

An Evaluation of Bus Bulbs on Transit, Traffic, and Pedestrian Operations

Prepared for:

**Transit Cooperative Research Program
Transportation Research Board
National Research Council**

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August 2000

ACKNOWLEDGMENT

This work was sponsored by the Federal Transit Administration (FTA) and was conducted through the Transit Cooperative Research Program (TCRP), which is administered by the Transportation Research Board (TRB) of the National Research Council.

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This report has not been edited by TRB.

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ACKNOWLEDGMENTS

The research reported herein was performed under TCRP Project A-10A by the Texas Transportation Institute. Texas A&M Research Foundation was the contractor for this study.

Kay Fitzpatrick, Research Engineer, Texas Transportation Institute, was the principal investigator and Kevin Hall, Associate Research Scientist, Texas Transportation Institute, was the co-principal investigator. The other authors of this report are: Stephen Farnsworth, Assistant Research Scientist, Texas Transportation Institute and Melisa D. Finley, Assistant Transportation Researcher, Texas Transportation Institute. The work was performed under the general supervision of Dr. Fitzpatrick and Mr. Hall.

The authors gratefully recognize the assistance of individuals that work for San Francisco MUNI and with the City of San Francisco. Duncan J. Watry (San Francisco MUNI) provided initial information on planned bus bulb projects in San Francisco, California. He also provided extensive assistance with TCRP Project A-10. More importantly, Duncan 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 San Francisco MUNI, also provided additional assistance and updates regarding the construction schedule and progress update for the south Mission Street renovation project. Other individuals that provided assistance to the research team in San Francisco include:

- Bond M. Yee, City Traffic Engineer, Department of Parking and Traffic, City and County of San Francisco
- Javad Mirabdol, Transportation Planner, Department of Parking and Traffic, City and County of San Francisco
- Steve J. Patrnick, Transit Planner, Service Planning, San Francisco MUNI

In addition, the authors wish to acknowledge the many individuals who contributed to this research by participating in the on-site interviews. The following individuals were able to provide extensive information on the use and construction of bus bulbs in their respective communities:

- Young Park, Manager of Capital Projects, Portland Tri-MET
- Douglas B. McCollum, Traffic Engineer, City of Portland, Oregon
- Ellen Vanderslice, Project Manager, Pedestrian Transportation Program, City of Portland, Oregon
- Leonard D. Madsen, Senior Project Manager, Transit Speed and Reliability Program, Seattle METRO
- Hiro-I Takahashi, Seattle Transportation, Seattle, Washington
- Tasha Leshefka, The Transpo Group, Seattle, Washington
- Cathryn Maggio, Makers Art. Company, Seattle, Washington
- Forrest P. Klotzback, Neighbourhood Transportation Branch, City of Vancouver, British Columbia, Canada
- Lon LaClaire, Neighbourhood Transportation Branch, City of Vancouver, British

- Columbia, Canada
Robert M. Hodgins, Strategic, Transportation Planning Branch, City of Vancouver,
British Columbia, Canada

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

ABSTRACT

Bus bulbs are a section of sidewalk that extends from the curb of a parking lane to the edge of the through lane. A major advantage of using bus bulbs is the creation of additional space at a bus stop for shelters, benches, and other bus patron improvements when the inclusion of these amenities would otherwise be limited without the additional space. The primary motivators for installing bus bulbs are to reduce congestion on sidewalks and to eliminate the bus-weaving maneuver into a bus bay stop. Bus bulbs are appropriate at sites with high patron volumes along crowded city sidewalks and where parking along the curb is permitted. An evaluation of pedestrian operations found that the average amount of available space for pedestrians and transit patrons improved after the bulb had been constructed. Vehicle and bus speeds also increased on the block and in the corridor. The average delay to buses attempting to re-enter the travel stream was constant from 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 the bus bulb.

The executive summary and body of the contractor's final report, along with Appendix A, has been published separately as *TCRP Report 65*, "Evaluation of Bus Bulbs."

APPENDIX B

CURBSIDE BEFORE-AND-AFTER STUDY

Transit activities can place great demands on sidewalks that are already crowded with pedestrians, street furniture, store front displays and/or transit shelters. Bus stop areas can become instantly undersized with the intermittent surges created by boarding and alighting activities. Therefore, bus stops become unintended bottlenecks or points of congestion on crowded urban sidewalks. With the typical arrangement of a bus stop on a sidewalk, there is limited space to segregate transit activities (e.g., boarding and alighting, waiting patrons) from normal pedestrian movement on the sidewalk. Bus bulbs appear to be the most logical strategy for improving pedestrian congestion in narrow or small areas. By extending the curb toward the outside travel lane through an on-street parking area, transit agencies can provide a defined waiting area for bus patrons away from the flow of pedestrian traffic on the sidewalk and can store amenities, such as bus shelters, off of the sidewalk altogether. The benefits, on the surface, appear to be rather obvious.

STUDY DESIGN

A total of nine bus stops were converted from bus bays to bus bulbs during the summer of 1999 along south Mission Street between Cesar Chavez and Cortland Avenue. The bus bulbs were a part of a greater street reconstruction project. San Francisco MUNI used the reconstruction project as an opportunity to extend the curbs from the sidewalk through the parking lane and directly adjacent to the outside travel lane. The newly created space provided much needed storage area for waiting bus patrons off and away from the busy sidewalks. The road reconstruction project created an opportunity to compare pedestrian operations in and around a bus stop zone between a bus bay and a bus bulb. Bus bay stops are a very common design configuration in San Francisco. In this configuration, a section of a parking lane is marked for buses servicing a particular stop. Bus bulbs exist when the sidewalk is extended into the parking lane to the edge of the travel lane. The major objectives of the pedestrian field studies were to:

- determine if the space available per pedestrian increases with the construction of the bus bulb, thereby improving walking speeds, reducing conflict points, and increasing storage area for waiting patrons;
- determine if the effective walkway width of the sidewalk improves with the addition of the bus bulb;
- determine if the corner operates at a higher level of service (LOS) with the additional room created by the bus bulb; and
- determine boarding and alighting characteristics on the available sidewalk space.

The before data collection trip when the bus bay configuration was present occurred in February 1999, and the after data collection trip when the bus bulb configuration was present took place in November 1999.

NEIGHBORHOOD CHARACTERISTICS

South Mission Street is an extension of the Mission District (South of Cesar Chavez/Army Street). The Mission District is a multi-cultural residential and shopping district in San Francisco. The community has evolved into an Hispanic center within the city. The area is characterized by three to five story buildings that contain street-level stores and single-room apartments/hotels or residential spaces above. Figure B-1 is a picture of south Mission Street looking towards downtown San Francisco. Note the dense urban pattern that is characteristic of the neighborhood.

Because of the residential density and shopping opportunities in the district, the sidewalks can become extremely congested with pedestrians. During the week, the highest pedestrian volumes along Mission Street coincide with the release of children from local schools. The period begins in the mid-afternoon with the release of elementary and middle school children and ends after the release of high school students later in the afternoon. However, the greatest demand occurs on Saturday mornings when residents do weekly errands in the neighborhood stores. It is not uncommon to see sidewalks completely saturated with pedestrians carrying multiple shopping bags on mid-afternoons and on Saturday mornings. There is no morning pedestrian peak period to note since neighborhood stores do not generally open before 10 o'clock in the morning.

In addition to the normal local pedestrian movement, the bus stops along Mission Street can cause tremendous surges of additional people onto the sidewalk. Bus stops can, in effect, become bottlenecks to pedestrian flow along the sidewalks in the Mission District. Transit ridership numbers along Mission Street are the highest west of the Mississippi. Six routes either serve all or part of the study corridor (14, 14L, 49, 67, 26, and Sam Trans). In fact, the Mission @ 20th Street location has the highest boardings in the city.

The boarding and alighting activities can cause bottlenecks when patrons form queues that block sidewalks. The mingling of boarding and alighting passengers with pedestrian movement on the sidewalk can cause temporary and intermittent points of congestion in and around the bus stops. Waiting patrons can also serve to restrict the flow of pedestrian movement along sidewalks. Along crowded settings such as the bus stops in San Francisco, waiting patrons choose to either stand along the edge of the curb or wait against storefronts. This type of behavior tends to restrict or funnel pedestrians into increasingly limited space at bus stops. This is especially true during peak periods when bus patronage is at its highest, and pedestrian flow is at its greatest. The surges of alighting passengers can also place great demands on the capacity of street corners and crosswalks. Crossing delays may incur by the large amount of pedestrians that are suddenly placed at the crosswalks.

The existing sidewalk width is further limited by the presence of street furniture (e.g., light poles, street signs, parking meters, and benches) and store front displays. Displays in front of stores are a common characteristic of the Mission District shopping culture. The presence of bus stop amenities, such as a bus shelter, also removes available sidewalk space for normal pedestrian operations.

Consequently, the justification for additional sidewalk space is clearly evident. However, the city cannot widen the sidewalk along the entire length of the road because the sidewalk is bounded by buildings on one side and curbside parking on the other. The existence of parking spaces in front of the store is believed to be critical for the health of the businesses. Since the bus stops represent the highest level of pedestrian bottlenecks along Mission Street and curbside parking is not permitted in the bus stop zone, the bus stops are the most logical location to extend or widen the sidewalk. The inclusion of a bus bulb will, hypothetically, create additional storage space for waiting bus patrons, increase the available sidewalk width for pedestrians, segregate bus boarding and alighting activities from sidewalk flow, create the necessary space for bus stop amenities (e.g., bus shelters), and reduce the exposure time of pedestrians crossing the intersection.

STUDY SITE CHARACTERISTICS

Only one of the bus stops along Mission Street has sufficient pedestrian activity for a pedestrian study—the southbound approach at the intersection of Mission Street and 30th Street. The site is a nearside stop with a bus shelter for waiting patrons. This site was chosen because it has the highest pedestrian and boarding and alighting volumes of any of the sites on South Mission Street where bus bulbs are being constructed. The high pedestrian and bus patronage volumes were confirmed by officials at MUNI and by observations made during the data collection trips. 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 in close proximity to the bus stop, and the high volume of children that ride the bus to and from school. Further adding to the pedestrian traffic at the site is the location of another bus stop on 30th Street, which serves as a transfer point from the Mission Street bus routes onto the Divisadero bus route. Another parallel bus route is available on San Jose Street, which is in close proximity of Mission Street.

Figures B–2 and B–3 show the configuration/layout of the entire intersection prior to and after the construction of a bus bulb. An interesting feature to this site is the position of the Safeway driveway relative to the bus stop. The bus stop zone actually extends beyond the upstream entrance to the driveway at this site. Presumably, this is to prevent parking near the bus stop zone. The proximity of the driveway actually reduces the length of the bus stop zone. When multiple buses arrive at the bus stop (bunching), only two buses can actually board and alight passengers directly from the curb and this is with quite a bit of maneuvering on behalf of the bus drivers. The zone extension was maintained even after the construction of the bus bulb. The bulb reduced the crossing distance of Mission Street but did not significantly impact the distance across 30th Street. A curb extension into 30th Street was probably infeasible because of the acute angle that 30th Street has with Mission Street. Additional parking was not removed for the purposes of constructing the bulbs.

Figures B–4 and B–5 are detailed dimensioned drawings of the area immediately adjacent to the bus shelter for both the bus bay and bus bulb configurations. The bus shelter is present in both bus stop configurations, however the placement was slightly changed when the bulb was

constructed. The bus shelter was moved slightly downstream on the bulb but away from the Walgreens storefront and placed closer to the edge of the curb in the bulb. The location of the streetlight and transit supervisor storage bin did not change. Therefore, the distance between the edge of the shelter and these existing features is reduced in the bus bulb configuration. The trash receptacle was moved to the upstream side of the bus shelter, presumably to increase the space between the bus shelter and the street light. This area between the bus shelter and the streetlight is where a majority of the boarding and alighting activities occur. Consequently, it needs to be free of any unnecessary features in order to provide unencumbered movement through this space.

Figure B-6 is a photograph of the Mission @ 30th Street bus bay taken during the before trip, and Figure B-7 shows the resulting space created by the bus bulb during the after trip. The pictures were taken from a similar position in order to illustrate the increased sidewalk area for pedestrians.

DATA COLLECTION/REDUCTION

The pedestrian studies focused on the southbound side of Mission Street at the intersection of 30th Street where a nearside bus stop is located. Additional bus arrival/departure information was collected on the northbound, farside stop. To study the pedestrian and transit operations around this particular bus stop in an urban area, data were collected on multiple days both prior to and after construction of the bus bulb.

Pedestrian data were primarily collected using palmtop computers with programs specifically created for the project. The palmtop computers were used to collect pedestrian and bus arrival and departure information. The TransLINK Data Collection unit of the Texas Transportation Institute developed the programs using Visual Basic software for use on the palmtop computers. The palmtop computers run on a Windows CE operating system that is compatible with Windows 95 or greater operating systems. The palmtops have a stylus and touch-screen as well as a mini-keyboard for manually entering text and/or numbers. Figure B-8 provides an example of the palmtop screen utilized during the bus arrival/departure data collection effort.

Table B-1 highlights the specific information that was identified as being required for the data collection effort. For each task, there are specific fixed data that remain the same for the entire data collection session, information pertinent to each individual record, and additional fields. The output of the programs is a comma-delimited text file that can be easily imported into a spreadsheet, and subsequently analyzed.

The data collection efforts were greatly enhanced with the introduction of the palmtop computers. For example, data were entered directly into a computer with an automatic time stamp for each observation. The data are then easily disaggregated into time segments to account for the presence of the bus at the bus stop. The effects of the bus arrival/departure sequence were captured in far greater detail than would have otherwise been possible without the palmtop computers. For pedestrian studies, it is critical to capture the intermittent surges of boarding and alighting passengers from the bus to determine the impact of this activity on sidewalk operations.

Still photographs were taken with a digital camera and standard lens camera to capture general attributes of the site as well as any notable events (e.g., cars parked in bus stop zone, articulated buses not fully in the bus stop zone, etc.) that may have occurred. The photographs, when appropriate, were also used to document pedestrian behavior in and around the bus stop zone (e.g., common waiting areas, boarding and alighting activities, and points of congestion).

For the analysis of pedestrian operations at the street corner, video cameras were used to capture peak-hour pedestrian movements at the northwest corner of the intersection of Mission Street and 30th Street. Two weekday afternoon peak periods were videotaped for approximately two hours each during both the before and after data collection trips. During the after data collection trip, video cameras were placed in identical locations in an effort to capture similar information.

Since the corner study needed signal cycle information, signal timing data were also collected during the before and after study trips. Signal timings were checked using stop watches, and detailed drawings were made of the sidewalk area adjacent to the bus stop zone at Mission Street and 30th Street.

PEDESTRIAN SPACE STUDY

A significant indicator of change for the benefit of pedestrians and transit patrons is available pedestrian space. Available space is determined by measuring the space per pedestrian or square feet per pedestrian in a defined area. Space utilized per pedestrian is the inverse of pedestrian density and is typically used since density has fractional values (pedestrians per square foot). Pedestrians adapt to the path of least resistance and greatest comfort, whether it is in motion (e.g., walking through the bus stop zone) or standing still (e.g., waiting for the next available bus). Similar to vehicular movement, as the available space is reduced and the density increases, pedestrian flow and comfort decreases. In this manner, pedestrian space can be quantified in Levels-of-Service by using readily developed criteria.

Significant studies of pedestrian flow indicate that as the space available per pedestrian decreases to a range of 5 to 9 sq ft (0.5 to 0.8 sq m) per pedestrian, the capacity of the sidewalk or area is attained.^(1,2) Any available space with a value of 4 sq ft (0.4 sq m) per pedestrian or less causes significant interruptions to pedestrian movement and in some cases, movement ceases to exist. In fact, some literature suggests that available space between the 5 to 9 sq ft (0.5 to 0.8 sq m) range causes significant intrusion into the natural “buffer” zone that unfamiliar pedestrians will create between them and other strangers.⁽³⁾ Studies into the relationship between pedestrian speed and space show thresholds at 6, 15, and 40 sq ft (0.6, 1.4, and 3.7 sq m) per pedestrian.^(1,2) Similar to the 5 to 9 sq ft (0.5 to 0.8 sq m) per pedestrian range noted above, it appears that in some cases at 6 sq ft (0.6 sq m) per pedestrian, the maximum capacity of a sidewalk to handle uninterrupted movement of pedestrians is attained. At 15 sq ft (1.4 sq m) per pedestrian, slow walkers are forced to change their pace in order to adjust for pedestrian congestion. The fastest pedestrian can reach a comfortable speed at 40 sq ft (3.7 sq m) per pedestrian. Observations made from photographic studies indicate that free flow is not truly achieved until the space available per pedestrian is at least 100 sq ft (9.3 sq m).⁽⁴⁾ Unchallenged movement is not attained until a pedestrian encounters a space that provides at least 130 sq ft (12.1 sq m) per pedestrian.

Another important consideration at bus stops is the ability to cross streams of traffic. This type of behavior commonly occurs at the point where buses board and alight. The ability to cross bi-directional traffic has been studied and similar threshold values have been developed. For example, at 15 sq ft (1.4 sq m) per pedestrian, almost all crossing movements are negatively impacted by pedestrian crowding.⁽³⁾ Additional research by anthropologists indicates that pedestrians that are in an unfamiliar setting with strangers would prefer a spacing of at least 12 ft (3.7 m), which would be unrealistic at a crowded bus bay stop.⁽⁴⁾ The values noted above may appear to be rather large, but as stated above, pedestrians, especially in strange settings with unfamiliar people, will naturally try to provide the greatest level of separation unless they are with friends or family. People that travel through a space on a regular basis will also gravitate to the same paths. Bus stops provide a unique setting for studying the change in available space. Bus stops, at times, are practically devoid of waiting patrons, while at other times, they experience tremendous surges of alighting patrons and have large groups of people waiting to board, either in informal congregations or slightly developed queues. Therefore, it is important to quantify the relationship of available pedestrian space between a bus bay and a bus bulb in order to definitively define the true value of a bus bulb versus a bus bay.

