

# TCRP

## REPORT 65

**TRANSIT  
COOPERATIVE  
RESEARCH  
PROGRAM**

### **Evaluation of Bus Bulbs**



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## TCRP REPORT 65

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### Evaluation of Bus Bulbs

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SUBJECT AREAS

Public Transit

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**TRANSPORTATION RESEARCH BOARD — NATIONAL RESEARCH COUNCIL**

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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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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.

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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.

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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](http://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 pro- vided additional assistance and updates regarding the construction schedule and progress update for the south Mission Street renova- tion project. Other individuals who provided assistance to the research team in San Francisco include the following:

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For this research project, unique software programs were devel- oped for use in data collection. Leonard Ruback of the Texas Trans- portation 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.

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## 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](http://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.
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## 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 near-side or farside relative to their position to the intersection. Near-side 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-

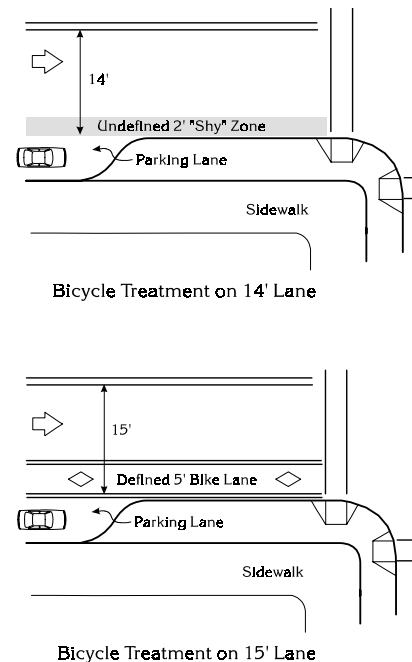


Figure 4. Bike lane treatments with bus bulbs (Portland).





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



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

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.

### 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 store-fronts 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

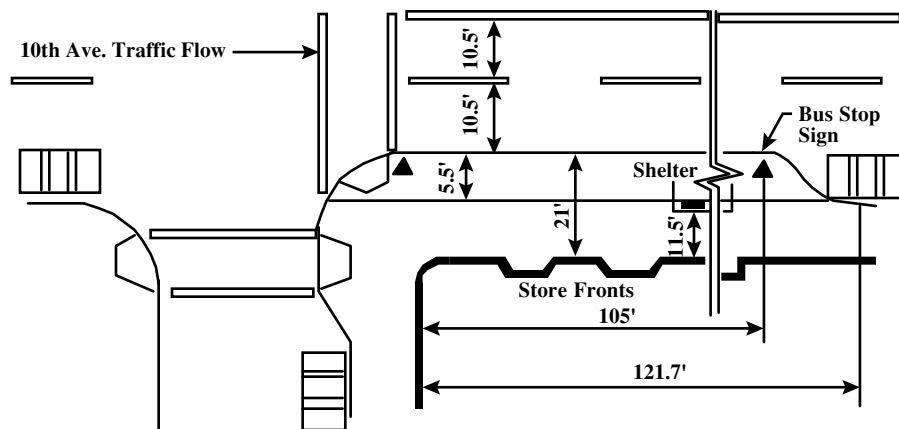


Figure 8. Bus bulge details (Vancouver).

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

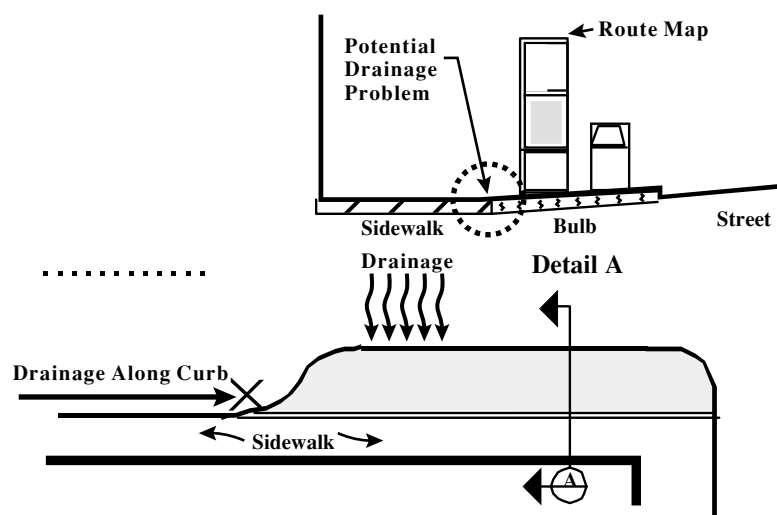


Figure 9. Potential drainage issues with bus bulbs (Seattle).

