EFFECTIVENESS OF BUS BULBS FOR BUS STOPS

FINAL REPORT

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Submitted by

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16. Abstract

The focus of this research is the use of nubs as a location for a bus stop zone. This application of bus nubs was proposed in *Transit Cooperative Research Program* (TCRP) *Report 19*, Guidelines for the Location and Design of Bus Stops (Fitzpatrick, 1996). In this report, some of the advantages cited for the use of nubs as a bus stop zone include that bus nubs: (1) remove fewer parking spaces than the traditional curb-side bus stop; (2) decrease the walking distance for pedestrians crossing the roadway; (3) provide additional sidewalk area for bus patrons to wait; and (4) result in minimal delay for the bus. When a bus stops at a bus nub, the bus remains in the travel lane, rather than weaving into and out of the curb lane as is typical of curbside bus stops. Removing this weaving has the potential of reducing conflicts between buses and other vehicles on the roadway as the bus does not have to merge back into the traffic stream after stopping at the bus stop.

The safety and effectiveness of bus nubs is questioned in urban locations where heavy vehicular volumes and possible long dwell-times at the bus stop may result in increased delays and possible head-on collisions as vehicles may attempt to go around the stopped bus. Benefits attributed to bus nubs, including reduced delays to buses and traffic calming effects, must be weighed against the delays to other vehicular traffic on the roadway as well as possible safety impacts. *TRCP Report 65 Evaluation of Bus Bulbs*, provides a review of the impacts related to bus bulbs. The findings of this study, however, may not be completely transferable to locations found in New Jersey. The research described in the report summarizes work performed on an evaluation on the effectiveness for bus nubs taking into account the particular conditions and driver population of this State.

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EXECUTIVE SUMMARY

Bus bulbs represent one type of bus stop design that is appropriate for use under certain transit, roadway and sidewalk conditions. Under this design, the sidewalk at an intersection is extended into the street to a distance equal to the depth of a typical parallel parking space. Buses stop in the traffic lane instead of weaving into and out of the bus stop. Bus bulbs create additional space to include bus stop amenities such as shelters and benches and also reduce the crossing distance of pedestrians at the intersection. The primary motivation for installing bus bulbs is to reduce sidewalk congestion and to improve transit operation by reducing bus delays through the elimination of bus-weaving maneuvers into and out of a curbside bus stop.

The safety and effectiveness of bus bulbs are questioned in urban locations where heavy vehicular volumes and possible long dwell-times at the bus stop may result in increased delays and possible head-on collisions as vehicles may attempt to go around the stopped bus. Benefits attributed to bus bulbs, including reduced delays to buses and traffic calming effects, must be weighed against the delays to other vehicular traffic on the roadway as well as possible safety impacts. The research performs an evaluation on the effectiveness for bus bulbs taking into account the particular conditions and driver population of this State.

Despite the recognized benefits of bus bulbs for improving transit operation, bus bulbs are not appropriate for all bus stop locations. For this reason, the research sought to develop a selection criterion for identifying potential locations where bus bulbs could be installed. A review of the literature showed that the only existing criteria for installing bus bulbs are the criteria used in *TCRP 65*. This reference states that bus bulbs are recommended at locations with high pedestrian activity, crowded sidewalks and permit curbside parking. The research found that the characteristics for installing bus bulbs outlined in TCRP 65 are not entirely transferable to dense urban areas as found in New Jersey. In some cases, locations with the characteristics where bus bulbs should be located, also possess characteristics of locations where bus bulbs should not be located. For example, bus bulbs are recommended at locations with high bus patronage and high pedestrian activity. These locations are also found to have high bus and vehicular volumes. Bus bulbs may not be appropriate for this type location, as high bus and vehicular volumes result in higher delays for buses at bus bulbs.

Bus bulb geometric design varies by location and depends on the specific objectives for the use of the bulb and the existing conditions at the intersection. The two primary considerations in the design of the bulb are the length and width. The length depends primarily on the length of the buses used on the route, the policy regarding how many doors are used for boarding and discharge, and if more than one bus will be accommodated at the bulb at any one time. The width of a bus bulb is its extension into the parking lane. The review of the lengths of bus bulbs conducted in this research showed that lengths that have been used vary from 20-ft (6.1 m) long, where boarding and discharge occurs from the front door, up to 140-ft (42.7 m) long, to accommodate the arrival of two articulated buses. Typically, New Jersey Transit buses are 45-ft (13.7 m) long with both front and rear discharge. As such, this is the nominal length that should be considered for the design of a bus bulb. The review also showed that standard bus bulb widths range from 6 to 7 ft (1.8 to 2.1 mm), which is about the width of a standard parking lane. A width of 6 feet is therefore recommended for design of NJDOT bus bulbs.

Drainage is an important issue in the retrofitting of an existing sidewalk to include a bus bulb as the bulbs may affect how water is drained both off the sidewalk and in the adjacent roadway. Retrofit bus bulb designs also may require the installation of new drainage grates and storm water piping in the parking lane prior to, or at the end of, the bus bulb. These new drains are needed due to street curb drainage flow blockage by the bus bulb extension into the street.

Data were collected at locations where bus bulbs were to be constructed on Cedar Lane in Teaneck and on Route 71 (Main Street) in Avon-by-the-Sea. The data collected included traffic volumes, existing signal timing, bus travel times, pedestrian flows, and bus speed profiles. An after study was not performed, however, due to very low pedestrian and bus volumes at the Avon-by-the-Sea location which could not allow an assessment of the bus bulb to be performed. No after study was performed at Cedar Lane due to continued delays in the construction of the bus bulbs.

An alternative approach to completing the before-after study was the development of a methodology for evaluating the potential bus travel time savings due to a bus bulb. Three traffic and bus characteristics were identified as being impacted by a bus bulb. These parameters include the bus travel time, bus re-entry delay, and signalized intersection control delay. An analysis of the components that comprise these parameters showed that the expected bus travel time savings from a bus bulb is the re-entry delay minus the increase in intersection delay after the bus bulb is constructed.

An operational analysis with and without a bus bulb for three locations was performed. Overall, the intersections perform at good levels of service with minimal delays. The analysis showed that installing a bus bulb would result in the reduction in the approach capacity between 8 and 11 percent and an increase in control delay from between 7 and 16 percent. Bus travel time savings as a result of the bus bulbs ranges between 15 and 30 seconds per bus stop. The bus travel time savings are reported per bus stop and suggests that for significant bus travel time savings to be achieved for the route, several bus bulbs would be warranted.

The research demonstrates that bus bulbs can be an effective alternative to curbside bus stops with the potential to reduce bus re-entry delays, increase bus speeds, decrease the walking distance for pedestrians, and provide additional sidewalk area for bus patrons. The research also demonstrates that achieving these benefits requires careful consideration of conditions at the bus stop prior to installation of the bus bulb. In urban areas, consideration must also be made to the impact of the bus bulb on the operation of the adjacent intersection.

Chapter I

INTRODUCTION

Overview

This report summarizes the results of the work performed under the project *Effectiveness of Bus bulbs for Bus Stops*. The focus of this research is the use of bus bulbs as a location for a bus stop zone. This application of bulbs was proposed in *Transit Cooperative Research Program* (TCRP) *Report 19*, Guidelines for the Location and Design of Bus Stops.(1) Bus bulbs represent one type of bus stop design that is appropriate for use under certain transit, roadway and sidewalk conditions. Under this design, the sidewalk at an intersection is extended into the street to a distance equal to the depth of a typical parallel parking space (see Figure 1). Buses stop in the traffic lane instead of weaving into and out of the bus stop. Bus bulbs create additional space to include bus stop amenities such as shelters and benches and also reduce the crossing distance of pedestrians at the intersection. The primary motivation for installing bus bulbs is to reduce sidewalk congestion and to improve transit operation by reducing bus delays through the elimination of bus-weaving maneuvers into and out of a curbside bus stop. Bus bulbs are recommended for use at locations with high pedestrian activity, crowded sidewalks and at locations that permit curbside parking.(2) Bus bulbs are currently being used in cities in the Pacific Northwest with high-density development areas, well-developed transit corridors and a high level of transit patronage.

Some of the advantages cited for the use of bulbs as a bus stop zone include that bus bulbs: (1) remove fewer parking spaces than the traditional curb-side bus stop; (2) decreases the walking distance for pedestrians crossing the roadway; (3) provides additional sidewalk area for bus patrons to wait; and (4) results in minimal delay for the bus. When a bus stops at a bus bulb, the bus remains in the travel lane, rather than weaving into and out of the curb lane as is typical of curbside bus stops. Removing this weaving has the potential of reducing conflicts between buses and other vehicles on the roadway as the bus does not have to merge back into the traffic stream after stopping at the bus stop.

Figure 1. Example of Bus Bulb (Source: TCRP 65).

Research Problem

The safety and effectiveness of bus bulbs is questioned in urban locations where heavy vehicular volumes and possible long dwell-times at the bus stop may result in increased delays and possible head-on collisions as vehicles may attempt to go around the stopped bus. Benefits attributed to bus bulbs, including reduced delays to buses and traffic calming effects, must be weighed against the delays to other vehicular traffic on the roadway as well as possible safety impacts. The recently completed *TRCP Report 65 Evaluation of Bus Bulbs*,(2) provides a review of impacts related to bus bulbs. The findings of this study, however, may not be completely transferable to locations found in New Jersey. The research performs an evaluation on the effectiveness for bus bulbs taking into account the particular conditions and driver population of this State.

Research Objectives

The research objectives of the work performed under Task Order No. NCTIP-43, Effectiveness of Bus bulbs for Bus Stops, include:

- Identify and evaluate factors under which bus bulbs result in changes in travel speeds for both buses and other vehicular traffic.

- Assess factors that impact the safety risks of bus bulbs for motor vehicle drivers and bus passengers compared to conventional bus stops.

- Determine the impacts of the bus bulbs on passenger comfort.

- Develop guidelines and procedures for the implementation and use of bus bulbs in New Jersey.

The tasks identified in the original proposal to achieve these objectives include:

<u>Task 1.</u> Identify a limited number of urban bus stop locations that could be considered for bus bulb installation.

<u>Task 2.</u> Develop from the literature or elsewhere a specification document that provides measurements and guidance for proposed test bus bulbs to be built.

<u>Task 3.</u> Prepare plans in sufficient detail for the agreed upon test bulbs to allow for contractor installation.

<u>Task 4.</u> Develop a methodology to evaluate effectiveness of the recently built bus bulb, and to compare them to the effectiveness of the locations before they changed to bulbs.

<u>Task 5.</u> Conduct a before-data collection.

<u>Task 6.</u> Install bus bulbs.

<u>Task 7.</u> Conduct an after-data collection.

Task 8. Analyze the data.

Task 9. With the assistance of NJDOT and NJ Transit, develop for general publication a document explaining the rules and guidelines for the use of "bus bulbs".

Task 10. Prepare a project schedule to submit a quarterly, interim, and final report that document the entire research effort.

The intent of the original study was to construct the bus bulbs and evaluate their effectiveness. This objective could not be addressed as in almost all cases, drainage at the bus bulb would need to be adjusted. As retrofitting drainage was outside the expertise of the contractor designated to construct the bulbs, the research team could not perform all of the tasks in the project as originally intended. Before data were collected at two locations where proposed bus bulbs are to be constructed. This data along with a methodology for estimating the impacts of bus bulbs on bus travel times are presented in the research.

Organization

This report is organized into eight chapters. Chapter I provides an introduction to the research, stating the research objectives and the tasks performed to accomplish these objectives. Chapter II provides a literature review covering topics on bus bulbs and the work performed in *TCRP 65*. Chapter III describes the work performed for identifying sites appropriate for installing bus bulbs. Chapter IV describes guidelines on the design of bus bulbs. Chapter V describes the data collection methodology to be used in assessing the effectiveness of bus bulbs. Chapter VI summaries the data collection effort performed at two locations where bus bulbs are proposed to be constructed. Chapter VII describes a methodology that can be used to evaluate the impact of bus bulbs on bus travel times. Chapter VIII describes the measuring of re-entry delays at bus stops in New Jersey. Finally, Chapter IX provides conclusions and guidelines for the use of bus bulbs in New Jersey.

Chapter II

LITERATURE REVIEW

Overview

Bus bulbs have been recognized as having potential for improving the safety and operation of bus transit and pedestrian movements. A bulb is a treatment made to the sidewalk extending the sidewalk and curb at an intersection into the street to a distance equal to the depth of a typical parallel parking space. A bus bulb is a sidewalk extension into the street with a bus stop located on the bulb. These bus bulbs are also referred to as bus bulbs, curb extensions, neckdowns, flares and chokers. Bulbs have been used as a solution for pedestrian safety, traffic calming purposes and as the location for bus stops. The bulbs reduce the walking time and crossing distance of pedestrians by extending the curb to the edge of the through lane. This reduction in walking time and travel distance equates to a reduction in the exposure of pedestrians to roadway vehicles, resulting in an increase in pedestrian safety. As a traffic calming measure, bulbs reduce the speeds of turning vehicles by creating a 90-degree corner.

Previous research on bus bulbs is limited to work performed by Fitzgerald on bus stop location and bus bulbs. The results of these research efforts are documented in two reports: *TCRP 19, Guidelines for the Location and Design of Bus Stops* [(1)] and *TCRP 65, Evaluation of Bus Bulbs.*[(2)] These documents provide a comprehensive review of the effects of bus bulbs on transit operations, vehicular traffic, and nearby pedestrian movements.