Data Collection Methodology

Using the palmtop computers and a program written specifically for this task, measurements were taken of the number of people in a specified area for the following three time intervals:

- one minute 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
- one minute after the bus had left the bus stop zone (*following* the bus departure).

The three time intervals were adopted in order to analyze the impact on the sidewalk LOS for the pedestrian surge created by a bus loading and alighting. The area utilized in this study is located on the sidewalk adjacent to the bus stop zone between the bus shelter and the corner of the Walgreens store because a majority of the boardings and alightings occur in the area. Figure B-9 shows the study area and dimensions of the bus bay stop configuration, and Figure B-10 shows the study area and dimensions with the bus bulb configuration. The total square footage of the study area was determined by accounting for the effective walkway width of the study area in the bus stop zone. The effective walkway width is essentially the width of the sidewalk minus the width of any features that cause pedestrians to avoid or move around them. Pedestrians will naturally provide a buffer between objects or other pedestrians in order to establish a “comfortable” distance to pass. The total area of available pedestrian space for the bus bay configuration was 308 sq ft (28.6 sq m) and 462 sq ft (43 sq m) for the bus bulb configuration. Within the adjacent area around the bus stop, it is immediately evident that the bus bulb configuration provides additional square footage to the study area.

The available space per pedestrian is determined by dividing the number of observed pedestrians during each of the above time intervals by the resulting total square footage of the selected study

area. The resulting available space per pedestrian is then associated to defined Levels of Service. Table B-2 shows the LOS categories by square feet per pedestrian as presented in the *Highway Capacity Manual*.⁽¹⁾

Bus Bay Configuration

A total of 20 bus arrival/departure cycles were collected on the first day, and eight were collected on the second day when the bus stop was configured as a bus bay. Table B-3 lists the resulting space per pedestrian and accompanying LOS for the period prior to the bus, when the bus was present, and following the departure of the bus for each cycle during the two-day bus bay data collection effort. The initial set of calculations shows that the bus bay is functioning at a fairly acceptable LOS for most cycles. Twenty-six of the total 28 cycles had a space per pedestrian that was lowest while the bus was present at the bus bay stop. Understandably, this can be expected since the amount of pedestrian traffic in the bus stop area is highest when the bus is in the zone. The average space per pedestrian while a bus was at the bus bay stop was reduced by over 50 percent.

The average space per pedestrian per cycle is 71 sq ft (6.6 sq m) in the prior phase, 33 sq ft (3.1 sq m) in the present phase, and 80 sq ft (7.4 sq m) in the following phase. These numbers correlate to an average LOS B for the prior phase, LOS C for the present phase, and LOS B for the following phase.

Prior to the bus arriving to the site, when it is likely to find patrons congregating in groups or developing informal queues, the LOS dropped below a C only once. However, there were six events when the bus stop had an available pedestrian space between 16 to 40 sq ft (1.5 to 3.7 sq m) per pedestrian. At this range, pedestrians have to adjust their stride to move through the site and as the space degrades closer to the lower end of the range, pedestrians are forced to make greater changes to their paths and speeds. The greatest number of events that fell in this range occurred while the bus was boarding and alighting passengers. A total of 19 boarding and alighting events caused the bus bay's available space to fall between the range of 16 to 40 sq ft (1.5 to 3.7 sq m) which represents 68 percent of the observations. Table B-3 summarizes the initial findings from the bus bay configuration by aggregating the data into LOS categories that are defined by available space. The impact of the bus boarding and alighting is evident in the number of events that occur below a LOS B.

The findings only consider the impact that existing features, such as the bus shelter, store front, and benches may have on the available space at the bus stop. However, the bus stop is never completely devoid of waiting patrons, passing pedestrians, or congregating groups of pedestrians. In reality, there are really two different sets of effective walkway conditions that exist at each site. The first effective walkway condition is the sidewalk width minus any perceived "safe passage" zones around fixed objects. The resulting area shows the available space that might be present if there were no other bus patrons or congregating pedestrians in the site. However, this type of condition rarely exists, especially during peak travel times when children are walking home from school with friends and family, people are toting copious amounts of grocery bags, people are congregating in groups, and several people are passing each other on the sidewalk.

Therefore, to represent typical conditions at a site, common bus patron and pedestrian congregation areas are figured into the calculation.

For the bus stop site at Mission and 30th Street, the research team observed a number of common areas where people tended to congregate thereby reducing the available space for pedestrians to pass through the bus stop zone. The most common areas were around the bus shelter, leaning against the light pole and MUNI supervisor storage bin, and against the Walgreens store. Typically, no more than three to four bus patrons simultaneously utilize the bus shelter to wait for the next available bus. If the shelter is full, people stand along the wall of the Walgreens store or behind/next to the shelter. The Walgreens store has an overhang that provides ample protection from the elements for pedestrians and waiting bus patrons alike. This adopted use of the overhang by waiting patrons effectively reduces the area available for pedestrians to travel through the zone. It was a fairly common condition to have people stop and chat behind the bus shelter or wait against the storefront with their bags of grocery. Another common occurrence was to have people standing two deep along the wall talking to each other. This further reduces the sidewalk width and overall available pedestrian space at the bus stop. The bus bay configuration was already confined by the limited sidewalk width in relationship to use and by the presence of a bus shelter at the stop.

Figure B–11 provides a graphical representation of the common waiting areas that were observed at the bus bay configuration. Dimensions of the reduced effective walkway width are also included in the figure. When waiting pedestrians/patrons are included in the space calculation, the available area in the bus bay is reduced from 308 to 173 sq ft (28.6 to 16.1 sq m). This is a fairly realistic inclusion since the bus stop zone is never completely void of waiting patrons, passing pedestrians, or people congregating in groups during the afternoon peak period.

The dimensions from Figure B–11 were used to determine a second set of LOS and available area calculations. Table B–5 compares the resulting available space per pedestrian and LOS between the two different sets of calculations. The data in the left side of the table were determined by only considering the existing street furniture. Calculations developed in order to account for waiting patrons and congregating pedestrians in the available space are shown in the far right side of Table B–5.

Figure B–12 compares the available space observed when the bus is present with only street furniture considered and when both street furniture and standing pedestrians are considered. Consideration of waiting patrons and pedestrians notably decreases the amount of space available for each pedestrian.

Figure B–13 graphically shows the available pedestrian space comparison between each phase of the bus arrival/departure episode at the bus bay zone for one of the data collection days. The figure was developed using the calculations with street furniture and waiting pedestrians. The impact of the boarding and alighting activities on available pedestrian space is clearly evident in the *present* phase when the bus is boarding and alighting passengers. The best example of the pedestrian surge created by boarding and alighting activities is evident in cycle 16. The bus stop zone is nearly empty prior to and following the departure of the bus but when the bus boards and

alights, the LOS that pedestrians and patrons encounter drops dramatically from an A to an E. This figure highlights the intermittent characteristics associated with pedestrian operations in and around bus stops.

Similar to the previous analysis of the bus bay, the available space per pedestrian drops by at least 50 percent when the bus is present at the zone. The bus bay stop zone experienced a total of 11 events when the LOS dropped to E when a bus was present and there were congregating pedestrians and/or waiting patrons. An additional 10 periods of boardings and alightings caused the LOS to be only a D. Consequently, approximately 75 percent of the time a bus boarded and alighted during the peak period at the bus bay stop, the LOS was at or below D.

More interestingly though, there were a total of 14 cycles during all three of the bus arrival/departure events that had an available space of less than 15 sq ft (1.4 sq m). At this size, almost every crossing maneuver encounters some kind of obstacle to movement. A majority of these events, nearly 80 percent, took place while the bus was boarding and alighting. During the highest moments of the peak period, all three doors were often used for boarding and alighting. It was also common to have more than one bus arrive at the stop at the same time. Boarding and alighting patrons were often faced with multiple streams of flow and crisscrossing patrons trying to either exit the site or board a bus. Twice, the available space per pedestrian in the bus stop zone dropped to only 7 sq ft (0.7 sq m) during the present phase. According to extensive research on pedestrian comfort, 7 sq ft (0.7 sq m) is the minimum level of comfort before crowding becomes intrusive and carrying capacity of the space is reached.

At 7 sq ft (0.7 sq m), lateral passage between standing pedestrians becomes extremely restricted. Another seven cycles yielded an available space of only 16 sq ft (1.5 sq m), which is barely above the 15 sq ft (1.4 sq m) threshold when crossing through pedestrian traffic becomes difficult.

The resulting average LOS for the prior phase and following phase was a B. The average space per pedestrian for these two phases was 40 and 45 sq ft (3.7 and 4.2 sq m), respectively. However, the average pedestrian space is only 19 sq ft (1.8 sq m) when the bus is boarding and alighting at a crowded bus bay, which equates to a LOS of D. At this level-of-service, pedestrian movements are restricted and the probability for conflicts are high. Table B-6 shows the total number of events that occurred at certain level-of-service during the bus arrival/departure sequence when waiting pedestrians are factored into the available space calculation.

Therefore, when typical conditions exist at a bus bay stop configuration, such as the presence of bus shelters, street furniture, waiting patrons, passing pedestrians, and congregating pedestrians, the bus stop reaches a critical level of saturation during boarding and alighting activities in peak conditions.

The impact of the boarding and alighting activities is also evident in common walkway paths that pedestrians choose in order to avoid areas with high levels of congestion. Pedestrians and patrons alike seek the path of least resistance, which sometimes involves people moving out onto the street pavement. One particular route that was chosen by pedestrians was passing between

the bus shelter and the curb or even on the street in front of the shelter. This creates conflicts with those bus patrons that are in the bus shelter waiting to board the bus and with any queues that are forming at the bus stop. Another potential danger exists with any unintentional interaction between the bus and walking pedestrians. One of the reasons MUNI constructs bus bulbs is to help limit any accidental sideswipes by the side mirrors on the bus with pedestrians. When a bus pulls into and out of a bus bay, the bus may have to take a strong entry angle into the zone, thereby causing the mirrors to overhang the sidewalk. If pedestrians are forced to use the space between the curb and shelter or to actually use the street to by pass pedestrian congestion, this can cause greater chances for the bus and pedestrians to interact. Common pedestrian walking paths that were observed at the bus bay stop configuration are shown in Figure B-14.

Bus Bulb Configuration

During the after data collection trip when the bus bulb configuration was present, a total of 13 cycles were collected on the first day, and 19 cycles were collected on the second day. Figure B-15 provides a graphical representation of the common waiting areas that were observed at or near the bus bulb. The dimensions of the reduced study area are also included in the figure.

The waiting or congregation patterns did not change significantly from the bay to the bulb configuration, but the change in available space is quite evident in the figure. The total area of the bus bulb that was studied was 462 sq ft (43 sq m). However, the reduced size is 284 sq ft (26 sq m) when areas that are prone to have waiting patrons are removed from the available space in the bulb.

Table B-7 lists the resulting space per pedestrian and accompanying LOS for the period prior to the bus, when the bus was present, and following the departure of the bus for the 32 cycles when street furniture and waiting pedestrians are considered. The average space per pedestrian on the bus bulb is 44 sq ft (4.1 sq m) in the prior phase, 44 sq ft (4.1 sq m) in the present phase (boarding and alighting), and 63 sq ft (5.9 sq m) in the following phase. These numbers correlate to a LOS of B for all phases.

Figure B-16 illustrates the average available pedestrian space for the second day of data collection at the bus bulb. Cycles 11 through 15 represent the period of greatest pedestrian congestion in and around the bus bulb. Even with the additional space afforded by the bulb, the area including the bulb and adjacent sidewalk only functions at a LOS of C or D during these five events. At only one time did the average space equate to a LOS above a C, which was a period immediately following the departure of a bus from the stop. The average available space available to waiting patrons and pedestrians during these five cycles is only 30 sq ft (2.8 sq m). This represents a degradation of approximately 250 sq ft (23.3 sq m) per pedestrian from the base case of 284 available sq ft (26.4 sq m), which is an 89 percent reduction in available space. This highlights the magnitude of patrons and pedestrians that use this space during peak periods as well as the basic need for additional space in and around the bus stop to accommodate the demand.

Comparison of Bus Bay to Bus Bulb

Similar to the bus bay, the presence of a bus (boarding and alighting patrons) in the zone has the greatest impact on available space within the bus bulb configuration. On the first day, nine of the 13 cycles had an available space per pedestrian that is the lowest while the bus is in the bus stop zone. On the second day, 12 of the 19 cycles showed a similar result. In comparison, though, the bus bulb reduces the percentage of times that boarding and alighting activities cause the available space to deteriorate to its lowest levels-of-service. When the bus stop was configured as a bus bay, the bus stop's available space dropped to its lowest levels all but two times when the bus boarded and alighted passengers. The bulb is clearly an improvement in this category.

Table B-8 shows the total number of events that a particular LOS occurs on the bus bay and bus bulb configurations. The table also shows the percentage of each event by bus arrival/departure sequence (prior, present, following).

Based on Table B-8, the bus bulb operates more efficiently than the bus bay configuration. Approximately 72 percent of events operate at a level-of-service of C or greater in the bus bulb configuration as compared to 60 percent for the bus bay design. More importantly, some of the greatest benefits in levels-of-service are evident in the present bus phase. Nearly 26 percent of the total observations made at the bus bulb when a bus was boarding and alighted operated at LOS greater than or equal to B. In comparison, only 4 percent of the observations made at the bay during the similar period operated at this level. At no time did the bay have a period when the LOS was an A during the present phase. Similar improvements are in the period after the bus has departed the stop. Level-of-service, though, does not adequately capture the true value of the bus bulb when analyzing pedestrian operations and space availability.

Table B-9 shows a direct comparison between the average space per pedestrian per cycle between the bus bay and bus bulb configurations. In almost every bus arrival/departure scenario, the bus bulb provides additional square footage for transit patrons and passing pedestrians in the bus stop zone (see also Figure B-17). The most dramatic differences occur during the boarding and alighting phase when the average available space increases from 19 sq ft (1.8 sq m) in the bay configuration to 44 sq ft (4.1 sq m) in the bus bulb configuration. This increase amounts to a difference of 132% or a factor greater than 2 when comparing available square footage. At approximately 19 sq ft (1.8 sq m), the average condition at the bay, walking speeds and paths need to be adjusted because of crowding, crossing through bi-directional traffic is difficult, and passing another pedestrian is close to the minimum 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 through bi-directional traffic is nearly unimpaired, and traveling through the zone is dramatically less impacted by other walking or standing pedestrians.

Similarly, there is a fairly significant difference in available space in the period immediately following the departure of a bus(es) from a bus stop, when a site may experience lingering delays caused by the queues of boarding and alighting passengers. The space available for pedestrians increased from 45 to 63 sq ft (4.2 to 5.9 sq m), which amounts to a 40 percent increase in available area for patrons and pedestrians to pass each other.

As expected the second lowest reading among the three events is the period prior to the arrival of a bus, when patrons are standing along the sidewalk, using the shelter, or leaning against store fronts. The average space available changed slightly from 40 to 44 sq ft (3.7 to 4.1 sq m) when the bulb was added to the bus stop. This finding may be related to the desire to use the overhang of the Walgreens as protection against the elements, regardless of the additional space created by the bus bulb. People still seek relief from the elements when they are waiting for their bus. If the bus shelter is full, people will naturally adapt to the next best available shelter, whether it's the shelter of a building overhang or a threshold to a door. Because of this, the capacity of the sidewalk is still impacted by the adaptive use practices of waiting patrons despite the additional space provided by the bulb. In a dense urban environment, such as San Francisco, this type of adaptive practice is unavoidable.

The bus bulb is clearly an improvement in available space per pedestrian for most observations. This finding is important since it was not uncommon to have more than one bus board and alight simultaneously (bunching). The greatest challenge to the capacity of the bus stop to adequately serve large amounts of people is when more than one bus is boarding and alighting. Patrons and pedestrians are most likely to encounter the greatest mix of multiple streams of traffic, queuing areas, and passing pedestrians during the boarding and alighting of buses. As previously mentioned, areas that have less than 15 sq ft (1.4 sq m) per pedestrian cause pedestrians to change their stride and make it difficult, at best, to cross different streams of pedestrian traffic. The bus bay configuration had a total of 14 events when the available space per pedestrian was at or below 15 sq ft (1.4 sq m) per pedestrian. Approximately 79 percent of these events occurred when the bus was present. Therefore, nearly 40 percent of the boarding and alighting activities that were observed at the bus bay stop configuration had densities that were significant enough to impact pedestrian behavior, comfort, and patterns. Not unlike the bus bay, the bus bulb had a total of 14 observed events when the bulb design had less than 15 sq ft (1.4 sq m) per pedestrian available. Approximately 64 percent of these events occurred, again, when the bus(es) were boarding and alighting. However, the percentage of times that crowding would be encountered when a bus was at the stop was reduced by nearly 28 percent, which represents a notable difference between the bay and bulb designs.

