bus or other traffic pass a stopped bus at a bulb without encroaching on the oncoming traffic lane? • Should a no-turn-on-red restriction be implemented to reduce traffic and pedestrian conflicts, especially if the queue from the farside stop enters the intersection or if there is a history of vehicles going around the bus stopped at a nearside stop to turn right?

TABLE 5 ***Continued***

Parking	• Is there 24-hr curbside parking available? • Will the addition of the bulb add or remove parking? • What types of parking control markings will be installed at the site—signs, tape, or paint? • Will additional parking enforcement be provided to reduce illegal parking at the bulbs and to reduce double-parking before and after the bulbs? • How will the placement of parking signs affect the operations of the wheelchair lift extension? • Will the conversion reduce illegal parking because drivers will be more hesitant to park in a travel lane rather than in a bus bay?
Length and Width of the Bus Bulb	• Will more than one bus be arriving at the site simultaneously? • Will articulated buses be arriving at the site simultaneously? • Is the site a transfer site? • What is the policy of the transit agency regarding which doors are used for boarding and alighting (e.g., all doors or just the front door)? • What is the policy of the transit agency regarding how fares are collected? Are fares collected on both inbound and outbound routes? • Will the bulbs be used to help consolidate bus stops in the corridor? • Will the bulbs also be fitted with pedestrian curb extensions on both approaches to the intersection? • Will bus stop amenities, such as shelters, be added to the bulb?
Construction / Design	• Will utilities (e.g., fire hydrants, light poles, signs) need to be relocated if bulbs are constructed? • How will the street storm water drainage be handled? • How will the sidewalk drainage be handled with the extension of the curb? • Will the design create areas on the sidewalk for standing water, which creates the potential for ice in colder climates? • What will the return radius be on the curb—does a motorized street cleaner need to maneuver in and around the bulb? • To encourage patrons to wait a foot from the curb, consider adding a colored concrete strip, stamped concrete, or brick pavers along the curb to provide a visible line between the waiting area or sidewalk and the roadway. • Bollards have been used to prevent vehicles from encroaching on the bus stop waiting area.

CHAPTER 4

SUMMARY OF FINDINGS AND SUGGESTED RESEARCH

SUMMARY OF FINDINGS

Following are the findings from the four objectives of this research project.

Review of Selected Cities' Practices

Bus bulbs are used in San Francisco, Portland, Seattle, and Vancouver. Characteristics of these cities as compared with other cities in North America are the high development density of the region, well-developed transit corridors, the urban form of the community, and the high level of transit patronage. Common reasons for installing bus bulbs in these cities included

- High transit ridership in a corridor,
- Re-entry problems for buses during peak vehicular times,
- The need for segregating transit and pedestrian activities on crowded sidewalks, and
- The need for transit amenities at bus stop sites that may be too small to accommodate additional street furniture.

The impetus for installing bus bulbs on a site-by-site basis was similar among the cities that already have bus bulbs. Issues such as transit ridership, traffic volumes, high pedestrian traffic along the sidewalk, and roadway operating speeds guided the inclusion of a bus bulb at a particular site. Most of the cities noted that bus bulbs are a fairly new design consideration in and around bus stops. Therefore, many of the initial installation sites were fact-finding studies as much as they were attempts to improve transit and pedestrian operations around the bus stops. Consequently, designs varied greatly among cities and within cities. Major site design findings and issues from those cities with bus bulbs are as follows:

- Bus bulbs were always located on streets with 24-hr curbside parking.
- The width of the bus bulbs was determined by the width of the parking lane. Bulbs are usually 6-ft (1.8-m) wide with a 1-ft (0.3-m) "clear zone" for bicyclists.
- The length of the bus bulbs varied greatly among the cities. Factors that were highlighted included
  - The total number of buses that could arrive at the bus stop at the same time;
  - Whether the fleet uses articulated buses,
  - The fare collection policy (e.g., are all doors used to board and alight or are boarding and alighting controlled?); and
  - Whether the bus stop is located at the far side or near side of the intersection (e.g., a short farside bus bulb may cause the back of the bus to remain in the intersection).
- The return radii for the curb were frequently determined with the turning radius of the street cleaning machines in mind. However, this was not an issue in Vancouver.
- The speed of the facility was typically below 35 mph (56.4 km/h).
- No Parking signs were typically attached to the same pole as Bus Stop signs, and the back face of the curb was painted to discourage illegal parking at the bus bulb. Most cities indicated that bus bulbs are a self-enforcing design.
- Drainage is a major issue when considering implementing a bus bulb. Retrofitting a stop with a bulb can create design challenges for drainage, grading, and ADA requirements, which can result in a significant increase in the cost of the project.
- Bus bulbs can provide the opportunity to consolidate bus stops and, therefore, increase the amount of curbside parking available on a street.
- The location of bus shelters was carefully coordinated to avoid blocking local business signs.
- The additional time afforded by the reduced crossing width was typically given to pedestrians—traffic signal timings were not adjusted.

Curbside Before-and-After Study

The objective of the curbside before-and-after study was to determine whether there was an improvement in pedestrian operations in and around the bus stop at the intersection of San Francisco's Mission and 30th Streets after the implementation of a bus bulb. The pedestrian data were collected during the afternoon peak periods in order to capture the highest demands on available space. The conclusions from this effort are as follows:

- The bus bulb design is clearly an improvement in size as compared with the bus bay design. The curb was extended by 6 ft (1.8 m) over the entire length of the bus stop zone.

- The greatest difference between the two designs is during the boarding-and-alighting phase of the bus arrival-and-departure sequence. The average amount of available space for pedestrians and transit patrons alike improved from 19 to 44 sq ft/ped (1.8 to 4.1 sq m/ped) after the bulb was constructed. This is an improvement of 132 percent, which represents a growth factor greater than 2 between the bay and bulb designs. More importantly, at 44 sq ft (4.1 sq m), it is far less likely that pedestrians or boarding and alighting transit patrons will have to adjust their walking speeds or paths of travel to avoid encountering other pedestrians or patrons. It is also easier for pedestrians to cross bidirectional streams of traffic, which is a common event during the boarding and alighting of passengers from several buses during the peak period.
- The average flow rate of pedestrians traveling along the sidewalk adjacent to the bus stop improved by approximately 11 percent from 4.0 ped/min/ft (13.1 ped/min/m) at the bay configuration to 3.6 ped/min/ft (13.4 ped/min/m) in the bulb configuration during the four highest 15-min increments studied. The data would have shown a greater improvement, but the location of certain street furniture did not change between the two designs. Consequently, the bottlenecks for pedestrians near the corner of the sidewalk and for boarding and alighting bus patrons still existed. The bulb, however, was a marked improvement because it provided ample space for pedestrians to choose alternative paths around the bottlenecks. For example, the available sidewalk space between the shelter and the store changed from 3 to 7.5 ft (0.9 to 2.3 m).
- The extension of the curb near the crosswalk after the bulb was constructed provided a larger queuing area for pedestrians at the corner. The larger area reduced the number of conflicts between those pedestrians waiting to cross the street and those approaching the corner. The curb extension also increased the number of people who complete the crossing of Mission and 30th Streets within the crosswalk lines. When the bay was present, a number of people were observed "cutting" the crosswalk to reduce their exposure in the street.

Roadway Before-and-After Study

The objective of the roadway before-and-after study was to analyze the operations at both farside and nearside bus stops before and after the implementation of bus bulbs to determine the advantages or disadvantages to traffic and bus operations in urban areas. The conclusions from this effort are as follows:

- The replacement of a bus bay with a bus bulb improved vehicle and bus speeds on the block. The block with the farside stop saw a statistically significant increase in vehicle travel speed both during the nonpeak period (speeds increased from 9.5 to 15.7 mph [15.3 to 25.3 km/h]) and during the peak period (speeds increased from 11.4 to 20.9 mph [18.4 to 33.6 km/h]).
- The average speed for vehicles and buses on the corridor increased with the installation of bus bulbs. Buses experienced approximately a 7-percent increase (about 0.5 mph [0.8 km/h]) in both the northbound and southbound directions. Vehicle speeds changed from approximately 15 mph (24.2 km/h) to 17 mph (27.4 km/h) (a 17-percent increase) or 22 mph (35.4 km/h) (a 46-percent increase) for the northbound and southbound directions, respectively. The finding for the vehicles moving in the southbound direction was statistically significant.
- Reductions in travel speeds are assumed to be the consequence of installing bus bulbs because buses are stopping in the travel lane rather than moving into a bus bay. In the before period when the bus bay configuration was present, the majority of the buses would stop partially or fully in the travel lane rather than pulling into the bay. In addition, buses pulling away from the bay would sometimes use both travel lanes to complete the maneuver. The number of buses affecting vehicles in the outside travel lane may not have greatly changed after the bulb's installation. The number of buses affecting vehicles in both travel lanes did decrease because bus drivers no longer needed to use both travel lanes to leave the bus bulb stop.
- Queues did occur more frequently with the bus bulb design; however, the queues were generally short—on average, only one- to two-vehicles long.
- During the peak period, the number of lane changes was similar for both designs at the farside stop. The nearside stop had a greater number of lane changes with the bulb design than with the bay design.
- The average delay to buses attempting to re-enter the travel stream was constant from the before to the after period at the farside stop. The nearside stop, which experienced higher delays to buses, saw a reduction in the average delay with the installation of the bus bulbs. With a bus bay design, the queues at the signal limited the opportunity for a bus driver to re-enter the stream traffic.

Computer Simulation

Computer simulation was used to evaluate the effect of bus stop design on traffic and bus operations. A corridor in San Francisco was used as a base for the corridor study to evaluate a series of intersections that closely represent a real-world environment. Bus stops at isolated intersections were also studied. The studies included both farside and nearside locations and bus bays and bus bulbs. Variables varied during the computer simulation included traffic volume and bus dwell time. Vehicle and bus speeds were the factors evaluated. The conclusions from the simulation are as follows:

- The computer simulation runs indicate that the two designs have minimal effect on bus and vehicle speeds within the corridor. The simulation results were compared with the data collected in the field during the peak period

to determine how well the program was simulating the actual conditions in the corridor. The field results indicate that the installation of the bus bulbs notably improves the travel speed for vehicles and slightly improves the travel speed for buses. The findings from the comparison of the simulation results with the field data indicate that the simulation program may not be sensitive enough to the nuances of how the bus stop design affects operations. Therefore, the design of the bus stop may have greater effect on travel speed than was found in the computer simulation study.

- For the isolated intersection study, it was determined that there is no practical difference between the bus bay and bus bulb designs when the bus stop is located on the far side of the intersection. The difference in speed was near or less than 1 mph (1.6 km/h) for all combinations.
- For nearside bus stops, it was determined that the bus bay design is beneficial over the bus bulb design with respect to traffic operations at higher volumes (above 1,000 vph). The advantages in average vehicle speed of a bus bay design compared with a bus bulb design ranged from approximately 1 to 8 mph (1.6 to 12.9 km/h).

SUGGESTED RESEARCH

Areas for additional research include the following:

- Florida has recently enacted a new law that require drivers to yield the right-of-way when a bus tries to re-enter a traffic stream from a bus bay bus stop (*4*). The effectiveness of this law in resolving some of the difficulties that bus drivers encounter when attempting to re-enter traffic is needed. The specific wording of the new law is as follows:

  > "Duty to yield to public transit vehicles. (1) The driver of a vehicle shall yield the right-of-way to a publicly owned transit bus traveling in the same direction which has signaled and is re-entering the traffic flow from a specifically designated pullout bay. (2) This section does not relieve the driver of a public transit bus from the duty to drive with due regard for the safety of all persons using the roadway."

- Reduction in travel speeds for passenger vehicles is assumed to be the consequence of installing a bus bulb. When a bulb is present, buses are stopping in the travel lane rather than moving into a bus bay. This study found that travel speeds *increased* for both buses and automobiles after the installation of the bus bulbs. In the before period when the bus bay configuration was present, buses would stop partially or fully in the travel lane. In addition, buses pulling away from the bay would sometimes use both travel lanes to complete the maneuver. Therefore, the number of buses affecting vehicles in the travel lanes did not change as greatly as it could have. Other locations in which buses move completely out of the travel lane and into a bus bay would be expected to have a different finding.
- The use of palmtop computers and specially written programs greatly enhanced the data collection efforts of the research team. Data were able to be collected more efficiently and with greater detail. For example, a time stamp was automatically entered for each data point, thereby allowing the research team to further disaggregate the data by time and by certain events (e.g., bus arrival and departure). Furthermore, the data could be quickly downloaded for analysis from the palmtop computers onto personal computers. The data did not need to be entered twice, which would have occurred if the data had been collected manually. While in San Francisco, the research team observed several Muni supervisors manually entering data with pencil and paper. The supervisors also used stop watches as time stamps. Based on knowledge of how other transit agencies gather data, it appears to be fairly common for transit authorities to rely on manual data entry, collection, and reduction. On the surface, this appears to be very time-intensive and creates greater opportunity for error. There is a need within the transit community to have programs in place for common data collection efforts (e.g., schedule adherence and boarding and alighting numbers).
- The strategy of implementing bus bulbs in a corridor is one of several measures that can be implemented individually or in tandem to improve overall route travel time and reliability. The nine bus bulbs on south Mission Street were the first phase of bus bulbs to be constructed in a multiphase implementation of bus bulbs on Mission Street. Additional bulbs are planned for Mission Street between 20th and 25th Streets. After the second phase of bulbs are completed on north Mission Street, no more bulbs are planned for the corridor. However, by 2001, Muni plans to have implemented signal preemption throughout the corridor. Muni, as well as other transit agencies, is interested in identifying the per-run and per-intersection travel-time savings of having both bus bulbs and signal preemption in operation. The cumulative travel-time savings could be quite significant for each route. The 14 Line on Mission Street has the highest transit ridership levels of any surface route west of the Mississippi River. Transit vehicle travel-time savings and per passenger travel-time savings could be analyzed and studied. Significant person travel-time savings within the study corridor may be realized.
- At some locations, the extension of the sidewalk toward the traffic lane could benefit from a warning marker on the extension or paint or tape markings along the curb to increase the extension's visibility to motorists. Acceptable markers and markings need to be identified and tested.

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3. *Special Report 209: The Highway Capacity Manual*. 3rd Edition. Transportation Research Board, National Research Council, Washington, D.C. (1994).

4. "New Florida Law Requires Drivers Yield Right-of-Way to Buses," *Urban Transportation Monitor*. Vol. 13, No. 19. (Oct. 15, 1999) p. 1.

APPENDIX A

REVIEW OF SELECTED CITIES' PRACTICES

Bus bulbs were studied as part of a more comprehensive research study of bus stop design and location, which was sponsored by TCRP (*1*). During the course of the study, it was determined that little documentation existed on the operation and design of bus bulb configurations, either in the general literature or within transit agency design manuals. Transit agencies were surveyed to determine the best practices being applied during bus stop design and location decisions. Questions regarding the use and design of bus bulbs were a part of this comprehensive study.

Relatively few transit agencies responding to the mail-out survey indicated use of bus bulbs. These agencies included those in Charlotte, North Carolina; Grand Rapids and Lansing, Michigan; Orlando and West Palm Beach, Florida; Portland, Oregon; San Francisco, California; and Seattle, Washington. The cities of Portland and San Francisco provided guidelines on bus bulb design and placement as part of their responses. Experience from the previous TCRP project (*1*) indicated that the actual definition of a "bus bulb" was interpreted in many different ways. For example, some responding agencies that indicated the use of bus bulbs were merely noting pedestrian curb extensions or "nubs" at intersections that happened to be near a bus stop. The buses did not or could not stop at the curb extension because it was not long enough to accommodate boarding and alighting activities.