The research performed in TCRP 65 was based on data collected before and after the conversion of nine bus bays in San Francisco to bus bulbs. The conversion was a part of several strategies designed to create a more "transit-friendly" environment within the city of San Francisco. The objectives of the research performed in TCRP 65 included:

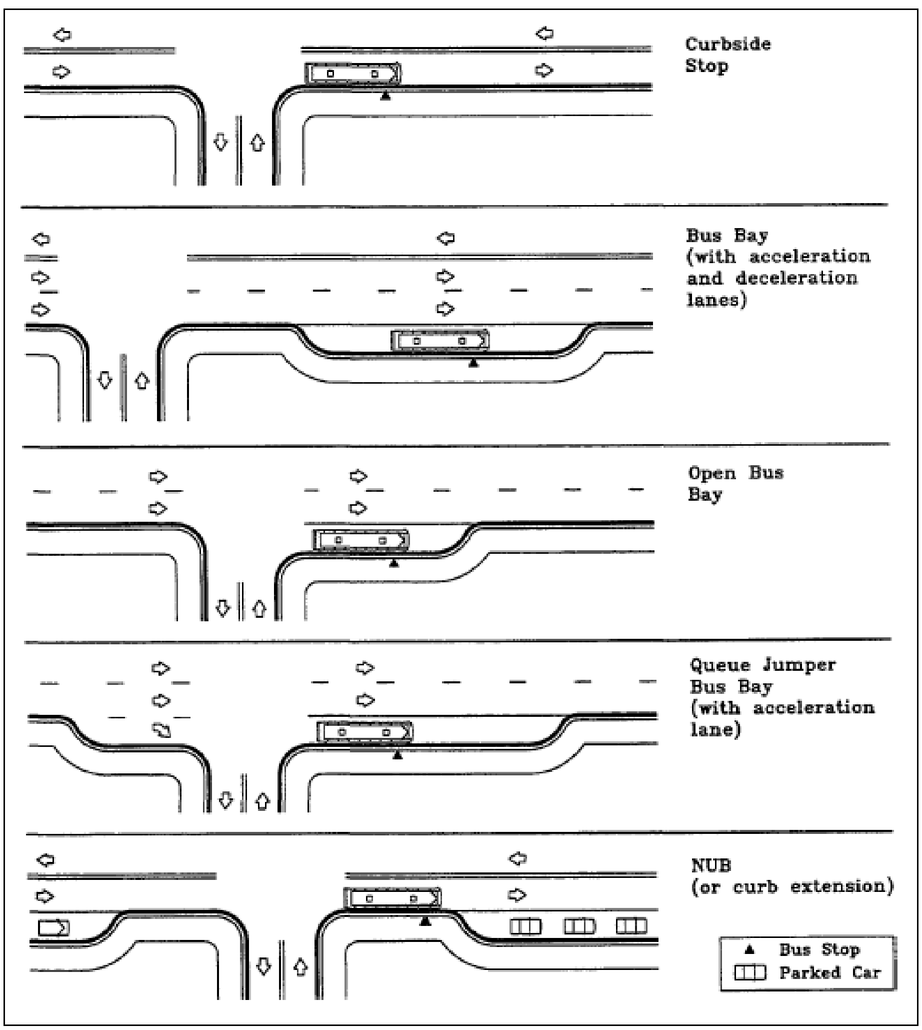
- To determine the effect of the installation of bus bulbs on transit operations, vehicular traffic, and nearby pedestrian movements.
- To collect information on when bus bulbs should be considered and lessons learned from those cities that use the bus bulb configuration.
- To identify vehicle and bus operations for bus bulbs located nearside and farside and along a corridor, using computer simulation.
- To evaluate conditions in which the installation and use of bus bulbs is advisable.

The following provides a review of these documents and supplemental work based on these initial reports.

Bus Stop Design

Bus bulbs are one of among several types of bus stop designs. Figure 2 shows alternative bus stop designs including curbside bus stops and bus bays. The choice of bus stop design is dependent on many factors related to the roadway and intersection geometry, adjacent land use, bus operation, and passenger and pedestrian related information. Curbside bus stops represent a simple and easy bus stop design requiring little modification to the roadway to accommodate the bus stop. The curbside design is similar to a bus bulb as the bus may stop in the travel lane with this design. Even if a parking lane is present upstream or downstream of the curbside bus stop, the bus may or may not pull off of the travel lane. In this bus stop design, bus patrons may also be required to enter the roadway, if the bus does not fully pull into the curb.

Bus-bays are an alternative bus stop design that allows the bus to fully exit the travel lanes to pick up or discharge bus patrons. For this reason, bus bays are primarily used on high-volume or high-speed roadways. The high-volume and high-speed conditions under which bus bays are installed create problems for buses reentering into the adjacent travel lanes. Where these conditions exists, bus bulbs may represent an improvement over bus bays as bus bulbs eliminate the problems associated with buses reentering the traffic stream.



Bus Bulb Location

The bus stop can be located just prior to the intersection (near side), just after the intersection (far side), or away from the intersection (mid-block). All three locations are used in practice. Examples of these bus bulbs at these locations are shown in Figures 3, 4, and 5. One of the objectives of the work performed in TCRP 65 was to identify vehicle and bus operations for bus bulbs located at nearside and farside bus stop locations. To accomplish this objective, a before-after study was conducted of Mission Street in San Francisco where nine bus bays were converted to bus bulbs. Mission Street is an undivided four-lane roadway with a posted speed limit of 25 mi/h. The before study showed that bus re-entry problems were more associated with nearside bus stops. Delays to buses trying to re-enter the traffic stream at nearside stops were observed to be higher than delays to buses at farside stops. After the bus bays were converted to bus bulbs, nearside stops experienced the greatest improvement with queues forming

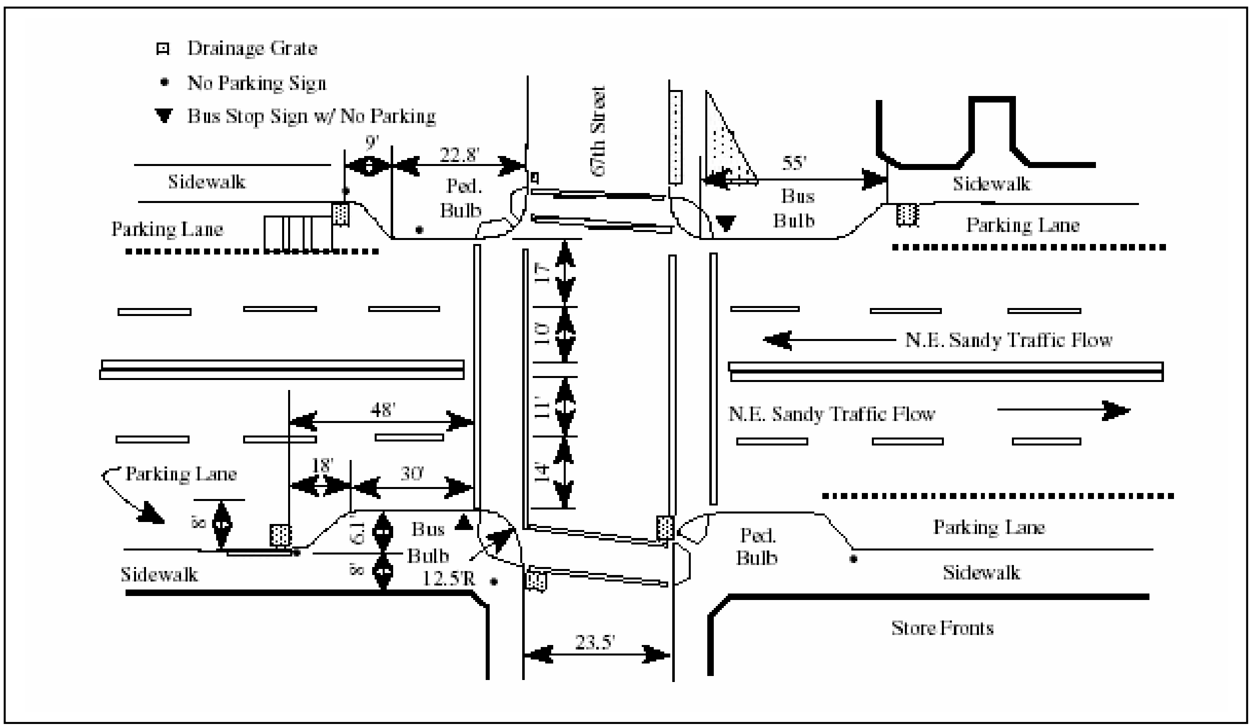


Figure 3. Nearside Bus Bulb Location (Source: TCRP 65).

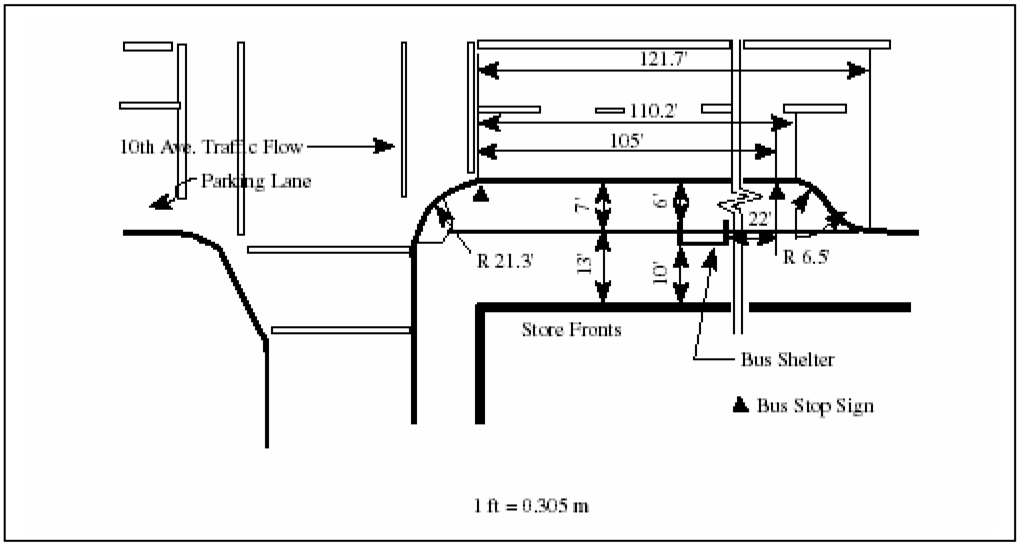


Figure 4. Farside Bus Bulb Location (Source: TCRP 65).

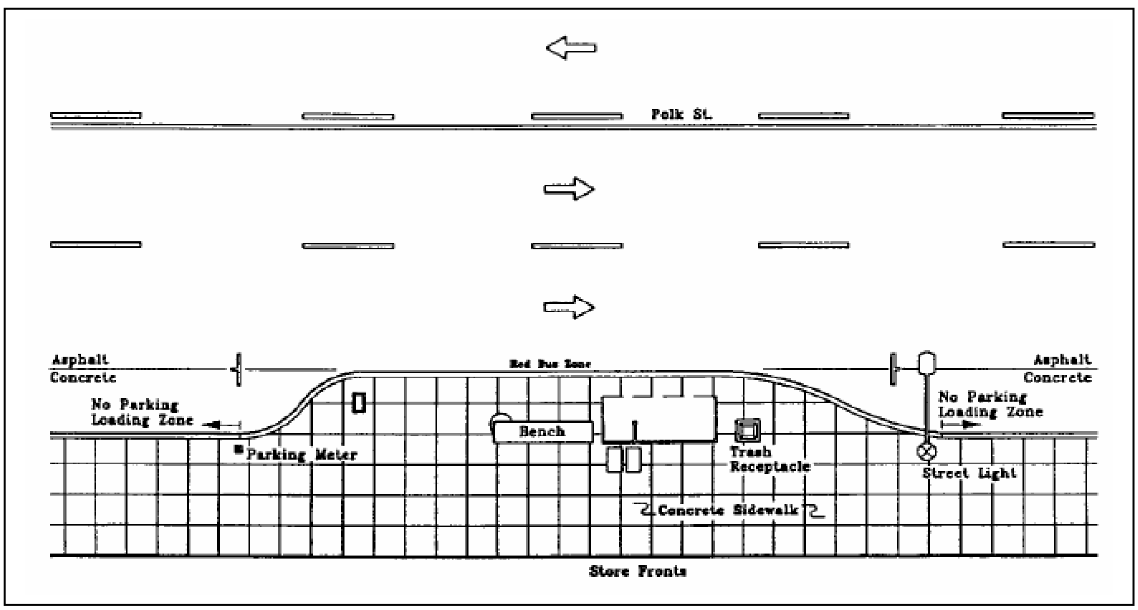


Figure 5. Midblock Bus Bulb Location (Source: TCRP 65).

less frequently at nearside stops and more frequently at farside stops. In addition, at nearside stops, the frequency of lane changes for vehicles going around the bus when a bus was stopped, increased after the conversion. At farside stops, the frequency of lane changes remained constant. The study concludes that nearside stops experience higher bus delays and have the greatest reduction in average delay with the installation of the bus bulbs. Some of the operational conditions that should be considered with farside and midblock bus bulb locations is that farside bus bulbs have the potential for blocking the intersection when cars following the bus stop within the intersection. Mid block bus bulb locations also have the potential for encouraging jaywalking.

Operating Characteristics

The before-after study performed in TCRP 65 included collecting operational data before and after the bus bulbs were introduced. Some of the data collected included: bus and vehicular speeds adjacent to the bus stop and for the corridor; the number of vehicles that queued while the bus was stopped; vehicular driver behavior while the bus was stopped; and bus operations. The following provides a summary of the operational characteristics associated with bus bulbs.

Average Speeds

The before-after study found at both farside and nearside bus stop conversions there was a statistically significant increase in vehicle speeds. At the farside bus stop, speeds increased from 11.4 mi/h to 20.9 mi/h during the peak period and from 9.5 to 15.7 mi/h during the non-peak period. At the nearside bus stop, there was an increase in speed of 4.5 mi/h. These increases in speed occurred despite an increase in vehicular volumes of between two and four percent. Bus speeds also increased between 0.2 to 2.2 mi/h along the arterial. Speeds along a 2400-foot length of the arterial were also compared. The comparisons showed that the average speed of all vehicles increased by 3 mi/h in the northbound direction and 7 mi/h in the southbound direction. Bus speeds along the arterial slightly increased by 0.5 mi/h.

Queue Lengths

Data collected on queue lengths after the bus stops were converted showed that there were typically between one to four buses queued for every seven to seventeen bus arrivals during the non-peak hours and a queue of about four vehicles during the peak hours. This shows that not every bus arrival resulted in a stop or a queue at the bus stop. The researchers also observed that before the bus stop was converted to a bus bulb, buses would stop in the travel lane. Although for both the bus bay and bus bulb configurations vehicles queued behind the stopped bus attempted to change lanes, there were slightly more lane changes after the bus stops were converted to bus bulbs.