More importantly, the total number of events, regardless of the bus arrival/departure sequence, where crowding was significant enough to impact pedestrian movement (e.g., one pedestrian passing another pedestrian) dropped between the two designs. Below 35 sq ft (3.3 sq m) per pedestrian, studies have shown that it becomes progressively difficult to cross streams of traffic or to pass a slower pedestrian.⁽³⁾ In 63 events, bus bays had an available space less than or equal to 35 sq ft (3.3 sq m). Conversely, exiting transit riders and pedestrians encountered this type of crowding about half of the time after the bulb had been constructed. Table B-10 summarized the total number of events that occur at various conditions of pedestrian crowding between the two bus stop designs.⁽³⁾ The table also presents the total number and percentage of crowding conditions that occur while the bus was present. The impact of a bus boarding and alighting at a bus stop on pedestrian crowding, regardless of design, is quite evident.

The widening of the sidewalk caused by the presence of a bus bulb had a significant impact in reducing the number of people passing between the bus stop shelter and the curb, or even

walking in the street in front of the shelter. Figure B–18 illustrates common pedestrian walking paths observed during the after data collection trip. The reconfiguration of the site also produced other positive results, one of them being the noticeable improvement in the number of people that stay within the crosswalk boundaries when approaching the site. Previously, pedestrians would “cut the corner” and not completely cross the street within the lines.

Another positive result was the significant reduction in the number of people walking into the street to see the arrival of the next bus. In the old site configuration, the primarily empty curbside lane provided the bus patrons a seemingly safe place to walk into in order to look downstream to see the location of the next bus. However, the bus bay zone was used by cars making right turns onto 30th Street. With the new configuration, the sidewalk is extended to the edge of traffic, and patrons do not need to step into the street to see the next bus.

SIDEWALK LEVEL-OF-SERVICE STUDY

Pedestrian flow levels on sidewalks are similar to those of vehicles on roadways. The freedom to choose a desired speed as well as the ability to bypass others are important elements. A method for quantifying the efficiency of a sidewalk is determining the pedestrian flow rate. Pedestrian flow rate is the total number of people passing a particular point in a specified period of time. The resulting value is in terms of pedestrians per minute per foot (ped/min/ft) and this value correlates to a specific level-of-service.

Sidewalk LOS data were collected at the Mission Street and 30th Street (southbound direction) site during two afternoon peak periods for both trips. With the bay configuration, pedestrian volumes were collected for an hour and a half on the first day and one hour the second day. Information was also collected for an hour and a half on the first day and two hours the second day after the site was reconfigured. The data were subsequently verified by videotape. In order to conduct an analysis as specified in the *Highway Capacity Manual*, bi-directional pedestrian volumes in 15-minute increments, as well as the effective walkway width of the sidewalk, are needed.

The effective walkway width is essentially the width of the sidewalk minus the width of any fixed features that cause pedestrians to avoid or move around them. Using only the effective walkway width provides one interpretation of the data. Another interpretation is to include common bus patron and pedestrian congregation areas in the calculation. These mobile features, while not fixed in a particular location, have a constant effect on the ability to comfortably travel on the sidewalk. For example, in Figure B–19 the effective walkway width of the empty curbside bus bay is 6 ft (1.8 m). However, if common waiting areas and congregation points are accounted for, the effective walkway width available for passage through the site is essentially reduced to 3 ft (0.92 m). Based on the research team’s observations of the frequency that this area contained waiting patrons, the most realistic conditions (with waiting patrons and congregating pedestrians) are presented in the findings.

The sidewalk level-of-service study relied primarily on the use of palmtop computers. Data were collected by positioning a member of the research team at a pre-determined spot near the end of the bus stop zone at approximately the same location for each bus stop configuration. As pedestrians and bus patrons passed a certain location in the zone, the research team member would enter a data point by clicking on a counter on the palmtop computer by using a stylus pen. Each entry is automatically recorded with a time stamp for the purpose of analyzing the impact of boarding and alighting activities on the sidewalk flow. The arrival and departure of a bus is recorded by the research team with another automatic time stamp that is available on the palmtop window screen.

The area between the corner of the Walgreens store and the light post at the far end of the bus stop zone was selected as the sidewalk LOS study area. This area represents the greatest level of pedestrian flow for the entire bus stop zone. As observed during the data collection trips, a majority of the boarding and alighting bus patrons typically used the sidewalk between the Walgreens store and the light post. The bus patrons are either moving from this bus stop to the adjacent bus stops (transfer point) on 30th Street or are going to the 30th Street or Mission Street crosswalks. A large number of school children with their book bags use the bus stop on Mission Street to go home in the evening. Pedestrians also utilize this space to move through the site. Most pedestrians are carrying shopping bags from the Safeway store and are usually traveling in groups (e.g., families and friends). Therefore bus patrons and pedestrians alike usually arrive and depart in groups and are a part of intermittent surges that place varying demands on this area to provide adequate space for unobstructed pedestrian movement.

Bi-directional pedestrian flow data were collected along the line between the Walgreens and the light pole to capture movement in both the northbound and southbound directions. The data were collected during the afternoon peak hours when school children were leaving school and parents were running errands with their children.

Figure B–19 shows the resulting walkway width of the bus bay configuration while Figure B–20 provides a cross section of the effective walkway width between the bus shelter and the Walgreens store. Figure B–21 shows the resulting walkway width of the bus bulb after construction and Figure B–22 provides a cross-section of the improved effective walkway width between the bus shelter and the Walgreens in the new configuration. Although the walkway width increased by the bus shelter, the effective walkway width did not change at the measuring point when the bus bulb was constructed because the street lights, signs, and supervisor storage bin did not move during the reconfiguration of the site. The movement of the shelter did increase the sidewalk width upstream of the intersection. The linear distance between the storefront and the back of the bus shelter changed from a width of 6 ft (1.8 m) in the bus bay configuration to a width of 10.5 ft (3.2 m) with the addition of the bus bulb. This change represents an improvement of approximately 75 percent for this specific area. At this stop, a majority of pedestrians and exiting bus patrons do not utilize this space. Therefore, this improvement would have minimal effect on the sidewalk performance at the choke point for this particular bus stop. At other locations where the directional traffic is more evenly split between the two sides of the bus stop zone, the relocation of the shelter would have a dramatic improvement in available

sidewalk space. The overall width of the sidewalk increased from 14 to 20.25 ft (4.3 to 6.2 m) for an improvement of approximately 45 percent.

Flow rate is measured in pedestrians per minute per foot, and the rate is used to determine the LOS on the sidewalk. As the flow rate increases, pedestrian speeds decrease and there are less opportunities for them to bypass other pedestrians. Consequently, the level-of- service will be degraded. The formula for determining sidewalk LOS in 15-minute increments is:

$$v = V_p / 15W_E \quad (1)$$

where:

- v = pedestrian unit flow rate (ped/min/ft)
- V_p = peak 15-minute bi-directional pedestrian count (ped/15-min)
- W_E = effective walkway width (ft)

The flow rates for four 15-minute peak time periods were determined for both the bus bay and bulb configurations. The results of the data are provided in Table B-11.

The flow rates for all analysis periods fall between 2.9 and 4.8 ped/min/ft (9.5 and 15.7 ped/min/m) and all equate to LOS B. While the highest flow rate was measured with the bulb configuration, when the four highest flow rates are averaged an improvement in sidewalk performance was found between the bay and bulb configuration. The average flow rate for the bay configuration is 4.0 ped/min/ft (13.1 ped/min/m), while the average for the bus bulb is 3.6 ped/min/ft (11.8 ped/min/m). Although this may seem like a minor improvement, it represents an 11 percent increase in the sidewalk flow level.

In addition to the 15-minute counts, the data were divided into one-minute increments. This was made possible by the time-stamps that were associated with the palmtop program developed for this data collection task. Having the data reduced into smaller segments provides a more complete view of the minute-by-minute conditions of the sidewalk. Using one-minute increments and an adjustment to the formula in the *Highway Capacity Manual*, the pedestrian flow rate and LOS were determined for all of the sidewalk LOS data that were collected. The modification of the formula used to calculate LOS in one-minute increments simply removes the factor of 15 used in the original formula and is as follows:

$$v = V_p / W_E \quad (2)$$

Using the data for November 12, 1999, from 2:53-3:08 pm, pedestrian flow rates were determined in one-minute increments for the bus bulb. Figure B-23 provides a summary of the sidewalk flow rates for this period. The figure also shows the periods when buses are and are not present in the bus stop zone for a particular one-minute increment. The highest pedestrian flows

are typically experienced when a bus is in the bus stop zone. After the bus departs the stop, there is a gradual decrease in the flow rate until the next bus enters the zone.

All of the data collected were reduced into one-minute increments, and the resulting flow rates are plotted in Figure B–24. The figure shows the cumulative frequency of all measured flow rates in addition to providing the level-of-service ranges. Table B–12 provides a summary of the flow rate values in terms of the number of observations (one-minute increments) and a percent of the total number of observations per configuration for each level-of-service. Over 90 percent of the level-of-services were in the A or B range. However, there are instances when the LOS drops to C and occasionally even D. The average flow rate for all one-minute increments in the bus bay configuration was 3.1 ped/min/ft (10.2 ped/min/m), while the average for the bus bulb was 2.8 ped/min/ft (9.2 ped/min/m). This equates to an 11 percent improvement in the flow on the sidewalk.

In order to account for the surges created when buses are boarding and alighting, the one-minute counts were divided into two scenarios: 1) when a bus was present and 2) when a bus was not present at the stop. The one-minute counts not only provided more individual determinations of LOS than using 15-minute counts, they also provided the analysis with a better interpretation of the impact of boarding and alighting activities on the level-of-service that might be encountered by a pedestrian.

The calculations considered whether a bus was present in the bus stop zone during the minute increment time period. Figure B–25 is a plot of the flow rates for bay and bulb configurations for scenarios when buses are and are not present during the minute time period. Intuitively, the average flow rate was better when buses were not present in the bus stop zone in both the bay and bulb configurations. 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 (9.2 to 7.9 ped/min/m). This equates to an improvement of nearly 17 percent. However, when buses were present, the average flow rate showed a small increase (approximately 2 percent). The flow rate changed from an average of 4.0 to 4.1 ped/min/ft (13.1 to 13.4 ped/min/m). However, as shown in Figure B–25, only on rare occasions does the LOS of the sidewalk drop below a C in either configuration. Table B–13 summarizes the total one-minute increments that were at or above a LOS D for both the bus bay and bus bulb configuration, taking into account whether or not a bus was present in the bus stop zone. The table also provides a percent value relative to the number of observations for each LOS as compared to the total number of observations for when a bus is in the bus stop zone and when it is not present in the zone.

The distribution of LOS observations is nearly identical when comparing the bay and bulb configurations when a bus is present in the bus stop zone. However, when a bus is not present in the bus stop zone, the percent of LOS readings that were A decreased from 52 percent in the bay configuration to 39 percent in the bulb. Subsequently, the number of LOS readings that were B in the bulb stop increased, meaning that there was a degradation in the level-of-service.

As previously mentioned, the critical dimension in the analysis was the distance between the Walgreens store and the MUNI supervisor storage box. This dimension did not change during the

reconfiguration of the site. Therefore, the change in level-of-service from the bay to bulb configuration can be misleading. According to the level-of-service calculations, the sidewalk adjacent to the bus stop functions at a rather consistent and high LOS. The findings showed minor improvements in most cases. This finding includes the peak period 15-minute counts, the individual one-minute counts, as well as when buses boarding and alighting were considered. Despite the fact that the physical dimensions of the data collection point did not change, the bus bulb provided a slightly improved flow rate in most instances.

CORNER LEVEL-OF-SERVICE STUDY

There are several reasons to study the LOS at a corner near a bus stop. Pedestrians will typically queue in random fashions at the corner while waiting for the “Pedestrian Walk” phase of the traffic light. Once the light changes, people will form several informal queues as they cross the street. Depending on the number of people that have been waiting at the corner, delay may or may not be experienced by pedestrians as they cross the street. If there are large numbers of pedestrians in the storage area of the corner, the likelihood of conflicts or people adjusting their paths to preserve a buffer between them and the next person increases.

For corners near bus stops (both farside and nearside), the area may experience large intermittent surges of alighting and boarding bus patrons. The boarding and alighting activities may or may not coincide with the “Walk” or “Do Not Walk” phase of the traffic signal. If alighting patrons are caught in the “Do Not Walk” phase, the corner could potentially become overcrowded with alighting bus patrons and pedestrians. The construction of a bus bulb provides additional storage area in and around the corner. Bus bulbs also provide additional room by the adjustment of the location of light poles, traffic signal poles, and vending machines.

Another advantage of constructing bus bulbs at the intersection is the reduced crossing width of the street. Although the width was reduced at the Mission Street at 30th Street location, the “Walk” phase was not changed between the bus bay configuration and the bus bulb configuration.

The afternoon peak period between 3:00 pm and 5:30 pm was selected for the corner level-of-service study due to the high pedestrian volumes that occurred during that time. After 3:00 pm, there is a significant increase in pedestrian activity due to children traveling home from school. Additionally, the two bus stops located on 30th Street are transfer points for transit riders. These factors, coupled with the location of the Walgreens store and the Safeway grocery store, helped generate significant pedestrian activity along the sidewalk adjacent to the bus stop zone.

A video camera mounted on a traffic sign directly across the street from the bus stop was used to collect pedestrian volumes at the corner of Mission Street and 30th Street. In accordance with Chapter 13 of the *Highway Capacity Manual*,⁽¹⁾ the data were reduced by viewing the videotape and documenting specific information. This information included:

- total signal cycle length,

- green and red signal times for both the major (Mission) and minor (30th) streets,
- pedestrian volumes crossing the major street in both the inbound and outbound direction,
- pedestrian volumes crossing the minor street in both the inbound and outbound direction, and
- pedestrians passing through the corner sidewalk area but not crossing either street.

Figure B–26 is a picture looking upstream toward the curbside bus bay at Mission Street and 30th Street. The site is rather constrained by the narrow sidewalk and the presence of street furniture. Figure B–27 is a plan view of the curbside corner study area.

Conversely, Figure B–28 is a picture showing the corner after the bulb has been constructed. The picture is taken at the same location for comparative purposes. The corner is noticeably larger with the addition of the bus bulb, which extends 6 ft (1.8 m) beyond the old curbside location. 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. Figure B–29 is the plan view of the bulb configuration.

The “Street Corner Analysis Worksheet” provided in the *Highway Capacity Manual*, served as the basis for the corner LOS evaluation. An example worksheet is shown in Figure B–30. The “Street Corner Analysis Worksheet” provides output in terms of square feet per pedestrian that can subsequently be translated into a LOS using the values listed in Table B–2. Each resulting LOS determination is for one complete signal cycle.

Using the three highest pedestrian crossing data from both the bus bay and bulb configurations, the research team was able to determine the corner space available per pedestrian. Table B–14 provides a summary of the corner LOS analysis. It should be stressed that the corner functions as a time-space zone. Pedestrians waiting to cross a street occupy the corner for longer periods of time, but they require less standing space, while circulating pedestrians require more space for shorter periods of time. The space element is strictly a function of the area, while the time element relates to the signal phasing and cycle length.⁽¹⁾

An initial review of the data in Table B–14 shows little, if any, improvement. All of the peak cycles are in the LOS B range. Another approach to examining the results is to compare how the corner would operate in the after period if pedestrian volumes did not change. The average number of pedestrians for the three peak cycles in the bus bay configuration is 32. The resulting average space per pedestrian is 52 sq ft (4.8 sq m). If the same number of pedestrians present in the bus bay count were applied to the bulb configuration (132 sq ft) [12.3 sq m], the average space per pedestrian would equal 58 sq ft (5.4 sq m), or an increase of 12 percent. This finding in itself shows the impact that the reconfiguration of the bus stop has on the corner level-of-service. By adding square footage to the corner area, the available space per pedestrian is noticeably improved.

The average number of pedestrians in the three peak cycles in the bulb configuration is 35, and the average space per pedestrian is 55 sq ft (5.1 sq m). However, if those 35 people were present in the bus bay configuration (100 sq ft) [9.3 sq m], the average space per pedestrian would be

reduced to 39 sq ft (3.6 sq m). This amount, would result in a LOS C which also supports the assertion that the bulb configuration provides an improved level-of-service to pedestrians.

In addition to the peak cycle analysis, all of the available corner LOS data were reduced and evaluated. This provided an overall summary of the conditions that were present over the duration of the data collection effort. The results of the analysis show that all of the corner LOS readings are in either the A or B range. There was a slight improvement in the space per pedestrian as a result of the reconfiguration of the corner area. Table B-15 provides the number of occurrences as a percent of the total observations of a particular LOS.

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. This amounts to an improvement of 9 percent. Although a majority of the LOS readings with the bus bay and bulb were either A or B, there were improvements observed as a result of the reconfiguration. In the site's configuration prior to the installation of a bus bulb, there were noticeable conflicts between pedestrians crossing the street in an inbound direction (towards the study site) and those pedestrians waiting to traverse the cross-street in an outbound direction. This 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 that pedestrians had to enter the pedestrian traffic flow on the bus stop side of the street. 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 also created fewer conflicts between pedestrians waiting to cross one street and those approaching the corner area on the other street.

BOARDING AND ALIGHTING CHARACTERISTICS

Boarding and alighting information as well as bus arrival and departure times were collected using the palmtop computers running a program specifically designed for this task. Data were collected over a period of five days during peak and off-peak periods at different sites during both data collection trips. Data retrieved from the palmtop data files include bus dwell times and the delay to buses re-entering the traffic stream. Observations on the length of dwell time and the amount of delay to buses are discussed in Appendix C, Roadway Before-and-After Study. The length of bus dwell time is also related to pedestrian activities. If the bus stop area is crowded, patrons may have difficulties in moving to the bus to board or alighting from the bus. The additional space provided by the bus bay may result in more efficient boarding and alighting operations. In addition to the data collected for determining the number of passengers that board or alight during the time that the bus is present at the bus stop, observations were made with regards to pedestrian behavior in the boarding and alighting zone.