Several large cities in the Pacific Northwest, however, are exploring the use of bus bulbs as one of many strategies to deploy a transit preferential program. Researchers visited four transit agencies in the West and Northwest that were known to use bus bulb configurations (Figure A-1). To observe and document existing and planned bus bulb configurations, the research team visited San Francisco, California; Portland, Oregon; Seattle, Washington; and Vancouver, British Columbia. The cities were previously identified in the aforementioned TCRP project, and further contact with the transit agencies revealed that bus bulbs now receive serious consideration at several existing stops. Each of these cities has a strong pedestrian and bicycle program to augment transit operations in the region.

The methodology used during the regional visit was similar to the one employed during the previous TCRP project. Each individual on the trip was responsible for his or her area of expertise. Site visits of existing bus bulbs were conducted prior to meeting with transit and city representatives. It was critical for the team to observe how sites were operating before interviewing knowledgeable staff. During the site visits, notes were made about site layout and facility characteristics, and observations were made regarding transit, vehicle, and pedestrian operations. Still photography was also used to capture site layout, neighborhood setting, and site details (e.g., placement of traffic control measures, drainage, and bus arrival activities).

While in the city, the research team met with transit and city representatives (e.g., city planners, pedestrian and bike program operators, and mobility coordinators) to discuss issues associated with bus bulb design and placement. Issues discussed during the meeting included

- The history of bus bulbs in the area;
- The impetus for considering the use of bus bulbs (e.g., high transit ridership in a corridor, re-entry problems for buses during peak vehicular times, the need for separating transit and pedestrian activities on a sidewalk; and the need for installing additional transit amenities);
- The typical characteristics for sites that would be and for sites that would not be good candidates for bus bulbs (e.g., traffic volumes, transit ridership, high pedestrian use, and roadway operating speeds);
- Experiences or "lessons learned" to date with bus bulb installation;
- The costs of constructing bus bulbs (e.g., retrofit versus new); and
- The development of design standards in the area.

The following pages document the findings from the regional visit. A general summary is presented for each city by a review of the following topics:

- Width and length of bulbs,
- Parking,
- Americans with Disability Act (ADA) wheelchair lift deployment,
- Drainage,
- Bus stop location,
- Pedestrians,
- Bicycles, and
- Cost.

A review of sites visited follows each city summary. Only unique characteristics are discussed for each site. The section on Seattle has a general overview of regional practices,

Figure A-1. Cities with bus bulbs visited.

but it also contains a very detailed review of a bus bulb demonstration project. Similar to Seattle, Vancouver also has a demonstration project underway with two sites near the University of British Columbia campus. Because Vancouver only had two examples at the time of the visit, the general overview and site details are one and the same.

SAN FRANCISCO, CALIFORNIA

The concept or use of bus bulbs in San Francisco dates back to the early 1970s with the adoption of the Transit Preferential Streets (TPS) program in 1973. Under this program, several "transit-first" strategies were identified, which were designed to create a more "transit-friendly" environment within the city of San Francisco, especially within those corridors where there was already a large dependence on transit to move people (*2*). San Francisco, as a city, is unique in North America. The city form is constrained geographically by the Pacific Ocean and surrounding hillsides, which encourages high-density expansion. Neighborhoods are densely built around narrow streets, and there is limited parking throughout the city, either on-street or in parking garages. The population and employment is diversely distributed throughout the city. In fact, San Francisco has the second highest population density in the United States. Because of all of the above factors, there is a heavy reliance on transit and sidewalks for mobility.

The increased emphasis toward pedestrian-oriented types of development within the TPS program and the adopted transit-first policy is to improve transit accessibility within San Francisco. Strategies that were first identified included bus bulbs, signal preemption for transit vehicles, increased parking enforcement at selected locations, exclusive bus-only lanes, and automobile turn restrictions (*2*). The deployment of the program was guided by a number of factors. Among these factors were identifying streets with the highest levels of transit ridership and frequency of service, streets with existing rail and trolley infrastructure, and locations where there was an unacceptable level of auto-to-transit conflicts (*2*). Streets were essentially scored based on these criteria. The higher the score a street receives, the greater number of TPS projects it could receive.

The first bus bulbs in San Francisco were built on Monterey Boulevard, Polk Street, and Stockton Street. The site characteristics for each of these locations are unique and point to the diversity of neighborhoods in the city. Monterey Boulevard is a residential four-lane arterial. Polk Street is a three-lane facility in a well-established mix of commercial and residential development near downtown San Francisco. The Stockton Street bulbs, which are entirely in Chinatown, were constructed to relieve extremely high pedestrian volumes along narrow sidewalks. During this time, there were also bulbs installed in and around Union Square, which is essentially the center of downtown and has high-rise hotels, offices, and commercial shopping buildings.

It was not until two decades later that additional bus bulbs were built within San Francisco proper. In 1996, four bus bulbs were built in the Castro District. Two bulbs are directly located at the intersection of Castro and Market Streets—one farside and one nearside. This intersection serves multiple transit lines, including subway, rail cars, and bus lines. Congestion relief for pedestrians and transferring transit riders was a major objective of the project.

The most recent additions occurred along south Mission Street. A total of nine bulbs were built between Cesar Chavez Street and Cortland Avenue. Mission Street is an historical shopping center with a mix of single-room hotels and small residential living spaces above local businesses. Sidewalks can become inundated with pedestrians, especially after area schools release children in the afternoons and on Saturday mornings when local residents do their weekly shopping. Further adding to the pedestrian demand are the intermittent surges of people created by the boarding and alighting activities of buses. The Mission Street transit volumes are the highest ridership numbers in a corridor west of the Mississippi River.

Another 15 to 18 bulbs are planned, the majority of which are for Mission Street between 20th and 25th Streets. The Mission Street at 20th Street bus stops have the highest number of boardings in San Francisco. Other notable locations are Stockton Street at Geary Street (downtown San Francisco) and Potrero Avenue at 23rd Street near San Francisco General Hospital. The Potrero Avenue site is near the city hospital; however, the most noteworthy item about this site is that it is on a six-lane arterial with posted speeds of 45 mph (72.5 km/h). This is the first bus bulb being considered on a facility with posted speeds greater than 30 mph (48.3 km/h) in the city of San Francisco. Figure A-2 shows the location of bus bulbs that have already been constructed in the city.

The following pages provide a general overview of practices and experiences with bus bulbs in San Francisco. Individual site descriptions follow.

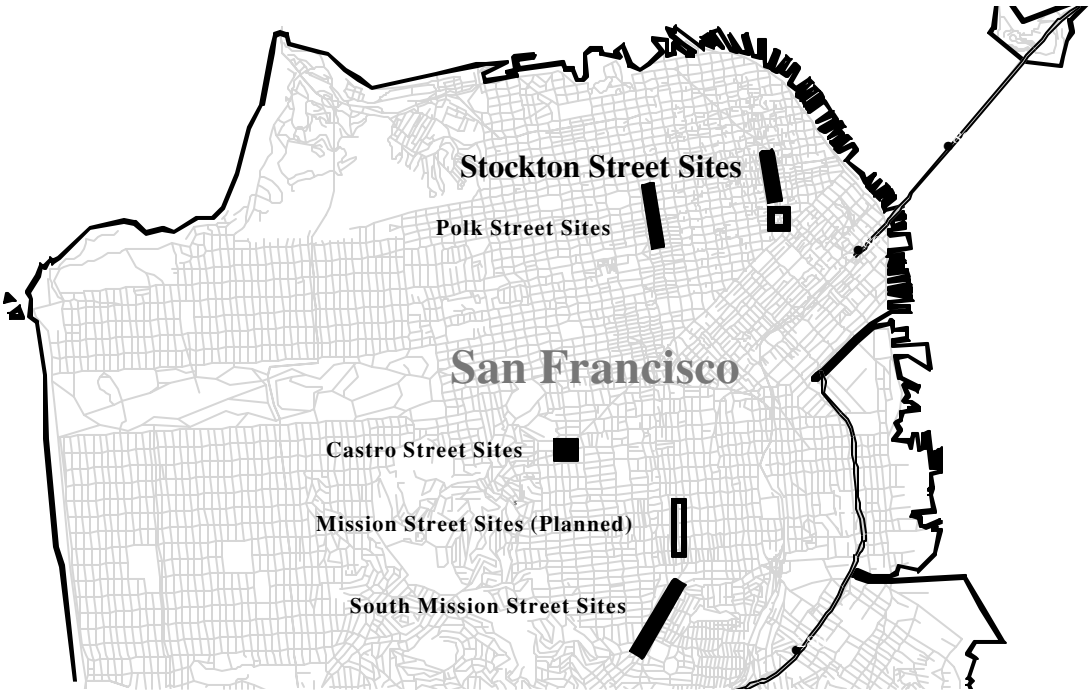


Figure A-2. Location of bus bulbs in San Francisco.

Overview of Practices and Experiences

Width and Length of Bulbs

The current standard width of bus bulbs in San Francisco is 6 ft (1.8 m), depending on any unique site characteristics. The additional distance provided by the bus bulb allows the San Francisco Municipal Railway (Muni) to move transit shelters off of the sidewalk and onto the bulb. Vending machines, benches, and trash receptacles are also moved onto the bulbs, which helps relieve pedestrian congestion along the adjacent sidewalk.

The standard length of a bus bulb is 140 ft (42.7 m). The length was expanded from 60 to 70 ft (18.3 to 21.4 m) in recent years to better accommodate the simultaneous arrival at the site of two articulated buses. Prior to the installation of bulbs, it was difficult for two articulated buses to completely stop in the bus bay at the same time. Figure A-3 is an example of a bus bay that is inadequately sized to handle multiple articulated buses at the same time.

On several occasions, it was not unusual for the research team to observe three buses arriving at a bus stop at the same time (sometimes referred to as "bunching," see Figure A-4). In these instances, even the greater length of the bus bulb is inadequate. Similar to the curbside arrangement, the third or last bus would either board and alight on the street or wait for the first two buses to depart. When the third bus waits for the first two buses to depart, the bus causes additional delay to any vehicles queued behind the bus.

Transit Vehicle Travel Time and Dwell Time

The foremost reason for installing the bulbs along Mission Street is the bus re-entry problem associated with bus bay stops. Bus drivers are extremely positive toward the construction of bus bulbs. Prior to the construction of bulbs, certain routes would experience delays, which were directly blamed on the bus re-entry problem. Drivers had a problem with staying on schedule along routes where the buses interacted with high vehicular volumes. Figure A-5 is an example of a bus on Mission Street during heavy vehicular volumes.

Figure A-3. Two buses are unable to park in bus bay stop.

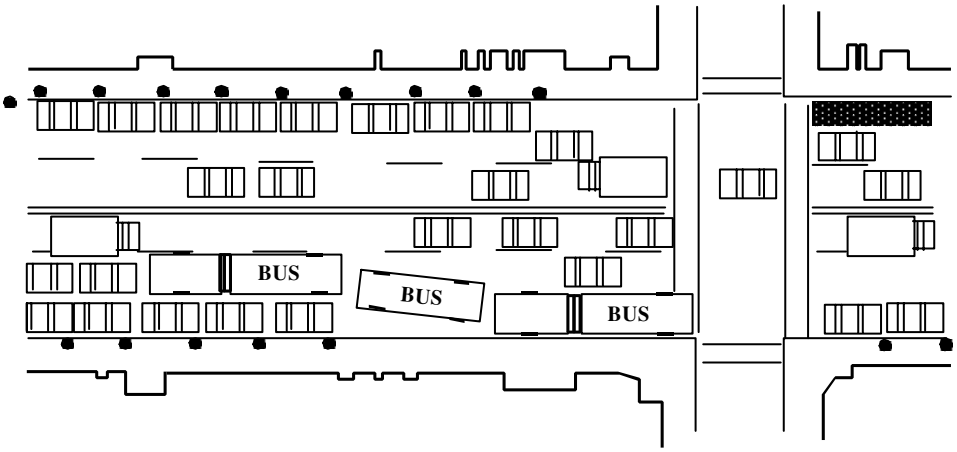


Figure A-4. Example of transit vehicle "bunching" at bus bay.

Further exacerbating the re-entry problem are illegally parked vehicles at the end of the bus stop zone or double-parked vehicles or trucks just beyond the bus stop zone (Figure A-6). Bus drivers must carefully maneuver around these parked vehicles and, at the same time, avoid hitting other vehicles in the travel lanes and oncoming vehicles. If bus drivers are not careful, the catenary connection between the bus and the overhead electrical wires can become dislodged, which causes the bus to stop in its tracks. This can add to the route delay if this event occurs often. The time difference can be quite substantial when bus drivers must slowly re-enter the flow of traffic with these unnecessary obstacles.

To avoid maneuvering around illegally parked vehicles in the bus stop zone or double-parked trucks just at the end of the zone, bus drivers will do one of two things: (1) board and alight the bus from the street (Figure A-7) or (2) partially pull into the zone to avoid the bus re-entry problem around a double-parked vehicle or truck (Figure A-8). Boarding and alighting passengers from the bus onto the street can create hazardous conditions for the patrons and expose the transit authority to liability. Partially pulling into the zone leaves all or a portion of the transit vehicle in the travel lane. When this partial pulling in occurs, the bus bay is functioning as a bulb in terms of blocking a travel lane.

Figure A-5. Bus operating during heavy vehicular volumes.

The bus re-entry problem was not the only source of delay mentioned as a problem for the bus trolley lines. Another source of significant delay is entry into the bus stop zone. Double-parked vehicles can cause changes in how the bus driver approaches the bus stop zone. Double-parking is a significant problem in areas with an abundance of local shops that have limited on-street parking.

During the on-site visit, the fare collection policy and bus dwell time were concerns. The current policy is to have patrons alight from the rear door of the bus and to board in the front of the bus. There are signs to this effect in the bus. However, during extreme crowding, it was observed that all doors were used for boarding and alighting to minimize dwell. If the bus driver did not open all of the doors, long queues would form in and around the bus stop and, in some instances, these queues would interfere with pedestrians on the sidewalk. This interference with pedestrians is especially true for bus stops that do not have bus bulbs. Muni will begin a proof-of-payment system that enables all doors to be open for boarding and alighting while still maintaining appropriate fare collection levels. It is hoped that this system will decrease the amount of time a bus is at a bus stop.

In another effort to improve transit vehicle time, Muni is considering signal preemption on a number of routes. Signal preemption is being installed along Mission Street as part of the street improvement plan. It is hoped that the installation of bulbs, the implementation of a new fare collection system, and the use of signal preemption will improve the end-to-end route travel times by 5 to 15 percent on Mission Street.

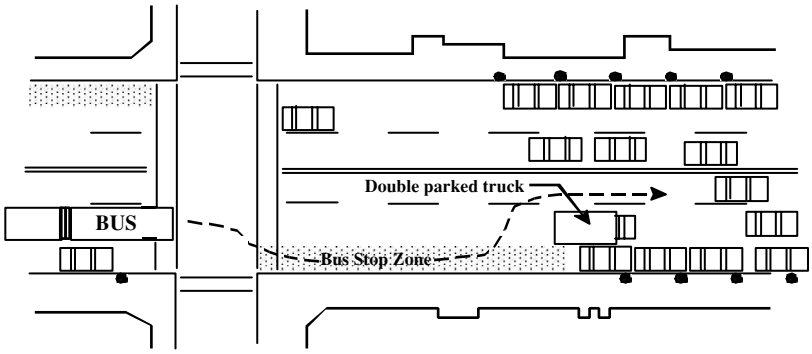


Figure A-6. Transit vehicle path impacted by double-parked truck at end of bus bay.

Parking

Parking is extremely limited throughout the city of San Francisco. On-street parking is typically available on both sides of the street. While the research team was in San Francisco, illegal parking at metered spaces was aggressively monitored. Despite these efforts, illegal parking in the curbside bus bay zone is a significant problem in certain areas of San Francisco. Motorists park in the curbside bus zone when parking spaces are full. Either a passenger or the driver will quickly run errands at local stores while the car is illegally parked. It was not an uncommon event for buses to encounter cars blocking the path into the curbside zone. Bus drivers will usually be forced to stop in the travel lane either completely or partially in order to have enough maneuvering room to return to the traffic stream safely. The bus then blocks the outside lane of travel, and cars either form a queue behind the stopped bus or weave into the inside lane to avoid the queue (Figure A-9).