Bus Dwell Times

To evaluate the impact of the bus bulbs on bus operations, dwell times of buses were recorded before and after the bus stop conversions. The dwell time was determined to be the difference between the time the vehicle stopped to the time that the bus doors were closed. The data showed that on average, dwell times at the bus bulb were longer than the average dwell time at the bus bay. The researchers did note that the difference was within three seconds. In addition, there were more occasions after the bus conversions when bus supervisors engaged the driver in a conversation at the bus stop, increasing the dwell time.

Chapter III

POTENTIAL SITES FOR BUS BULBS

Overview

Despite the recognized benefits of bus bulbs for improving transit operation, bus bulbs are not appropriate for all bus stop locations. For this reason, the research sought to develop a selection criterion for identifying potential locations where bus bulbs could be installed. This chapter summarizes the work performed under Task 1 to identify potential sites for installing bus bulbs. This chapter provides both the criteria used in identifying the sites and a description of the sites selected.

Selection Criteria

A review of the literature showed that the only existing criteria for installing bus bulbs are the criteria used in *TCRP 65*. This reference states that bus bulbs are recommended at locations with high pedestrian activity, crowded sidewalks and permit curbside parking. The bulbs are typically used in locations with high-density development, well-developed transit corridors and a high level of transit patronage. Based on a review of the placement of bus bulbs in selected cities, TCRP 65 summarized some criteria on where bus bulbs should and should not be placed. This summary is provided in Table 1.

The research team found that the characteristics for installing bus bulbs outlined in TCRP 65 are not entirely transferable to dense urban areas as found in New Jersey. In some cases, locations with the characteristics where bus bulbs should be located, also possess characteristics of locations where bus bulbs should not be located. For example, bus bulbs are recommended at locations with high bus patronage and high pedestrian activity. These locations are also found to have high bus and vehicular volumes. Bus bulbs may not be appropriate for this type location, as high bus and vehicular volumes result in higher delays for buses at bus bulbs. In addition, the research team found that one traffic engineering technique used to improve the capacity of bus stops with high bus volumes is to eliminate parking directly upstream and downstream of the bus stop. Without on-street parking, both upstream and downstream of the bus stop, bus bulbs could not be considered at these locations.

Table 1. Criteria for Installing Bus bulbs.

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

(Source: TCRP 65)

As a result of these sometimes conflicting conditions, the research team began an initial selection of locations by first ensuring that the locations met some basic criteria. These criteria included that:

1. Bus volumes were large enough to warrant the added treatment.

2. Existing roadway volumes created delays for buses at the bus stop, as shown by site inspection.

3. Roadways were State routes where NJDOT had jurisdiction.

4. Pedestrian activity existed where bus patron amenities may be considered.

Lacking a central database containing transit corridors on State routes, the research team attempted to identify potential locations for installing bus bulbs by first identify high volume routes and then identifying transit corridors. Routes designated as both high volume and within transit corridors would then be investigated to determine the jurisdiction responsible for the roadway and appropriateness for installing bus bulbs.

To identify high volume routes, the New Jersey Department of Transportation Data Reference System was used to determine roadways with the highest average annual directional traffic (AADT). The research focused on roadways found within the State's designated Urban Centers. The Urban Centers, as stated in Table 2, provided a geographical mix of locations within the State. These locations were also believed to provide locations with some amount of pedestrian activity. Bus routes on these roadways were then identified using the New Jersey Transit website. These routes were identified by first selecting all routes traveling within the particular Urban Center. Line diagrams, which provide portions of the bus routes, were then viewed to identify the roadways used by the bus routes. Bus routes coinciding with high volume roadways were then identified. Finally, information on the number of lanes, number of signalized intersections, and other geometric information was obtained from NJDOT's Straightline diagram for each of the roadways identified.

Table 2. New Jersey Urban Centers.

City	County
1. Atlantic City	Atlantic County
2. Camden	Camden County
3. Elizabeth	Union County
4. Jersey City	Hudson County
5. New Brunswick	Middlesex County
6. Newark	Essex County
7. Paterson	Passaic County
8. Trenton	Mercer County

The search identified 28 locations, which are shown in Table 3. Included in this table are locations where either it was known that pedestrian bulb outs were to be constructed, or were recommended by NJ Transit as a potential location.

Table 3. Potential Locations for Bus bulbs.

County Name	City	NJ Cty. Rte. No.	Street Name	2-Way Volume	No of Lanes	Width (ft)	No. of Signals	Speed Limit	Bus No. by City
Essex	Newark		Ferry Street	NA	2	40	8	25	1,25,34
	Newark	NA	Broad Street	30,585	6	90	37	NP	41,42,43, 44,59,61, 62,65,66, 67,70,71, 72,73,74, 75,76,78, 79,90,
	Montclair	506	Bloomfield Avenue	23,740	4	56-60	33	25-35	11,28,34, 92,93,94, 96,99,
	Belleville	7	Washington Avenue	NA	4	60	10	30	13
Camden	Cherry Hill	38	Kaighn Avenue	50,940	4	50	8	50	450
	Lindenwold	673	Laurel Road	36,260	2	36	8	25	454,459
	Haddon	130	Crescent Blvd	36,200	4-5-6	36-48-36	6	40-45	
	Gloucestor	534	Clementon Road	26,650	2-4-2	24-40-72	6	40-45	403
	Cherry Hill	673	Springdale Road	22,794	2-3-4	34-40	7	40-45	406
Mercer	Trenton		Liberty Street	13,144	2	30	7	25	
	Trenton	653	Calhoun Street	23,800	2	43-34	8	NP	606
	Trenton	206	Brunswick Avenue	20,940	2	40	10	25	
	Trenton	650	Lalor Street	20,790	2	30	2	NP	607
	Trenton	33	Greenwood Avenue	17,150	3-2	36-40	12	25-30	606

Table 3. Potential Locations for Bus bulbs (cont'd)

County Name	City	NJ Cty. Rte. No.	Street Name	2-Way Volume	No of Lanes	Width (ft)	No. of Signals	Speed Limit	Bus No. by City
Hudson	Jersey City	501	JFK Blvd	22,047	4	60	95	25	2,80,84,88
	Jersey City		Palisades Avenue	21,380	1-2	30-50	20	25	84,87,89
	Jersey City	602	Danforth Avenue	13,540	2	40	8	25	80
	Jersey City	617	Summit Avenue	12,570	2	30-45	22	25	80,83,84,85,87
Atlantic	Atlantic	87	Huron Avenue	28,640	4-5-6	50	3	45	501,505
	Atlantic	NA	Atlantic Avenue	27,443	4	66	27	30	501,502,504,505,507,508,509,554
	Atlantic	NA	MLK Blvd	NA	4-2	40-30	9	25-35	505,554
Passaic	Paterson	601	Main Street	18,688	2	40	5	NP	702,703,704,707,744,746,748,770
	Paterson	NA	Broadway Avenue	NA	2-4	42-52-24	10	NP	72,74,704,722,744,748,770
Middlesex	New Brunswick	680	Howes Lane	21,062	2	40	3	NP	NA
	New Brunswick	-	New Street	11,352	2	40	4	25	NA
	New Brunswick	27	Somerset Street	22,740	4	40-30	31	40-25-30	NA
Mercer	Princeton	27	Nassau Street	11,521	2	24-52	8	25-45	NA
Monmouth	Avon-by-the-Sea	71	Main Street	NA	2	60	3	35	NA

Site Visits

Based on the review of geometric conditions and bus activity on the routes, sites with the most promise were selected for visiting and gathering further information. Sites in Camden and Mercer Counties were not visited as these sites did not indicate a large number of buses using the roadways. The following provides a discussion of some of the visits to these locations.

Figure 6. Ferry Street, Newark.

<u>Ferry Street, Newark</u>

Ferry Street is a two-lane municipal roadway located in the City of Newark (see Figure 6). This location was identified as a potential location for installing bus bulbs through a recommendation from NJ TRANSIT and also through a meeting with the Traffic Engineer for the City of Newark, Bahman Izadmehr. Ferry Street is a two-lane, two-way roadway with parking on both sides of the roadway. The street is located in the historic Ironbound District of Newark with several restaurants and businesses located on the roadway. On-street parking is limited within the area and, as a result, the area is plagued with parking violations of patrons in the bus zones. The volumes on the roadway are high during the peak hour, with sufficient pedestrian and bus volumes to warrant a bus bulb on this street.

Based on the criteria provided in *TCRP 65*, bus bulbs should not be placed on roadways with two travel lanes. This location is still recommended for bus bulb installation, however, because site visits showed that at present, bus drivers do not pull into the bus stop, causing bus patrons to enter the roadway while loading the bus. It is also believed that bus bulbs on this roadway may also eliminate parking violations of vehicles stopping and parking in the bus stop.

Figure 7. Broad Street, Newark.

<u>Broad Street, Newark</u>

Broad Street is a major roadway within the City of Newark (see Figure 7). The roadway is designated as an urban principal arterial with between four to six travel lanes provided. Volumes on this roadway are one of the highest for local roadways providing both access to businesses located on the roadway and providing mobility through Newark and to adjacent communities. The roadway also is a heavy transit corridor with over 20 bus routes using Broad Street. Broad Street intersects with several major roadways including Interstate 280, Route 21 (McCarter Highway), Route 510 (Market Street), and Route 508 (Central Avenue).

On the initial site visits, the intersection of Broad Street and Market Street was identified as a potential location for including a bus bulb. This location was seen to have very high volume of bus patrons with limited sidewalk area. The site visits also showed that at this location there is no on-street parking with a bus lane operating during the AM and PM peak hours on both Broad Street and Market Street. This location was recommended as a location for installing a bus bulb by the City of Newark Traffic Engineer. However, the presence of a bus lane and no-parking would make this location infeasible as a potential location for installing a bus bulb.

Figure 8. Bloomfield Avenue and Park Street, Montclair.

Route 506 (Bloomfield Avenue), Montclair

Bloomfield Avenue is an urban principal arterial roadway in Montclair, extending through the City of Montclair and into adjacent communities. The roadway has between four and five travel lanes with parking providing on both sides of the roadway (see Figure 8). In Montclair, volumes on this roadway are high during the peak hour with several businesses located on the roadway. The roadway has eight bus lines traveling in the Montclair area.

Visits to the site showed that the County had installed pedestrian bulb outs at the intersection of Bloomfield Avenue and Park Street. Pedestrian bulb outs were placed on each corner, except for the corner with a bus stop. The research team contacted the County and obtained the plans for the design of these bump outs. This site holds good potential for installing a bus bulb physically and could be acceptable to the community as pedestrian bulb outs are currently being used. The installation of a bus bulb, however, would require that existing catch basins be moved to accommodate the bus bulb.

Route 7 (Washington Avenue), Belleville

Route 7, Washington Avenue, is one of the few State routes with a bus route in Essex County. The roadway has four travel lanes with parking generally provided on both sides. Volumes on the roadway are not the highest in the County. However, during peak periods, volumes are high at some locations on the roadway. There is one bus line using the roadway. However, this bus route has several branches with high frequency during the peak periods. This roadway is within the jurisdiction of the State and could be considered for installing a bus route.

Route 501 (JFK Boulevard), Jersey City

John F. Kennedy Boulevard is an urban principal arterial extending for about fifteen miles through the cities of Bayonne, Jersey City, and North Bergen. The roadway has one of the highest volumes in Hudson County providing access to businesses and residences located adjacent to the roadway and providing mobility through this region.

The roadway has between four and six travel lanes with parking generally provided on both sides of the roadway. JFK Boulevard is a heavy transit corridor for buses providing connections to rail at Journal Square, which is located on the Boulevard. The heavy vehicular volumes and large number of buses using the roadway makes this location difficult for installing a bus bulb.

Paterson, Passaic County

Route 601 (Main Street) and Broadway Avenue in Paterson were identified as roadways with potential for installing bus bulbs. These roadways were identified as having high bus volumes with several bus routes including a significant number of paratransit vehicles with routes between New York and New Jersey. In general, both roadways have two travel lanes with parking on both sides of the roadway. A large number of businesses result in significant pedestrian activity within the area. These locations, however, were not considered for installing a bus bulb due to high level of congestion in the area. The high number of double-parked vehicles and unscheduled stops by some of the paratransit vehicles, also created a complex area not amenable to installation of a bus bulb.

Route 27 (Nassau Street), Princeton

Route 27 (Nassau Street) in Princeton was recommended by NJ Transit as a community which may be amenable to traffic calming and pedestrian amenities. The roadway has two travel lanes in each direction with parking on both sides of the roadway. Bus bulbs were considered at locations of Route 27 across the street from the Princeton University campus. The vehicular and bus volumes, as well as the pedestrian volumes at this location provided a good location for considering the installation of a bus bulb. The site visit revealed that the location with the highest bus volumes and congestion was also used as a taxi waiting area and no parking provided on either side of the roadway. For this reason, a bus bulb could not be considered for

Figure 9. Route 71 and Lincoln Avenue.

Figure 10. Route 71 and Sylvania Avenue.

this location.

<u>Route 71 (Main Street), Avon-By-The-Sea</u>

Route 71 (Main Street) in Avon-By-The-Sea was identified as a roadway where pedestrian bulb-outs are to be constructed as part of the "Route 71 - Main Street Streetscape Improvements" project. The project involves traffic calming measures including the use of pedestrian bulb-outs at intersection corners and extending the width of the sidewalk at mid-block sections. Pedestrian bulb-outs will be placed at intersection corners where bus stops exist, creating an effective bus bulb. These effective bus bulbs will be located at the southeast corner of Route 71 and Sylvania Avenue and the southeast corner of Route 71 and Lincoln Avenue. The existing roadway has two travel lanes in each direction with a parking lane provided on both sides of the roadway. The improvement project will provide two 16 ft travel lanes in each direction and a center turn lane. Volumes on Route 71 are generally low with two bus routes on the roadway. Pedestrian volumes and bus patrons are also very low at the location where the bus bulbs would be constructed. Field visits to the roadway indicated that the low volumes and low bus frequency did not result in delays to buses. Data were collected, however, prior to the construction of the bus bulbs. The data collection was used as an opportunity for the research team to train students performing the data collection and to refine the data collection methodology.