Data were collected at two sites: Mission and 30th Street (nearside stop) in the southbound direction and Mission and 30th Street (farside stop) in the northbound direction. One site is

adjacent to the study area and the other across the street. Both sites contributed pedestrians to the sidewalk studies being conducted. In the analysis of the bus dwell times, the dwell time of the bus was plotted relative to the number of total passengers boarding and alighting the bus. Dwell times less than 40 sec were used in the analysis. Longer dwell times were associated with drivers meeting with supervisors or other similar reasons rather than being associated with pedestrian activities.

A closer look at the numbers shows that average dwell time (in seconds) per passenger boarding and alighting decreased by nearly one second in the off-peak period at Mission @ 30th Northbound. The remaining analysis groups all showed an increase in the average dwell time per passenger boarding and alighting. Table B-16 provides a summary of the averages.

This finding is misleading in that during the after study of the bus bulbs there were several occasions where a street supervisor stopped the bus and talked with the driver creating an inflated dwell time. These delays ranged from several seconds to almost three minutes. Although there were instances of street supervisors talking to bus operators in the before data collection trip, they seemed to create more delay during the after trip.

Figures B-31 and B-32 provide a before and after overview of the Mission @ 30th southbound site, while Figures B-33 and B-34 provide similar information for the Mission @ 30th northbound site. A review of the dwell time figures reveal an intuitive trend of having longer dwell times associated with higher numbers of patrons boarding and alighting.

Other observations made during the bus arrival departure study were the pedestrian behavior in the bus stop zone when buses were boarding and lighting. Figures B-35 and B-36 provide an overview of common walkway paths made by pedestrians during the boarding and alighting process. The figures show the alighting passengers and their subsequent paths as a solid black line. The boarding passengers are shown as thick gray arrows, and the area where high conflicts occurred are shown as cross-hatched boxes. In the after study, a noticeable improvement was observed at the front door of the bus where patrons alighted and boarded. In both the before and after data collection trips, high levels of congestion were noted in and around the front door of the bus. However, in the before configuration, the congested areas consumed a large portion on the sidewalk space. In the after configuration, the primary congestion occurred on the bus bulb. This allowed for less disruption on traffic on the sidewalk.

CONCLUSIONS

The objective of this study was to evaluate and compare two different bus stop designs – bus bay and bus bulb – on pedestrian operations in and around the bus stop zone. A nearside bus stop located at the intersection of Mission Street and 30th Street was selected as the study site. The bus stop has the highest pedestrian and bus patron volumes among the bus stops located on south Mission Street that was part of the project to reconfigure several bus bays to bus bulbs. The conclusions from this effort are presented in the following sections.

Pedestrian Space

For this study, the number of pedestrians and bus patrons in a defined area in and around the bus shelter were counted for three time intervals: one minute *prior* to the bus arriving, while the bus was *present* with patrons boarding and alighting, and one minute *following* the bus departure. The amount of space available per pedestrian can then be translated into pre-defined levels-of-service. When the bus bay configuration was present, approximately 60 percent of the time the area immediately adjacent to the bus shelter operated at a level-of-service C or greater. After the bulb was constructed, the bus stop operated at a LOS C or greater approximately 72 percent of the time, which is an improvement of 20 percent. The most notable improvement between the bay and bulb designs is the available space per pedestrian during the boarding and alighting activities at the bus stop. The average amount of space for pedestrians and transit patrons improved from 19 sq ft (1.8 sq m) per pedestrian to 44 sq ft (4.1 sq m) per pedestrian after the bulb had been constructed. This is an improvement of 132 percent, which represents a growth factor greater than 2 between the bay and the bulb designs. A similar, though less significant, improvement was observed in the period immediately following the departure of a bus from the bus stop, when the average square footage available per pedestrians increased from 45 to 63 sq ft (4.2 to 5.9 sq m), which is approximately a 40 percent improvement from the bus bay design to the bus bulb design. Therefore, there is significantly more room for pedestrians and transit patrons alike during the boarding and alighting phase when the bus stop is likely to experience the greatest demand for space. This was expected since the bulb essentially extends the curb another 6 ft (1.8 m) from the previous location. There is also significantly more options as far as location for transit patrons to choose to wait, other than on the sidewalk.

Sidewalk Level-of-Service

The pedestrian characteristics studied to evaluate sidewalk operations were pedestrian flow rates during the afternoon peak period. During the four highest 15-minute increments of pedestrian volumes near the bus stop zone, the average flow rate increased by approximately 11 percent from 4.0 ped/min/ft at the bay configuration to 3.6 ped/min/ft in the bulb configuration. This improvement was anticipated to be higher; however, the location of some critical street furniture was not changed. The growth rate does represent a real improvement between the bay design and bus bulb configuration. The bulb design provides more options for pedestrian paths; however, if the location of street furniture is not changed between the two configurations, the same bottleneck points still exist.

When the data are divided into one-minute increments to account for the presence of a bus at or not at the stop, similar results exist. The average flow rate on the sidewalk improved by 17 percent between the bay and bulb designs when the bus was not present at the bus stop boarding and alighting passengers. The average flow rate decreased from 2.8 to 2.4 ped/min/ft (9.2 to 7.9 ped/min/m). Intuitively, the conclusion from this data might suggest that the bulb is providing the necessary space for patrons to wait for their next bus off of the sidewalk, thereby, improving the conditions on the sidewalk. Contrary to this finding, the average flow rate increased with the bulb design when the bus was present boarding and alighting passengers. The rates changed from 4.0 ped/min/ft (13.1 ped/min/m) on the bay to 4.1 ped/min/ft (13.4 ped/min/m) on the bulb, which represents a degradation of only 2 percent. Once again, this finding may indicate that

since the location of street furniture did not change between the two configurations (with the exception of the bus shelter), the bus bulb at Mission and 30th Street did not truly achieve enhanced pedestrian movement characteristics during peak conditions, such as what is experienced during the boarding and alighting of buses. Despite the fact that the physical conditions of the data collection point did not change, the bus bulb did appear to be a marked improvement for pedestrians passing through the site and for bus passengers that were boarding and alighting from the buses.

Street Corner Level-of-Service

For this study, the operating characteristics of the corner were evaluated during the afternoon peak period. Pedestrian volumes, signal timings, and area data were collected for the bus bay and bulb configurations. During the three peak signal cycles in the bus bay configuration, there was an average space per pedestrian of 52 square feet. If the same number of pedestrians were present in the bulb configuration, the average space per pedestrian would be 58 sq ft (5.4 sq m), or an increase of 11 percent. When all of the available corner LOS data were analyzed, the results showed that all of the readings fell into the LOS A or B categories. The bus bay had 79 percent of its readings in the LOS A range, while the bus bulb had 86 percent of its reading in LOS A. This represents an improvement of 9 percent. The extension of the curb in the bulb configuration provided a larger queuing area for pedestrians. The larger area reduced the occurrence of conflicts between those pedestrians waiting to cross the street and those approaching the corner. Additionally, the extension of the curb increased the number of people that crossed the street entirely within the crosswalk.

Board and Alighting

Data were collected at two sites in order to determine the boarding and alighting characteristics on the adjacent sidewalk. Using a farside and nearside bus stop in both bus bay and bulb configurations, dwell times were assessed. Dwell times of greater than 40 sec were not evaluated because they were associated with bus drivers talking to supervisors rather than boarding and alighting activities. The average dwell time (in seconds) per passenger decreased by nearly one second in the off peak period at Mission Street and 30th Street in the northbound direction. In the peak period for this site, as well as both the peak and off peak periods for the Mission Street and 30th Street in the southbound direction, there was a slight increase in the average dwell time per passenger. The bulb design provided more space for boarding and alighting activities, as well as moved the area where these activities occurred. In the bus bay configuration, boarding and alighting took place on the sidewalk. This resulted in a disruption of the pedestrian flow on the sidewalk. In the bulb configuration, the boarding and alighting took place on the bulb itself. Therefore, the primary area of congestion was moved out of the pedestrian stream on the sidewalk.

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3. Fruin, J.J., *Pedestrian Planning and Design*. Metropolitan Association of Urban Designers and Environmental Planners. (1971).
4. Hall, D. *The Hidden Dimension*. Doubleday and Co., (1966).



Figure B – 1. South Mission Street Neighborhood

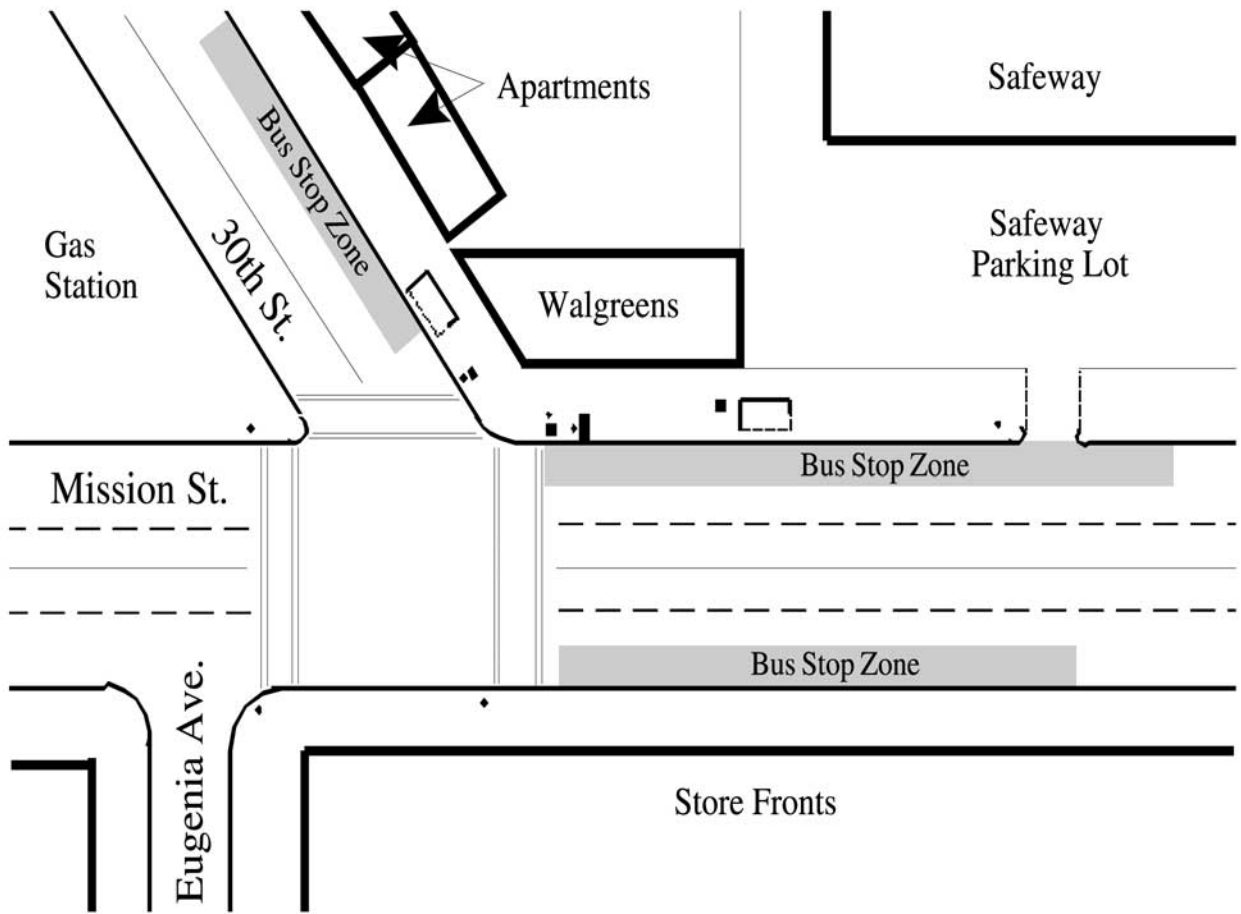


Figure B-2. Mission @ Street Intersection (Bus Bay Configuration).

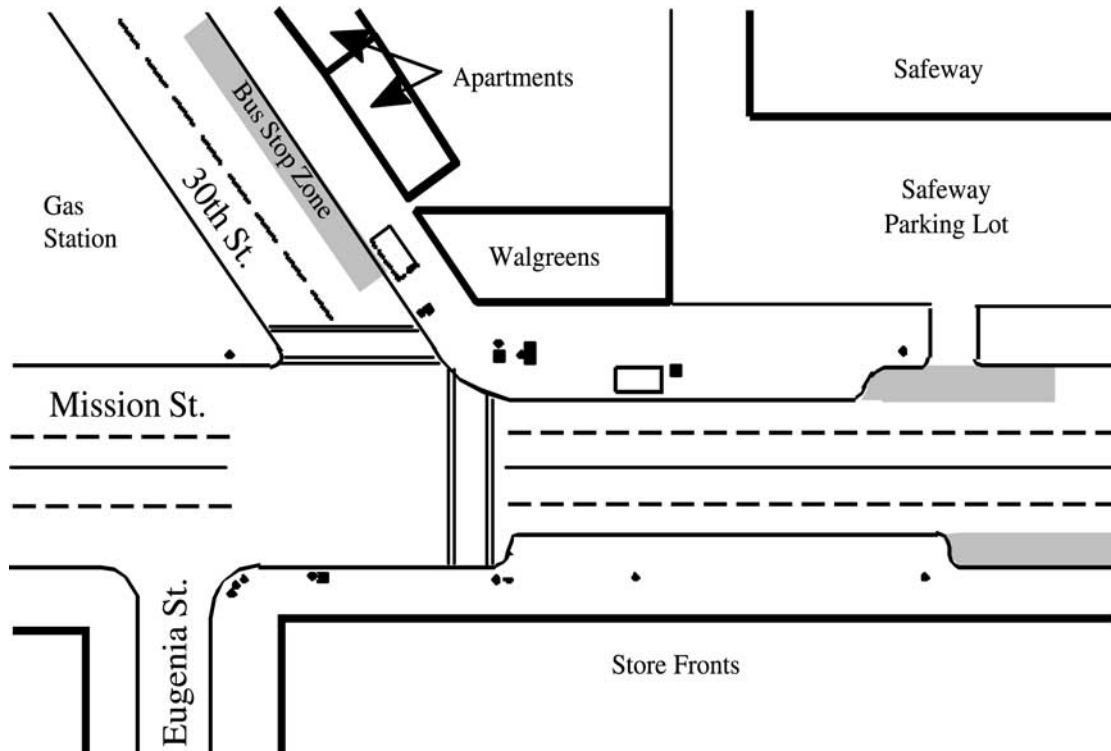
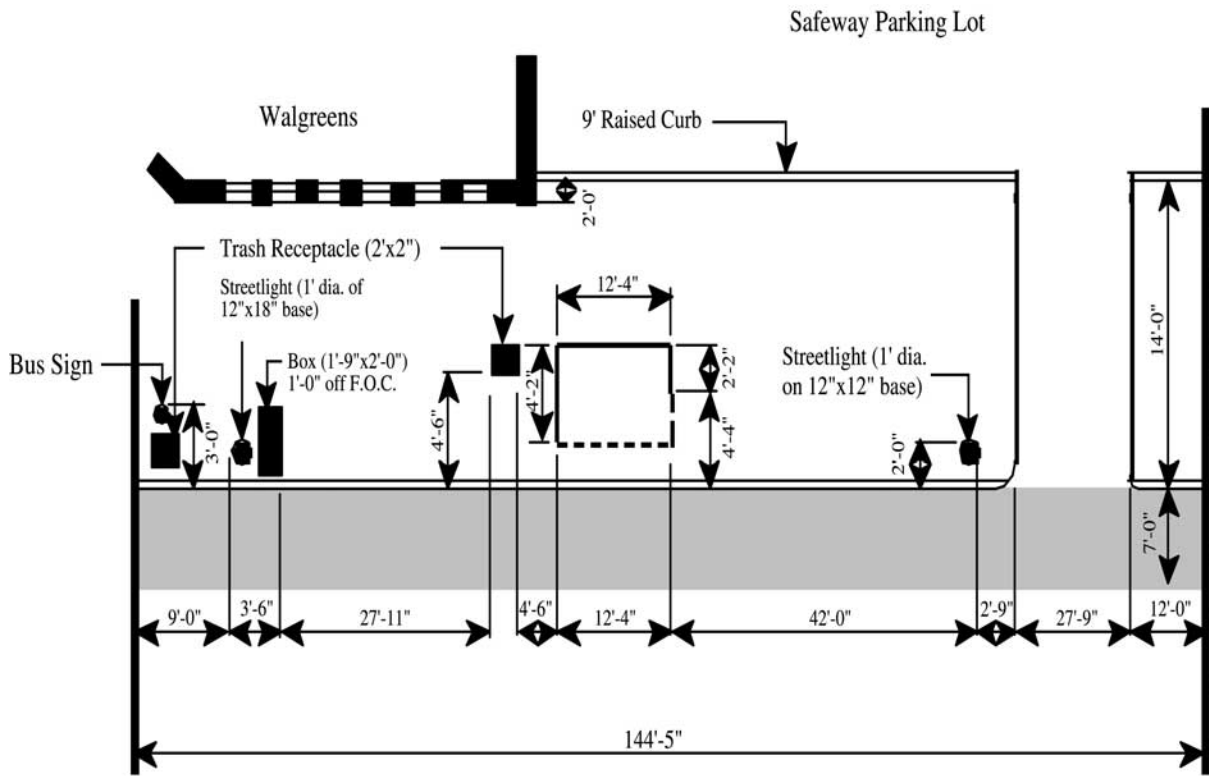
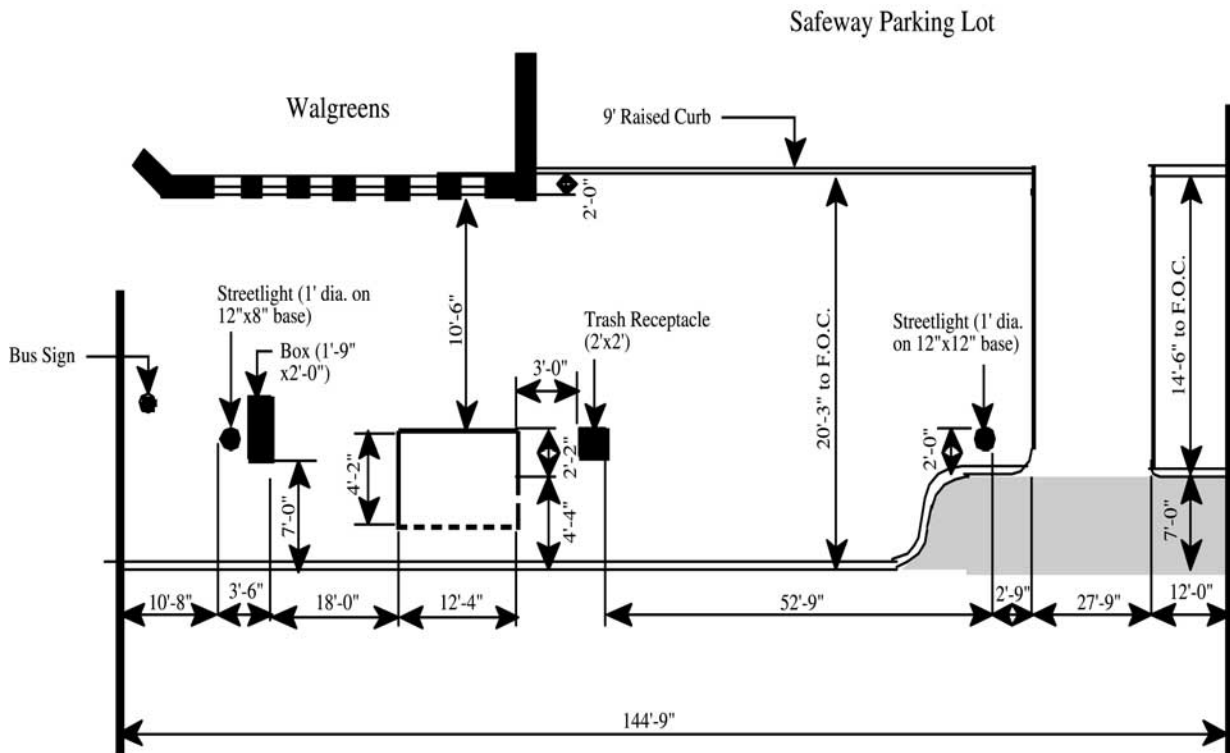