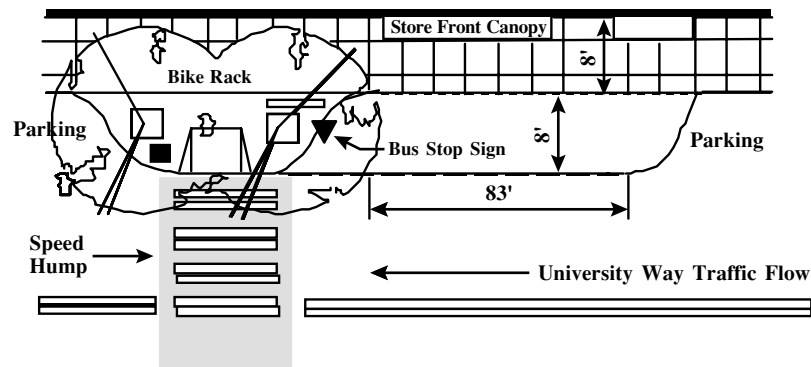


Figure 10. Detail of northbound demonstration bulb (Seattle).

- 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
<b>San Francisco, California</b>	<ul style="list-style-type: none"> <li>• High bus patronage</li> <li>• High pedestrian activity on sidewalk</li> <li>• Bus re-entry problems</li> </ul>	<ul style="list-style-type: none"> <li>• High-speed facilities</li> <li>• Lack of community commitment</li> <li>• Concerns with queues forming behind stopped buses</li> </ul>
<b>Portland, Oregon</b>	<ul style="list-style-type: none"> <li>• Reduce pedestrian exposure at the crosswalk</li> <li>• Traffic calming</li> <li>• Attract riders</li> </ul>	<ul style="list-style-type: none"> <li>• Two-lane streets intersecting with two-lane streets</li> <li>• Locations with significant boarding activity</li> <li>• Layover locations</li> <li>• Signalized intersections with capacity concerns</li> <li>• Locations with speeds greater than 45 mph (72.5 km/h)</li> <li>• Locations where the bus would turn right after the bulb</li> </ul>
<b>Seattle, Washington</b>	<ul style="list-style-type: none"> <li>• Isolated streets</li> <li>• High pedestrian volumes</li> <li>• Neighborhood in which street is perceived to be pedestrian-oriented</li> <li>• Sites with neighborhood "feel"</li> <li>• Areas in which bus stop consolidation is desired</li> </ul>	<ul style="list-style-type: none"> <li>• Low transit ridership</li> <li>• High vehicular volumes</li> <li>• Two-lane streets</li> <li>• Narrow streets (sideswipe potential)</li> </ul>
<b>Vancouver, British Columbia</b>	<ul style="list-style-type: none"> <li>• High pedestrian demand</li> <li>• Traffic calming</li> <li>• Communities in which transit is given high priority</li> </ul>	<ul style="list-style-type: none"> <li>• Where 24-hr parking is not available</li> <li>• Locations with striped parking (on one side only during peak periods)</li> </ul>

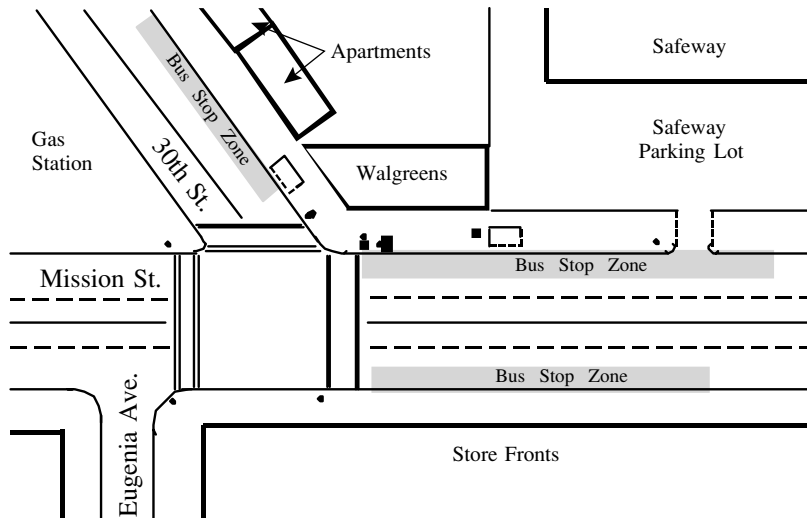


Figure 11. San Francisco's Mission and 30th Streets intersection (bus bay configuration).