Streetscapes Projects

Another approach taken by the research team to identify locations where bus bulbs may be considered was to contact municipalities with planned improvements to the municipality's Main Street. These "Streetscape Projects", which receive funding through the Transportation Trust Fund, Statewide Transportation Improvement Program, and the Transportation Equity Act for the 21^{st} Century (TEA-21), provide aid to municipalities and counties for local transportation improvements.

In fiscal year 2002, 44 projects received Transportation Enhancement Grants. Of these 44 projects, 18 were identified as receiving funds for Streetscapes Improvement projects. To determine which of these projects would involve roadways on transit routes involving sidewalk improvements, the research team contacted and met with the District 2, Local Aid and Economic Development District 2 office in Newark. This office handles local aid projects in Bergen, Essex, Hudson, Passaic and Union Counties. The office was able to provide information on the nature of the streetscape improvements, time schedule for when the work would be complete, and contact information for the municipalities where these projects were to be constructed.

Based on information provided by the District office, the research team then contacted the following locations to obtain further information on the projects:

- Irvington Avenue Streetscape Infrastructure and Landscaping Project.
- Bloomingdale Town Center (two-lane roadway).
- Downtown Plainfield Central Business District Streetscapes Project.
- Maplewood: Springfield Avenue (Route 124).
- Prospect Park Borough.
- Clifton: Van Heltan Avenue.

Information on bus bulbs was then mailed to these municipalities. One municipality who approached New Jersey Department of Transportation about bus bulbs was Teaneck Township. This municipality received Transportation Enhancement Funds for the "Teaneck Revitalization Project Cedar Lane Improvements". The project involves improvements to Cedar Lane including the installation of pedestrian bulbouts and bus bulbs. The bus bulbs are to be constructed at three locations. The research team has contacted the municipality and will be performing before and after studies at this location.

Additional contacts were made to other municipalities outside District 2's jurisdiction and the following provides a summary of information gathered about other Streetscapes Projects:

- Atlantic, Buena Borough, Central Avenue Pedestrian Sidewalk Improvements. This is the second phase in a three phase project. The first phase involved putting in sidewalks, lighting, etc. The next phase involves putting in one bus bulb. The city needs to purchase an area of approximately 100 ft by 100 ft for the bus shelter. The municipality is in the preliminary design phase, and hopes to have more detail designs by early Spring 2003. It is anticipated that construction will be complete before the end of the year.

- Bergen, Moonachie Borough, The Moonachie Road Streetscape Project: The municipality has not begun their preliminary design and could not say whether they would be including pedestrian bulb outs. This is a heavy volume roadway connecting Route 46 and the Meadowlands. The municipality anticipates that design will begin in February 2003. The goal of the project is not to introduce traffic calming as the route is heavily traveled.

- Camden, Gloucester City, Gloucester City Streetscape Improvements: There are no buses on this route.

- Mercer, Hamilton Township, South Broad Street Streetscape: The municipality has not determined whether pedestrian bulbouts will be considered in this project. It is anticipated that the design process will be started in February 2003.

- Middlesex, Metuchen Borough, South Main Street Corridor Traffic Calming and Streetscape Improvement Project: This project involves replacing cracked damage sidewalk area. Four bumpouts will be included as a gateway to slow vehicles down coming off of Route 1. This project is not quite in the downtown area, but south of the downtown area. The cross streets for the project are at Orchard and Lincoln. Plans for the project could be obtained from the municipality.

- Monmouth, Neptune Township, West Lake Avenue, Neighborhood Center and Streetscape Project: This project is in the preliminary phase. Pedestrian bulbouts will be included at bus stops. The research team is currently seeking to obtain a copy of the project plan.

Final Selected Locations

After an initial review, the locations selected for further study for bus included:

- Ferry Street, Newark.
- Bloomfield Avenue, Montclair.
- Cedar Lane, Teaneck.

After considering the drainage requirements for Ferry Street and Bloomfield Avenue, it was determined that the project would not construct bus bulbs at locations requiring changes in the drainage system for the roadway. For this reason, the streetscape project in Cedar Lane, is currently the only location where bus bulbs will be evaluated in this project.

Chapter IV

GUIDELINES ON THE DESIGN OF BUS BULBS

Overview

Bus bulb geometric design varies by location and depends on the specific objectives for the use of the bulb and the existing conditions at the intersection. This report provides an overview of the width and length of the bus bulb, parking, ADA, drainage, bus stop location, pedestrian treatment and costs associated with bus bulb installation. The information provides a basis for developing specifications for use of bus bulbs in New Jersey.

Selected Cities Bus Bulb Designs

TCRP 65 provides descriptions of the designs of bus bulbs used in San Francisco, Portland, Vancouver and Seattle. Information collected from these cities on bus bulb design and practices are summarized in Table 4.

Length and Width

The two primary considerations in the design of the bulb are the length and width. The length, as shown in Figure 11, depends primarily on the length of the buses used on the route, the policy regarding how many doors are used for boarding and discharge, and if more than one bus will be accommodated at the bulb at any one time. San Francisco uses the longest bus bulb length of 140 ft (42.7 m) to accommodate the arrival of two or more articulated buses at the bus stop. In Portland, bus bulb lengths depend on several factors including the width of the street, the amount of existing parking, and the policy regarding how many doors are used for boarding and alighting the transit vehicle. As the city no longer uses articulated buses and boarding and alighting occurs from the front door, shorter bus bulb lengths of 30 ft (9 m) or 20 ft (6 m) in downtown areas were considered. In Vancouver the bus bulb lengths are approximately 105 feet, which allows for more than one transit vehicle to be accommodated. Seattle uses a bus bulb length of 80 ft to handle several factors including the fact that several bus stops at the locations where the bus bulbs were installed were consolidated, and additional parking was needed. Also the potential for having two articulated buses arrive at the same time was considered and the ability to have all doors on an articulated bus be used for boarding and alighting was considered in determining the bulb length.

Table 4. Design for Bus Bulbs in Selected Cities.

City	Length	Width	Cost
San Francisco, CA	140 ft (42.7 m)	6 ft (1.8 m)	$500,000*
Portland, OR	Variable	6 ft (1.8 m)	$15,000-$30,000**
British Vancouver	105 ft (32.0 m)	6.5 ft (2.0 m)	$48,000**
Seattle, WA	80 ft (24.4 m)	N/a	$48,000 **

* For nine bus bulbs, ** For a pair of bulbs

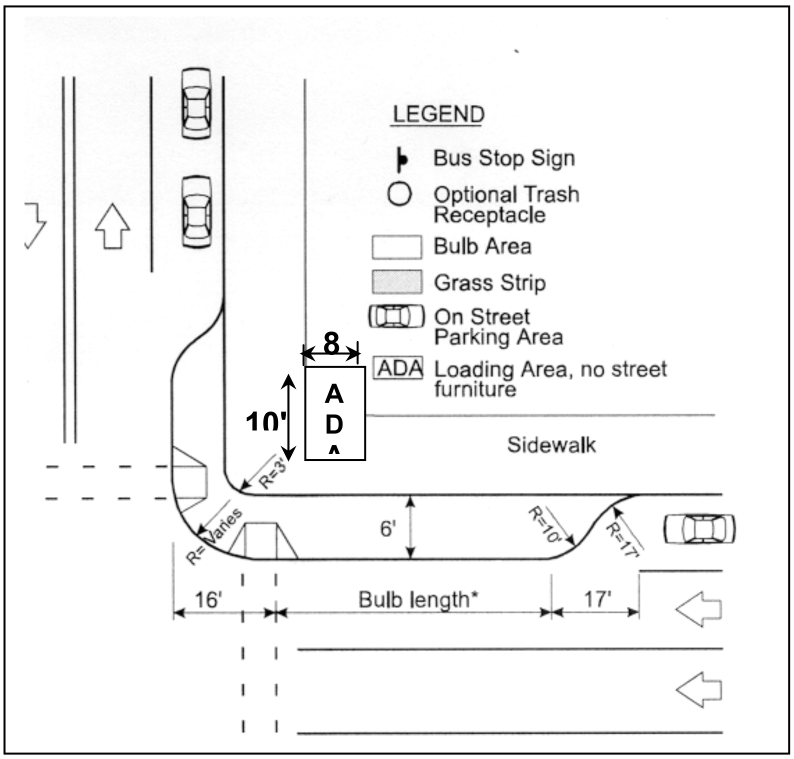


Figure 11. Typical Dimensions for a Bus Bulb (Source: TCRP 65).

The width of a bus bulb is its extension into the parking lane. Both San Francisco and Portland use a standard width of a bus bulb of 6 ft (1.8 m), which is about the width of a parking lane. Portland also provides a 2 ft (0.6 m) "shy" zone between the bulb and traffic for bicyclists who use the curbside parking lane as a travel lane. The "shy" zone has been contested by motorists and Portland is now considering a 7-ft (2.1 m) wide bulb. In Vancouver, the width of the bus bulb was constrained by the width of the street on which the bus bulbs were installed. The bus bulbs were restricted to a width of 6.5 ft (2.0 m) to minimize the potential of having a stopped bus encroach on the second travel lane.

The review of the lengths of bus bulbs conducted in this research showed that lengths that have been used vary from 20-ft (6.1 m) long, where boarding and discharge occurs from the front door, up to 140-ft (42.7 m) long, to accommodate the arrival of two articulated buses. Typically, New Jersey Transit buses are 45-ft (13.7 m) long with both front and rear discharge. As such, this is the nominal length that should be considered for the design of a bus bulb. The review also showed that standard bus bulb widths range from 6 to 7 ft (1.8 to 2.1 mm), which is about the width of a standard parking lane. A width of 6 feet is therefore recommended for design of NJDOT bus bulbs.

Curb Radii

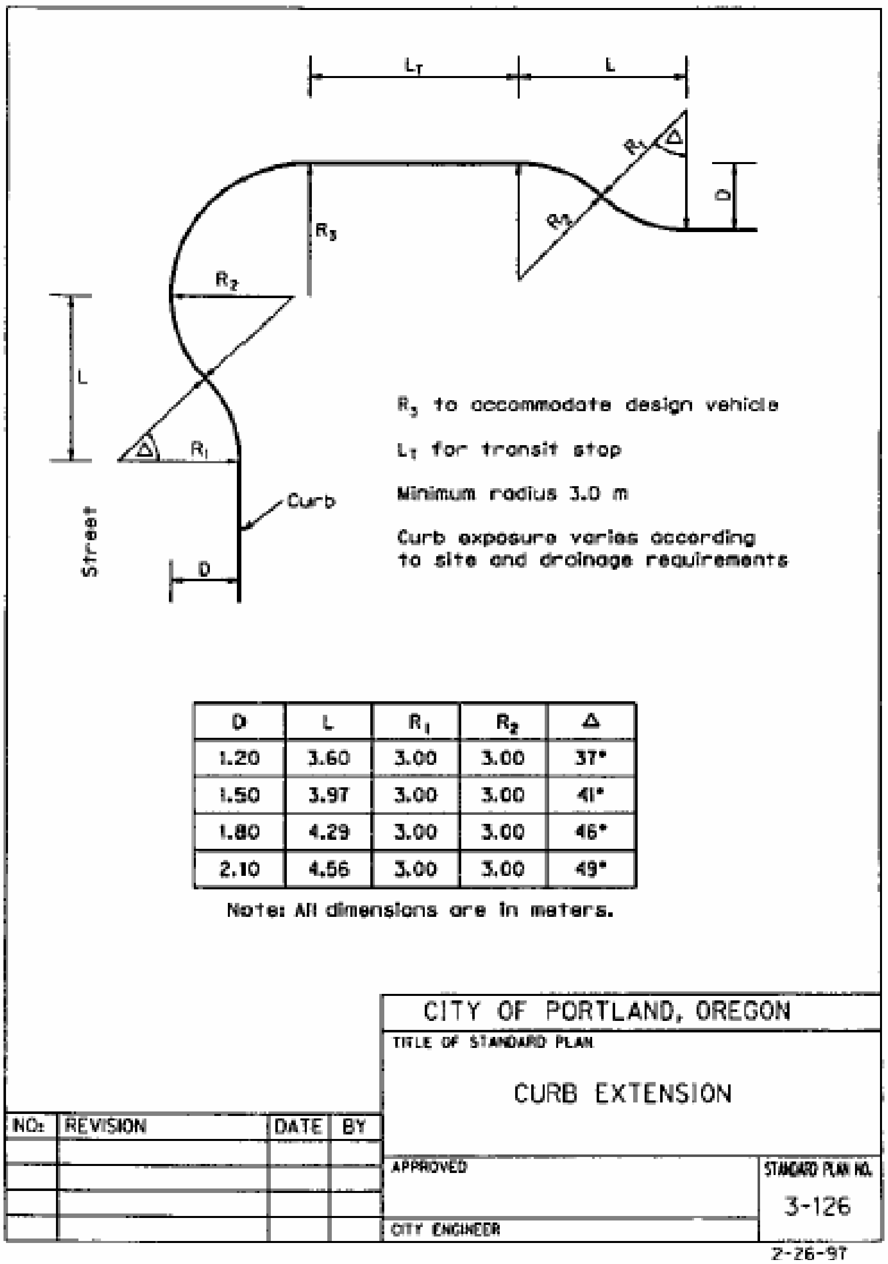
The Federal Highway Administration's *Implementing Pedestrian Improvements at the Local Level* [3] provides guidelines on the use of curb extensions, which are similar to bus bulbs but are implemented primarily to facilitate pedestrian movement. These guidelines can be adapted for the use of bus bulbs. The guidelines call for intersection curb radii at bus bulbs, as shown in Figure 11, of between 10 ft (3 m) and 15 ft (4.5 m) to be used where residential streets intersect other residential streets and arterial streets. A curb radius of 20 ft (6 m) or less should be used at the intersection of arterial streets that are not bus or truck routes. On arterial streets used as bus and/or truck routes, curb radii of 25 ft (7.5 m) to 30 ft (9 m) or less should be used.

Parking curb to bus bulb curb transitions, as shown in Figure 11, are typically accomplished with double radii from 10 to 20 ft. These radii are used to accommodate street cleaning and snow removal. The City of Portland has developed curb extension design standards, as shown in Figure 12, which use a double 10 foot radii for all transitions. An alternate design using an angled 45 degree transition results in a 8-1/2 ft curb transition length. This maximizes on-street parking but leaves a corner where mechanical street cleaning is difficult.