Figure B-3. Mission @ 30th Street Intersection (Bus Bulb Configuration).



1 ft = 0.305 m

Figure B-4. Mission @ 30th Street Bus Bay Dimensions.



1 ft = 0.305 m

Figure B-5. Mission @ 30th Street Bus Bulb Dimensions.



Figure B-6. Bus Bay Configuration.



Figure B-7. Bus Bulb Configuration.

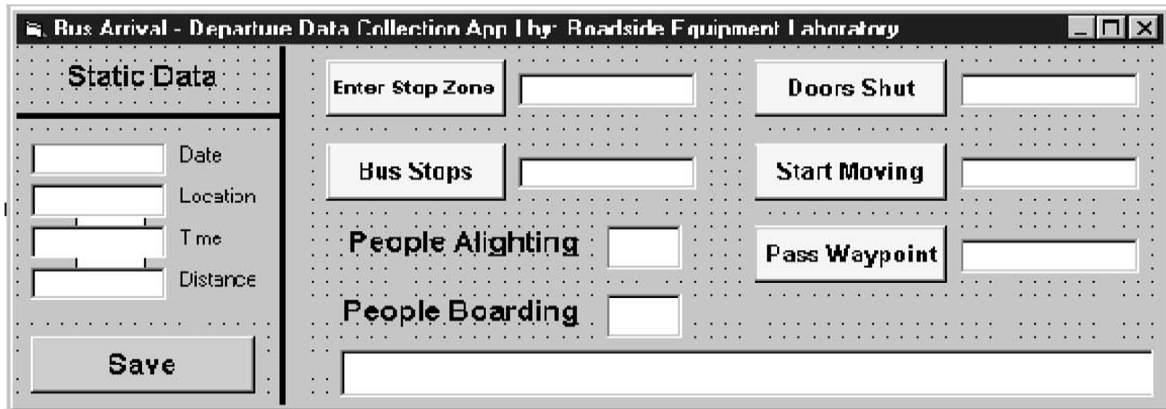


Figure B-8. Palmtop Screen.

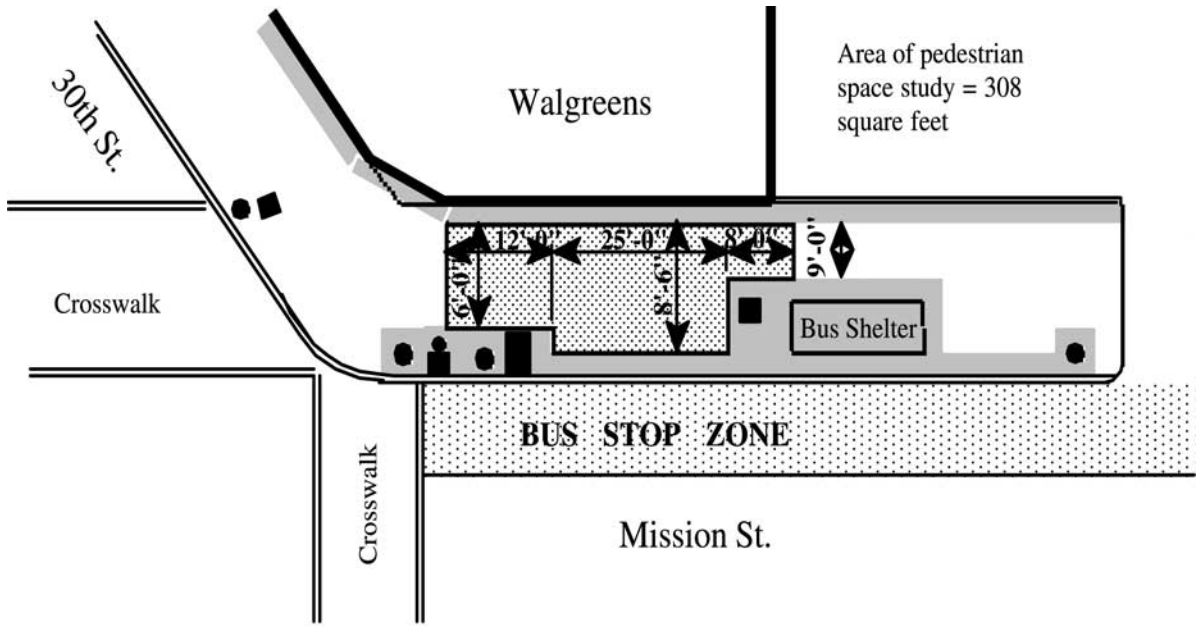
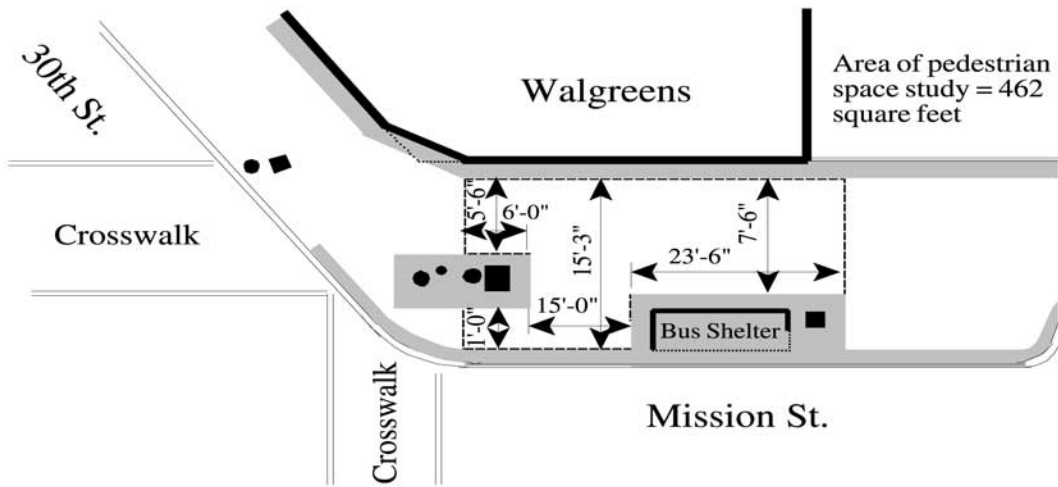


Figure B-9. Walkway Space Study (Bus Bay Configuration).



1 ft = 0.305 m

Figure B-10. Walkway Space Study (Bus Bulb Configuration).

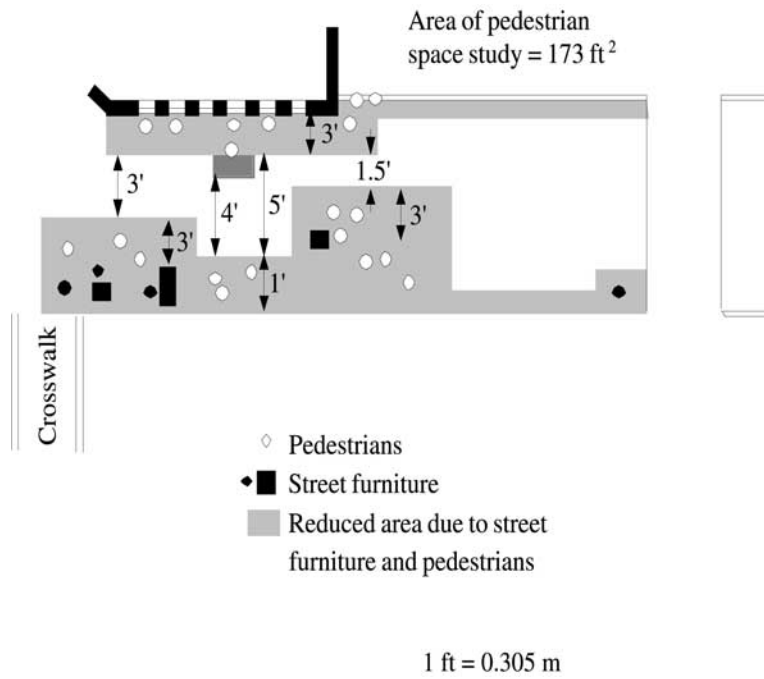


Figure B-11. Common Pedestrian Waiting Areas at Bus Bay.

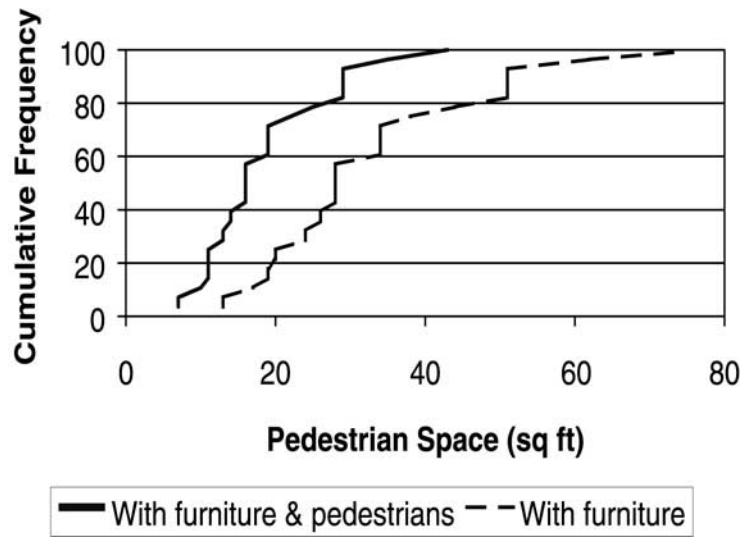


Figure B-12. Comparison of Pedestrian Space When Bus Is Present in the Zone.

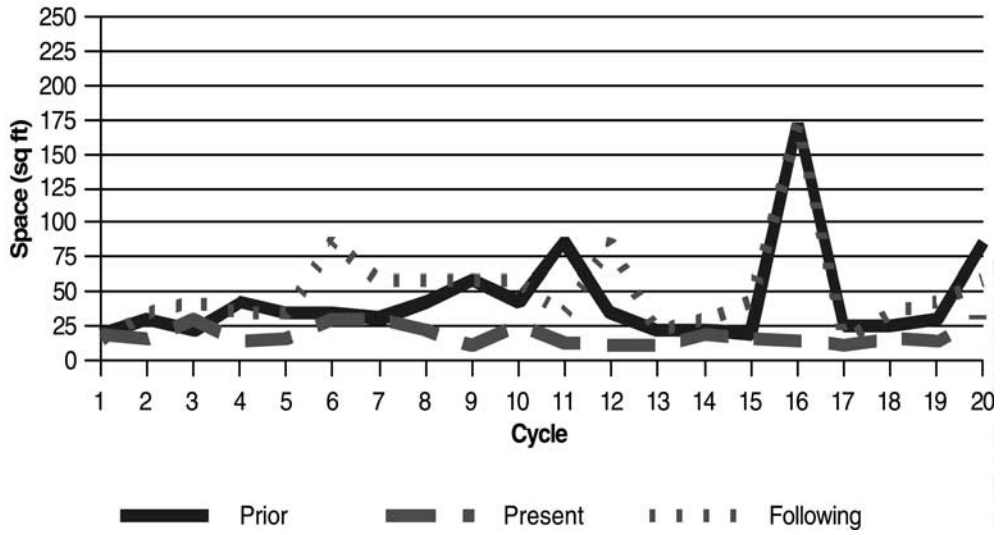


Figure B-13. Pedestrian Space with Reduced Area at Bus Bay.

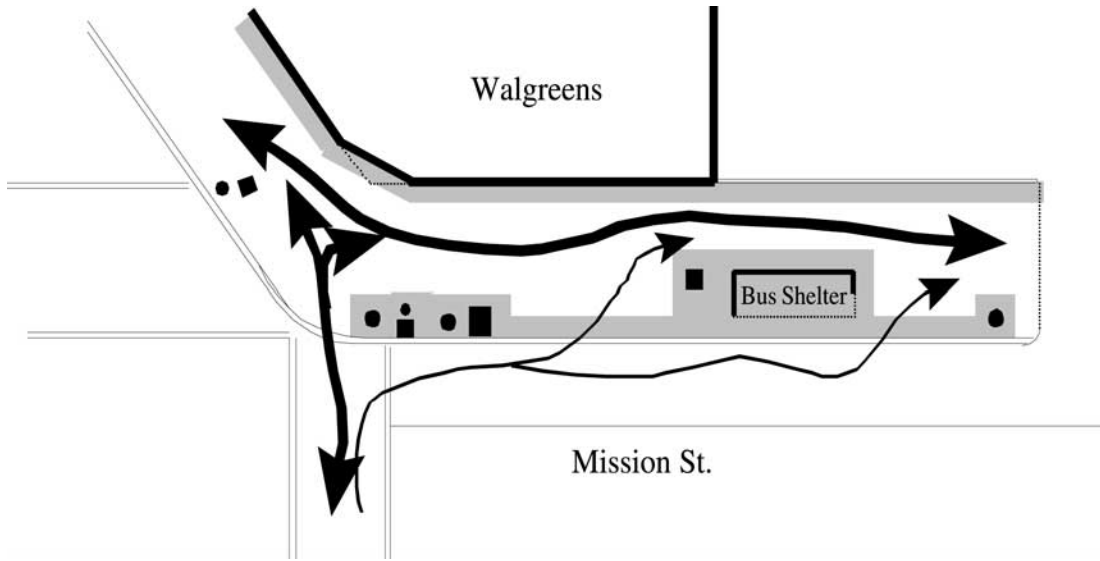
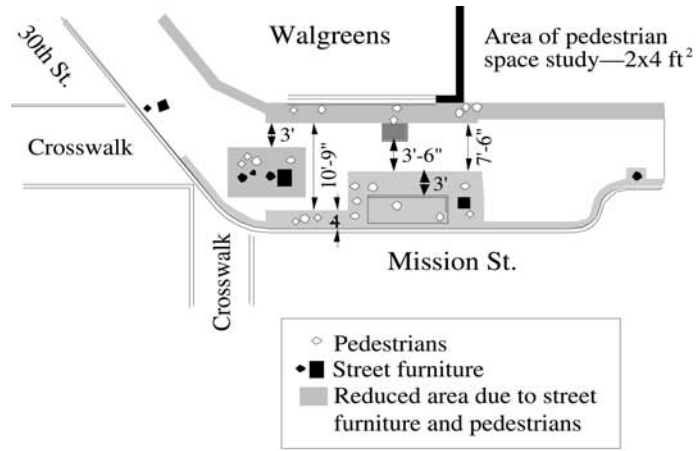


Figure B-14. Common Walkway Paths Through the Bus Bay Zone.