Double-parking either before or after the zone can also affect the overall travel time of the route. Because of the limited on-street parking, delivery trucks load and unload in the outside lane of travel. If this activity occurs near the bus stop zone (either before or after), the bus driver must adjust the path of travel dramatically to maneuver around the double-parked vehicle. Muni believes that bus bulbs are a self-enforcing parking design. Bus bulbs highly discourage any motorists from temporarily parking in the bus stop zone because of the amount of traffic the illegally parked vehicle would block.

Bus bay stops are clearly marked with signage on posts and red paint along the curb over the entire bus stop zone. The curbside zone is also marked with Bus Stop and a large white box that defines the zone on the pavement. The bulbs have the same signage on posts and red curb markings, but the street does not have any markings. Figure A-10 shows downstream parking near a bus bulb on Mission Street.

The construction of the bus bulbs on Mission Street did not remove any parking spaces from the parking lanes. However, in this case, perception is greater than reality. A few of the local store owners made it a point to tell the research team during the data collection efforts about how the bus stops removed parking in front of their respective stores. The bulbs, in this regard, were not well received by these local business owners.

Figure A-7. Buses board and alight on street to avoid parked vehicle.

Figure A-8. Bus partially pulls into bus stop to avoid bus re-entry problem.

Figure A-9. Illegally parked car affects bus and general-purpose movement.

Drainage

Drainage is a major contributor to increasing the cost of a bus bulb project. Because bus bulbs have been constructed in San Francisco since the 1970s, the city has more experience with overcoming design problems associated with constructing what essentially amounts to curb extensions. Most of the cost is associated with regrading the street to accept the extension. The Mission Street bus bulb project was part of an overall road reconstruction project. Consequently, retrofitting a bus bulb to existing grades was not as much of an issue as it might have been at other sites.

The greatest design issue is how to connect the curb extension to the existing grades of the sidewalk and roadway while maintaining proper drainage to storm gutters. The earliest approach was to place a covered drain between the existing curb and the bulb (Figure A-11). However, this approach was

Figure A-10. Example of defined curbside parking near a bus bulb.

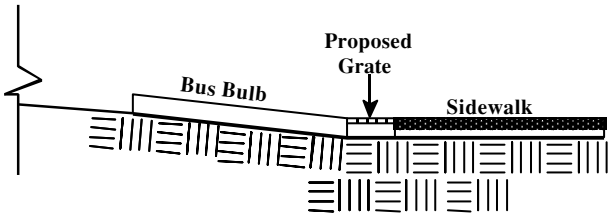


Figure A-11. Proposed drainage system.

abandoned for numerous reasons—mainly, maintenance of the covered drain.

The street gradient on Mission Street is fairly strong, and the city could rely on gravity to propel water around the bulbs. Where the grade was fairly shallow, the city did install some grates to handle runoff from the street and from intersecting streets that were draining downhill toward Mission Street (Figure A-12).

General-Purpose Traffic

Bus bulbs, as previously mentioned, are one of many strategies that can be implemented under the TPS program. Obviously, in these corridors, the emphasis is placed on the people-

Figure A-12. Drainage detail.

carrying capacity of buses rather than on automobiles. The 14 Line on Mission Street is the single heaviest surface line west of the Mississippi River with 80,000 patrons per day. Although vehicular volumes are fairly active throughout the day along Mission Street and other corridors, the roads are not overly saturated with automobiles, and by no means do the number of people moved on the roads compare with the number of people moved in the corridor by transit. Traffic volumes and speeds play an obvious role in the decision-making process, but it is as much a recognition of policy as it is a design decision.

Mission Street has always been viewed as a street designated primarily for transit. Despite this, there were concerns that the bulbs could be viewed as traffic-calming measures and that some traffic would divert to Valencia Street, which is a parallel alternative to Mission Street. The issue is more acute at the intersection of Mission and 30th Streets, which has a farside and nearside bus bulb that are directly across from each other. The new reduced street cross section could conceivably be perceived as a traffic-calming measure (Figure A-13).

Stockton Street is a two-lane facility. During congested periods drivers either move to another road or wait through the delays caused by a bus stopped at the bulb. Similar to Mission Street, there are a tremendous number of people being moved aboard transit and on sidewalks through Chinatown.

For the Polk Street bus bulbs, Van Ness Boulevard is a more attractive alternative for vehicles than is Polk Street. There may have been some regular drivers of Polk Street who diverted to a parallel facility, but this was not mentioned as an issue observed by Muni. Drivers may have simply accepted any delays the buses represented as a normal activity associated with the facility. Prior to the installation of the bulbs on Mission Street, the bus bays essentially operated like bus bulbs during peak vehicular times. Bus drivers avoided leaving the travel lane because of concerns with the bus re-entry problem. Vehicles either queued or changed lanes prior to encountering the stopped bus (Figure A-14). Figure A-15 is an example of the traffic queue and "tie-up" behind a bus that has partially pulled into the bus bay. Bus stop spacing on Mission Street is approximately every block or every other block. Consequently, stopped buses are not an uncommon event for drivers, and, in most instances, drivers anticipated encountering a stopped bus and avoided using the outside travel lane.

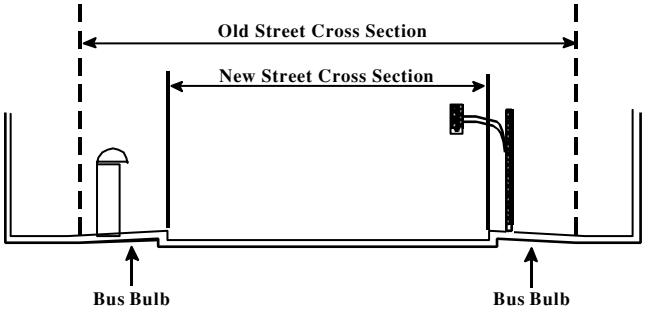


Figure A-13. Is this traffic calming (Mission and 30th Streets)?

Another bus–auto interaction concern is right-turning vehicles from intersecting streets. The problem may be heightened by the addition of a bulb near the intersection (Figure A-16). When a bus completely pulls into the bus bay stop, there is a clear travel lane for a vehicle turning right from the minor street onto the major street. However, a bus stopped at a bus bulb can block the path of a right-turning vehicle into the outside lane. The problem can also occur with bus bays during peak hours. Figure A-17 is an example of a right-turning vehicle encountering a stopped bus that has not completely pulled into a bus bay stop.

Bus Stop Location

San Francisco does not appear to have a preferred bus stop location. Any combination of farside, nearside, and midblock stops can be found on almost any route. Bulbs have been built at all three location types within San Francisco.

Pedestrians

A major impetus for installing bus bulbs in the San Francisco area is pedestrian crowding in and around bus stops. Pedestrian volumes can cause sidewalks to reach saturation levels in some areas of the city, especially in areas in which there is a mix of residential and commercial land uses. Pedestrian crowding can also occur at the street corners when surges of transit patrons board and alight from a vehicle.

Pedestrian crowding on sidewalks is highly variable in San Francisco and is extremely dependent on the neighborhood and its characteristics. Not unlike vehicular peak periods, most pedestrian crowding revolves around business hours of operation. The downtown bus stops are no exception to this rule. The periods before and after working hours have the highest pedestrian and transit volumes.

However, neighborhoods within San Francisco are extremely diverse in culture and in characteristics. Along Mission Street, the peak period for pedestrians during the weekday is between 2:30 P.M. and 4:00 P.M., when elementary and high school students are walking home from school. The highest pedestrian volumes, however, occur on Saturday morning when local residents shop in the many different businesses that are located on Mission Street. Figure A-18 is an example of the pedestrian crowding that occurs on Saturday mornings on Mission Street.

Like Mission Street, Stockton Street experiences its largest pedestrian volumes on Saturdays. Because people are walking to and from the shops, they are carrying their purchases. Waiting patrons who are carrying multiple bags require more room than pedestrians who are not carrying bags. The combination of shoppers and tourists in Chinatown tends to

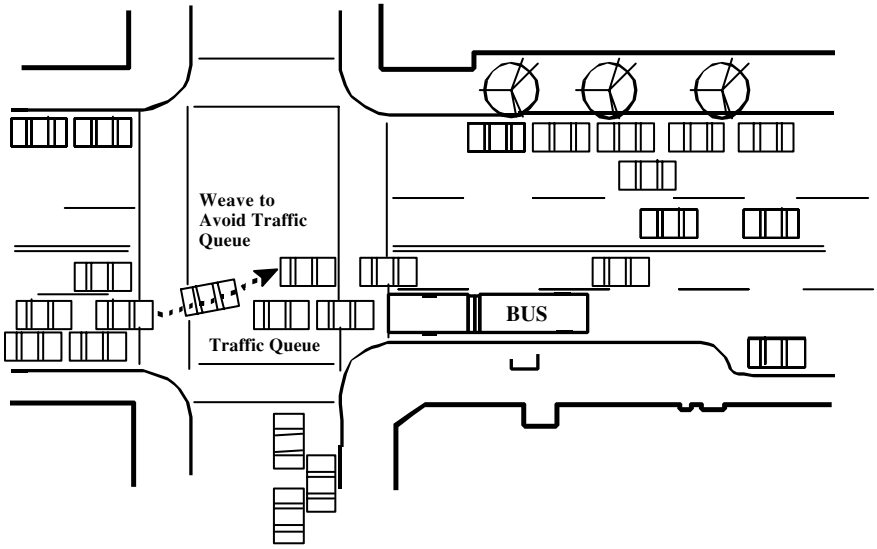


Figure A-14. Examples of driver behavior when encountering a stopped bus.

overwhelm the limited capacity of the sidewalks in this area of San Francisco.

Sidewalks are often crowded with street furniture (e.g., light poles, fire hydrants, benches, trash receptacles, trees, and vending machines). In the Mission District, it is not uncommon for sidewalk vendors to set up impromptu operations on the sidewalk. This is especially true on the weekends when pedestrian and transit patronage is the highest. Local businesses also extend displays beyond the storefront (e.g., fruit stands or hanging clothes). All of these local factors reduce the available walkway width in and around bus stops.

These same types of activities also occur near the Stockton Street sites. In Chinatown, local merchants selling food receive fresh shipments throughout the morning. Merchants load and unload directly in front of their stores. Used crates and boxes are discarded in parking stalls or are stacked along the sidewalk in front of the stores. These storage areas serve as choke points for pedestrians and transit patrons. The bulbs help to segregate waiting patrons from passing pedestrians and shoppers.

Figure A-15. Traffic queue behind stopped bus.

Bus stops with bus shelters can also serve to reduce the walkway width that is available for passing pedestrians. Muni moved shelters off the sidewalk and onto the bulbs to create additional room on the sidewalk. Queues of bus patrons can also crowd the adjacent sidewalk at curbside bus stops. The bus bulbs provide an additional 6 ft (1.8 m) of sidewalk width in and around the bus stop zone; this extra width appears to be the greatest source of relief for pedestrian crowding.

The addition of bus bulbs reduces pedestrian exposure time in crosswalks. The city of San Francisco does not plan to change signal timing at any of the intersections for additional benefits to either pedestrians or vehicles. The extra time is given to the pedestrian at locations with bulbs. The bus stops at nearside and farside locations can cause intermittent surges of pedestrians at the street corner during boarding and alighting activities. Figure A-19 shows an example of the surge of pedestrians at a corner created by the presence of the bus. Bus bulbs at these locations provide additional room for pedestrians at the street corner.

Another interesting item associated with bus bay stops is the level of pedestrian–transit vehicle interaction and pedestrian safety. In most cases, regardless of whether there is a double-parked vehicle or an illegally parked vehicle in the bus stop zone, bus drivers provide some room between the side of the bus and the back-face of the curb. Drivers park away from the curb to avoid hitting waiting patrons and to avoid hitting pedestrians with the vehicle's side mirrors. Muni keeps a record of these incidents, and one of the items the agency is interested in comparing between bus bays and bus bulbs is pedestrian safety. Are the bus bulbs safer than bus bays in this regard? Muni believes that these types of incidents will decrease at sites with bus bulbs.

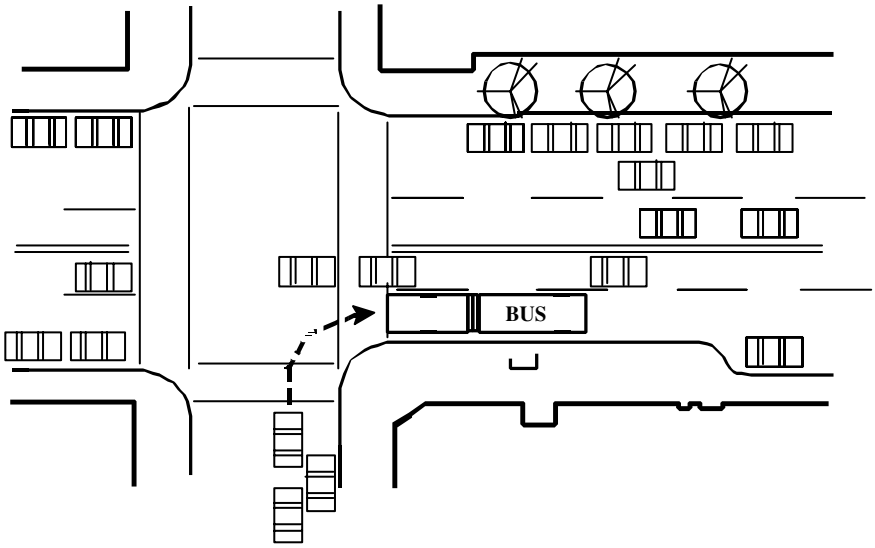


Figure A-16. Right-turn conflict at bus bulbs.

Bicycles

Defined bike lanes were not present on any of the observed examples of bus bulbs in San Francisco. Because vehicular volumes are so heavy and the streets are so narrow, it is rare to see bicyclists on any of the heavy transit routes. Because the bulbs do not encroach on the vehicular lanes, there is no impact on bicyclists, according to Muni. The width of the bulbs is essentially the same as the width of the parking lane. Therefore, bicyclists must share the travel lanes with motorists and transit vehicles alike.

Figure A-17. Car encountering stopped bus.

Cost

The nine Mission Street bus bulbs cost approximately $500,000 to design and construct. The bus bulbs were included in a roadway reconstruction project and were not a stand-alone project. The neighborhood specifically requested that the bulbs be built during the road reconstruction to reduce the overall construction time in front of neighborhood storefronts. The total cost of the project was approximately $2,000,000.

Figure A-18. Pedestrian crowding on a Saturday morning along Mission Street.

Figure A-19. Surge of alighting patrons at crosswalk.

Figure A-20. Midblock bus bulb on Polk Street.

The first phase of the reconstruction effort was relocating the overhead electric wires for the buses. Because the buses would no longer be pulling into and out of a bus bay, the wires could be relocated into better positions to avoid having the catenary hook slip off the wire. It is unclear whether this would have been done without the reconstruction of the road.

A major portion of the cost of the Mission Street bulbs was relocating fire hydrants, street lights, and traffic lights. Muni signs were also relocated, but this was minor in comparison. As was discovered in other regions, drainage is a challenging and costly portion of the overall bill for bus bulbs. Of major concern was the connection between the bulb and the existing sidewalk. The curbside channel for storm water is effectively blocked by the curb extension. Muni initially allowed a covered channel between the curb and the bulb for curbside drainage. This channel is present on some of the older bulbs. However, because the road was being reconstructed and regraded, the Mission Street bulbs were built without the channel. Storm water street grates were added before and after the bulbs to handle on-street drainage.

Polk Street Sites

Polk Street is a mix of residential and established local businesses and restaurants adjacent and parallel to Van Ness Boulevard. Polk Street has a medium level of transit ridership. The sidewalks, however, are used heavily throughout the day by local residents and shoppers.