This research recommends that NJDOT adopt a double 10 ft radii design for curb extension, which allows for mechanical street cleaning and requires a 14-1/2 foot curb transition length for a 6 ft wide bus bulb.

Drainage

Drainage is an important issue in the retrofitting of an existing sidewalk to include a bus bulb as the bulbs may affect how water is drained both off the sidewalk and in the adjacent roadway. Sidewalks and streets are generally both designed with a drainage slope to curb. For a 6-ft wide bus bulb extension into an existing street, the drainage slope on the bus bulb extension is reversed, as shown in Figure 13. This slope reversal presents the potential for water ponding on the sidewalk. If there is sufficient longitudinal sidewalk slope there is no problem. However, where the longitudinal slope is minimal or flat a ponding and freezing problem is created. Some municipalities have installed covered slot drains at these locations but this approach is not recommended due to maintenance issues. Street grading prior to retrofit bus bulb installation is another potential, but costly, solution to this drainage problem.



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

Figure 12. Portland, Oregon Bus Bulb Design Standards (Source: TCRP 65).

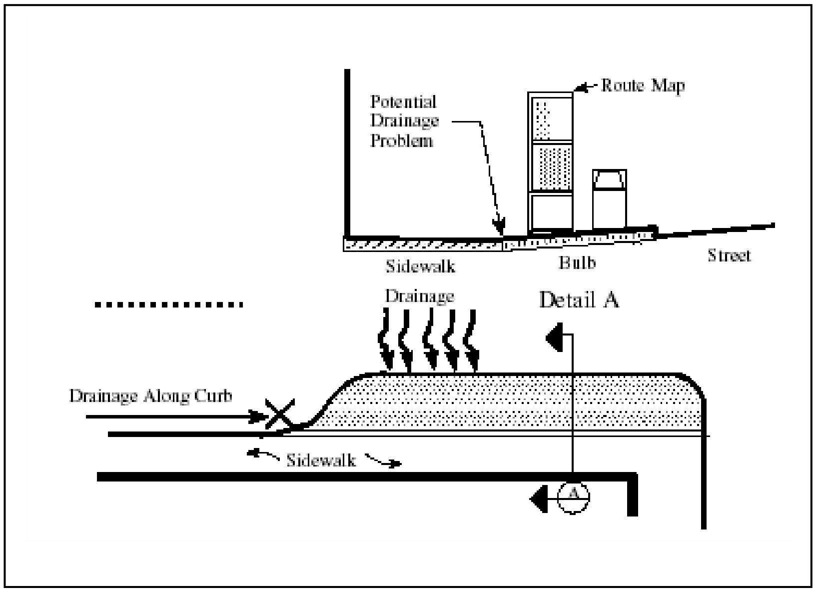


Figure 13. Potential Drainage Issues with Bus bulbs (Source: TCRP 65).

Retrofit bus bulb designs also may require the installation of new drainage grates and storm water piping in the parking lane prior to, or at the end of, the bus bulb. These new drains are needed due to street curb drainage flow blockage by the bus bulb extension into the street.

ADA Considerations

The Americans with Disabilities Act (ADA) of 1990 provide guidelines for the design of bus stops, bus stop pads, bus stop shelters, and the paths leading to these structures. These guidelines ensure that transportation facilities are constructed so that the facility is readily accessible to, and usable by, individuals with disabilities, including individuals who use wheelchairs. The impact of ADA guidelines on the installation of bus bulbs primarily surrounds the need to provide a bus stop pad where a bus lift or ramp is to be used. The bus stop pad must have a minimum length of 96 in and a width of 60 in. There should also be a 5-ft clear wheelchair maneuvering space beyond the 60 in minimum width. This results in a clear bus stop ADA space requirement of 8 feet long by 10-ft wide, as shown in Figure 11. The ADA clear space must be located to correspond with the position of the wheelchair lift for the buses using that route. The slope of the pad, to the maximum extent possible, should be the same as the roadway and the maximum slope perpendicular to the roadway should be two percent.

Signage

Bus bulbs are a self-enforcing no-parking design. They discourage motorists from temporarily parking in the bus stop zone because of the traffic blockage that would be caused by the illegal parked vehicle. Bus bulbs must be clearly marked with signs and paint along the curb over the entire bus stop zone. Figures 14, 15, 16, and 17 are examples of signage that should be used at bus bulbs. The use of bollards at nearside and midblock bulb locations needs to be considered where there is a "No Parking During Snow Emergencies" policy on the subject street.

Figure 14. No Parking Sign (Source: TCRP 65).

Figure 15. Traffic Control Sign (Source: TCRP 65).

Figure 16. No Parking Sign (Source: TCRP 65).

Figure 17. No Parking Tape (Source: TCRP 65).

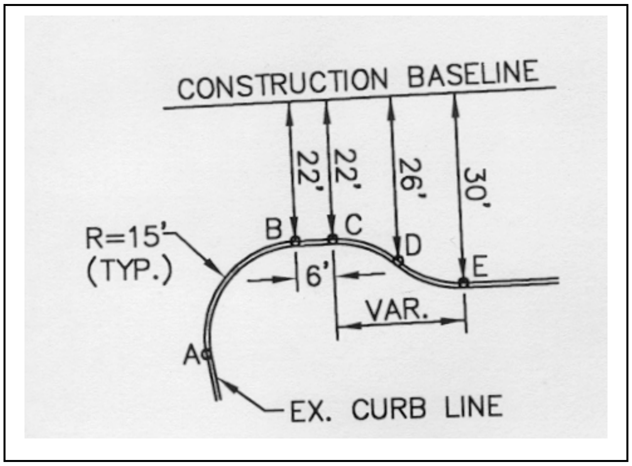


Figure 18. Typical Pedestrian Bulbout on Route 71.

Bus Bulb Designs

Examples of designs of bus bulbs used locally can be seen in two locations: Route 71 (Main Street) in Avon-By-The-Sea, and on Cedar Lane Road in Teaneck. The following provides details of the designs used.

Main Street, Avon-By-The-Sea

As described in Chapter III, pedestrian bulbouts are to be constructed on Route 71 in Avon-By-The-Sea in Monmouth County New Jersey. These bulbouts are to constructed at several intersection corners including two bus stop locations at Sylvania Avenue and at Lincoln Avenue. Figure 18 shows a typical pedestrian bulbout design and Figures 19 and 20 shows the design of the pedestrian bulb outs at the two bus stop locations. The length of the pedestrian bulbouts at the two bus stop locations is 38 ft at Sylvania Avenue and 36 ft at Lincoln Avenue with a width of 8 ft.

Cedar Lane, Teaneck

Cedar Lane in Teaneck, Bergen County has also included pedestrian bulbouts and bus bulbs in its "Cedar Lane Streetscaping Improvements" Project. The bus bulbs are to be constructed at three locations on Cedar Lane including at both the northwest and southeast corners of Cedar Lane and Elm Avenue, the northwest corner of Cedar Lane and Garrison Avenue, and at Chestnut Avenue. At Elm and Garrison Avenue, the bus bulbs are at both farside bus stops. At Chestnut Avenue, the bus bulb can be considered to be either a farside or midblock bus stop. Figures 21 and 22 show the bus bulbs at Elm Avenue and at Garrison Avenue, respectively. The length and width of the bus bulbs are approximately 36 ft and 10 ft, respectively.

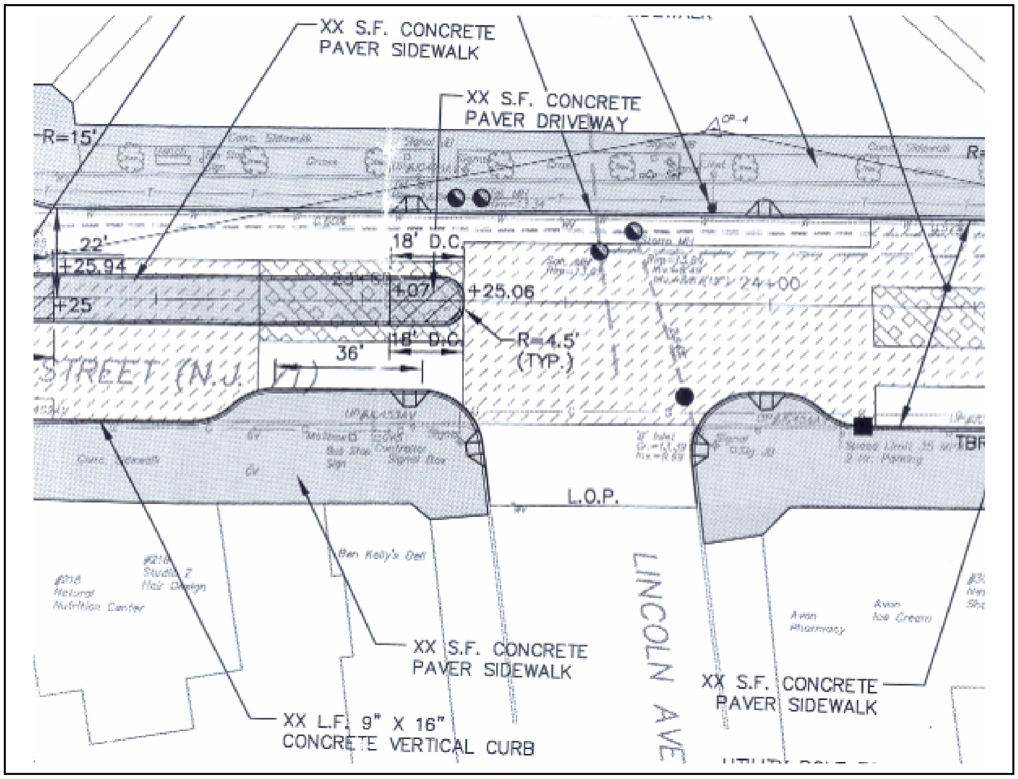


Figure 19. Main Street and Lincoln Avenue Bus Bulb.

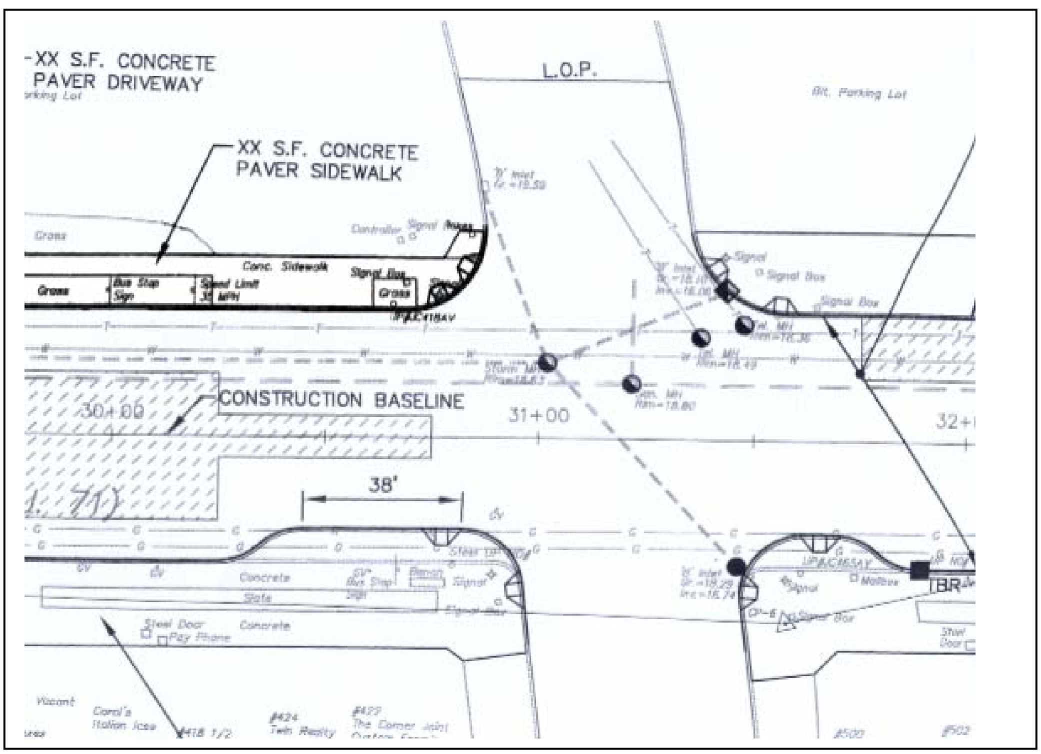


Figure 20. Main Street and Sylvania Avenue Bus Bulb.

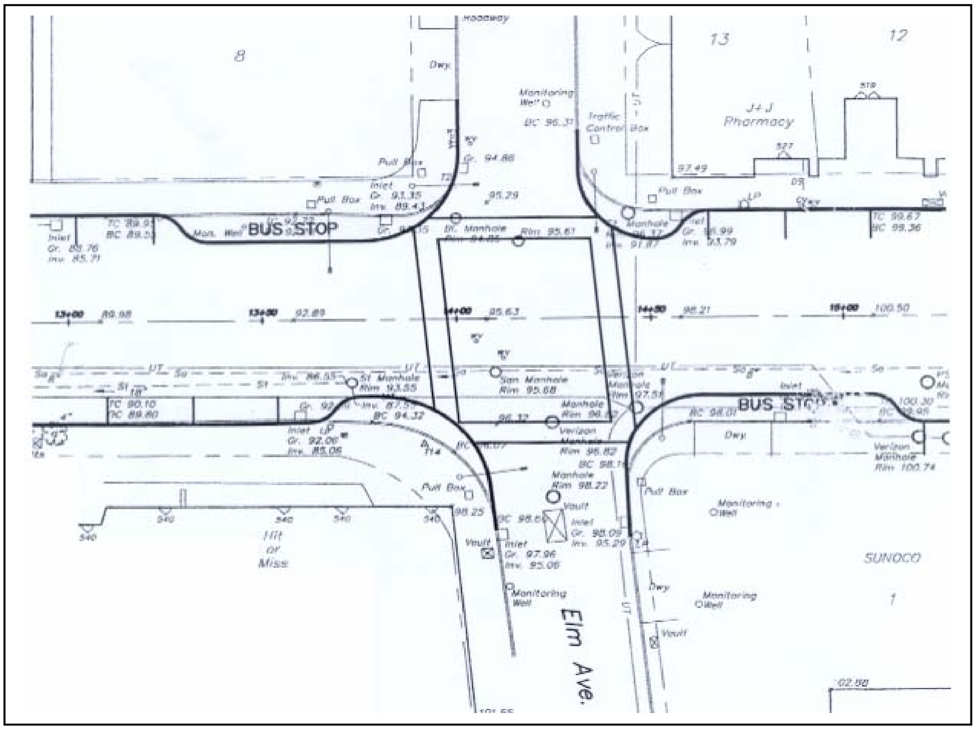


Figure 21 Cedar Lane and Elm Avenue Bus Bulb.