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

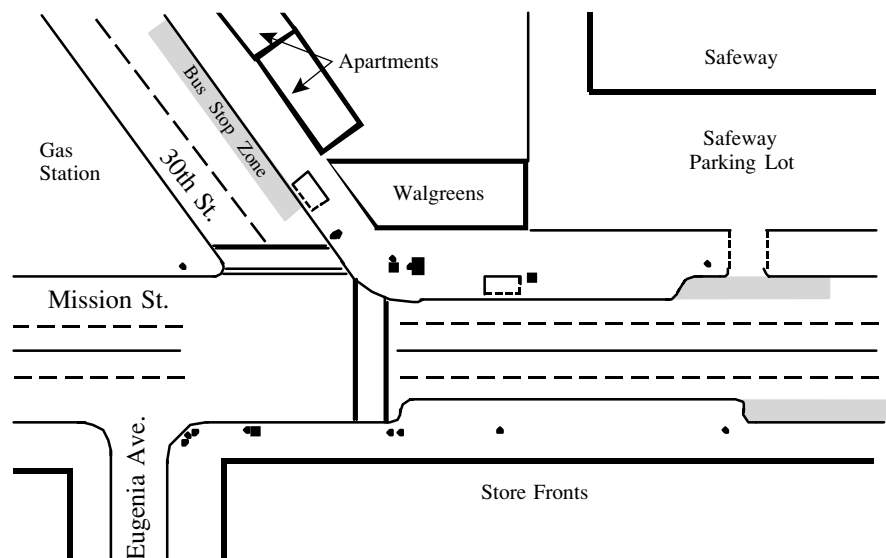


Figure 12. San Francisco's Mission and 30th Streets intersection (bus bulb configuration).

- 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

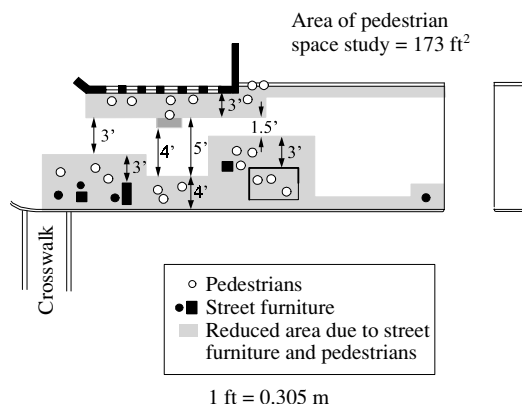


Figure 13. Common pedestrian waiting areas at bus bay.

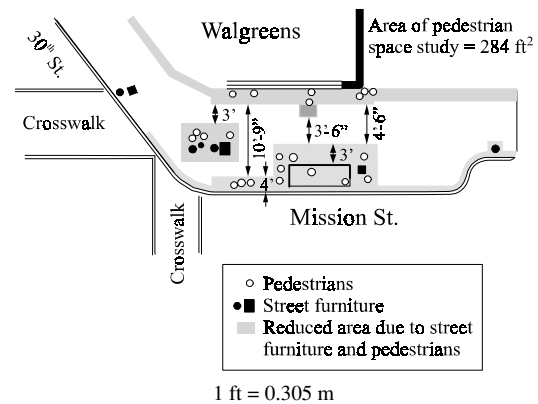


Figure 14. Common pedestrian waiting areas at bus bulb.

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**

<b>Level of Service (LOS)</b>	<b>Characteristics</b>
<b>A</b>	<p>Pedestrian Space: <math>\geq 130</math> sq ft / ped Flow Rate: <math>\leq 2</math> ped / min / ft</p> <p>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.</p>
<b>B</b>	<p>Pedestrian Space: <math>\geq 40</math> sq ft / ped Flow Rate: <math>\leq 7</math> ped / min / ft</p> <p>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.</p>
<b>C</b>	<p>Pedestrian Space: <math>\geq 24</math> sq ft / ped Flow Rate: <math>\leq 10</math> ped / min / ft</p> <p>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.</p>
<b>D</b>	<p>Pedestrian Space: <math>\geq 15</math> sq ft / ped Flow Rate: <math>\leq 15</math> ped / min / ft</p> <p>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.</p>
<b>E</b>	<p>Pedestrian Space: <math>\geq 6</math> sq ft / ped Flow Rate: <math>\leq 25</math> ped / min / ft</p> <p>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.</p>
<b>F</b>	<p>Pedestrian Space: <math>\leq 6</math> sq ft / ped Flow Rate: variable</p> <p>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.</p>

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

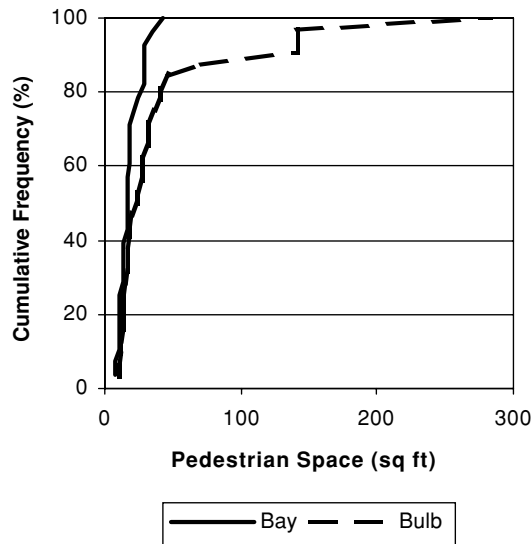


Figure 15. Available pedestrian space measurements when bus is present.