Polk Street is a three-lane facility—two lanes in the southbound direction and one lane in the northbound direction. The bulbs were built on only one side of the street in the southbound direction. A majority of the bulbs were built at the intersection's nearside. There is one midblock stop between Sacramento and Clay Streets and a farside stop at Pine Street. Figure A-20 is a picture of the midblock stop at Polk Street. Figure A-21 is a plan view of the midblock bus bulb.

The bulbs at the intersections (both farside and nearside) provide much needed space at the intersection for crossing pedestrians. The capacity of the sidewalk to handle pedestrians and waiting transit patrons is clearly improved with the addition of the bulbs. Although the bus bulbs were not created or intended to be used in this fashion, the bulbs have become a storage haven for the large numbers of vending machines that are present on Polk Street. Figure A-22 is a plan view of the farside bus bulb at the intersection of Pine and Polk Streets.

Stockton Street Sites

Like Polk Street, Stockton Street is a three-lane facility—two lanes in the southbound direction and one lane in the northbound direction. Stockton Street is the main thoroughfare through Chinatown, and it eventually transitions into North Beach (Little Italy). Consequently, the sidewalk is congested with local residents and tourists alike. Transit volumes in this neighborhood are extremely high, especially on Saturday mornings when residents do their weekly shopping. The sidewalks are very narrow in relationship to the number of pedestrians who move through the corridor. Street vendors, storefront displays, and discarded boxes from local stores all serve to reduce the available space on the sidewalk.

The bus bulbs were created for the purpose of providing storage for waiting transit patrons. Prior to the installation of the bulbs, the bus stops would create bottlenecks for pedestrian movement because of the number of transit riders waiting for their next available bus. Only the bus bulb on Stockton Street at Sacramento Street has a bus shelter. For maximum storage area, the other bus bulbs in this neighborhood are devoid of any street furniture. The bulbs obviously serve their intended purpose of relieving choke points on the sidewalk. Figure A-23 is an example of a bus boarding and patrons alighting at the intersection of Stockton and Sacramento Streets.

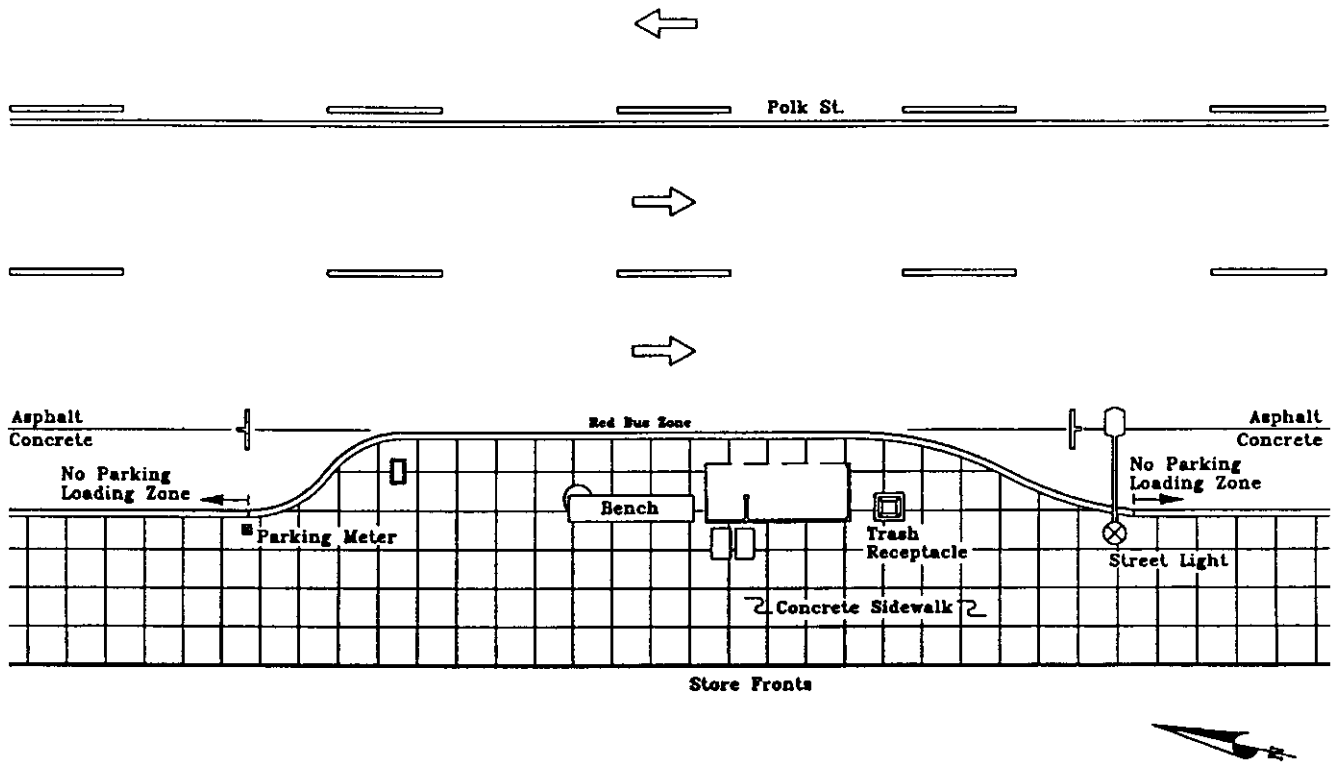


Figure A-21. Plan view of midblock bus stop on Polk Street.

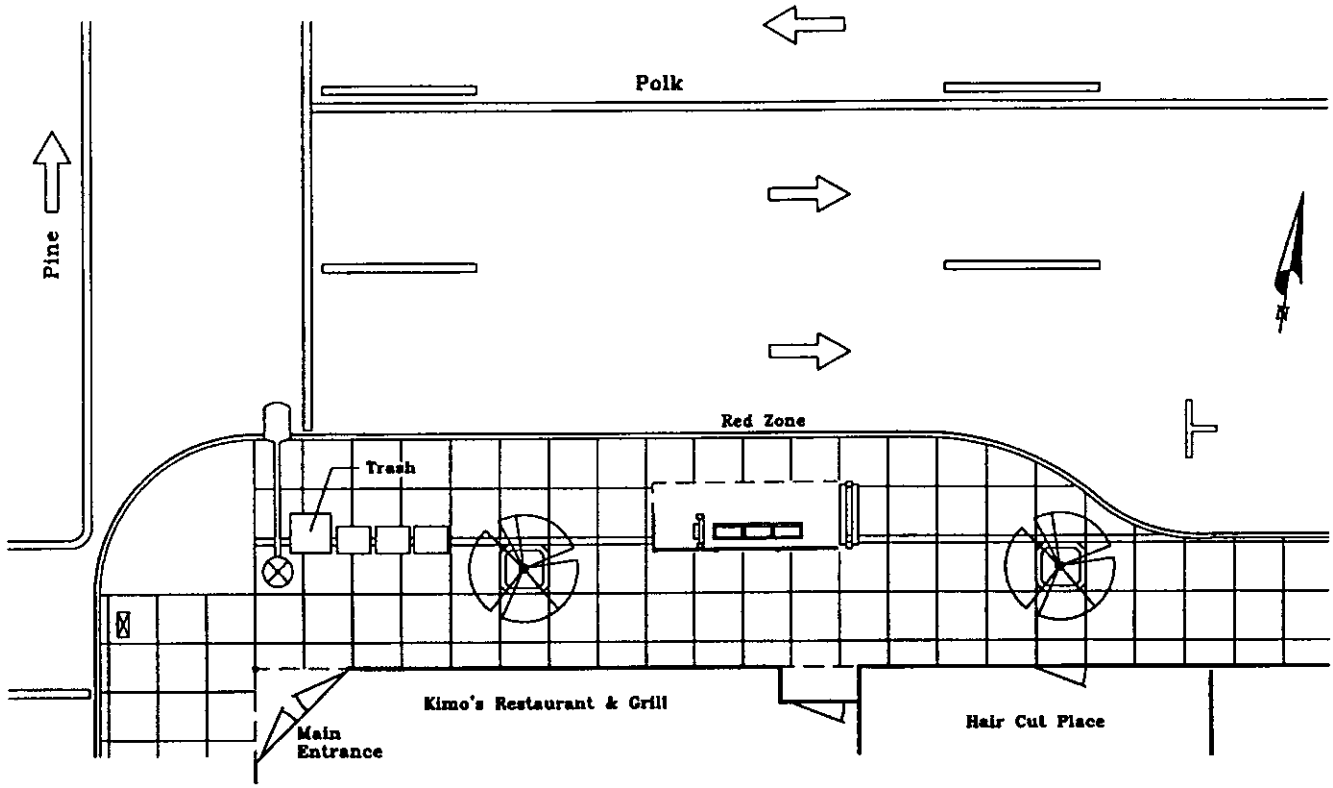


Figure A-22. Plan view of farside bus bulb at Pine Street.

Figure A-23. Bus bulb on Stockton Street.

Figure A-25. Sidewalk congestion at the Castro and Market Streets bus bulb.

Castro Street Sites

The Castro Street sites were installed in mid-1996 because more room was needed for pedestrian movement and waiting passengers. A total of four bulbs were built—two bulbs at the intersection of Market and Castro Streets and two bulbs at the intersection of 18th and Castro Streets. Each pair of bulbs consists of one nearside and one farside stop. Figure A-24 is a picture of the farside bus bulb on Castro Street at the intersection of Market Street. This configuration helps reduce the crossing time for pedestrians using the crosswalks. Castro Street is a three-lane facility with designated left-turn bays. Curbside parking is available on either side of the street.

The bus stop sites at the corner of Market and Castro Streets are transfer points for people trying to move between the bus lines and the Muni subway station nearby. Because of these transfer points, the stops sometimes serve a tremendous number of transit riders during peak travel hours (Figure A-25). The sidewalks are used heavily in this area of San Francisco because the Castro District is a popular shopping and dining location. The district also has a mix of multilevel row housing. Residents either use curbside parking or park in small at-grade garages.

Figure A-24. Farside bus bulb on Castro Street at Market Street.

The addition of the bulbs permitted Muni to move the bus shelters and other pedestrian furniture and amenities (e.g., vending machines) off the sidewalk and onto the bulbs, thereby increasing the effective sidewalk width at the corner of Market and Castro Streets. Figure A-26 shows waiting patrons using the bulb and the shelter to wait for the next available bus. Figure A-27 shows how the bus shelter and vending machines at the nearside 18th Street and Castro Street site are no longer impeding the sidewalk because the items were moved onto the bulb.

VANCOUVER, BRITISH COLUMBIA

The transportation mission statement of Vancouver, British Columbia, is to emphasize transit movement rather than vehicle movement. The City Council, based on a recommendation from an administrative report, has adopted a transit-first policy. Therefore, no more construction or expansion of freeways is planned, and the city has placed greater emphasis on increased bus service. At this time, bus bulges, as bus bulbs are called in Vancouver, have been identified as a potential transit priority measure. Bus bulges, it is assumed, will increase bus travel-time savings by allowing the bus to stop in the travel lane rather than to have to exit and re-enter the stream of traffic. Bus bulges are also viewed as traffic calming and pedestrian improvements.

The city of Vancouver is currently studying the effect of two demonstration bulges near the University of British Columbia on west 10th Avenue. The city is planning to install additional bus bulges at locations with high bus volumes to improve transit service and to improve the pedestrian environment. At the locations being considered for new bus bulges, the buses do not stop in the travel lane; rather, buses stop

Figure A-26. Waiting patrons on bulb.

Figure A-27. Vending machines on bulb.

along curbside stops within defined parking lanes. More than Can$650,000 has been set aside in the city budget for future bus bulges. Currently, there are no warrants or guidelines developed for the installation of bus bulges. The city hopes that the 10th Avenue sites will yield good information on the operation of bus bulges.

West 10th Avenue at Sasamat Street Demonstration Bus Bulges

The city of Vancouver currently has a total of two bulges. They are located, as a pair, on opposing sides of west 10th Avenue at the farside of the Sasamat Street intersection (Figures A-28 through A-31). West 10th Avenue is a four-lane facility (two lanes in each direction) with parking lanes on either side. The location is near the University of British Columbia and is the approximate center of the shopping district on west 10th Avenue. The bulges were installed in May and June 1998. The site was selected as the candidate for demonstration because of the unique conditions associated with this site. While the University is in session, the area has high pedestrian volumes and transit ridership. An express bus route is also being added to 10th Avenue, which will stop at the 10th Avenue and Sasamat Street bus bulge location. The stop location will provide a quick ride to the University from the surrounding community. The corridor has moderate traffic volumes and 24-hr curbside parking that is used heavily.

Width and Length of Bus Bulges

The width of the bus bulges is constrained by the narrowness of the facility. The actual width of 10th Avenue is only 52 ft (15.9 m). Because of this, the width of the bulge was restricted to 6.5 ft (2 m) to minimize the potential of having a stopped bus encroach on the second travel lane. Another concern is having enough room to pass the stopped bus without sideswiping the stopped vehicle or encroaching on the opposing lane. The city of Vancouver is also concerned with vehicles striking the curb edge of the bulge. The return S-curve radii was motivated by the desire to limit vehicles from striking the curb face while parking. Unlike San Francisco, the S-curve radii

Figure A-28. Westbound bus bulge: west 10th Avenue at Sasamat Street.

Figure A-29. Eastbound bus bulge: west 10th Avenue at Sasamat Street.

was not initiated by the need to have the street cleaner equipment successfully navigate along the bus bulge curb return.

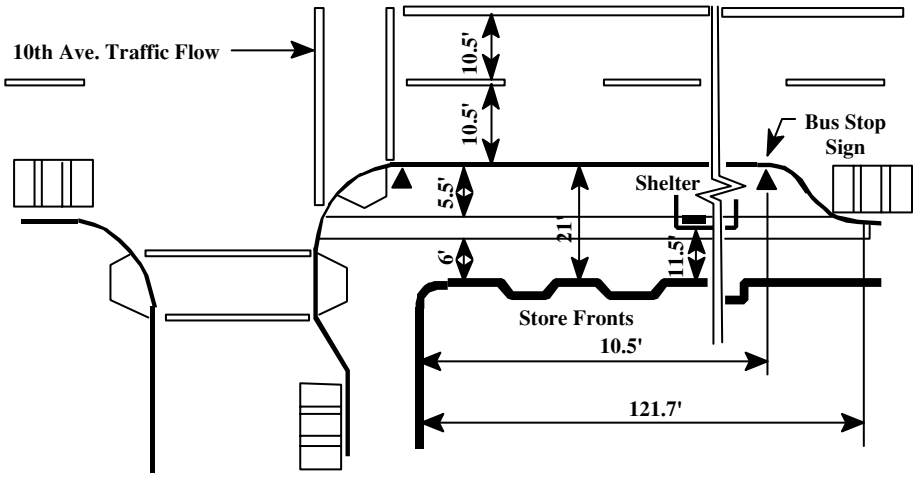
The length of the curb bulge is approximately 105 ft (32 m). The length of the bus bulges was determined by the need to accommodate more than one transit vehicle arriving and stopping at the site: Articulated (60 ft) (18.3 m) + Trolley (40 ft) (32 m). Vancouver transit, however, does not use all three doors on an articulated bus to board and alight. Therefore, the overall length of the bulges is not influenced by the number of doors used to board and alight from the transit vehicle—a policy similar to that of Portland, Oregon.

Transit Vehicle Travel Time and Dwell Times at Stops

A major reason for installing the bus bulges at this location was to eliminate the weaving of buses in and out of the curbside parking lane bus stop. A bus re-entry problem at the 10th Avenue sites exists because of the high vehicular volumes during school months. The city of Vancouver believes that the bus bulges will provide a travel-time savings because they will solve the re-entry problem.