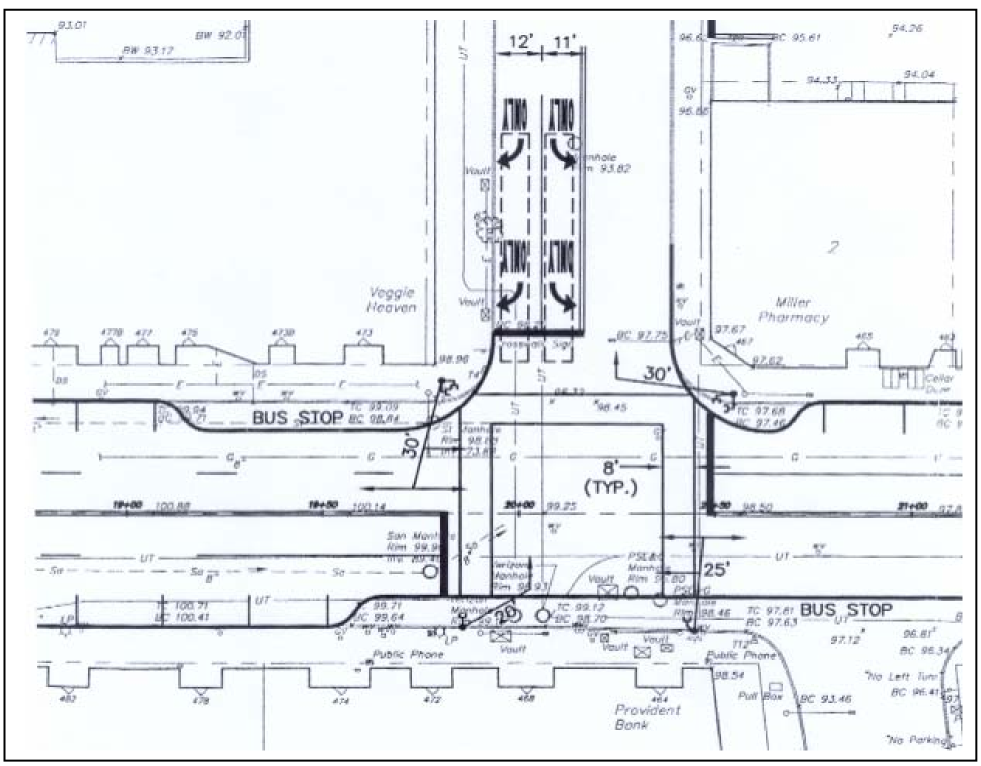


Figure 22 Cedar Lane and Garrison Avenue Bus Bulb.

Chapter V

EVALUATION METHODOLOGY

Overview

The evaluation of the bus bulbs includes an assessment of several components including an operational and capacity analysis of the bus stop, pedestrian facilities, and the roadway. In Fitzgerald's research,[2] the effectiveness of bus bulbs was determined by evaluating curbside and roadway conditions before and after the implementation of the bus bulb. In the curbside evaluation, pedestrian space, walking speeds, and waiting area of bus patrons were evaluated. The capacity analysis focused on changes in the sidewalk level-of-service (LOS) and corner as described by the 1994 *Highway Capacity Manual.*[4] The roadway evaluation focused on changes in bus and vehicular speeds near the bus stop and in the corridor. Queue lengths behind stopped buses and bus operations were also assessed.

In this research, the effectiveness of bus bulbs was determined by first identifying the potential impacts of bus bulbs on the roadway and adjacent pedestrian facilities before installing the bus bulbs. This evaluation was used to determine whether the location chosen for the bus bulb is appropriate. Determination of the potential impacts was based on the recently published 2000 *Highway Capacity Manual.* [5] This version of the manual includes an updated research methodology and analysis approach for transit and pedestrian facilities. Expected changes in the level of service and operation of the adjacent signalized intersection due to the installation of the bus bulb were assessed. The following sections describe the methodological approach taken for each component of the assessment.

Bus Stop Evaluation

The appropriateness of installing a bus bulb at a particular location can be determined using the procedures provided in the Transit Capacity Chapter of the *Highway Capacity Manual* [5] and the *Transit Capacity and Quality of Service Manual.* [6] These manuals provide procedures for evaluating bus capacity as a function of the vehicle and person capacity of the bus service. Vehicle capacity describes the number of buses that can be served by a loading area, bus stop, bus lane, or bus route during a specified period of time. Person capacity describes the number of people that can be carried past a given location during a given time period under specified operating conditions. Although both vehicle and person capacity are impacted by the bus stop, the research focuses on vehicle capacity as this capacity is more directly affected by the bus stop design.

The research project evaluated the vehicle capacity for those locations where bus bulbs are installed and compare this capacity before and after the bus bulb installation. Vehicle capacity is determined in three locations: the loading area; bus stop; and bus lane. The specific components of vehicle capacity that was evaluated in assessing the effectiveness of the bus bulb was the bus clearance time.

Clearance time is the time while the bus is exiting a bus stop that the loading area at the bus stop is not available for use. This time includes the time required for a bus to start up and travel its own length plus the re-entry delay or the time associated with waiting for a sufficient gap to allow a bus to pull back into the travel lane. For on-line bus stops, like bus bulbs, where the bus loads and unloads from the travel lane, there is no re-entry delay.

The *Highway Capacity Manual* [(5)] provides a procedure for estimating the capacity of a mixed-traffic bus lane for two types of bus lanes. A Type 1 bus lane is a mixed-traffic lane with one traffic lane in the direction the bus operates and is shared by buses and other vehicles. A Type 2 mixed-traffic lane has two or more traffic lanes in the direction the bus operates. Traffic uses any lane, but the buses typically operate in the curb lane. The bus vehicle capacity is then determined as:

$$B = B_{bb} N_{eb} f_m$$

where: B = mixed-traffic bus lane capacity (buses/h).
B_{bb} = maximum number of buses at critical bus stop (buses/h).
N_{eb} = number of effective loading areas at critical bus stop.
f_m = mixed-traffic adjustment factor.

The mixed-traffic adjustment factor, fm, is calculated as:

$$f_m = 1 - f_l\left(\frac{v}{c}\right)$$

where: f_m = mixed-traffic adjustment factor.
f_l = bus stop location factor.
v = curb-lane volume at critical bus stop.
c = curb-lane capacity at critical bus stop.

Pedestrian Conditions

The *Highway Capacity Manual* [(5)] provides methodologies for evaluating the capacity and level-of-service of facilities serving pedestrians. These facilities include: walkways and sidewalks; pedestrian queuing areas; shared (pedestrians and other non-motorized traffic) off-street paths; pedestrian crosswalks; and pedestrian facilities along urban streets. The pedestrian facilities impacted by the bus bulb include sidewalks adjacent to the bus bulb and the queuing area or corner at the bus bulb. The evaluation of the bus bulb installation was performed by determining the level-of-service for the adjacent sidewalk and the queuing area or corner of the bus bulb.

The level-of-service of a sidewalk is a function of the amount of space provided to each pedestrian. The pedestrian unit flow rate is also used to assess the operation of the sidewalk. To determine the level of service of the sidewalk the effective sidewalk width was determined. The effective width is the width of the sidewalk that is available for use by pedestrians and is determined as the total width minus the width and shy distances from obstructions on the sidewalk. The pedestrian unit flow rate is then determined as the peak 15-minute pedestrian count divided by the effective sidewalk width. The level-of-service criteria for walkways and sidewalks from the *Highway Capacity Manual* is then used to assign a level of service to the sidewalk.

The level-of-service for the bus stop queuing area is a function of the average space available to each pedestrian and the degree of mobility allowed. The level of service analysis for corners compares available time and space with pedestrian demand. The pedestrian needs at street corners include the need for circulation to accommodate pedestrians crossing the roadway and the need to hold pedestrians waiting during the red signal phase at the intersection. The performance measure used to assign a level of service is the product of time and space (or time-space) where these parameters are a function of the available space as well as the signal timing at the intersection.

Roadway Conditions

Bus bulbs affect roadway conditions at the bus stop and the adjacent intersection. Although bus speeds may improve as a result of not having to wait to reenter the travel lane, other vehicles on the roadway will experience some delay due to the stopped bus. The impacts of the bus bulb on the roadway and adjacent intersection were assessed before the installation of the bus bulb using field studies. Field studies were performed and statistical analyses conducted to evaluate the overall effectiveness of the bus bulbs. The methodology for evaluating the effectiveness of the bus bulbs was to collect data on vehicular and pedestrian movements before and after the installation of the bus bulbs and to compare this data to determine statistically significant differences. In this study only before were collected and therefore a full before/after study could not be conducted. The before data and the methodology used for collecting this data is presented and can be used at a later date to assess the impacts of the bus bulb.

For evaluating roadway conditions, bus speeds and travel times were collected. The intent of the speed study is to show differences in the speed profile of the bus before and after the installation of the bus bulb. The speed profile was obtained my measuring the speed of the bus at specific locations as it approaches the bus stop and as it departs from the bus stop. The dwell time of the bus at the bus stop and the clearance time, the time while the bus is exiting a bus stop that the loading area at the bus stop is not available for use, is also included in the speed profile. The clearance time also includes the time required for a bus to start up and travel its own length plus the re-entry delay or the time associated with waiting for a sufficient gap to allow a bus to pull back into the travel lane. A comparison of bus speed profiles before and after the installation of the bus bulbs will provide detailed information on the changes in speeds before and after the bus bulb installation.

Bus Bulb Impact Analysis

The procedures of the *Highway Capacity Manual* can be modified to estimate bus travel time savings and impacts on intersection operation due to bus bulbs. The modifications involve estimating the re-entry delays for buses weaving backing into a travel lane from a curbside bus stop. Although the *Transit Capacity and Quality of Service Manual* (TCQSM) provides an estimate of this re-entry delay, the estimate applies only to buses not waiting for a queue from a signal to clear before re-entering the roadway. This assumption limits the application of the TCQSM estimates of re-entry delay at many near-side bus stops. Hence, in this study, the procedure mentioned in TCQSM has been modified to improve the quantification of bus re-entry delay. Also, the procedure in HCM was modified to estimate the travel time savings to buses as a result of installing a bus bulb.

Chapter VI

DATA COLLECTION

Overview

Data were collected at locations where bus bulbs have been proposed for installation to determine the impact of these bus bulbs on the bus stop capacity, roadway and pedestrian conditions. Using the methodology described in Chapter V, Evaluation Methodology, travel time, speed data, and other data describing bus operations were collected on the roadways on which the bus bulb are to be installed. The procedures used during the field study and subsequent analyses are described in the following sections.

Field Data Collection

The data collection for the project was divided into three main categories: bus characteristics, vehicle characteristics, and curbside characteristics. Bus characteristics consists of bus volume, travel time, and speed profile. Vehicle volumes, including turning movement volumes, were collected to determine the impact of the bus bulb on the operation of the adjacent signalized intersection. Finally, pedestrian volumes and their direction of movement were collected to determine pedestrian characteristics. The methodology and procedures used for collecting data are described in the previous Chapter. The general layout of the field data collection is shown in Figure 23. The figure shows the locations for the placement of data collectors and field equipment.

Bus Travel Time and Speed

Travel time data were collected for buses traveling on the roadway where bus bulbs are proposed to be installed. Travel times were measured from a location upstream of the proposed or installed bus bulb to a downstream location. Using a stop watch, the time traversed by each bus along a predefined section was collected and the total travel time to traverse the entire section was calculated. Since there was only one bus traveling at a time, there was no need to match license plate number to identify them.

Bus speeds were collected using a laser gun. A data collector with a laser gun was positioned strategically near the intersection proposed for the construction of bus bulb. The bus speed was collected at a predefined time interval while the bus approached the intersection and after it passed the intersection. Hence, a bus speed profile was obtained for a stretch of time before and after the bus passed the intersection.

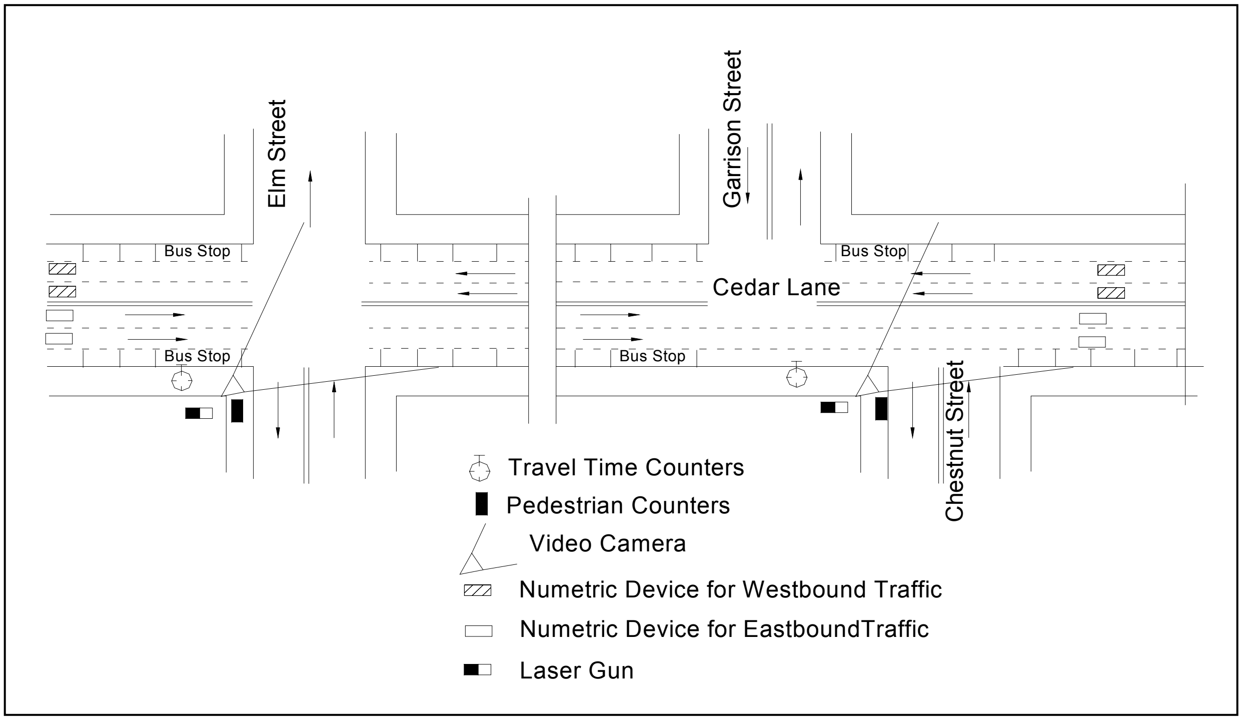


Figure 23. Layout of Field Work.