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-

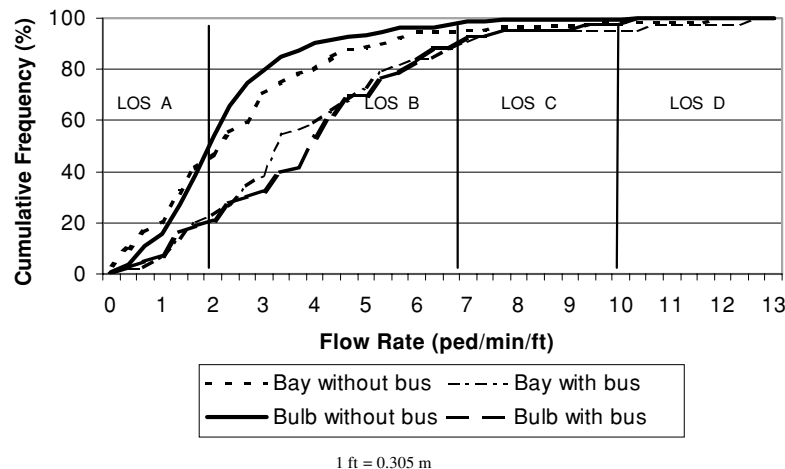


Figure 16. Pedestrian flow rates.





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



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

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.

## 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 18. Corner LOS study area for bus bay.

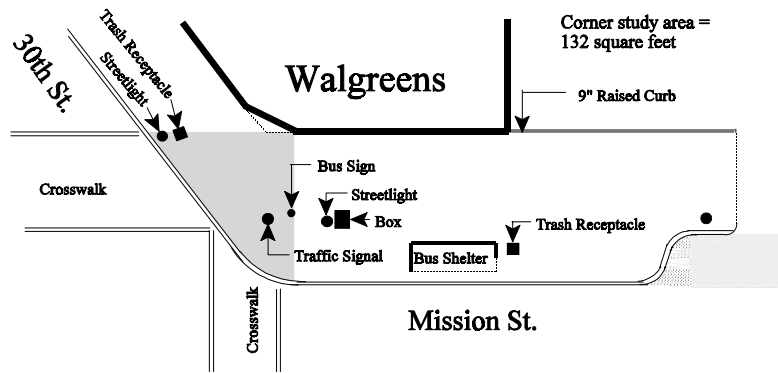


Figure 20. Corner LOS study area for bus bulb configuration.

- Bus and vehicle speeds near a bus stop (peak and non-peak 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.

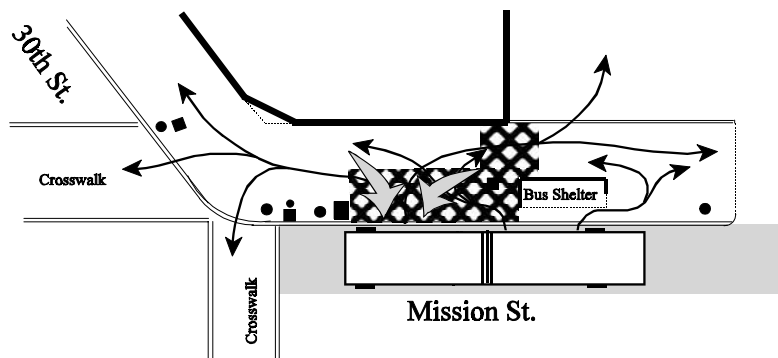


Figure 21. Pedestrian walking paths (bay configuration).

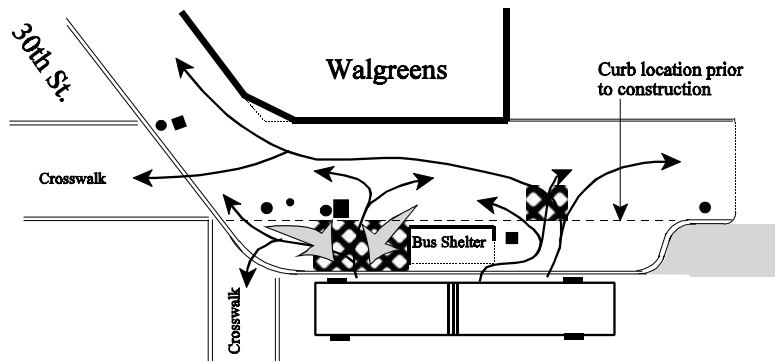


Figure 22. Pedestrian walking paths (bulb configuration).