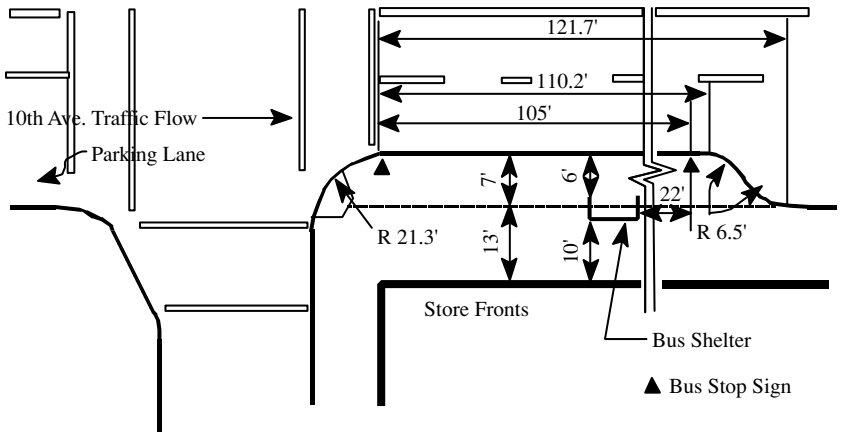
Parking

The curbside parking lane on either side of 10th Avenue is used heavily. The city is admittedly aggressive about ticketing and removing vehicles that are illegally stopped or parked in the travel lane during peak periods. Although illegal parking in the bus stop zone was not mentioned as a problem at this site, the city believed that the other sites being considered for bulges occasionally had problems with cars



1 ft = 0.305 m

Figure A-30. Farside bus bulge, 10th Avenue at Sasamat Street (westbound).



1 ft = 0.305 m

Figure A-31. Farside bus bulge, 10th Avenue at Sasamat Street (eastbound).

illegally parking in the zone, which cause the buses to stop in the travel lane. Double-parking near the bus stop rarely occurs. No Parking signs were attached to the Bus Stop Zone sign to help define the no-parking region in and around the bus bulge. Figures A-32 and A-33 are examples of the signage at the bus bulge.

The construction of the bus bulges removed 1.5 parking spaces from each farside parking lane. Because of the high use of the parking lanes, a pedestrian bulge was not added to the opposing curbs at either bus bulge site. The signals are already timed in favor of crossing pedestrians, and the bulges are believed to have removed at least 1 s of crossing time.

Drainage

Drainage is a major issue in the design and construction of these bus bulges. A noticeable slope adjoining the sidewalk to the bus bulge exists on the University-bound farside stop at 10th Avenue and Sasamat Street. This appears to be the result of retrofitting the bulges to the existing street crown rather than a design decision. Figure A-34 is a cross section of the westbound bus bulge at 10th Avenue and Sasamat Street. Low-floor articulated buses will be added to the transit fleet, which may necessitate changes to curb height at the bulges.

General-Purpose Traffic

General-purpose vehicular traffic experiences some delays caused by the bus stopping in the moving traffic lane (Figure A-35). Because the bus stops are located at the far side of the intersection, there is concern over the potential for the queuing of and increased weaving movements of general traffic at these locations.

As of July 1998, there have been no observed conflicts between vehicles turning right from Sasamat Street onto 10th Avenue and buses at the bus bulge. The city will continue to monitor this issue.

The city believes that the potential exists for the bulges being perceived as traffic-calming devices. Vancouver has several traffic-calming strategies already in place, and the bus bulges are seen as another strategy to discourage traffic flow on the facility. Drivers may see the bulges and switch to a parallel route, thereby increasing the traffic volumes on that facility. The city has received two calls from the public regarding the bus bulges on 10th Avenue, one of which was concerned about the perceived capacity loss caused by the buses stopping in the traffic lane.

The installation of the bus bulges may highlight an already existing problem. The travel lanes are considered too narrow on west 10th Avenue, and a bus passing a stopped bus may have to encroach on the opposing lane. With the implementation of an express route on this corridor, greater potential exists for an express bus to encounter a bus stopped at the bulge. The passing bus may have to encroach on the opposing travel lane in order to navigate successfully around the stopped bus. While at the west 10th Avenue bus bulges, the research team did observe this type of passing behavior.

Bus Stop Location

The city of Vancouver generally locates all bus stops at the far side of the intersection. The two bus bulges on west 10th Avenue are located at the farside intersection of Sasamat Street. Bus bulges at farside locations, it is believed, will further encourage pedestrians to use the crosswalks at the intersections rather than to jaywalk at the midblock of the facility.

Pedestrians

The bus bulges have already improved pedestrian movement along the sidewalks. West 10th Avenue is a significant

Figure A-32. Traffic control sign.

Figure A-33. Traffic control sign detail.

shopping district. Because of the increased sidewalk capacity, local store owners have readily accepted the construction of the bus bulges. The implementation of the bus bulges has allowed the city to move trash receptacles, vending machines, and bus shelters off the sidewalk and onto the bulge, thereby increasing the capacity of the sidewalk (Figure A-36). The reduced width of the west 10th Avenue bulges has limited the number of pedestrian and bus patron amenities placed at that site. The city plans to add additional amenities to other bus bulge sites.

The construction of the bus bulges caused the removal of two existing street trees, which have not been replaced. A clear space of at least 9 ft (2.7 m) between the storefront edges and the beginning of the bus bulges was created on the sidewalk. A bike rack was placed adjacent to the bus shelter on the bulge.

The signal timing at 10th Avenue and Sasamat Street was not changed by the implementation of bus bulges at this intersection. The bus bulge has reduced the crossing distance by approximately 7 ft (2.1 m), which could result in the addition of about 1 s to pedestrian crossing time. However, the reduced exposure in the intersection and greater crossing time are seen as added pedestrian benefits. The area also has several older citizens, and the increased crossing time will benefit them. Additional pedestrian bulges were not added to the opposing curbs because of the need to maintain parking.

Bicycles

Because of the narrowness of the travel lanes and the presence of a well-defined bicycle lane on a parallel facility two blocks north, minimal attention was given to bicyclists at this site. Many of the bicyclists traveling to and from the University use the bikeway close to 10th Avenue. Bike racks are present on both bus bulges.

Cost

The cost of the bus bulges was Can$48,000 for the pair. The city has set aside an additional Can$650,000 for future bus bulges.

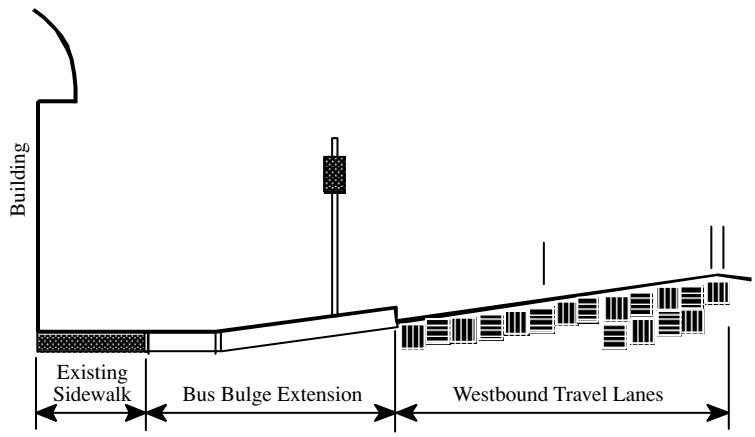


Figure A-34. Cross section of westbound bus bulge (10th Avenue at Sasamat Street).

PORTLAND, OREGON

The city of Portland has several existing and pending bus bulb locations. Unlike other cities' reasons for needing bus bulbs, a majority of the bulbs in Portland are needed for reasons other than transit. The pedestrian and bicycle program in Portland is strong and influential. Consequently, a majority of the bulbs are being installed as part of traffic-calming measures or to reduce pedestrian crossing times at intersections. The one exception is the Sandy Boulevard bus bulbs between 66th and 79th Streets where the goal is to improve transit ridership.

The Sandy Boulevard and Broadway Street sites are the newest bus bulbs in the region. The oldest examples of bus bulbs in Portland are located on northwest 23rd Avenue. The bulbs are approximately 10 years old. Similar to other bulb projects in Portland, the northwest 23rd Avenue sites were initiated as part of a pedestrian improvement and traffic-calming program in the corridor. Figure A-37 shows the approximate location of the bus bulbs in the Portland region.

Overview of Practices and Experiences

Width and Length of Bulbs

Currently, the standard width of all bulbs in Portland is 6 ft (1.8 m), which provides a 2-ft (0.6-m) "shy" zone between the bulb and traffic on a 36-ft (11-m) wide cross section. However, drivers would prefer that this zone not exist, and Portland is now considering a 7-ft (2.1-m) wide bulb to accommodate this desire. The length of the bulbs is highly variable throughout the city and appears to be dependent on the width of the street, the amount of existing parking, and the policy regarding how many doors are used for boarding and alighting the transit vehicle. Tri-County Metropolitan Transportation District of Oregon (Tri-Met) is phasing out articulated buses; however, the buses currently are being used in the Sandy Boulevard corridor. Tri-Met will convert its fleet to low-floor, 40-ft (12.2-m) long buses. The length of the bulbs along Sandy Boulevard is approximately 30 ft

Figure A-35. Traffic queue at bus bulge.

Figure A-36. Placement of vending machines on bus bulge.

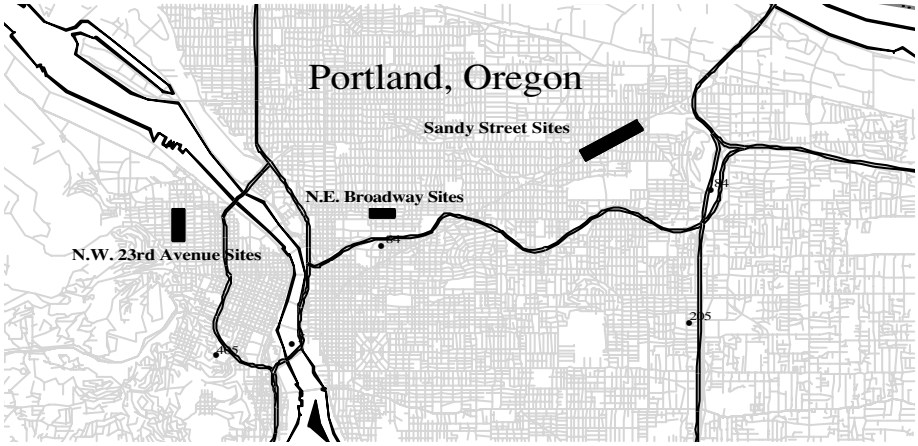


Figure A-37. Location of existing bus bulbs in Portland, Oregon.

(9.2 m). Tri-Met is debating whether to install 20-ft (6.1-m) bulbs in the downtown area where boarding and alighting would occur in the front of the bus only. Bulbs will be installed to service a downtown streetcar system. Although the streetcars will be low-floor vehicles, the platform will still have to be 10 in. high for boarding and alighting purposes.

Parking

All of the bulbs observed in Portland are installed on streets that have curbside parking lanes. The parking lanes are delineated with several parking signs. All bus bulbs have No Parking signs to discourage illegal parking along the curb by general-purpose vehicles. In most instances, the No Parking sign is on the same pole as the Bus Stop sign (Figure A-38). An additional No Parking sign was installed at bus bulb locations where there were pedestrian curb extensions at the intersection. The curb facing of some bulb locations is marked with yellow tape to help further delineate the no-parking area. The city is now considering painting the entire curb face at all bulb locations rather than using tape.

ADA Wheelchair Lift Deployment

Retrofitting or rebuilding the street to install a bulb has raised some issues associated with ADA wheelchair lift deployment—primarily, the issue of maintaining the appropriate slope at the bus stop. However, other comments were also made concerning lift deployment. At sites where bulbs are short in length, it is difficult to accommodate the lift. Transit vehicle operators have noted patrons experiencing difficulty navigating in and around Bus Stop and No Parking signs and vending machines. Vending machines especially were noted as a problem. The city is considering taping or painting pathways at the stops to illustrate where vending machines *cannot* be placed.

Drainage

Drainage is a major issue with both rebuilt and retrofitted designs. A major percentage of the overall cost of installing a bulb is associated with drainage. The bulbs dramatically affect how water drains into the gutter. Drains were installed in the parking lane just prior to the bulb and on the pedestrian curb extension on most of the Sandy Boulevard sites (Figure A-39). The city has also tried different drain types to reduce the amount of maintenance associated with the drains. Strip drains were a maintenance problem at some sites.

Bus Stop Location

The preferred location of bus stops in the Portland region is the near side of intersections. Because of the front-end boarding-and-alighting policy and the retirement of articulated buses, Portland Tri-Met can consider shorter bulbs than can other areas of the country. Tri-Met is concerned with trapping vehicles in the intersection when bus bulbs are located at the far side of the intersection. The city will consider extending the all-red phase if requested to do so; however, no extensions have been requested as of July 1998.

Pedestrians

As mentioned previously, strong attention is paid to pedestrian and bicycle concerns in Portland. A majority of the bulbs are installed to reduce pedestrian crossing times at intersections, thereby reducing pedestrian exposure while in the crosswalk. Several of the bus bulbs observed in Portland had pedestrian curb extensions at opposing intersections to further reduce pedestrian crossing times. A major goal of the bus bulbs that were installed on northwest 23rd Avenue was

Figure A-38. No Parking/Bus Stop sign.

Figure A-39. Typical upstream drainage.

to reduce any type of disruptions caused by the bus activities to passing pedestrians and to nearby businesses. The Sandy Boulevard sites are a part of a larger pedestrian-to-transit strategy. The bulbs are meant to improve pedestrian accessibility to transit in the corridor.

Bicycles

The interaction of bicycle lanes with bus bulbs is an issue in Portland. The issue is especially acute when bicyclists are using an underutilized parking area for travel, and they encounter a bulb. The bus bulb moves the bicyclist to the general-purpose lanes. The current 6-ft (1.8-m) width at the Sandy Boulevard sites provides a 2-ft (0.6-m) shy zone from the edge of the travel lane to the curb for bicyclists when the bicyclists encounter a bulb (Figure A-40). The city will not stripe a bike lane on a lane that is less than or equal to 14 ft (4.3 m). Portland will consider striping a bike lane when the lane width is 15 ft (4.6 m) or more.

Cost

The approximate cost is $15,000 to $30,000 per bulb pair. The cost is dependent on whether the site is retrofitted to a bulb or is rebuilt entirely. Another major cost factor is drainage. Drainage is a problem with both rebuilt and retrofit designs. The total preliminary engineering cost estimate for the five bulbs on Division Street is approximately $17,000 per bulb.

Sandy Boulevard Sites

Several bus bulbs were recently installed between 66th and 79th Streets on Sandy Boulevard. The Sandy Boulevard bus bulbs were installed to encourage greater transit ridership in the corridor, which is the goal of the "Pedestrian to Transit" demonstration project. The bulbs are meant to improve the attractiveness of the corridor by improving pedestrian access. Currently, the corridor has lower-than-expected ridership levels based on the area's demographics. Portland Tri-Met would like to increase the number of choice riders (i.e., individuals

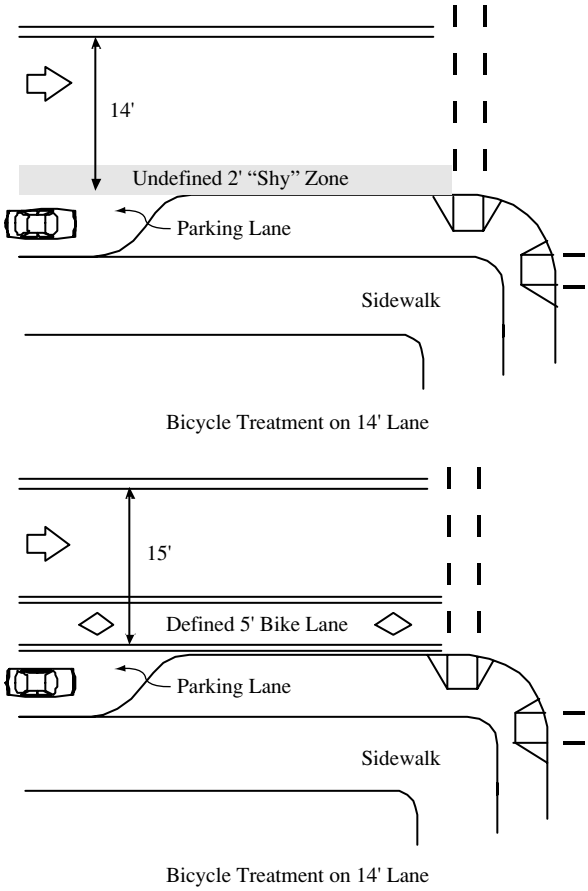


Figure A-40. Bike lane treatments with bus bulbs.

who have a choice between driving or using transit) in the corridor based on these demographics. The question was how to get people from the surrounding areas to use transit. Several pedestrian treatments, such as well-defined crosswalks, overhead flashing crosswalk signals, pedestrian refuge islands, increased landscaping, and pedestrian curb extensions, were added to the corridor. Additional lighting and transit amenities were also added. The presence of bus bulbs also allows more amenities at each stop. Although sidewalk congestion is not an issue along Sandy Boulevard, the existing sidewalk widths were not conducive for transit amenities such as shelters, bike racks, and benches. The bulbs would provide the necessary space for these types of amenities.