1 ft = 0.305 m

Figure B-15. Common Pedestrian Waiting Areas at Bus Bulb.

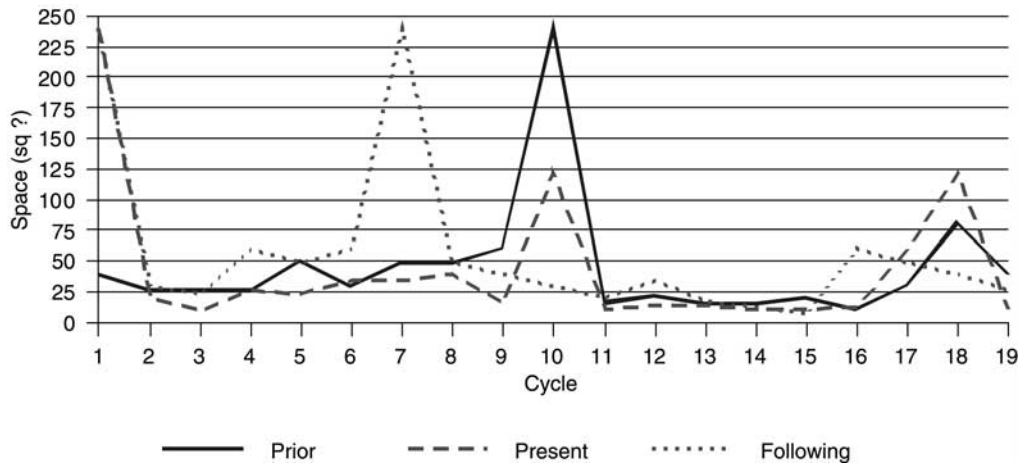


Figure B-16. Pedestrian Space with Reduced Study Area at Bus Bulb.

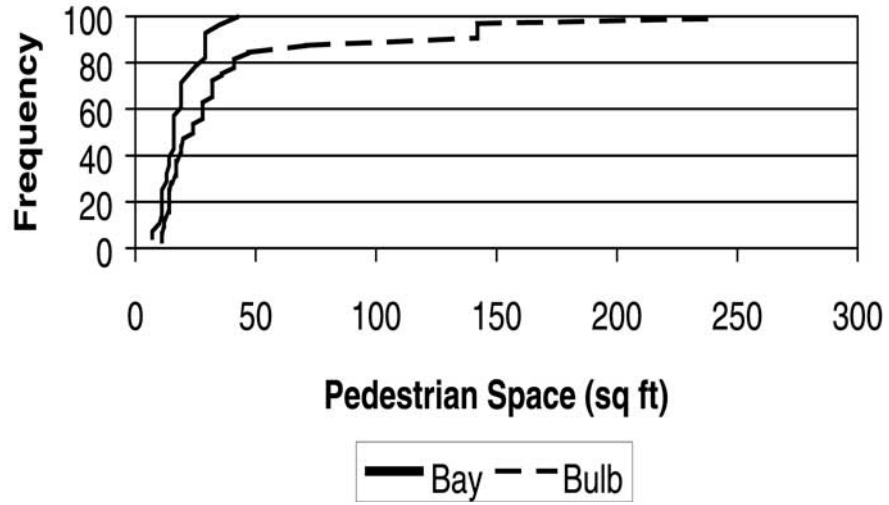


Figure B-17. Comparison of Pedestrian Space Available During Boarding/Alighting Activities (Bus is *Present*).

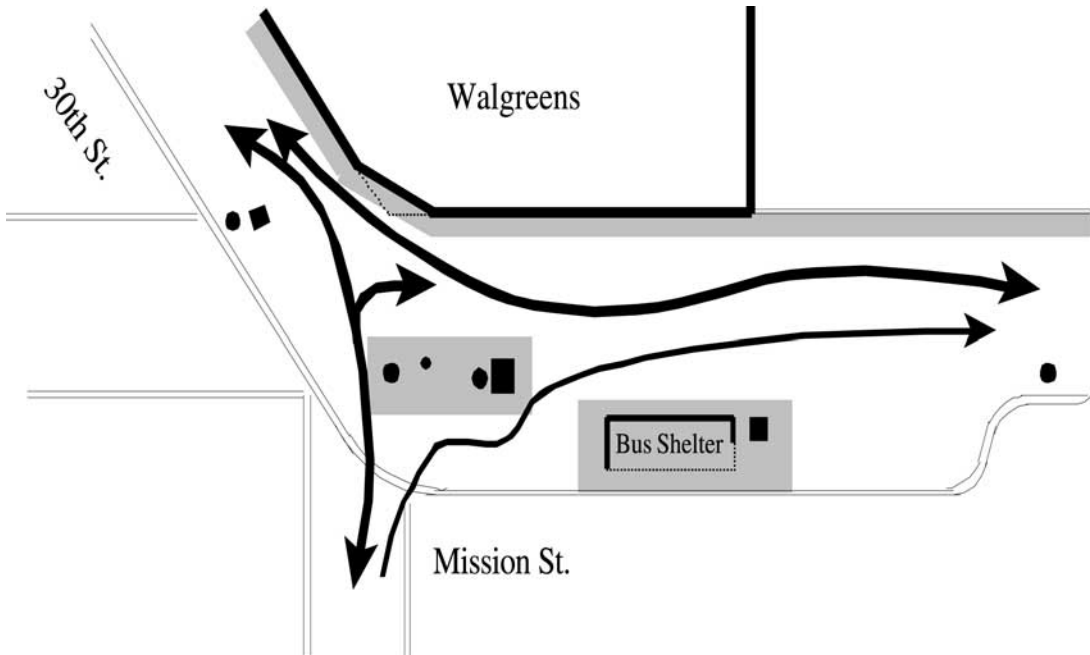


Figure B-18. Common Walkway Paths (Bulb Configuration).

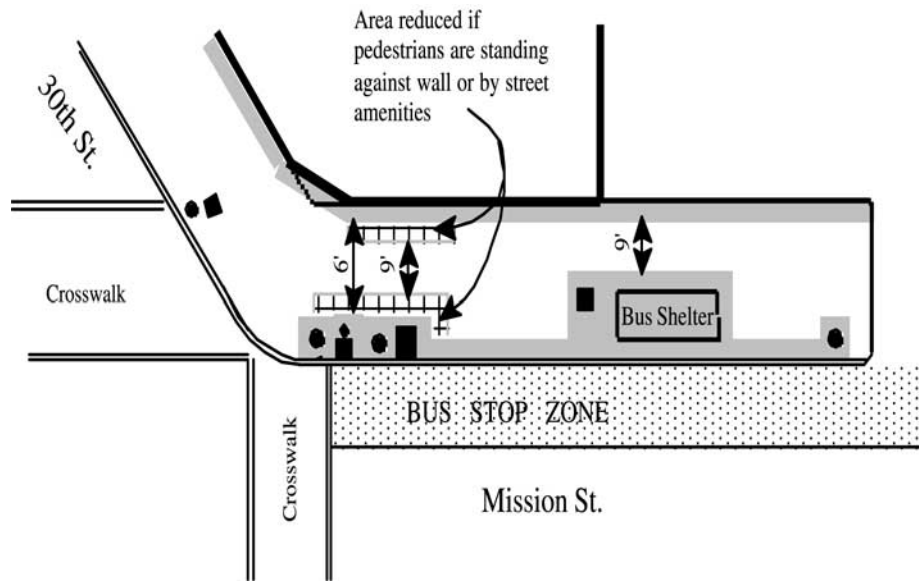


Figure B-19. Sidewalk LOS Study Area of Bus Bay.

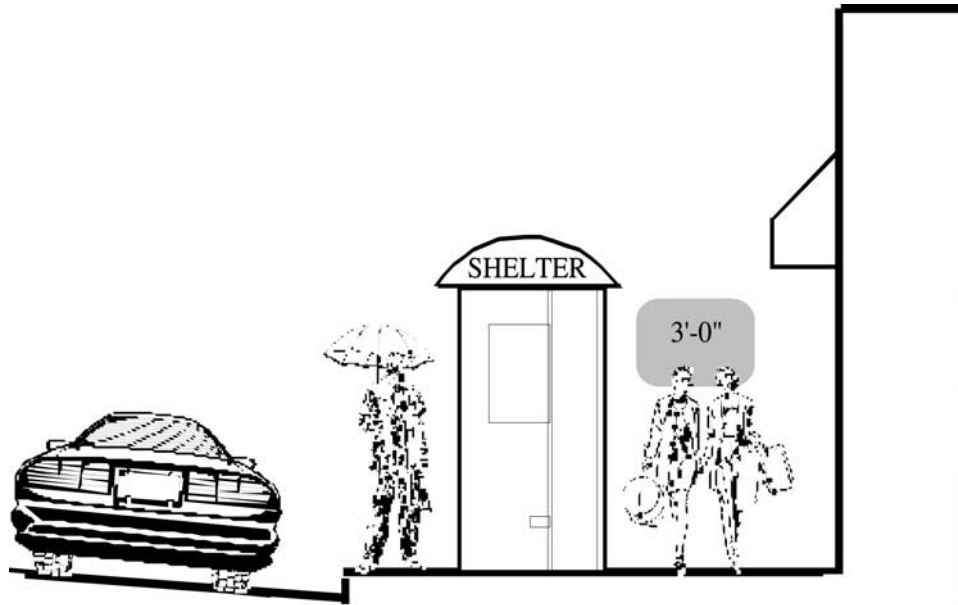


Figure B-20. Cross-Section of Effective Walkway Width Between Bus Shelter and Walgreens (Bay Configuration).

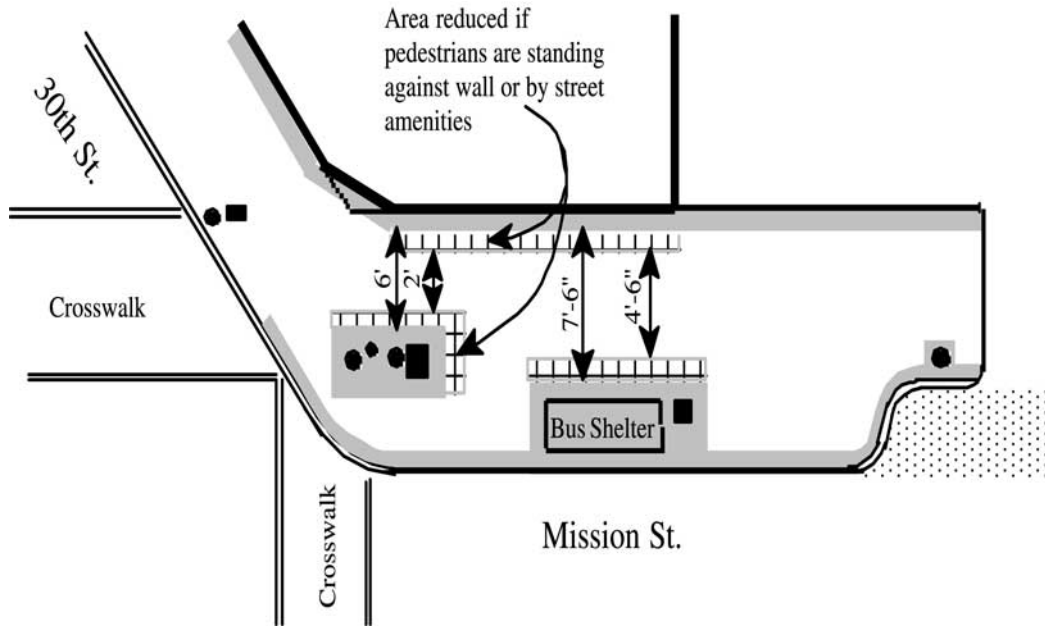


Figure B-21. Sidewalk LOS Study Area of the Bus Bulb Configuration.

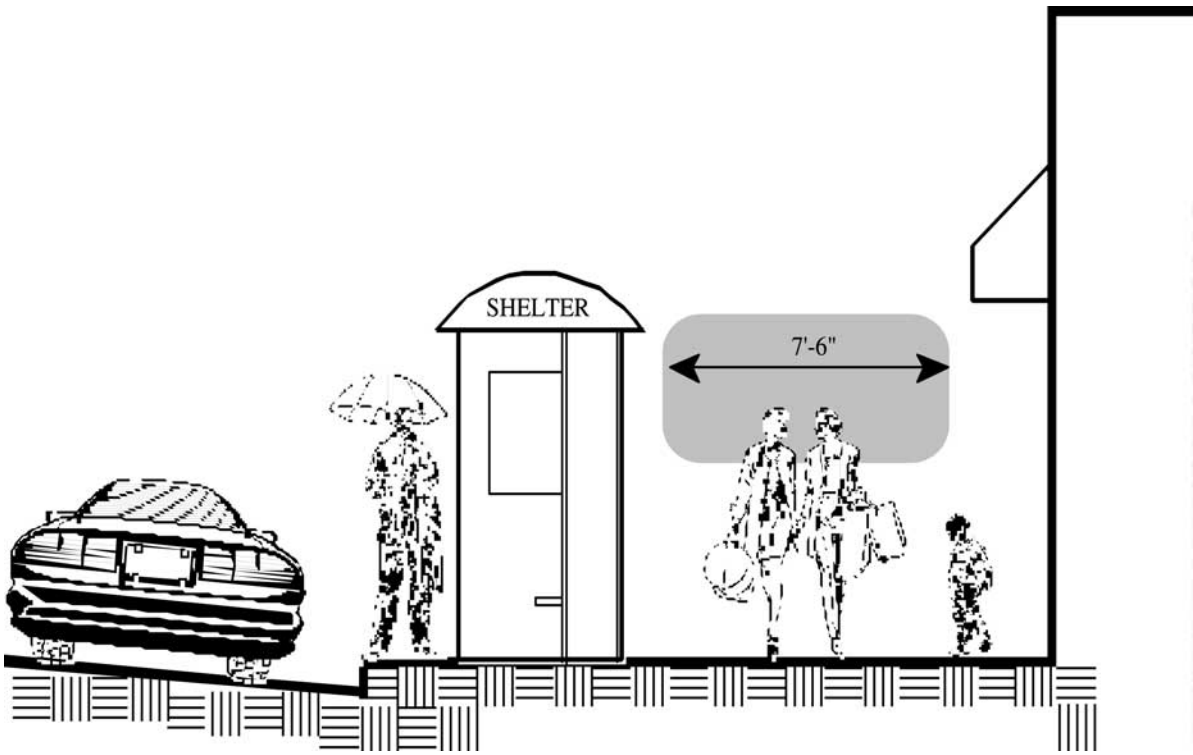


Figure B-22. Cross-Section of Effective Walkway Width Between Bus Shelter and Walgreens (Bulb Configuration).

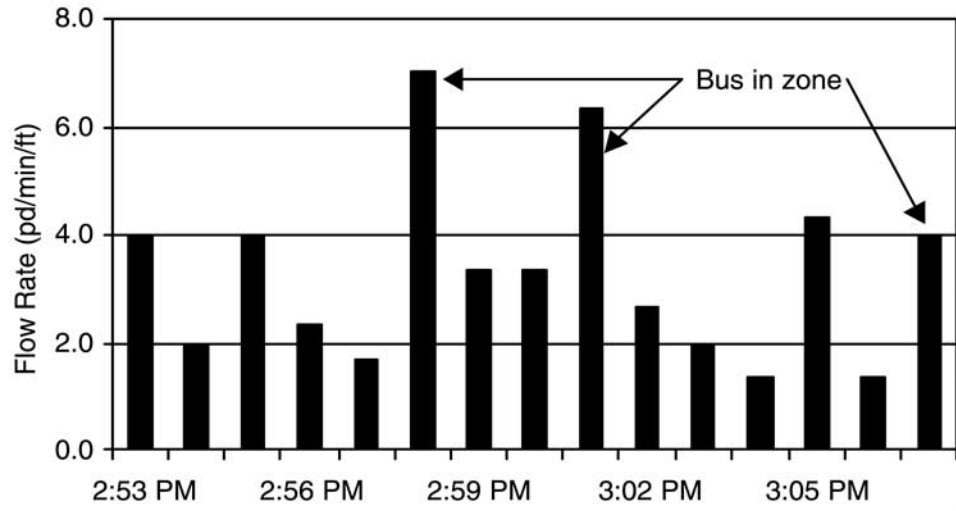


Figure B-23. Summary of Peak 15-Minute Period Divided Into One-Minute Intervals.

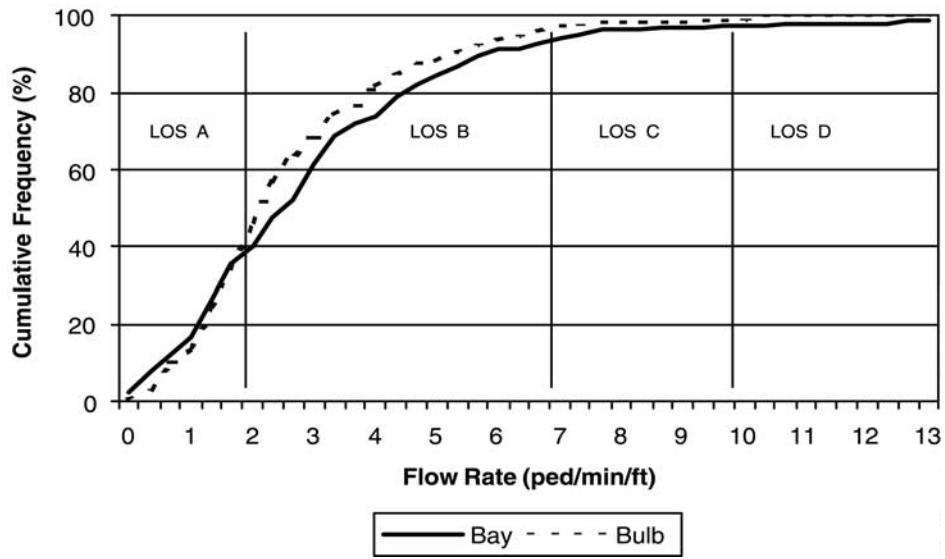


Figure B-24. Pedestrian Flow Rates (Using Data Divided into One-Minute Segments).