#### 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.

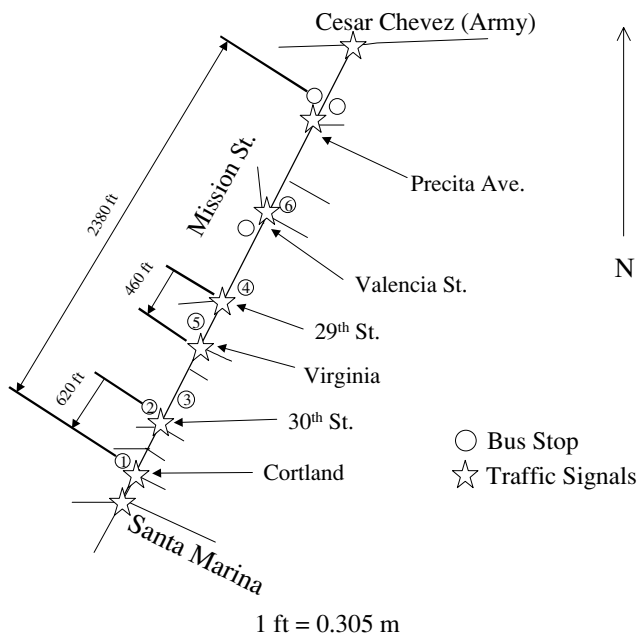


Figure 23. Travel time collection locations.

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

\* 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.

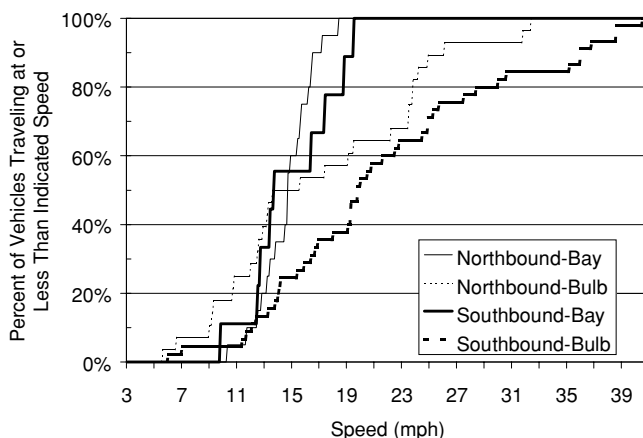


Figure 24. Vehicle speeds in corridor between Cortland and Precita Avenues.

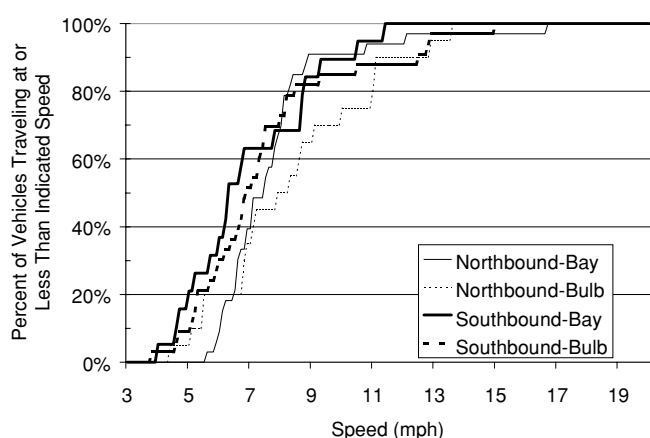


Figure 25. Bus speeds in corridor between Cortland and Precita Avenues.



Figure 26. Bus completely stopped in lane.

## 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 capabil-



Figure 27. Bus partially stopped in lane.

ity 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).

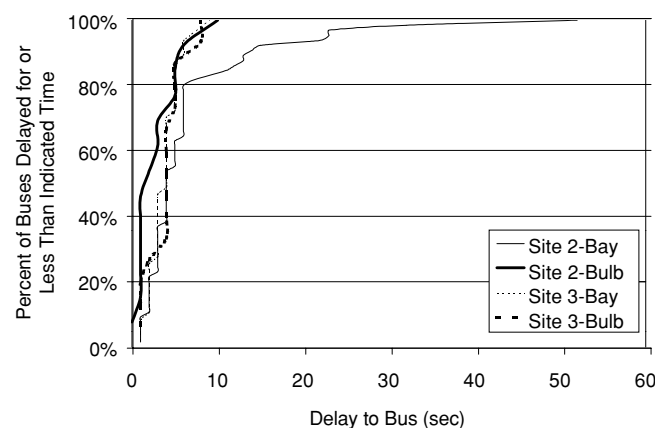


Figure 28. Nonpeak bus delay.

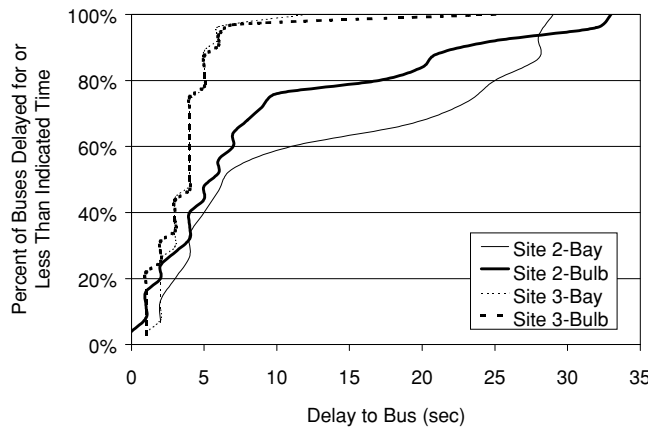


Figure 29. Peak bus delay.