The widths of the bulbs are 6 ft (1.8 m) along Sandy Boulevard (Figure A-41). This width allows the 2-ft (0.61 m) shy zone around the bulbs for bicycle riders who use the parking lane to travel. The bulbs are located at the nearside of the intersection. Most bulb examples are coordinated with pedestrian curb extensions to further reduce pedestrian crosswalk exposure (Figures A-42 and A-43). The Sandy Boulevard at 67th Avenue site is an example of combined bus bulbs and pedestrian curb extensions.

The one negative note thus far with the Sandy Boulevard sites is that motorists and bus operators accidentally hit or run over the bulb/curb extensions. Turning vehicles occasionally have trouble negotiating the turning radius at the bus bulb sites (Figures A-44 and A-45). The issue was discussed in the meeting with city and transit agency representatives. The posted speed limit along the Sandy Boulevard corridor is 35 mph (56.4 km/h).

Northwest 23rd Avenue Sites

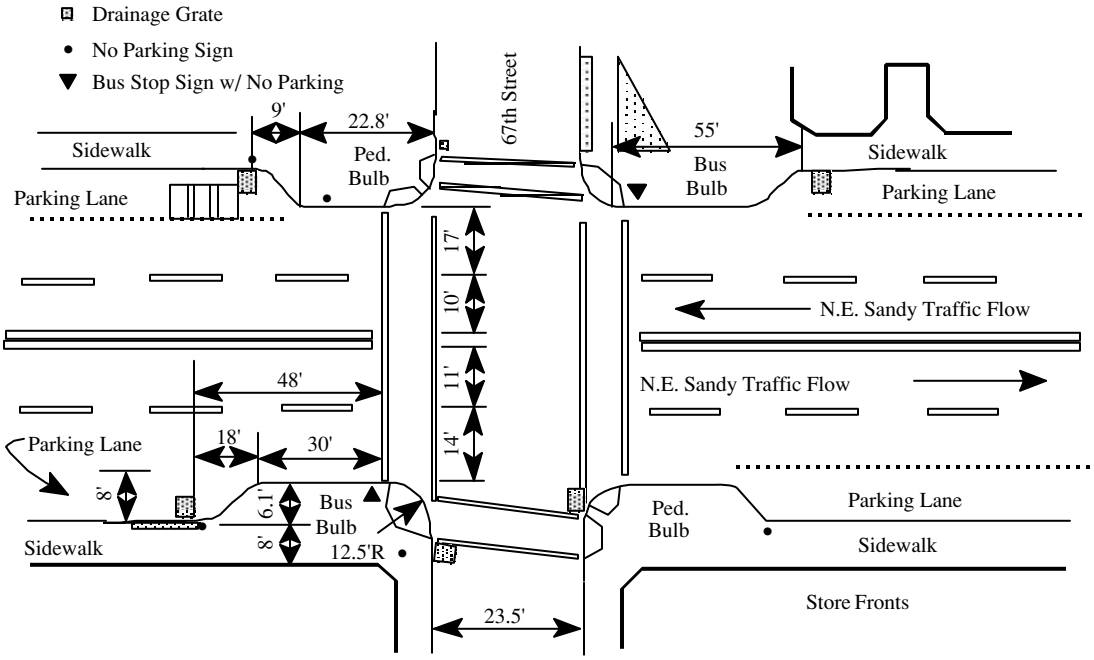
The northwest 23rd Avenue sites are the oldest examples of bus bulbs in Portland. The bulbs were installed between 1990 and 1991 and were initially conceived of as pedestrian and traffic-calming improvements. Transit was an afterthought in the project. To avoid the re-entry problem after boarding and alighting, buses were operating as if bulbs were already present at the bus stops. However, having a bus stop in the roadway was a major issue of the project.

The northwest 23rd Avenue area of Portland can be characterized as a fairly upscale neighborhood shopping and residential area. The area seems to be well established, and the neighborhood has a traditional feel with walk-in shops and well-kept housing just behind the shops. The goal of the project was to provide additional room along the sidewalks to segregate pedestrian and business activities from transit activities. Figures A-46 and A-47 are examples of how the bulb has provided separation of pedestrian and bus boarding and alighting activities and has provided additional sidewalk space for pedestrians and business activities.

Each of the bus bulbs on northwest 23rd Avenue was also extended as a pedestrian bulb on the cross street. Figure A-48 shows the pedestrian bulb at one of the bus bulbs along northwest 23rd Avenue. The presence of pedestrian bulbs places further emphasis on pedestrian movement in the corridor. The combination of bus bulbs and pedestrian bulbs noticeably slowed traffic along northwest 23rd Avenue and turning vehicles along intersecting streets. The city did not change the signal timing with the installation of the curb extensions. In the opinion of Tri-Met, the bulbs have accomplished their intended goal, but the impact of the bulbs on transit operations is negligible.

The curb-to-curb width of northwest 23rd Avenue is only 36 ft (11 m). This width means that there is an 18-ft (5.5-m) shared parking and travel lane. The street is lined with older trees, which gives the corridor an impression of increased narrowness. The bulbs vary in width from being as wide as a parking lane to half as wide as a parking lane, depending on the narrowness of the cross section of the street (Figure A-49). Since the bulbs have been installed, there have been some sideswipe accidents between buses and cars. The bulbs must also be signed so that automobile drivers cannot illegally park in the bus stop zone, which was mentioned as an occasional problem (Figure A-50).

As part of the project, Tri-Met consolidated stops to a three-block spacing. Prior to this consolidation, the spacing



1 ft = 0.305 m

Figure A-41. Bus and pedestrian bulbs on northeast Sandy Boulevard at 67th Avenue.

between stops was two blocks. This strategy increased the amount of parking on northwest 23rd Avenue and improved the speeds of transit vehicles. Although the transit vehicle speed between stops increased, the travel time in the corridor has remained the same because of the increased dwell times at the bus stops caused by more people boarding at fewer stops. The posted speed along northwest 23rd Avenue is 25 mph (40.3 km/h). A study has not been conducted to determine the effects of the bulbs on general vehicular speeds or volumes.

The length of the bulbs on northwest 23rd Avenue is rather short. Boarding and alighting activities occur at the front door. Shelters have also been installed at some of the sites as a patron amenity. The shelters are located toward the upstream end of the bulbs. Therefore, boarding and alighting activities, as well as the ADA wheelchair landing pad activities, occur at

Figure A-42. Nearside bus bulb on north Sandy Boulevard at northeast 67th Avenue (looking downstream).

Figure A-43. Nearside bus bulb at north Sandy Boulevard at northeast 67th Avenue (looking upstream).

Figure A-44. Tire marks over curb on bulb.

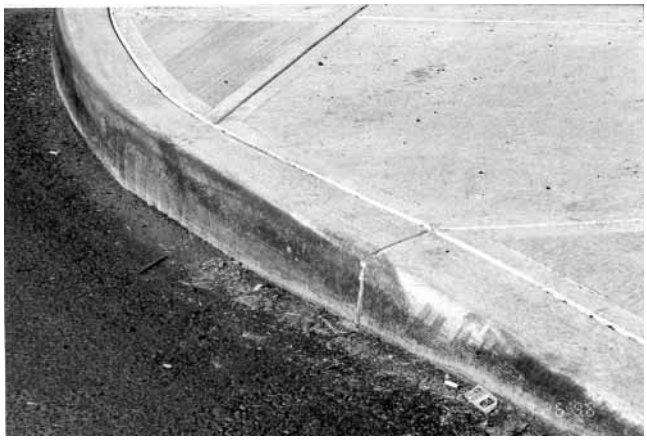


Figure A-45. Evidence of automobiles hitting curb on bulb.

Figure A-46. Separation of pedestrian and bus activities (northwest 23rd Avenue and Flanders Street).

Figure A-47. Increased sidewalk space (northwest 23rd Avenue at Irving Street).

Figure A-48. Pedestrian bulb used with bus bulb.

Figure A-49. Example of a narrow bulb (northwest 23rd Avenue and Burnside Street).

Figure A-50. Traffic control signs at bulb.

the downstream end of the bus bulbs. Transit vehicle operators have noted difficulties for patrons navigating wheelchairs around the Bus Stop and No Parking signs and vending machines.

Aggressive placement of vending machines on the bulbs is another concern with wheelchair lift operations on bulbs that are already constrained by shelters and signage (Figure A-51). Tri-Met is considering the placement of a painted or taped "pathway" to illustrate where vending machines cannot be placed.

Northeast Broadway Street Sites

Several new bus bulbs were installed on northeast Broadway Street between 10th and 16th Streets. Northeast Broadway Street is a three-lane, one-way facility that eventually moves through downtown Portland. The bulbs are installed across the Willamette River near a newer suburban retail development. There is an older residential development north

Figure A-51. "Crowding" at bulb for lift deployment.

of Broadway Street. Strip retail development, mixed with apartment complexes, characterizes the corridor near the bulbs. Figure A-52 shows the cross section of northeast Broadway Street near the bus bulb at the intersection of 12th Street.

Parking is available on either side of the street. Tri-Met uses a combination of No Parking signs and yellow tape masked to the top of the curb to help define the bus stop zone (Figures A-53 and A-54). There were two No Parking signs on the bulbs—one at the beginning of the bulb and another on the pedestrian curb extension at the intersecting street.

Similar to other bus bulbs in the Portland region, the northeast Broadway Street sites were also constructed with pedestrian curb extensions (Figure A-55). The opposing curb was also extended to reduce pedestrian exposure in the intersection. Both sides of 12th Street have well-defined pedestrian crossings across northeast Broadway Street.

A defined bike lane runs along the outside lane. When a bus is stopped at the bulb, it is stopped directly on the bike lane (Figure A-56). It was not known whether bicyclists wait

Figure A-52. Cross section of northeast Broadway Street near bus bulb.

Figure A-53. No Parking sign.

Figure A-54. No Parking tape along curb.

behind the stopped bus or attempt to pass the bus using the main travel lanes.

Tri-Met used the standards shown in Figure A-57 for the construction of the bus bulbs along northeast Broadway Street. All dimensions are in meters. The *Portland Pedestrian Design Guide* (*3*) provides guidelines on using curb extension (Figure A-58).

SEATTLE, WASHINGTON

The city of Seattle is actively considering the use of bus bulb configurations at bus stops. Currently, there are three general locations of bus bulbs within Seattle proper—northwest Market Street, northeast Lake City Way, and University Way (Figure A-59). The University Way location is serving as a test case for bus bulbs in the region. The city is considering using bulbs in other locations; however, the city is awaiting the outcome of the demonstration project on University Way. Several suburban communities surrounding Seattle are also considering bus bulbs; however, some of the potential sites create concerns because of the use of van services with very slow lift deployment, which can block traffic for extended periods of time.

In the greater Seattle region, there are two sites where "bulbs" have been in place for a number of years—northwest Market Street and northeast Lake City Way. Each site has a pair of bulbs. Neither of these locations were planned or built as bus bulbs. Each of these sites has been in place for several years, prior to the advent of any design standard. Because of the age of each of these sites, a majority of the institutional experience in the region associated with the design and construction of bus bulbs will be fostered from the University Way Demonstration Project. Each existing site is unique in length and in design. A common sight at each of these locations is the large, well-defined pedestrian crosswalks at the intersecting streets. It was visibly apparent during the researchers' visit that strong attention is paid to pedestrian movement in the region. Two of the four existing bus bulb sites have bus shelters present at the bus stop.

Figure A-55. Pedestrian curb extension.

Figure A-56. Bike lane next to bulb.

Overview of Practices and Experiences

Width and Length of Bulbs

The northwest Market Street and northeast Lake City Way bulb sites were developed as a pedestrian amenity (e.g., pedestrian bulb or crosswalk location). Seattle Metro later made the bulbs into bus stop locations; therefore, no bus stop design standards were used for these sites.

The newly constructed bus bulbs on University Way are 80 ft (24.4 m) in length. This design allows for two articulated buses to be present at the same time and for the use of all doors for boarding and alighting. The University sites are retrofit designs; therefore, it is unclear whether the lengths used at those locations would be applied to entirely new locations in the future.

Parking

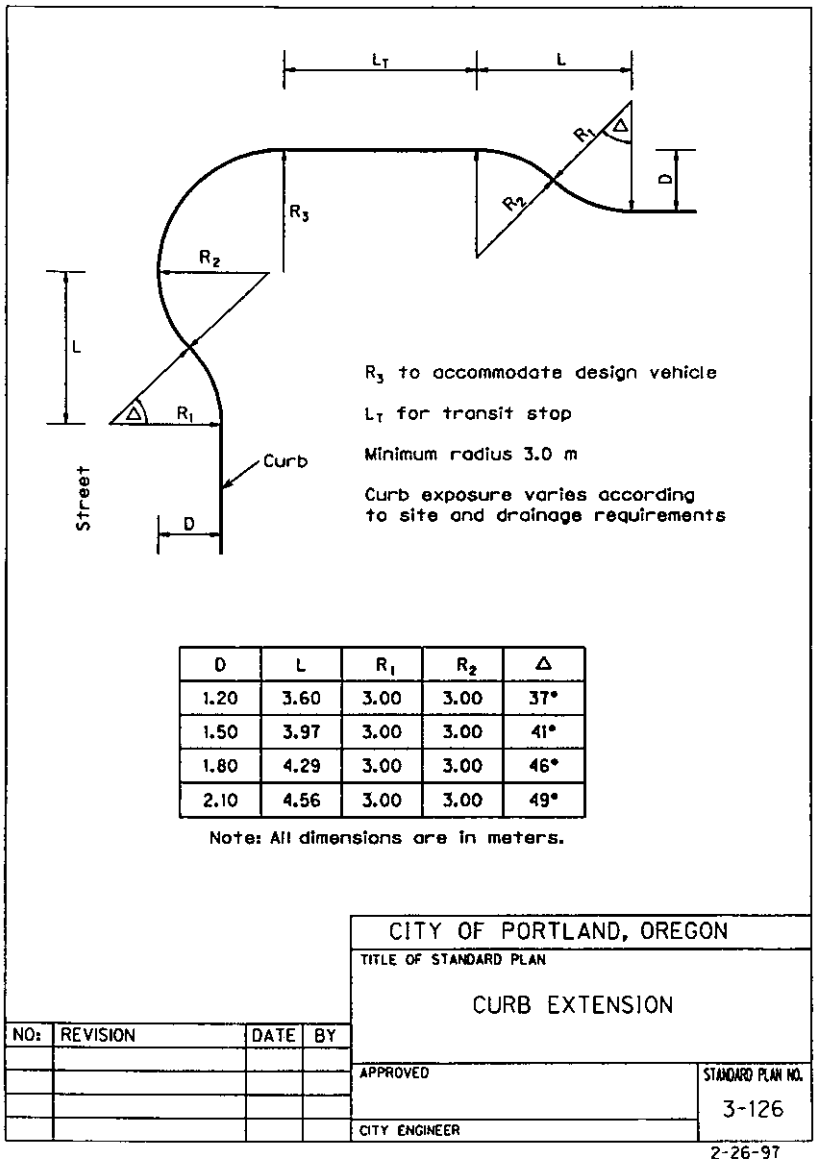
Five of the six locations in Seattle have curbside parking lanes, with the one exception of northwest Market Street at 15th Avenue where there is a 30 Minute Load and Unload Only zone just downstream of the bulb. The parking lanes adjacent to the bulbs are clearly marked. However, there are no No Parking signs on the bulbs. The bulbs are marked as bus stops with alternating yellow and red markings on the curb face. Each site also has a Bus Stop sign to help further delineate the purpose of the bulb.