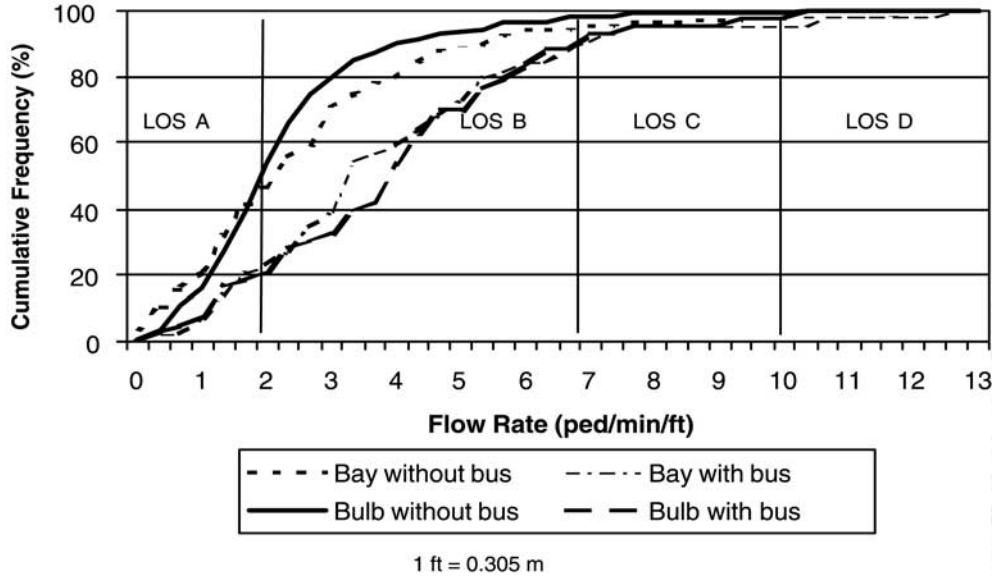


Figure B-25. Pedestrian Flow Rates.



Figure B-26. Corner of Mission @ 30th Street (Bus Bay Configuration).

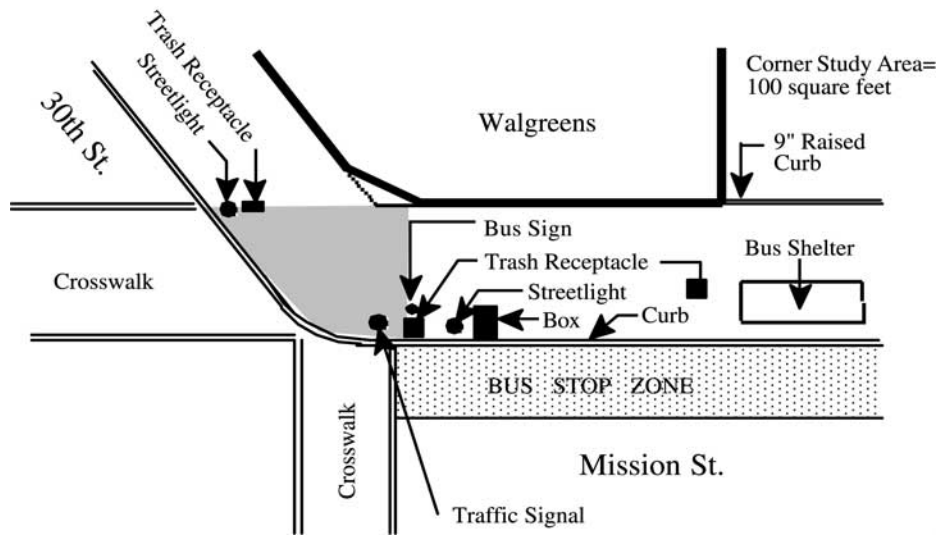


Figure B-27. Corner LOS Study Area for Bus Bay.



Figure B-28. Corner of Mission @ 30th Street (Bus Bulb Configuration).

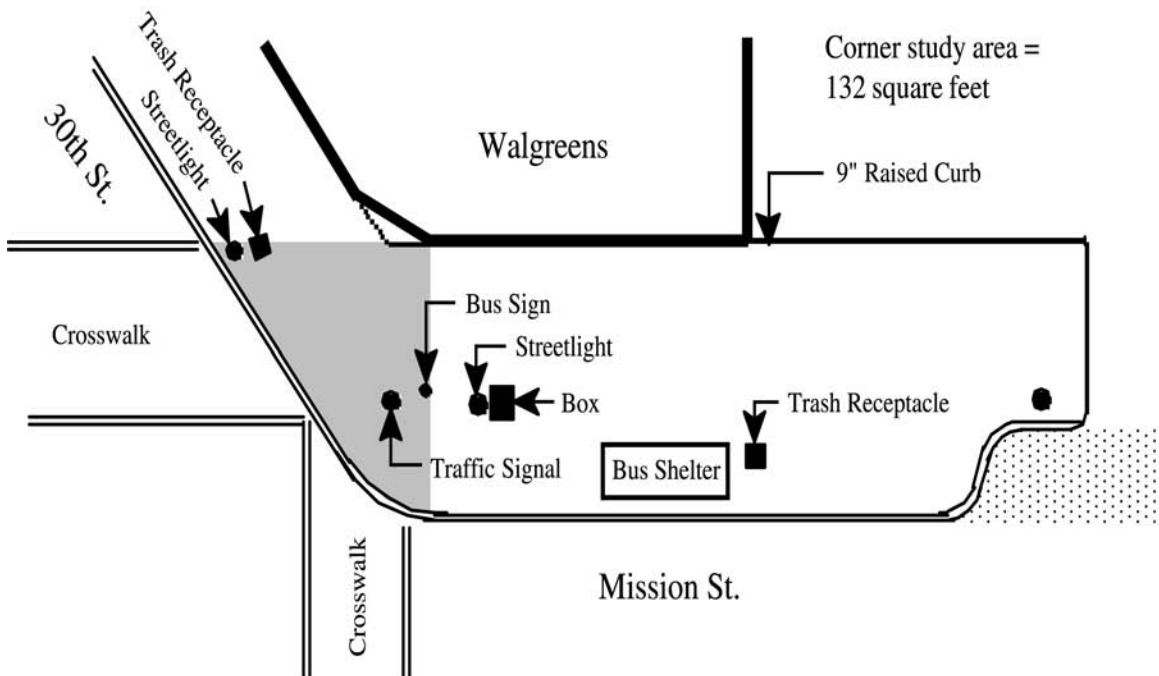


Figure B-29. Corner LOS Study Area for Bus Bulb Configuration.

STREET CORNER ANALYSIS WORKSHEET			
Location: _____	SIGNAL TIMING (sec)		
City, State: _____	C = _____		
	G _{mj} = _____ R _{mj} = _____		
	G _{ml} = _____ R _{ml} = _____		
	PEDESTRIAN VOLUMES		
	Flow	Ped/Min	Ped/Cyc
	v _{ci}		
	v _{co}		
	v _{di}		
v _{do}			
v _{a,b}			
v _{tot}			
NET CORNER AREA	$A = W_a W_b - 0.215R^2 =$ _____ sq ft		
AVAILABLE TIME-SPACE	$TS = A \times C / 60 =$ _____ sq ft-min		
HOLD AREA WAITING TIMES (use ped/cycle)	$Q_{tco} = [(v_{co}) (R_{mj}/C) (R_{mj}/2)] / 60 =$ _____ ped-min $Q_{tdo} = [(v_{do}) (R_{ml}/C) (R_{ml}/2)] / 60 =$ _____ ped-min		
HOLD AREA TIME-SPACE	$TS_h = 5 (Q_{tco} + Q_{tdo}) =$ _____ sq ft-min		
CIRCULATION TIME-SPACE	$TS_c = TS - TS_h =$ _____ sq ft-min		
TOTAL CIRCULATION VOLUME	$v_c = v_{ci} + v_{co} + v_{do} + v_{di} + v_{a,b} =$ _____ ped		
TOTAL CIRCULATION TIME	$t_c = v_c \times 4 / 60 =$ _____ ped-min		
PEDESTRIAN SPACE AND LOS	$M = TS_c / t_c =$ _____ sq ft/ped; LOS = _____ <div style="text-align: right; font-size: small;">(Table 13-3)</div>		

Figure B-30. Highway Capacity Manual Corner LOS Worksheet. ⁽¹⁾

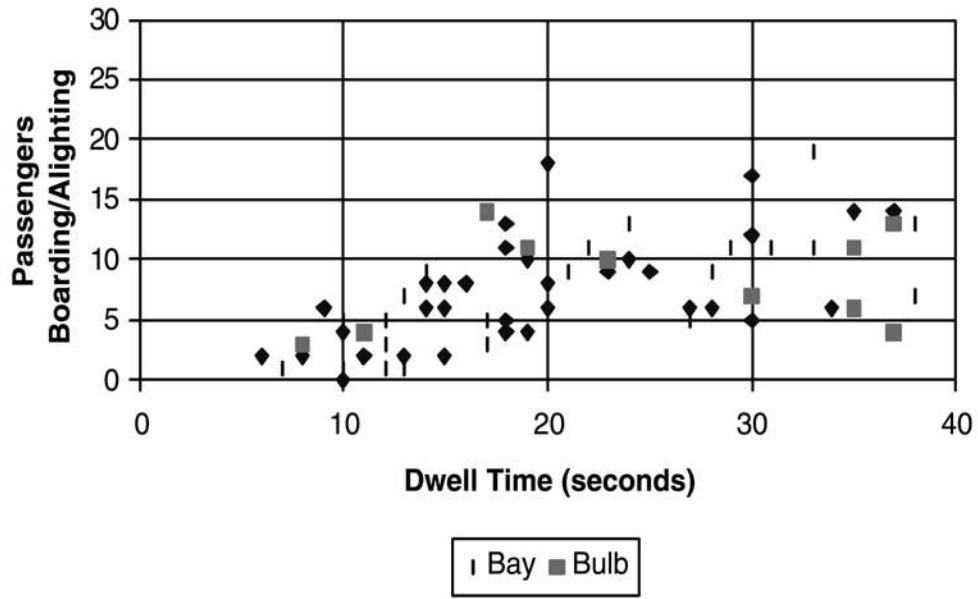


Figure B-31. Mission @ 30th Southbound Off-Peak Dwell Times.

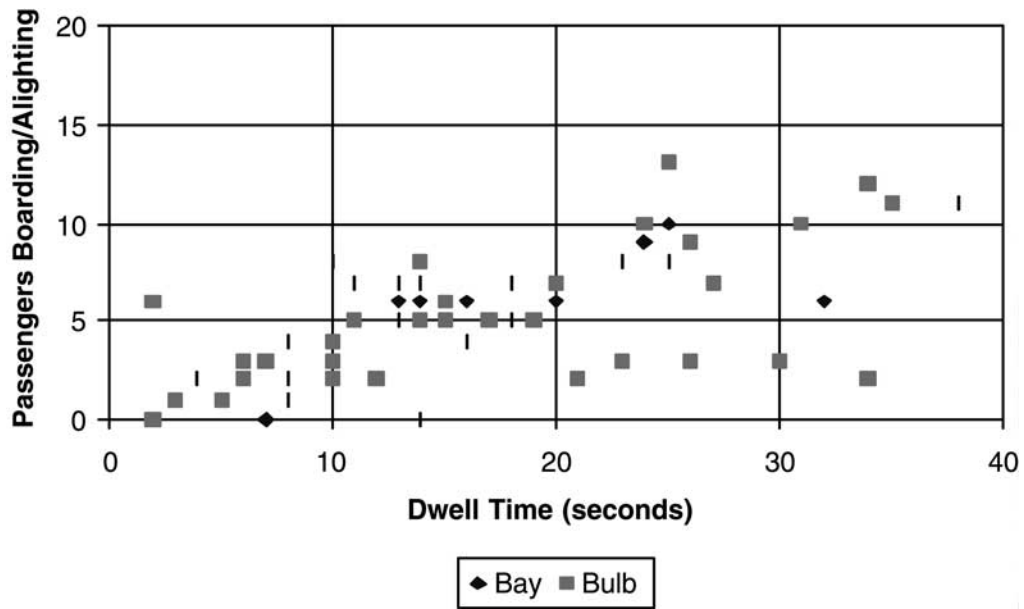


Figure B-32. Mission @ 30th Northbound Peak Bus Dwell Times.

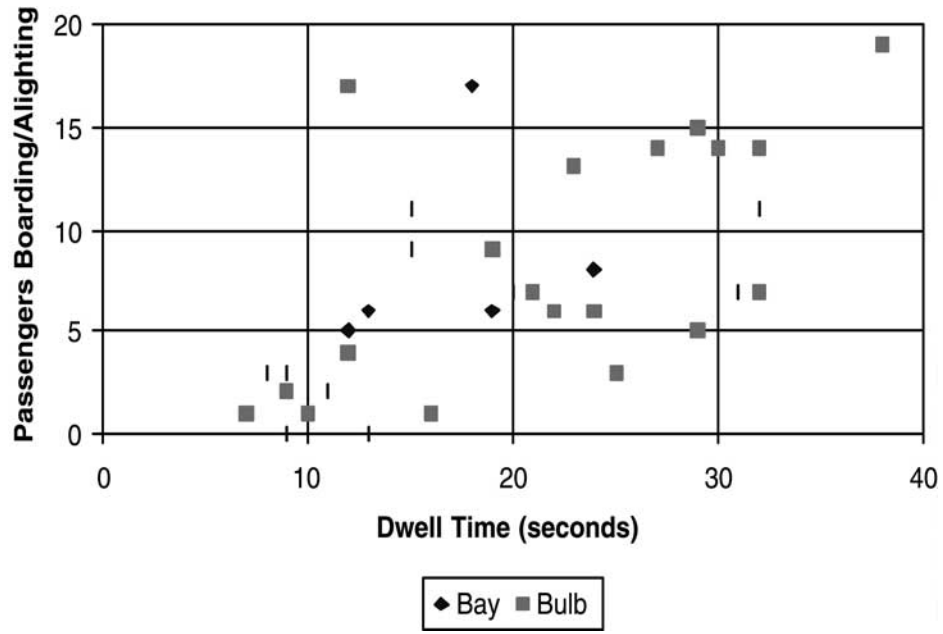


Figure B-33. Mission @ 30th Southbound Peak Bus Dwell Times.

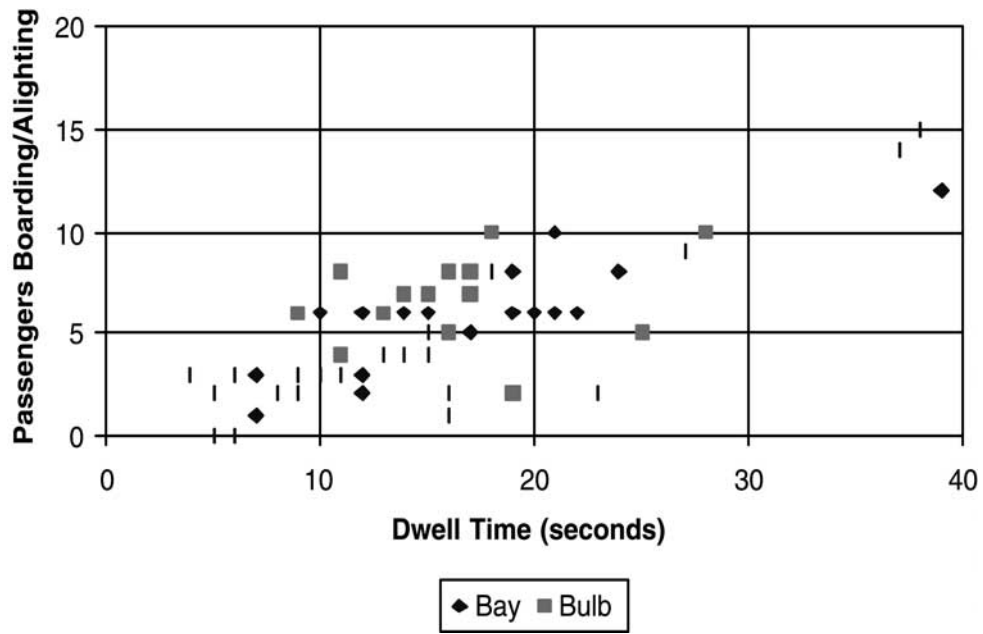


Figure B-34. Mission @ 30th Northbound Off-Peak Bus Dwell Times.