### 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

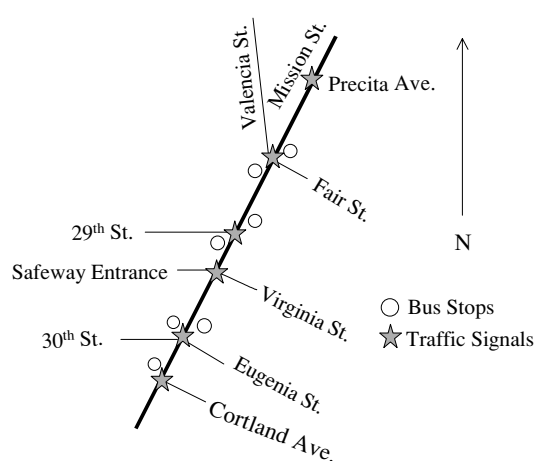


Figure 30. Bus stops included in the corridor simulation.

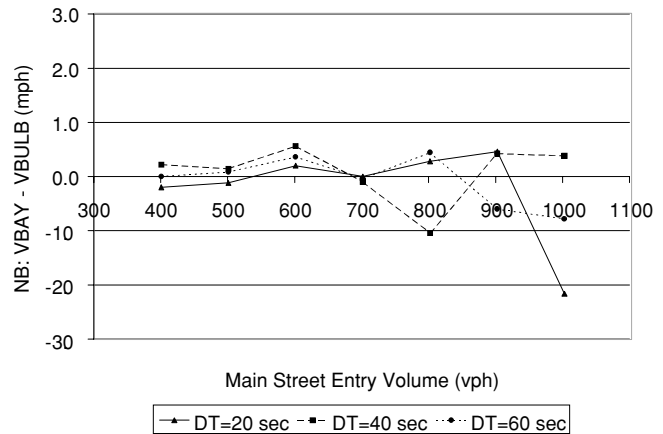


Figure 31. Northbound average vehicle speed difference between bus bay and bus bulb design.

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 ( $\geq -2$  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

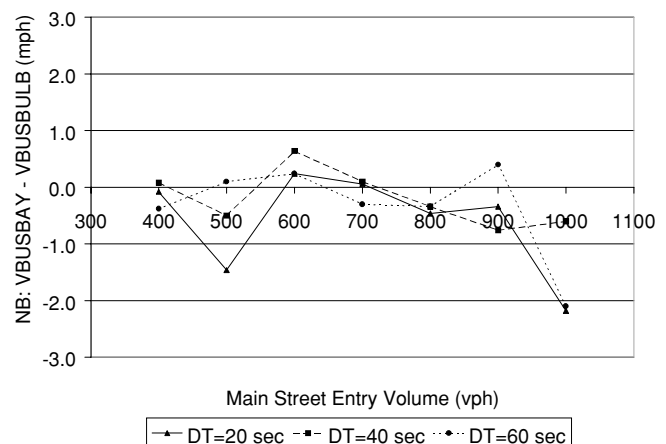


Figure 32. Northbound average bus speed difference between bus bay and bus bulb design.

dwelling 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 Speed (mph)
<i>Northbound</i>	Bay	Field	14.5	7.8
		NETSIM	17.0	10.6
	Bulb	Field	17.0	8.4
		NETSIM	16.8	10.4
<i>Southbound</i>	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

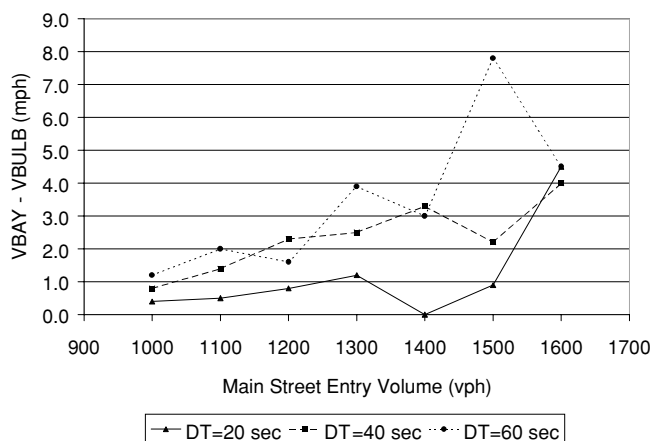


Figure 33. Average vehicle speed difference between bus bay and bus bulb design for a nearside location.

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).