ADA Wheelchair Lift Deployment

Complying with design standards as set forth by the ADA guidelines was mentioned as being a challenge. In the process of retrofitting the University Way demonstration sites, the city had to grind the street lower to achieve minimum slope standards. Seattle Metro also noted that installing bulbs in suburban locations would pose certain problems, especially to general-purpose traffic. Suburban sites are served by bus and van service. The lift deployment systems in vans are very slow, thereby prolonging the length of time a stopped vehicle would be present in the travel lane. This fact would discourage the construction of bulbs for most suburban locations with high travel speeds and high traffic volumes.

Drainage

Like other regions that are considering installing bus bulbs, Seattle found drainage to be a major issue associated with the design and cost of the bulbs. In Seattle, retrofitting sites with bulbs poses unique problems with drainage because of the regional climate—plenty of rain and occasional ice in winter. Therefore, designers are concerned not only with on-street drainage but also with on-sidewalk drainage. Standing water on the sidewalk could become ice and pose potential dangers to pedestrians and waiting passengers. This problem is



D	L	R_1	R_2	Δ
1.20	3.60	3.00	3.00	37°
1.50	3.97	3.00	3.00	41°
1.80	4.29	3.00	3.00	46°
2.10	4.56	3.00	3.00	49°

1 ft = 0.305 m

Figure A-57. Potential bus bulb design standards.
SOURCE: City of Portland, Oregon.

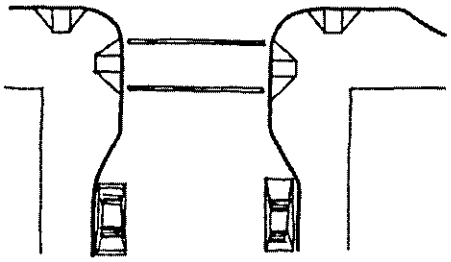
particularly acute where the bulb joins the sidewalk. Designers are wary of creating joints that would allow water to accumulate rather than to drain.

Bus Stop Location

The preferred location for bus stops in Seattle is the far side of the intersection. With the one exception of the midblock stop on northeast Lake City Way, all of the bus stops observed were farside locations. The midblock stop was initially constructed as part of a pedestrian crossing zone along a retail shopping center. The bus stop was added at a later date.

Pedestrians

Safe pedestrian movement is a high priority in the region. Well-defined crosswalks and signs assist with the safe movement of pedestrians in and around the existing bulbs. The University Way Demonstration Project is a clear example of



Curb extensions

Curb extension

Purpose: To minimize pedestrian exposure during crossing by shortening crossing distance and give pedestrians a better chance to see and be seen before committing to crossing.

Reference: (new standard plan under development)

Where to use: Appropriate for any crosswalk where it is desirable to shorten the crossing distance and there is a parking lane adjacent to the curb. (Note that if there is no parking lane, the extensions may be a problem for bicycle travel and truck or bus turning movements.)

Guidelines:

- In most cases, the curb extension should be designed to transition between the extended curb and the running curb in the shortest practicable distance.
- For purposes of efficient street sweeping, the minimum radius for the reverse curves of the transition is 2.5 m (8 ft) and the two radii should be balanced to be nearly equal.

Curb ramps

Purpose: to make the sidewalk accessible from the roadway level of the crosswalk.

Reference: Title 17.28.035; Standard Plans 3-119a through 3-124; ADA Intermim Final Rule 36 CFR Part 1191, Appendix A: Accessibility Guidelines14.2.4.

Where to use: At every intersection location where there is a crosswalk, whether or not the crosswalk is indicated with pavement markings.

Guidelines: See Section B, Guidelines for Street Corners and Curb Extensions

SOURCE: Tri-County Metropolitan Transportation District of Oregon. *Portland Pedestrian Design Guide*. Portland Pedestrian Program, Portland, OR (1998).

Figure A-58. Curb extension guidelines.

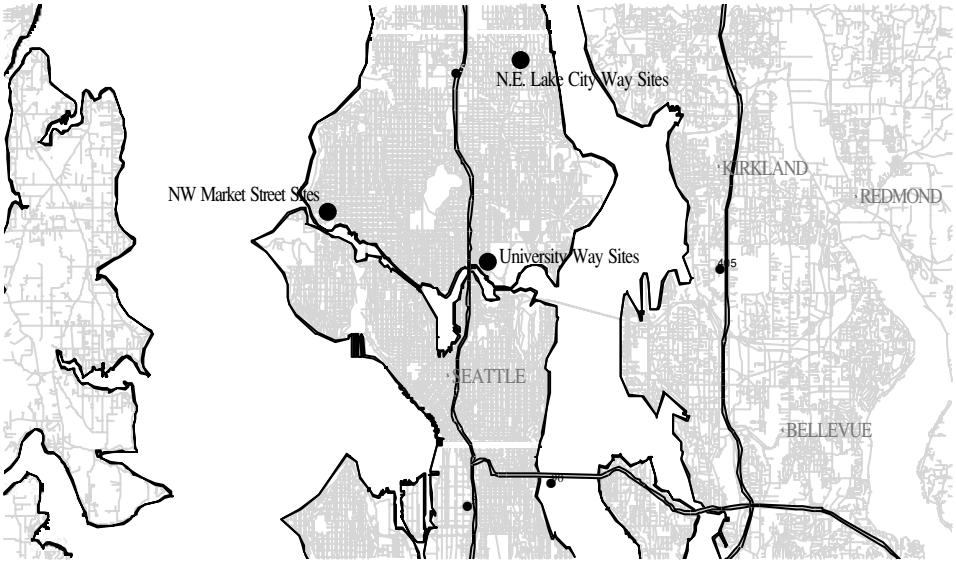


Figure A-59. Location of existing bus bulbs in Seattle, Washington.

placing greater importance on pedestrian and transit movement in a corridor.

Bus Bulb Demonstration Project—University Way

The University Way Demonstration Project was originally conceived of by the city of Seattle. The city approached Metro with the bulb idea. The retail core of the area was deteriorating and the Greater University Chamber of Commerce, business owners, and community members wanted to improve the streetscape as part of a greater redevelopment plan to improve the aesthetics of the corridor. The first phase of the redevelopment plan is a 6-month bus bulb demonstration project. The concept of bus bulbs in the corridor was actually discussed as a possible transit priority strategy more than 20 years ago. High-occupancy-vehicle lanes have also been discussed because of the high transit volumes.

University Way is directly north of the University of Washington campus and has several stores with above-store lofts that cater to students. The area links the campus with surrounding student housing. More than 50 percent of travel in the corridor occurs as either pedestrian or bicycle or on transit vehicles. Responding to the high degree of pedestrian volumes, a local community group requested that the sidewalks be widened to better accommodate pedestrians. Simply widening the sidewalks would create a situation in which the buses would partially block through-traffic movement anyway. The bus bulb concept would essentially increase the effective sidewalk width at these points and segregate bus patron activity from pedestrian activity. To further accommodate pedestrians, the city also approached Metro about consolidating bus stops on University Way to reduce the number of bottlenecks on the sidewalk created by waiting bus patrons.

Bus re-entry problems were also cited as reasons to study the bus bulb configuration on University Way. Prior to installing the test bulbs, the buses used curbside stops in parking lanes, which essentially operate as pull-outs. Pull-outs are considered an operational problem on two-lane facilities. Illegal parking in the zone and double-parking just beyond the bus stop zone were also problems in this corridor.

Vehicular traffic and speeds along University Way are low. However, the intersecting street, 45th Street, does have high vehicular volumes. The bus bulb project on University Way was created to demonstrate or to provide the following improvements:

- An increase in the pedestrian-carrying capacity of the sidewalks,
- An improvement in transit travel times in the corridor by consolidating stops and eliminating the bus re-entry problem,
- A reduction in or elimination of adaptive use of storefronts by providing a defined space for waiting bus patrons,
- The provision of a potential location for bus patron amenities (e.g., bus shelter), and
- A demonstration of and/or the development of "reasonable criteria" for installing bus bulbs at bus stops.

As previously mentioned, the neighborhood is highly involved in the demonstration project. Figures A-60 through A-62 show the demonstration bulbs as constructed on University Way.

Public interviews can determine reactions to the project from both pedestrians and store owners. Interviews were conducted in early 1998 prior to construction of the bulbs in April 1998. Early reactions to the project are favorable. Local businesses like how the bulbs reinforce separation between bus activities and businesses. Because there are no bus shelters at these stops, waiting patrons stand under storefront awnings, using them as shelter against the elements. Bus ridership levels have not changed since the advent of the bulbs. At the end of the project, the city will determine whether the bulbs are to remain in place. The following pages are "lessons learned" and issues encountered during the initial stages of the bus bulb demonstration project on University Way.

Transit Vehicle Travel Time and Dwell Time at Stops

A major objective of the bus bulb demonstration project was to determine whether the installation of bus bulbs improved transit vehicle travel times. Prior to the installation of the bulbs, transit vehicles were encountering bus re-entry problems with the curbside stops. University Way is only a two-lane facility, which further exacerbates the problem. The bulbs would allow the bus to stop in the travel lane rather than weave in and out of traffic. Another strategy to improve transit vehicle travel times was the consolidation of bus stops in the corridor. The University Way Demonstration Project calculated travel-time savings per person for the transit riders

Figure A-60. Nearside bus bulb—University Way at 45th Street.

Figure A-61. Midblock demonstration bus bulb—University Way.

using average ridership volumes within the study segment and average transit travel times (*4*). Transit ridership was found to be approximately 1,091 passengers in the northbound direction and 574 passengers in the southbound direction between the study hours of 3 P.M. and 6 P.M. A comparison between the pre- and post-installation transit travel time data shows a savings of 50 s in the northbound direction and 2 s in the southbound direction. The total P.M. peak transit travel-time savings in terms of person-hours equates to 15.4 person-hr. Vehicle travel times were not collected as part of the impact assessment; however, the magnitude of vehicle delay was estimated using the number of vehicles during peak period, an assumed vehicle occupancy rate of 1.6, and intersection approach delay data collected at University Way and northeast 42nd Street. In the post-installation study period, vehicles on the northbound and southbound approaches experienced 7 s more delay than did the vehicles in the pre-installation study period, a total travel impact of 3.2 person-hr. Transit travel-time savings and pedestrian flow improvements outweighed the estimated vehicle delay that resulted from the use of bus bulbs.

Figure A-62. Bus operations at nearside demonstration bulb.

Parking

As in other cities, parking or the availability of parking can be a controversial issue in Seattle. The length of the bus stop zone prior to the installation of the bulbs was 120 ft (37 m). The length of the bulbs after installation is approximately 80 ft (24.4 m), with additional space for the dual curb returns. With this configuration, an additional parking space was added to each side of the street, which helped ease any fears that business owners may have had about the removal of parking spaces in their corridor. Furthermore, the consolidation of stops also provided additional room for parking because two curbside stops have been temporarily removed for the demonstration project. Figure A-63 shows the parking lane near one of the bulbs.

The city believes that the bus bulb configuration will help reduce the number of illegally parked cars in the bus stop

Figure A-63. Parking lane prior bulb.

zone. This is a major issue with curbside stops in this corridor. An alternating red-and-yellow marking was added to the curb edge of the bulb to further define the area as a bus stop (Figures A-64 and A-65). Parking signs are also located on either end of the bulb to further define legal parking spaces.

ADA Wheelchair Lift Deployment

The bulbs have been designed and built to meet all current accessibility guidelines. To accommodate wheelchair lift deployment, a 2-percent grade is needed at each site. The city ground the entire street to provide the necessary slope at the bulb sites. Maintaining accessibility is a major issue associated with sites that are reconstructed to handle the bulb configuration. The overall cost of the project is dramatically affected by the extent and nature of the reconstruction.

Drainage

The most expensive element of the project is drainage. The street had to be ground down to provide the necessary slope for drainage and lift deployment. The curb extension is an impediment to water flow along the curb effacement. Furthermore, the area where the bulb joins the sidewalk is another potential drainage problem. Water needs to be removed from the sidewalk before the water is allowed to freeze. The curb radii are 20 ft/20 ft (6.1 m/6.1 m) to allow for sweeping. Figure A-66 shows the drainage treatment at the downstream end of the nearside demonstration bulb. A smaller radii is also being used to consume fewer parking spaces (10 ft/20 ft [3.1 m/6.1 m]). Figure A-67 illustrates the potential drainage concerns associated with a retrofitted bus bulb.

Figure A-64. Example of curbside markings.

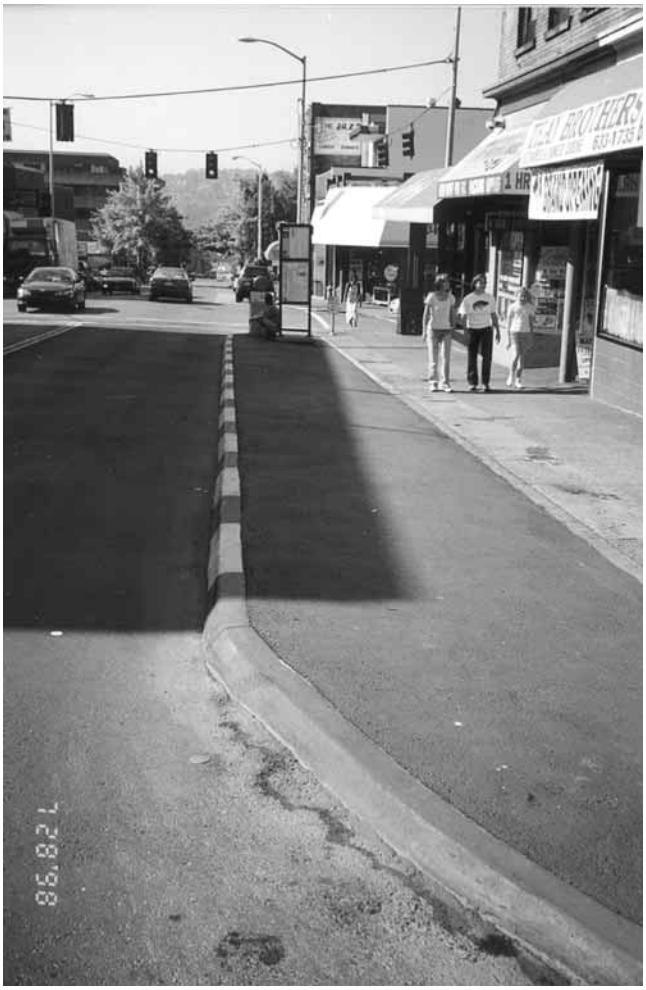


Figure A-65. Another example of curbside markings.

General-Purpose Traffic

A major benefit of installing bus bulbs is eliminating the potential for sideswipes that might occur during bus re-entry into the general flow of traffic. University Way was restriped with double-yellow lines on the centerline to prohibit passing near the demonstration bulbs. Additional parking enforcement

Figure A-66. Drainage solution.

was added to minimize illegal parking or double-parking before and after the bulbs. Queuing behind a stopped bus is a concern that is being closely monitored during the demonstration project (Figure A-68).