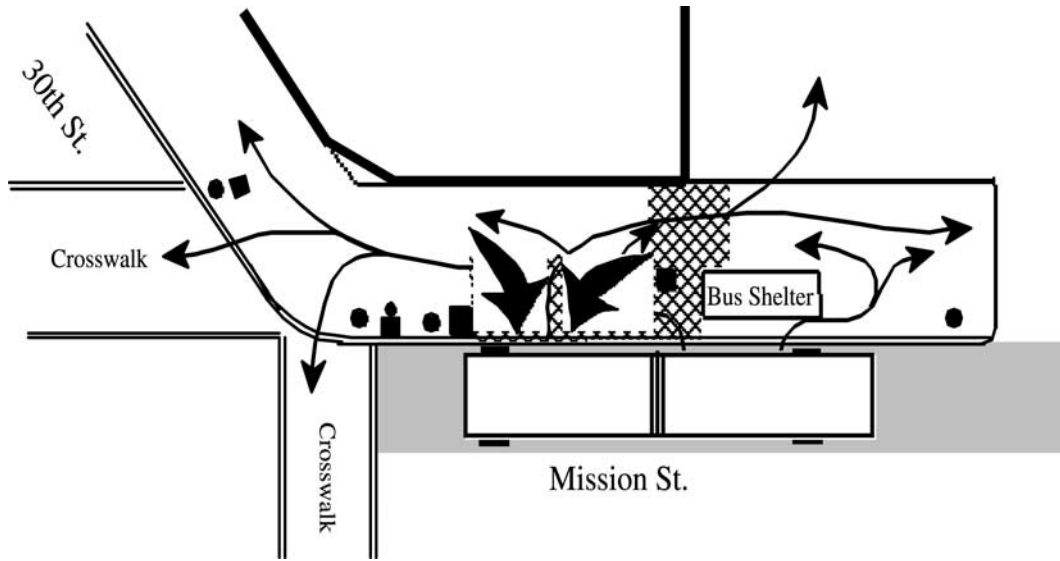


Figure B-35. Pedestrian Walking Paths (Bay Configuration).

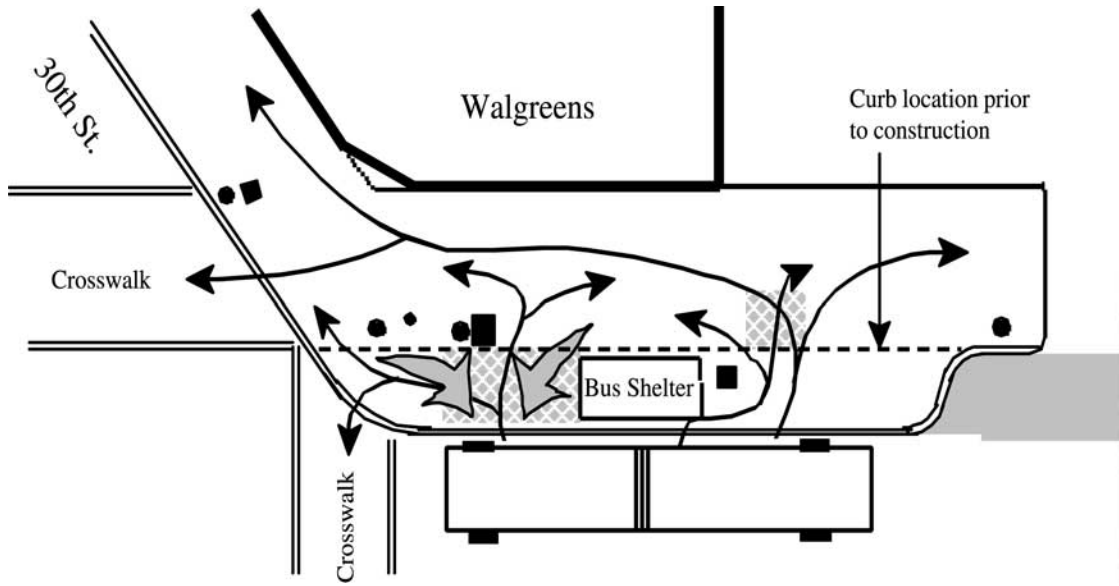


Figure B-36. Pedestrian Walking Paths (Bulb Configuration).

Table B-1. Data Collected for Each Pedestrian Study.

Study	Data to be Collected		
	Fixed Data (same for each record)	For Each Record	Additional Field(s)
Sidewalk LOS	<ul style="list-style-type: none"> • Date • Location • Time 	<ul style="list-style-type: none"> • Clicker (accounts for one person per direction per keystroke) • Time stamp • Direction traveling • Comment field 	<ul style="list-style-type: none"> • Time stamp for bus arrival • Time stamp for bus departure
Pedestrian Space	<ul style="list-style-type: none"> • Date • Location • Time 	<ul style="list-style-type: none"> • Section number • Data field (number of people in section) • Time stamp • Comment field 	<ul style="list-style-type: none"> • Time stamp for bus arrival • Time stamp for bus departure • Timer (0-60 seconds) • Beep at one- minute interval
Bus Arrival/ Departure	<ul style="list-style-type: none"> • Date • Location • Time • Distance (from end of bus stop zone to fixed point downstream) 	<ul style="list-style-type: none"> • Time stamp bus enters zone • Time stamp bus stops • Time stamp bus doors open • Time stamp bus starts moving • Time stamp bus reaches fixed point downstream • Number of people boarding • Number of people alighting • Bus Route • Bus Number • Red Light Encountered? • Comment field 	

Table B-2. Pedestrian Level-of-Service Categories for Walkways.

LOS	Space (sq ft/ped)
A	\$ 130
B	\$ 40
C	\$ 24
D	\$ 15
E	\$ 6

1 sq ft = 0.093 sq m

Table B-3. Available Space and Resulting LOS for Bus Bay Stop Configuration.

Total Available Area Without Waiting Patrons/Pedestrians (308 sq ft) [28.6 sq m]							
Day/Cycle		Prior ^a		Present ^b		Following ^c	
		Space ^d	LOS ^e	Space	LOS	Space	LOS
1	1	34	C	28	C	28	C
1	2	51	B	28	C	62	B
1	3	38	C	51	B	77	B
1	4	77	B	26	C	62	B
1	5	62	B	28	C	62	B
1	6	62	B	51	B	154	A
1	7	51	B	51	B	103	B
1	8	77	B	38	C	103	B
1	9	103	B	20	D	103	B
1	10	77	B	44	B	103	B
1	11	154	A	24	D	62	B
1	12	62	B	19	D	154	A
1	13	38	C	17	D	38	C
1	14	38	C	34	C	51	B
1	15	34	C	28	C	77	B
1	16	308	A	26	C	308	A
1	17	44	B	19	D	28	C
1	18	44	B	28	C	62	B
1	19	51	B	24	C	77	B
1	20	154	A	62	B	103	B
2	1	24	C	13	E	62	B
2	2	51	B	20	D	38	B
2	3	51	B	34	C	62	B
2	4	77	B	77	B	103	B
2	5	103	B	51	B	51	B
2	6	15	D	13	E	26	C
2	7	51	B	34	C	44	B
2	8	44	B	34	C	31	C

^aPrior = one minute prior to bus arriving
^bPresent = while patrons are boarding and alighting
^cFollowing = one minute following bus departure
^dSpace available for each pedestrian (sq ft/pedestrian)
^eBased on *Highway Capacity Manual* categories (see Table B-2)
1 sq ft = 0.093 sq m

Table B-4. Summary of Initial Observations at Bus Bay Configuration.

Level of Service	Space (sq ft/ped)	Prior	Present	Following
A	\$ 130	3	-	3
B	\$ 40	18	7	20
C	\$ 24	5	13	5
D	\$ 15	1	6	-
E	\$ 6	-	2	-

Table B-5. Comparison of Available Space at Bus Bay Configuration.

		Without Waiting Patrons/Pedestrians = 308 sq ft (28.6 sq m)						With Waiting Patrons/Pedestrians = 173 sq ft (16.1 sq m)					
Day/ Cycle		Prior ^a		Present ^b		Following ^c		Prior		Present		Following	
		Space ^d	LOS ^e	Space	LOS	Space	LOS	Space	LOS	Space	LOS	Space	LOS
1	1	34	C	28	C	28	C	19	D	16	D	16	D
1	2	51	B	28	C	62	B	29	C	16	D	35	C
1	3	38	C	51	B	77	B	22	D	29	C	43	B
1	4	77	B	26	C	62	B	43	B	14	E	35	C
1	5	62	B	28	C	62	B	35	C	16	D	35	C
1	6	62	B	51	B	154	A	35	C	29	C	86	B
1	7	51	B	51	B	103	B	29	C	29	C	58	B
1	8	77	B	38	C	103	B	43	B	22	D	58	B
1	9	103	B	20	D	103	B	58	B	11	E	58	B
1	10	77	B	44	B	103	B	43	B	25	C	58	B
1	11	154	A	24	D	62	B	86	B	13	E	35	C
1	12	62	B	19	D	154	A	35	C	11	E	86	B
1	13	38	C	17	D	38	C	22	D	10	E	22	D
1	14	38	C	34	C	51	B	22	D	19	D	29	C
1	15	34	C	28	C	77	B	19	D	16	D	43	B
1	16	308	A	26	C	308	A	173	A	14	E	173	A
1	17	44	B	19	D	28	C	25	C	11	E	16	D
1	18	44	B	28	C	62	B	25	C	16	D	35	C
1	19	51	B	24	C	77	B	29	C	13	E	43	B
1	20	154	A	62	B	103	B	86	B	35	C	58	B
2	1	24	C	13	E	62	B	13	E	7	E	35	C
2	2	51	B	20	D	38	B	29	C	11	E	22	D
2	3	51	B	34	C	62	B	29	C	19	D	35	C
2	4	77	B	77	B	103	B	43	B	43	B	58	B
2	5	103	B	51	B	51	B	58	B	29	C	29	C
2	6	15	D	13	E	26	C	9	E	7	E	14	E
2	7	51	B	34	C	44	B	29	C	19	D	25	C
2	8	44	B	34	C	31	C	25	C	19	D	17	D

^aPrior = one minute prior to bus arriving

^bPresent = while patrons are boarding and alighting

^cFollowing = one minute following bus departure

^dSpace available for each pedestrian (sq ft/pedestrian)

^eBased on *Highway Capacity Manual* categories (see Table B-2)

1 sq ft = 0.39 sq m

Table B-6. Summary of LOS Readings When Waiting Areas Are Included in LOS Calculations.

Level of Service	Space (sq ft/ped)	Prior	Present	Following
A	\$ 130	1	-	1
B	\$ 40	8	1	11
C	\$ 24	12	6	10
D	\$ 15	5	10	5
E	\$ 6	2	11	1

Table B-7. Available Space and Resulting LOS for Bus Bulb Configuration.

Day/ Cycle		Total Available Area in Bus Bulb Configuration = 284 sq ft (28.6 sq m)					
		Prior ^a		Present ^b		Following ^c	
		Space ^d	LOS ^e	Space	LOS	Space	LOS
1	1	28	C	20	D	47	B
1	2	28	C	32	C	47	B
1	3	16	D	12	E	36	C
1	4	36	C	28	C	57	B
1	5	32	C	24	C	47	B
1	6	36	C	28	C	28	C
1	7	15	D	15	D	142	A
1	8	24	C	32	C	16	D
1	9	14	E	11	E	28	C
1	10	28	C	36	C	95	B
1	11	71	B	142	A	95	B
1	12	32	C	17	D	41	B
1	13	41	B	19	D	36	C
2	1	47	B	284	A	284	A
2	2	32	C	24	C	36	C
2	3	32	C	11	E	28	C
2	4	32	C	32	C	71	B
2	5	57	B	28	C	57	B
2	6	36	C	41	B	71	B
2	7	57	B	41	B	284	A
2	8	57	B	47	B	57	B
2	9	71	B	19	D	47	B
2	10	284	A	142	A	36	C
2	11	18	D	12	E	24	C
2	12	24	C	17	D	41	B
2	13	18	D	17	D	20	D
2	14	19	D	14	E	15	D
2	15	22	D	14	E	9	E
2	16	12	E	14	E	71	B
2	17	36	C	71	B	57	B
2	18	95	B	142	A	47	B
2	19	47	B	14	E	32	C

^a Prior = one minute prior to bus arriving

^b Present = while patrons are boarding and alighting

^c Following = one minute following bus departure

^d Space available for each pedestrian (Sq ft/pedestrian)

^e Based on *Highway Capacity Manual* categories (see Table B-2)

1 sq ft = 0.093 sq m

Table B-8. LOS comparison Between a Curbside Bus Stop and a Bus Bulb Configuration ^a.

LOS	Curbside Bus Stop ^b						Bus Bulb Bus Stop					
	Prior		Present		Following		Prior		Present		Following	
	Total ^d	%	Total	%	Total	%	Total	%	Total	%	Total	%
A	1	4	0	0	1	4	1	3	4	13	3	9
B	8	29	1	4	11	39	9	28	4	13	16	50
C	12	43	6	21	10	36	14	44	9	28	9	28
D	5	18	10	36	5	18	6	19	7	22	3	9
E	2	7	11	39	1	4	2	6	8	25	1	3

^a Waiting patrons and pedestrians factored into space calculations
^b Total of 28 observations
^c Total of 32 observations
^d Total observations in each phase by LOS

Table B-9. Average Space and LOS Between Curbside and Bud Bulb Configurations.

Curbside Bus Stop						Bus Bulb Bus Stop					
Prior		Present		Following		Prior		Present		Following	
Space ^a	LOS	Space	LOS	Space	LOS	Space	LOS	Space	LOS	Space	LOS
<i>Without Waiting Patrons and Pedestrians</i>											
71	B	33	C	80	B	71	B	71	B	102	B
<i>Waiting Patrons and Pedestrians Accounted for In Space Calculations</i>											
40	B	19	D	45	B	44	B	44	B	63	B
^a Space available for each pedestrian (sq ft/pedestrian) 1 sq ft = 0.093 sq m											

Table B-10. Comparison of Pedestrian Crowding Conditions Between a Bay and Bulb.

Type of Pedestrian Crowding Condition	Available Space per Pedestrian (sq ft/ped)	Total		Percent of Total		Total Events Occurring When Bus Present		Percent of Events Occurring When Bus Present	
		Bay ^a	Bulb ^b	Bay	Bulb	Bay ^c	Bulb ^d	Bay	Bulb
Crossing Movement Difficult	\$ 15	14	14	17%	16%	11	9	40%	28%
Passing Others is Nearly Impossible	\$ 18	23	21	27%	22%	16	12	57%	38%
Passing Others is Difficult	\$ 35	63	50	75%	52%	27	23	95%	72%
^a Total number of bus arrival/departure events observed at bay = 84 ^b Total number of bus arrival/departure events observed at bulb = 96 ^c Total number of bus boarding and alighting events observed at bay = 28 ^d Total number of bus boarding and alighting events observed at bulb = 32 1 sq ft = 0.093 sq m									

Table B-11. Sidewalk LOS Summary (Peak Period 15-Minute Increments).

Bay				Bulb			
Date	Time	Ped. Flow Rate (pd/min/ft)	LOS	Date	Time	Ped. Flow Rate (pd/min/ft)	LOS
Feb. 25, 1999	3:43-3:58 PM	3.7	B	Nov. 12, 1999	2:17-2:32 PM	2.9	B
Feb. 23, 1999	3:48-4:03 PM	3.9	B	Nov. 12, 1999	2:53-3:08 PM	3.3	B
Feb. 25, 1999	3:26-3:41 PM	4.1	B	Nov. 15, 1999	4:13-4:28 PM	3.6	B
Feb. 23, 1999	4:17-4:32 PM	4.3	B	Nov. 15, 1999	3:40-3:55 PM	4.8	B

Table B-12. Sidewalk LOS Using One-Minute Time Increments.

LOS	Flow Rate (ped/min/ft)	Bay		Bulb	
		Observations	Percent	Observations	Percent
A	# 2	60	40%	63	34%
B	# 7	82	54%	113	62%
C	#10	5	3%	6	3%
D	#15	4	3%	2	1%

Table B-13. Summary of Sidewalk Level-of-Service Data.

LOS	Bay Configuration					Bulb Configuration				
	Total	Bus in Zone		Bus not in Zone		Total	Bus in Zone		Bus not in Zone	
		Obs ^a	% ^b	Obs ^a	% ^c		Obs ^a	% ^b	Obs ^a	% ^c
A	60	13	21	47	52	63	8	19	55	39
B	82	41	67	41	46	113	30	70	83	59
C	5	4	8	1	1	6	4	9	2	1
D	4	3	4	1	1	2	1	2	1	1

^a Number of observations for corresponding LOS
^b Percent of observations for corresponding LOS when bus is in zone
^c Percent of observations for corresponding LOS when bus is not in zone

Table B-14. Corner LOS Summary for Peak Cycles.

Configuration	Period	Total Peds	Signal Cycle Length	Area (sq ft)	Ped Space (sq ft/ped)	LOS
Bay	1	34	60	100	41	B
	2	38	60	100	50	B
	3	23	60	100	64	B
Bulb	1	42	60	132	45	B
	2	33	60	132	57	B
	3	30	60	132	61	B

1 sq ft = 0.093 sq m

Table B-15. Resulting LOS at corner of Mission Street and 30th Street.

Site Configuration	Total Signal Cycles	LOS A Cycles	% LOS A	LOS B Cycles	% LOS B
Bay	156	123	79%	33	21%
Bulb	273	234	86%	39	14%

Table B-16. Average Dwell Time ^a Per Passenger Boarding and Alighting (in seconds).

Mission @ 30th Southbound			
Off-Peak		Peak	
Bay	Bulb	Bay	Bulb
2.9	3.1	2.4	2.6
Mission @ 30th Southbound			
Off-Peak		Peak	
Bay	Bulb	Bay	Bulb
3.2	2.3	2.7	3.4
^a Dwell times less than 40 sec used in calculations. Longer dwell times were associated with meetings with supervisors rather than boarding and alighting activities.			