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 ( $\leq 900$  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.*

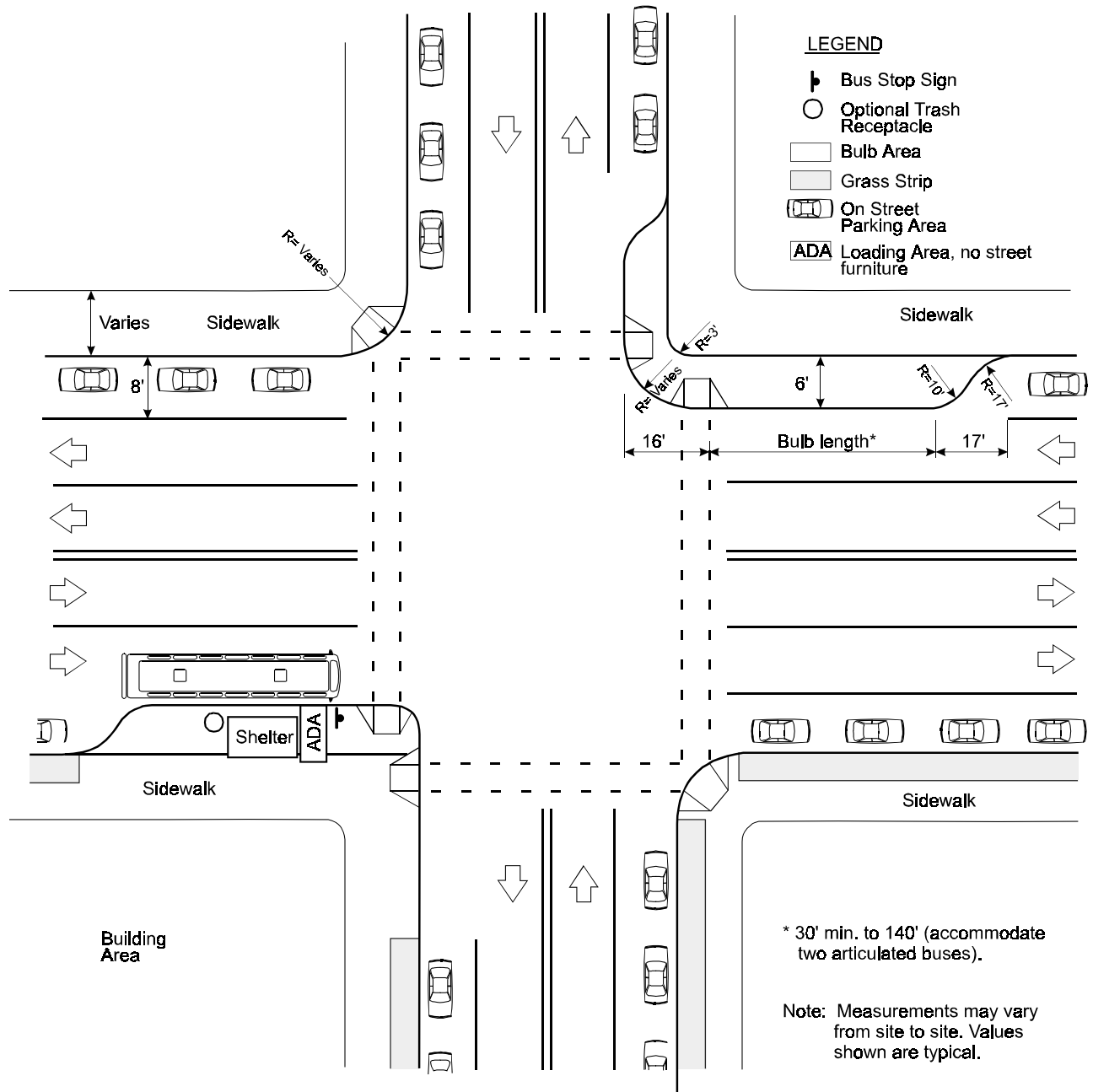


Figure 37. Typical dimensions for a bus bulb.