Bus Stop Location

The general policy regarding bus stop location at Seattle Metro is to locate stops at the far side of the intersection. However, the location of the bus bulb demonstration raised some concerns that vehicles would queue in the intersection behind a stopped bus. The high vehicular volumes on 42nd Street increased the concerns of locating the bus bulb on the far side of the intersection of University Way and 42nd Street. University Way is a two-lane facility with no passing in the vicinity of the bus stops. In response to this configuration, a decision was made to locate one stop at the near side of the intersection of 42nd Street and the other at the mid-block of University Way. Figure A-69 illustrates the location of the two demonstration bulbs with respect to 42nd Street.

Length of the Demonstration Bulbs

The demonstration bulbs are approximately 80 ft (24.4 m) in length. The length was determined by considering several factors: the desire to consolidate bus stops and to add parking, the potential for having two buses arrive at the same time, and the ability to accommodate an articulated bus at the bulb if all doors are used for boarding and alighting. The width of the bulb is the same width as the existing parking lane. Figures A-70 and A-71 illustrate the basic dimensions of the two demonstration bus bulbs on University Way.

Pedestrians

As mentioned previously, pedestrian volumes are extremely high on University Way. Prior to the installation of the bus bulbs, there were no bus stop amenities, such as shelters or benches, at the stops. Consequently, there was a high degree of adaptive use of the awning overhangs by waiting patrons to avoid exposure to the elements. If the bus bulb demonstration project is deemed successful, Seattle Metro plans to install shelters at the stops to help further segregate pedestrian and business activities from bus stop activities. Thus far, Metro has received several positive comments concerning the relief of pedestrian congestion along University Way's sidewalks (Figure A-72). Local business owners also have approved of the bulbs, which encourage patrons to congregate away from storefronts. There have been some concerns about how the bulbs have reduced the crossing distance across University Way and how this reduction might encourage jaywalking. Crosswalk visibility is another closely watched issue.

Bicycles

There is no special treatment for bicyclists in this corridor. The lane widths are too small to stripe a lane, and parking-lane use is too high for bicycle riders to use the lanes. Each approach to the bulb has a bike rack located on the sidewalk.

Cost

The cost to construct the two demonstration bulbs was $35,000. A majority of the expenses are related to drainage and accommodating wheelchair lift deployment. Seattle Metro is considering using bulbs in other locations, pending the outcome of the demonstration project.

Northwest Market Street at 20th Avenue

The first northwest Market Street site is located at the far-side intersection of 20th Avenue. The "bulb" was originally installed as a pedestrian improvement for the area, which is a local urban shopping and retail district. A pedestrian bulb is also present on the approaching curb intersection, which further reduces pedestrian exposure in the intersection (Figure A-73).

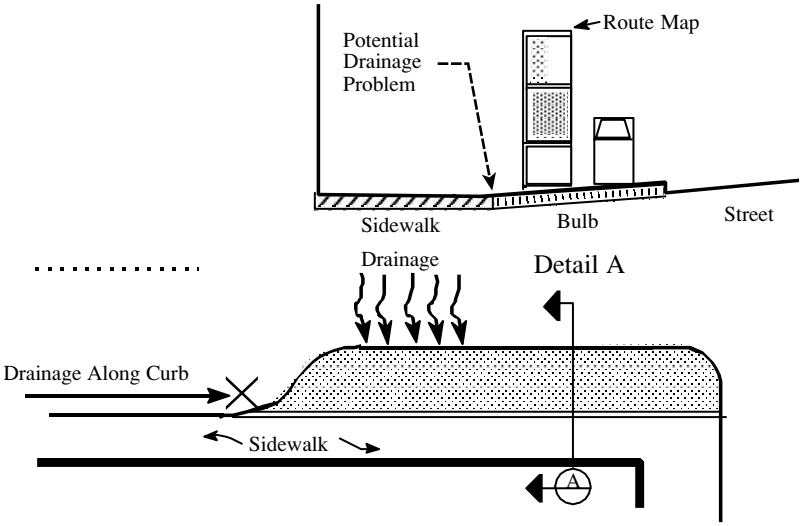


Figure A-67. Potential drainage issues with bus bulbs.

Figure A-68. Traffic queued behind stopped bus.

Seattle Metro later installed a bus stop at the bulb, thereby having the site function as a bus bulb. The site does not have a bus shelter or bench, but the bulb clearly provides a waiting area for bus patrons (Figures A-74 and A-75). The overall length of the bulb is only 35 ft (10.7 m) (Figure A-76). The pedestrian bulb is highlighted by the presence of an object warning marker located at the crosswalk. The marker warns motorists of the curb extension at the intersection (Figure A-77).

Northwest Market Street at 15th Avenue

The second bus bulb on northwest Market Street is also a farside configuration at the intersection of 15th Avenue. Unlike 20th Avenue, the site does not have a pedestrian bulb

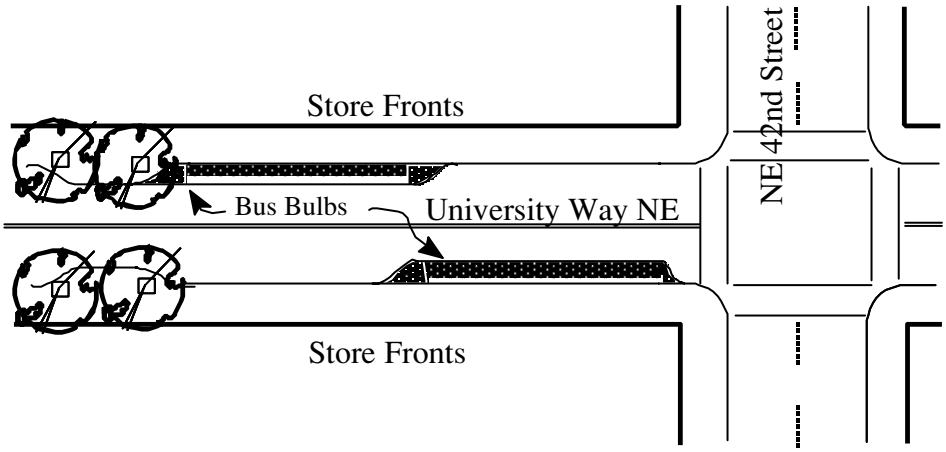


Figure A-69. Location of bus bulb demonstration project.

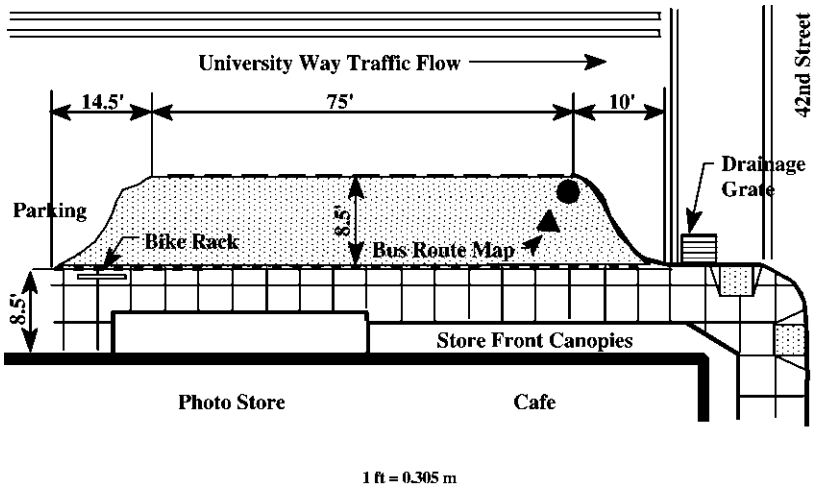


Figure A-70. Detail of southbound demonstration bulb.

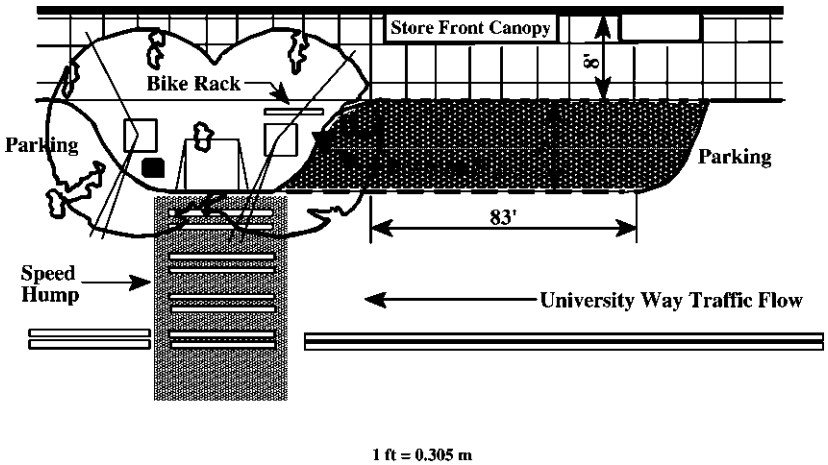


Figure A-71. Detail of northbound demonstration bulb.

Figure A-72. Pedestrians queuing on bus bulb to board bus.

on the opposing curb at the crosswalk, and a bus shelter was installed at the site to provide a defined waiting area for bus patrons (Figure A-78). At approximately 95 ft (29 m), the bulb is also three times longer. Like the bulb on 20th Avenue, the Market Street bulb has street trees planted along its outer edge. The bulb clearly provides the additional space needed to plant street trees that would not otherwise be present at this site (Figure A-79). A unique feature of this site is the loading area just beyond the end of the bus bulb (Figures A-80 and A-81). Cars were observed using this space as a temporary parking area.

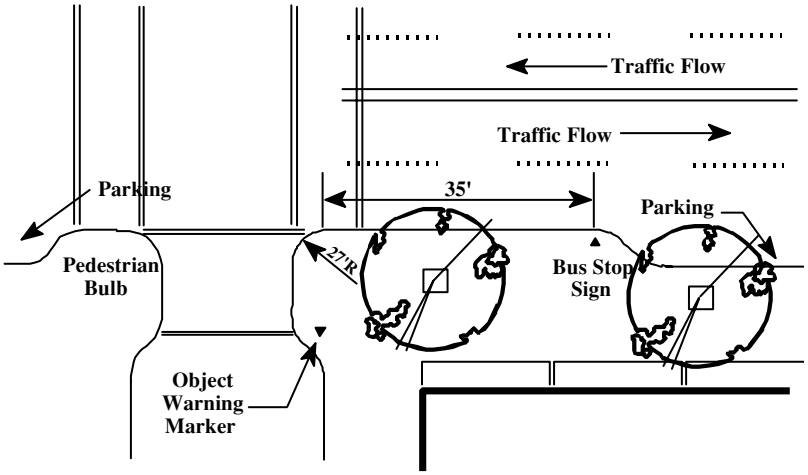
Northeast Lake City Way—Midblock Site

Similar to the northwest Market Street sites, the two bus bulb sites on northeast Lake City Way—one midblock stop

Figure A-73. Approaching pedestrian bulb.

Figure A-74. Farside bus bulb on northwest Market Street at 20th Avenue.

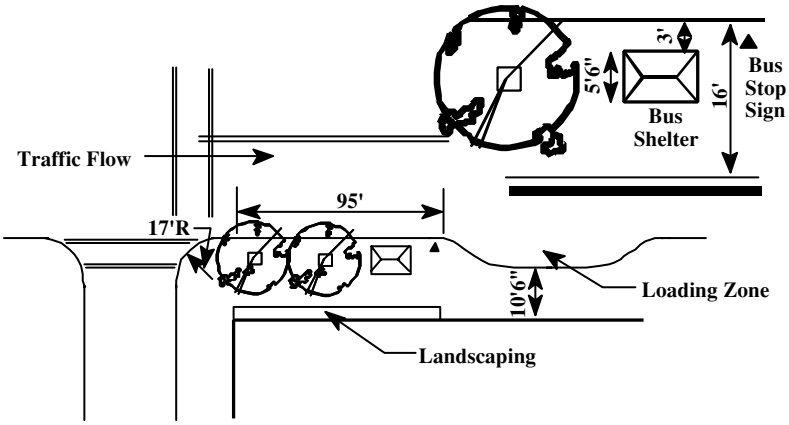
Figure A-75. Traffic approaching northwest Market Street bus bulb.



1 ft = 0.305 m

Figure A-76. Northwest Market Street at 20th Avenue: farside bus bulb.

Figure A-77. Warning marker in bulb.



1 ft = 0.305 m

Figure A-78. Northwest Market Street at 15th Avenue: farside bus bulb.

Figure A-79. Extra sidewalk space, northwest Market Street at 15th Avenue.

Figure A-81. Loading zone downstream of bus bulb.

Figure A-80. Bus shelter on bulb.

and one farside stop—were preexisting. Both sites appear to be pedestrian and traffic-calming projects adopted as bus stop sites at a later date. The one block area of northeast Lake City Way is an older shopping district that may have had significant walk-in customers at one time. The bus stops are located at high pedestrian-crossing locations. The midblock site has a pedestrian bulb across the street that is connected by a wide pedestrian crossing; pedestrian exposure is further reduced by the presence of a median in the road (Figure A-82). A flashing pedestrian crosswalk sign is cantilevered over the road to further warn motorists of the pedestrian activity (Figure A-83).

Both sides of the street and the median are tree-lined, which further reduces the scale of the area. The site is physically and visibly tighter than the typical cross section along other parts of northeast Lake City Way. There are no benches or shelters for waiting patrons (Figure A-84).

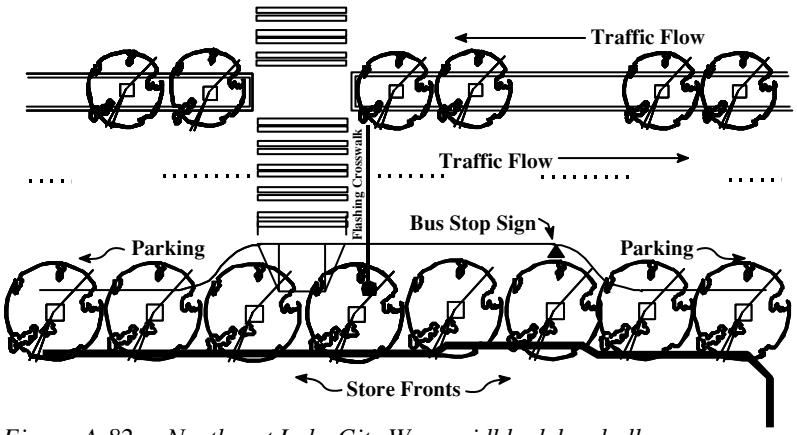


Figure A-82. Northeast Lake City Way: midblock bus bulb.

Figure A-83. Midblock bus bulb with pedestrian crossing sign, Lake City Way.

Figure A-85. Sidewalk clearance created by bulb.

Northeast Lake City Way at 125th Street—Farside Site

Another bus bulb exists on northeast Lake City Way. The bulb is located on the far side of 125th Street in the southbound direction. The bus bulb created the necessary sidewalk clearance for the inclusion of a bus shelter (Figure A-85). An alternating red-and-yellow stripe along the curb identifies the bulb as a transit stop as well as a No Loading zone. The same markings exist on the midblock stop down the street.

The posted speed limit on this facility is 30 mph (48.3 km/h) (Figure A-86). General-purpose traffic was also rather heavy in the corridor. It appears as though the area, at one time, served more pedestrians than vehicles; however, the corridor now appears to be serving more vehicles that travel through the area than those that stop and shop. As with previous bus bulb examples, a parking lane exists downstream of the bus bulb (Figure A-87).

Figure A-86. Farside bus bulb, northeast Lake City Way at 125th Street.

Figure A-84. Waiting patron on midblock bus bulb, Lake City Way.

Figure A-87. Parking lane downstream of farside bus bulb.

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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
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

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