Traffic Volume

Traffic volumes were counted using numetric traffic counters placed in the middle of the travel lanes before and after the intersection where the bus bulb is to be constructed. The location of traffic counters are shown in Figure 23. Since the counters are not able to collect turning movement counts, a video camera was used to videotape the intersection for later use in counting the turning movements. The data from the numetric counters produced volume and speed information within one minute level. By viewing the videotape, turning movement counts were collected for a 15-minute time period and were used for the intersection analysis. There were little discrepancies between counts made from the video and data obtained from the numetric device. Therefore, traffic volumes obtained from video count were used.

Pedestrian Count

To determine the operation of pedestrian crosswalks adjacent to the bus bulb, the effective width of the crosswalk was determined. The pedestrian movements were counted by manually and recorded for the movements shown in Figure 24. The total number of pedestrians was counted for each 15-min time period. The manual count was also verified using the videotape of the intersection.

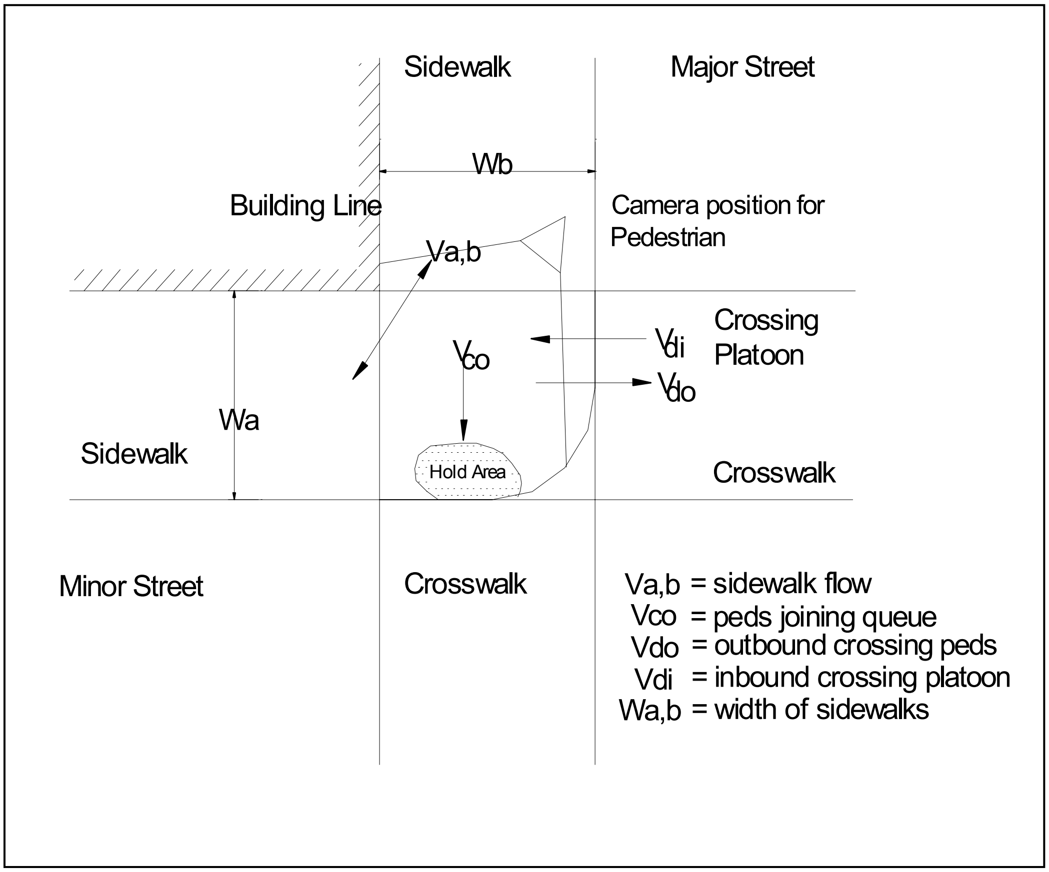


Figure 24. Layout for Pedestrian Data Collection.

Cedar Lane, Teaneck

The research team collected data at locations where bus bulbs are to be constructed on Cedar Lane in Teaneck. Four bus bulbs are scheduled to be constructed with the completion of the construction anticipated for late Fall 2003. The bus bulbs to be constructed are the intersections of the Cedar Lane and Elm Street and Cedar Lane and Garrison Avenue.

<u>Location Analysis</u>

Cedar Lane is located in downtown Teaneck, Bergen County. The busier section stretches from Lincoln Avenue to Windsor Avenue and is served by number of bus routes. Cedar Lane is six-lane and two-way roadway, with parking allowed on both sides. Due to parking, only two lanes are available for through traffic in each direction. The section of the Cedar Lane between Elm Street and Windsor Street has the highest vehicular volumes due to the number of shops and restaurants located on the roadway. This section of roadway also has the highest demand for on-street parking. Elm Street is one-way in one approach and two-way in another approach. Garrison Avenue is two-lane two-way street. Chestnut street is also two-way street but has been proposed to be closed after the construction of the bus bulb. On all eastbound approaches along Cedar Lane, right turn during red is not allowed. The existing bus stops are at the near side of the intersection for both westbound and eastbound approach. The roadway has 7 bus lines traveling in the Teaneck area. Figure 27 and 28 illustrates the geometry and lane configuration of the intersection of Elm Street and Cedar Lane and the intersection of Garrison Avenue and Cedar Lane. Moderate pedestrian levels and high roadway and bus volumes during the peak hours make this roadway ideal for the location of bus bulbs

Data Collection

Data collection was performed during afternoon peak period of four to six PM for both directions. The field layout shown in Figure 23 was used for data collection. Numetric traffic counters were placed before Elm Street for the eastbound approach and before Chestnut Avenue for the westbound approach. In addition to numetric counters, video cameras were used to count turning movements. Traffic volumes collected at Cedar Lane are shown in Table 5. Besides, traffic volume, existing signal timing plans for both intersections studied were also collected. Bus travel time was counted from Lincoln Avenue to Windsor Avenue for both the eastbound and westbound approaches and is shown in Table 7. Pedestrian movements were collected at the intersections of Cedar Lane and Elm Street and the intersection of Cedar Lane and Chestnut Street. The pedestrian flow rates were determined for these intersections and are presented in Table 8. Finally, the bus speed profile was obtained using a laser speed measuring device. The bus speed profile was captured as the bus approached and departed bus stops on Cedar Lane at Elm Street and Cedar Lane at Garrison Avenue. These profiles are presented in Figures 25 and 26.

Table 5. Traffic Volume Counts on Cedar Lane.

Time Period	Volume Count at Cedar Lane and Elm Street								
	Cedar Lane Eastbound			Cedar Lane Westbound			Elm Street Northbound		
	Left	Through	Right	Left	Through	Right	Left	Through	Right
4:00 - 4:15	7	190	9	7	155	11	23	4	1
4:15 - 4:30	5	183	7	10	156	6	13	3	0
4:30 - 4:45	3	180	8	11	149	5	11	3	0
4:45 - 5:00	3	200	10	6	158	18	11	8	0
5:00 - 5:15	2	212	9	15	189	10	14	7	1
5:15 - 5:30	5	223	6	10	156	6	15	11	15
5:30 - 5:45	3	220	11	12	182	11	15	12	15
5:45 - 6:00	5	225	7	8	165	11	19	8	15

Table 5. Traffic Volume Counts on Cedar Lane (cont'd).

Time Period	Volume Count at Cedar Lane and Garrison Avenue								
	Cedar Lane Eastbound			Cedar Lane Westbound			Garrison Avenue Southbound		
	Left	Through	Right	Left	Through	Right	Left	Through	Right
4:00 - 4:15	18	163	12	-	149	21	62	-	16
4:15 - 4:30	21	157	11	-	154	25	57	-	14
4:30 - 4:45	25	177	8	-	144	21	56	-	14
4:45 - 5:00	28	167	7	-	164	19	41	-	10
5:00 - 5:15	32	189	14	-	158	26	49	-	12
5:15 - 5:30	24	213	9	-	158	29	57	-	14
5:30 - 5:45	34	181	12	-	173	18	58	-	15
5:45 - 6:00	12	158	8	-	144	18	49	-	12

Table 6. Bus Travel Time on Cedar Lane.

Bus Travel Times (min) - Eastbound				Bus Travel Times (min) - Westbound			
Bus Trips	Lincoln To Elm	Elm To Garrison	Garrison To Windsor	Bus Trips	Elm To Lincoln	Garrison To Elm	Windsor To Garrison
1	0.63	0.77	0.88	1	0.85	0.75	0.50
2	0.40	0.55	0.38	2	0.68	0.70	0.45
3	0.48	0.67	0.77	3	0.28	0.92	0.38
4	0.32	0.87	0.77	4	0.97	0.55	0.60
5	0.25	0.98	0.97	5	0.18	0.50	0.97
6	0.33	0.83	0.73	6	0.90	0.57	0.73
7	0.28	0.53	0.38	7	0.48	0.85	0.72
8	0.43	0.45	0.50	8	1.13	0.80	0.58
9	1.10	0.40	0.42	9	0.18	0.87	0.33
10	0.62	0.65	0.63	10	0.47	0.73	0.20
11	0.47	0.68	0.47	11	1.22	0.63	0.45
12	0.87	1.07	0.58	12	0.23	0.53	0.35
13	0.25	1.12	0.78	13	0.77	0.65	0.70
14	0.72	0.97	1.92	14	0.17	0.67	0.47
15	0.23	0.68	0.50	15	0.65	0.98	0.97
16	0.52	0.65	0.38	16	0.52	0.87	0.42
17	0.57	0.47	0.47				
Average	*0.5*	*0.73*	*0.68*		*0.61*	*0.71*	*0.59*

Table 7. Pedestrian Flow Rate at Cedar Lane.

Pedestrian Count (Westbound)						
Time Period	Cedar Lane - Elm Street			Cedar Lane - Chestnut Street		
	15-min Pedestrian Count	Effective Walkway Width	Pedestrian Flow Rate	15-min Pedestrian Count	Effective Walkway Width	Pedestrian Flow Rate
	(Numbers)	(m)	(p/min/m)	(Numbers)	(m)	(p/min/m)
4:00-4:15	29	3.3	0.59	63	2.68	1.57
4:15-4:30	14	3.3	0.28	51	2.68	1.27
4:30-4:45	23	3.3	0.46	47	2.68	1.17
4:45-5:00	15	3.3	0.30	32	2.68	0.80
5:00-5:15	40	3.3	0.81	42	2.68	1.04
5:15-5:30	36	3.3	0.73	38	2.68	0.95
5:30-5:45	30	3.3	0.61	48	2.68	1.19
5:45-6:00	30	3.3	0.61	26	2.68	0.65

Pedestrian Count (Eastbound)						
Time Period	Cedar Lane - Elm Street			Cedar Lane - Chestnut Street		
	15-min Pedestrian Count	Effective Walkway Width	Pedestrian Flow Rate	15-min. Pedestrian Count	Effective Walkway Width	Pedestrian Flow Rate
	(Numbers)	(m)	(p/min/m)	(Numbers)	(m)	(p/min/m)
4:00-4:15	30	2.07	0.97	45.00	2.07	1.45
4:15-4:30	26	2.07	0.84	29.00	2.07	0.93
4:30-4:45	24	2.07	0.77	36.00	2.07	1.16
4:45-5:00	38	2.07	1.22	53.00	2.07	1.71
5:00-5:15	28	2.07	0.90	49.00	2.07	1.58
5:15-5:30	28	2.07	0.90	28.00	2.07	0.90
5:30-5:45	24	2.07	0.77	22.00	2.07	0.71
5:45-6:00	23	2.07	0.74	41.00	2.07	1.32

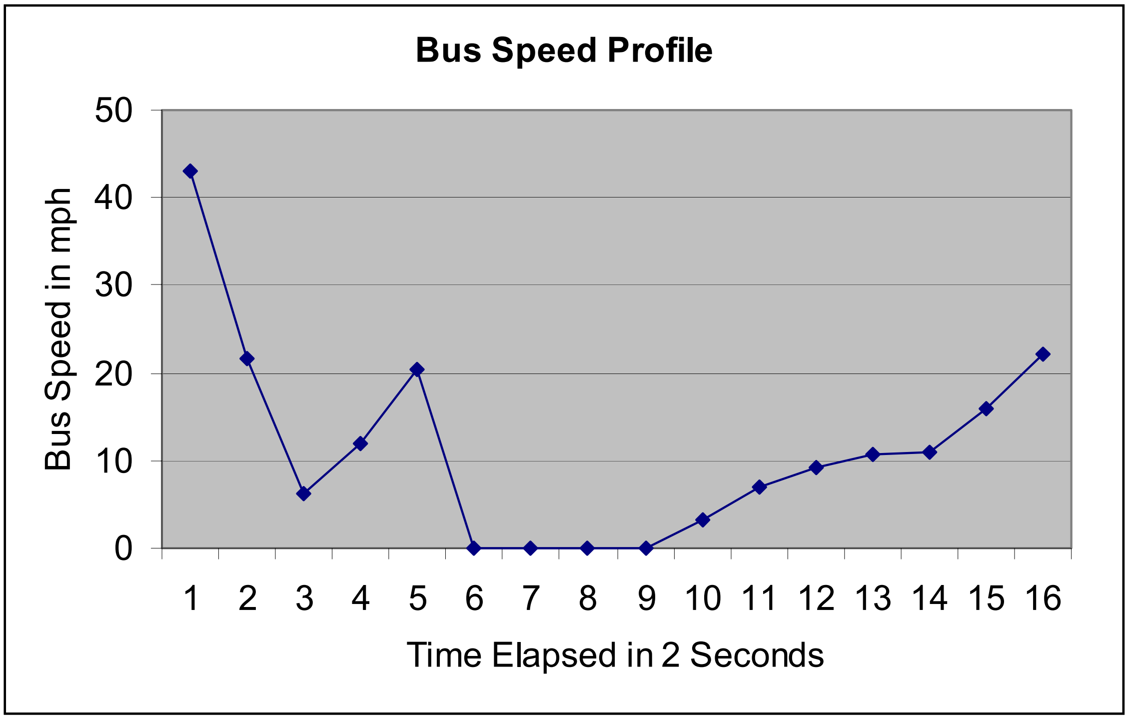


Figure 25. Bus Speed Profile at Cedar Lane and Elm Street.