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

<b><i>Community / Neighborhood</i></b>	<ul style="list-style-type: none"> <li>• Does the area have a neighborhood feel?</li> <li>• How involved will the citizens be in the project?</li> <li>• Will the bulbs help pedestrian accessibility?</li> <li>• Will the presence of bulbs on one street cause cut-through traffic on a parallel street (i.e., traffic calming)?</li> <li>• Is transit an acceptable means of transportation within the community?</li> </ul>
<b><i>Business Owners</i></b>	<ul style="list-style-type: none"> <li>• Will business owners support construction in front of their stores?</li> <li>• Will business owners perceive that the bulbs are removing parking spaces?</li> </ul>
<b><i>Pedestrians</i></b>	<ul style="list-style-type: none"> <li>• Does the area have high pedestrian demand?</li> <li>• Is the sidewalk congested at or near the bus stops?</li> <li>• Is there a need to add amenities at the bus stops?</li> <li>• 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.</li> <li>• Will a midblock bulb encourage jaywalking?</li> <li>• Is there a need to place a greater emphasis on nonmotorized transportation in the corridor or region?</li> </ul>
<b><i>Bicyclists</i></b>	<ul style="list-style-type: none"> <li>• Do bicyclists currently use the parking lane as a travel lane?</li> <li>• How will bicyclists interact with buses that are stopped at the bus bulbs if there is no defined bicycle lane?</li> <li>• Are there defined bicycle facilities on parallel streets (e.g., bike lanes)?</li> </ul>
<b><i>ADA Wheelchair Lift Deployment</i></b>	<ul style="list-style-type: none"> <li>• 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)?</li> <li>• Where will the bus shelter, benches, and signs be placed with respect to the ADA landing pad?</li> <li>• How will placement of vending machines be controlled to avoid machines being placed near the pad?</li> </ul>
<b><i>Transit Operations</i></b>	<ul style="list-style-type: none"> <li>• Are there high transit ridership numbers in the corridor?</li> <li>• Are there a high number of boardings and alightings at a stop?</li> <li>• Is the site a transfer point?</li> <li>• Will more than one bus be arriving at the site at the same time? Will articulated buses be stopping at the site?</li> <li>• What is the preferred location of bus stops—nearside, farside, or midblock?</li> <li>• What is the frequency of stops?</li> <li>• Will the presence of bulbs provide an opportunity for consolidation of stops?</li> </ul>
<b><i>Traffic</i></b>	<ul style="list-style-type: none"> <li>• Are there high traffic volumes on the roadway?</li> <li>• Are the speeds on the street too fast for bus bulbs?</li> <li>• Is the posted speed 45 mph or higher?</li> <li>• Is there a concern for the speed differentials between stopped or slower transit vehicles and faster-moving, general-purpose traffic?</li> <li>• Is the bus having re-entry difficulties at the bus bay stop?</li> <li>• Are buses currently stopping in the travel lane to avoid the re-entry problem?</li> <li>• Will bus bulbs be perceived as traffic-calming measures?</li> <li>• Are erratic maneuvers frequent in and around the bus stop to avoid the stopped bus?</li> <li>• Does the potential exist for conflict between right-turning vehicles and the stopped buses?</li> <li>• Will the all-red phase be extended to avoid having cars trapped in the intersection at farside stops?</li> <li>• Will the back-end of the bus extend into the intersection and block the intersection at a farside stop?</li> <li>• Are there signalized intersections with general-capacity concerns?</li> <li>• How frequently will the bus stop in the travel lane?</li> <li>• Will a stopped bus in the travel lane create unacceptable traffic queues behind the bus?</li> <li>• 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?</li> <li>• 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?</li> </ul>

TABLE 5 *Continued*

<b><i>Parking</i></b>	<ul style="list-style-type: none"> <li>• Is there 24-hr curbside parking available?</li> <li>• Will the addition of the bulb add or remove parking?</li> <li>• What types of parking control markings will be installed at the site—signs, tape, or paint?</li> <li>• Will additional parking enforcement be provided to reduce illegal parking at the bulbs and to reduce double-parking before and after the bulbs?</li> <li>• How will the placement of parking signs affect the operations of the wheelchair lift extension?</li> <li>• Will the conversion reduce illegal parking because drivers will be more hesitant to park in a travel lane rather than in a bus bay?</li> </ul>
<b><i>Length and Width of the Bus Bulb</i></b>	<ul style="list-style-type: none"> <li>• Will more than one bus be arriving at the site simultaneously?</li> <li>• Will articulated buses be arriving at the site simultaneously?</li> <li>• Is the site a transfer site?</li> <li>• 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)?</li> <li>• What is the policy of the transit agency regarding how fares are collected? Are fares collected on both inbound and outbound routes?</li> <li>• Will the bulbs be used to help consolidate bus stops in the corridor?</li> <li>• Will the bulbs also be fitted with pedestrian curb extensions on both approaches to the intersection?</li> <li>• Will bus stop amenities, such as shelters, be added to the bulb?</li> </ul>
<b><i>Construction / Design</i></b>	<ul style="list-style-type: none"> <li>• Will utilities (e.g., fire hydrants, light poles, signs) need to be relocated if bulbs are constructed?</li> <li>• How will the street storm water drainage be handled?</li> <li>• How will the sidewalk drainage be handled with the extension of the curb?</li> <li>• Will the design create areas on the sidewalk for standing water, which creates the potential for ice in colder climates?</li> <li>• What will the return radius be on the curb—does a motorized street cleaner need to maneuver in and around the bulb?</li> <li>• 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.</li> <li>• Bollards have been used to prevent vehicles from encroaching on the bus stop waiting area.</li> </ul>

## 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.
- 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.

### 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]).

### 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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