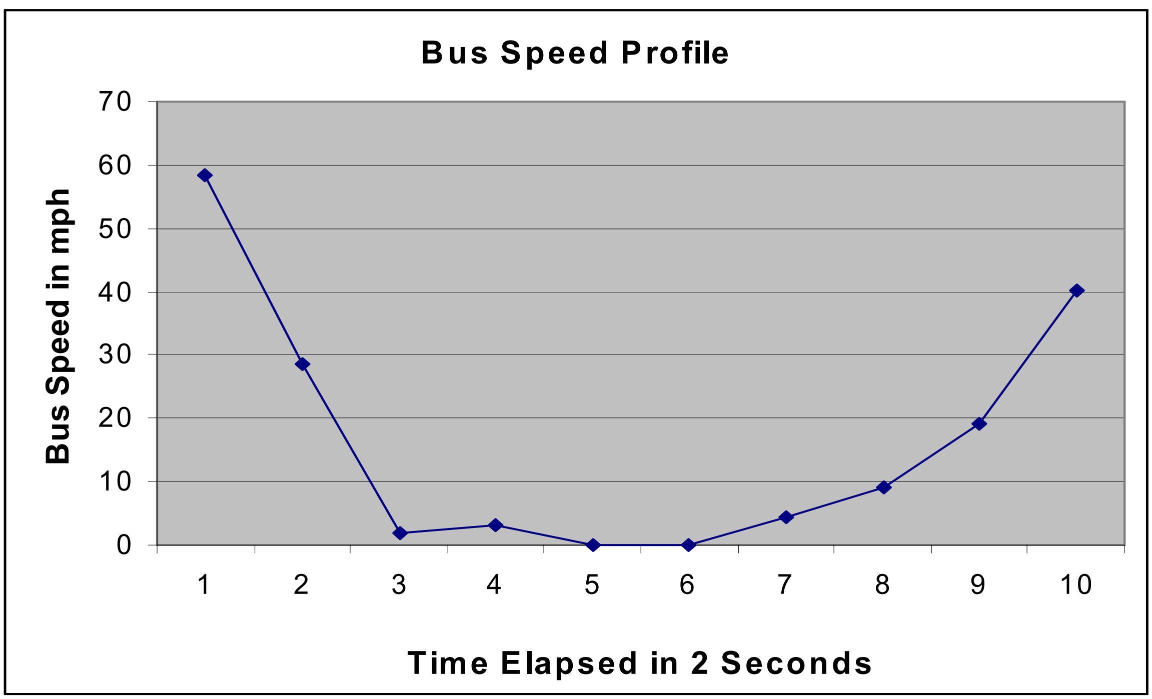


Figure 26. Bus speed Profile at Cedar Lane and Garrison Avenue.

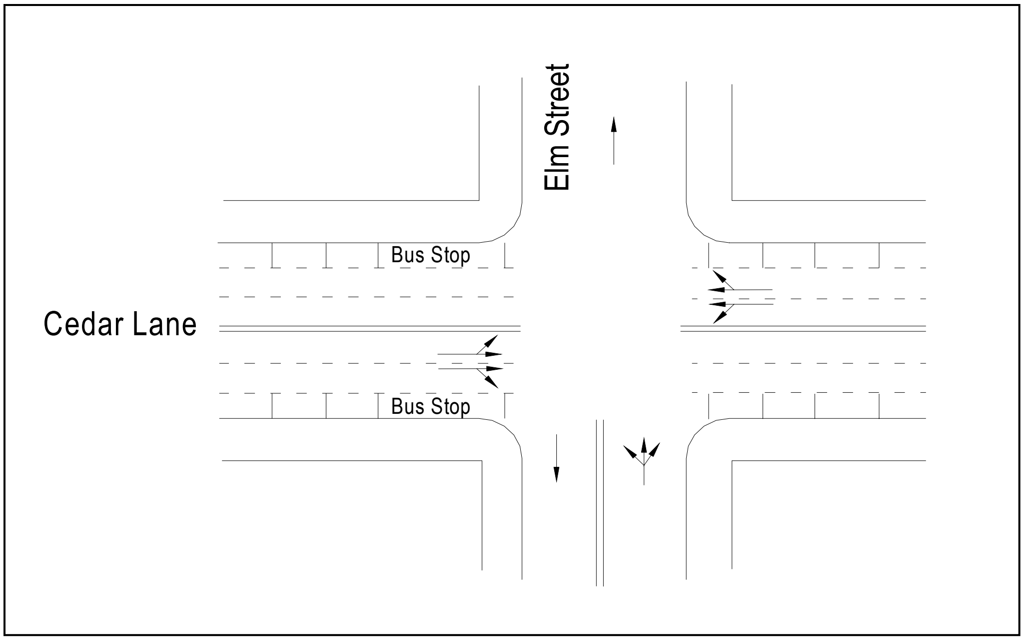


Figure 27. Geometry and Lane Configuration of Cedar Lane and Elm Street.

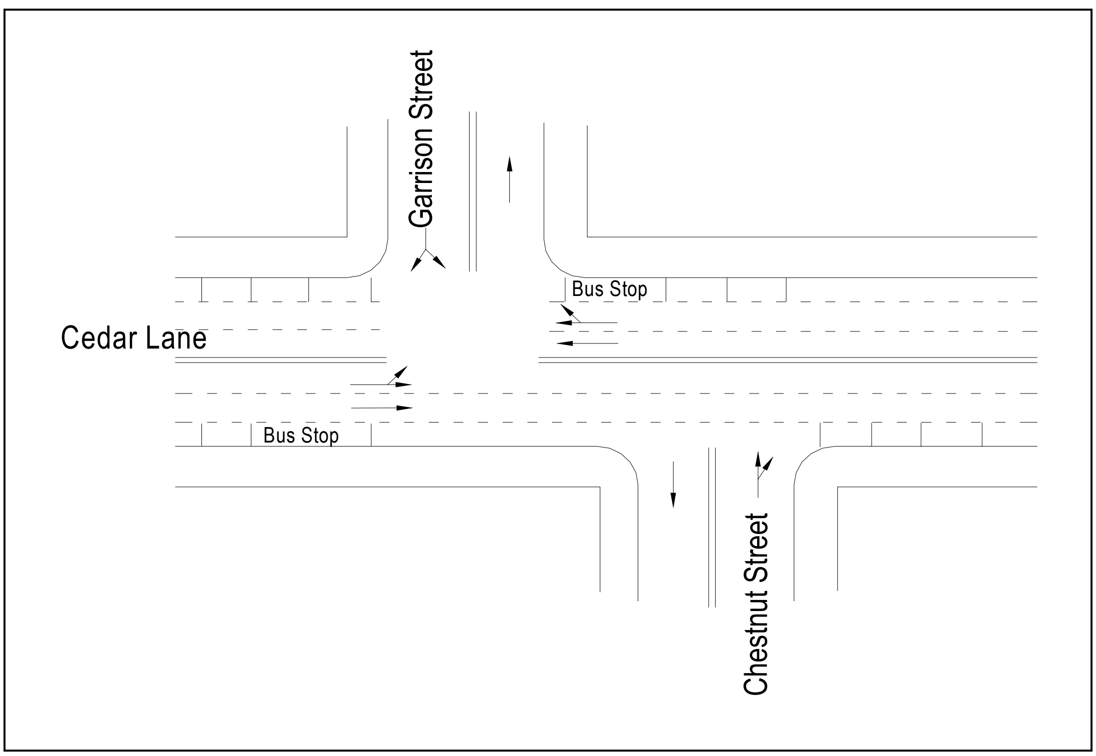


Figure 28. Geometry and Lane Configuration of Cedar Lane and Garrison Avenue.

Traffic volumes observed during afternoon peak hour are shown in Table 5. Bus volumes in the westbound and eastbound directions are eighteen buses per hour and seventeen buses per hour respectively. Pedestrian counts are provided in Table 7. The pedestrian flow rate at both intersections during peak hour was found to be at level of service A. Hence, no real congestion of pedestrians exists at the intersections. The average bus travel time along eastbound and westbound approach (measured from is Lincoln Street to Windsor Street) is 1.90 minutes for an average bus speed of 10.3 mph. During the field observations, buses were found to pull over completely into the bus stop.

Main Street, Avon-by-the-Sea

The research team collected data at the bus bulbs to be constructed on Main Street (Route 71) at Avon-by-the-Sea. Two bus bulbs are scheduled to be constructed at the intersections of Main Street and Lincoln Avenue and at the intersection of Main Street and Sylvania Avenue.

<u>Location Analysis</u>

Main Street (Route 71) Lane is located in downtown Avon-by-the-Sea, Monmouth County. The street is about three blocks from the beach and is popular for beach goers during the summer months. The busier section stretches from Jefferson Street to Norwood Lane and is served by number of bus stops. Main Street is a six-lane two-way roadway, with parking allowed on both sides. Due to parking, only two lanes are available for through traffic. The section of the Main Street from Lincoln Street to Sylvania Street is the busiest because of shops and restaurants and this location has the highest demand for on-street parking. The existing bus stops are at the near side of the intersection for both westbound and eastbound approach. The geometry and lane configurations are shown in Figure 29 and 30.

<u>Data Collection</u>

Data collection was performed during the afternoon peak period between four and six PM in both directions. The equipment layout for performing the field studies is shown in Figure 23. Numetric traffic counters were placed before Lincoln Street and Sylvania Avenue for the northbound traffic. The traffic volume count at Main Street is shown in Table 8. Bus travel times were not collected due to the fact that no buses stopped at the bus stops located within the study area. Pedestrian movements were not collected little to no pedestrians used the sidewalk location at the intersections studied.

Table 8. Traffic Volume Counts on Main Street.

Time Period	Volume Count at Main Street (Northbound)	
	Before Washington Ave.	After Sylvania Ave.
4:00 - 4:15	116	166
4:15 - 4:30	92	162
4:30 - 4:45	98	168
4:45 - 5:00	90	185
5:00 – 5:15	100	168
5:15 – 5:30	68	157
5:30 – 5:45	122	172
5:45 – 6:00	122	165

The volume count near Sylvania Avenue is much higher than volume near Lincoln Avenue as shown in Table 8. One of the reasons could be the fact that Sylvania Avenue accesses a ramp to Route 35. Route 35 is a major roadway in this area connecting several small towns located on the Shore. Pedestrian volumes during the AM and midday peak periods were not significant. This volume may increase during summer weekends when there are more beach goers. Bus frequencies in this area are also low. Field observations indicated bus headways of about one hour with no buses stopping at Lincoln or Sylvania Avenues where the data collection was being performed. The average travel time of bus from Washington Avenue to Sylvania Avenue was about 0.5 minutes for an average bus travel speed of 26 mph.

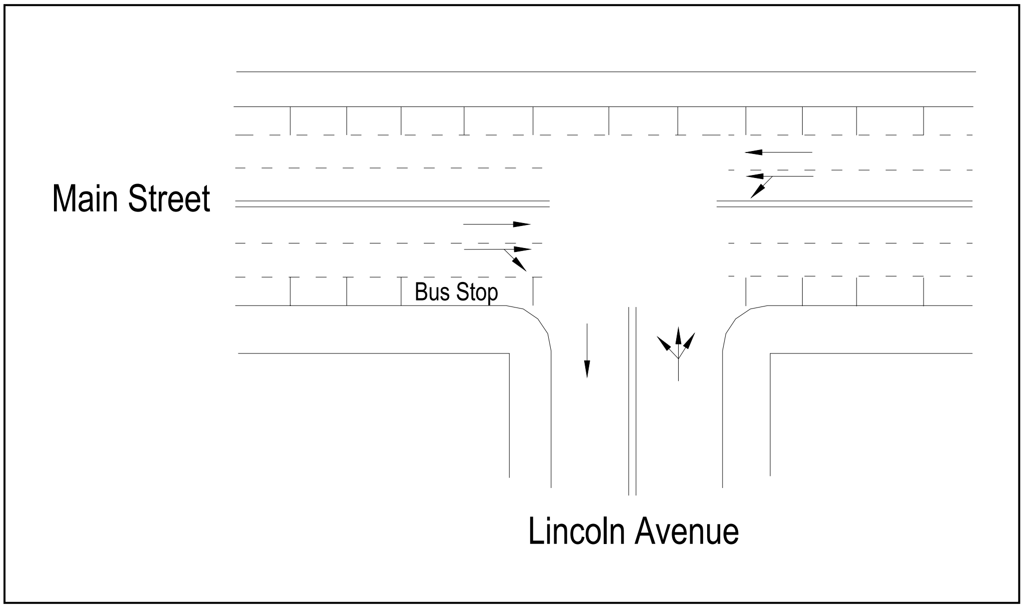


Figure 29. Geometry and Lane Configuration of Main Street and Lincoln Avenue.

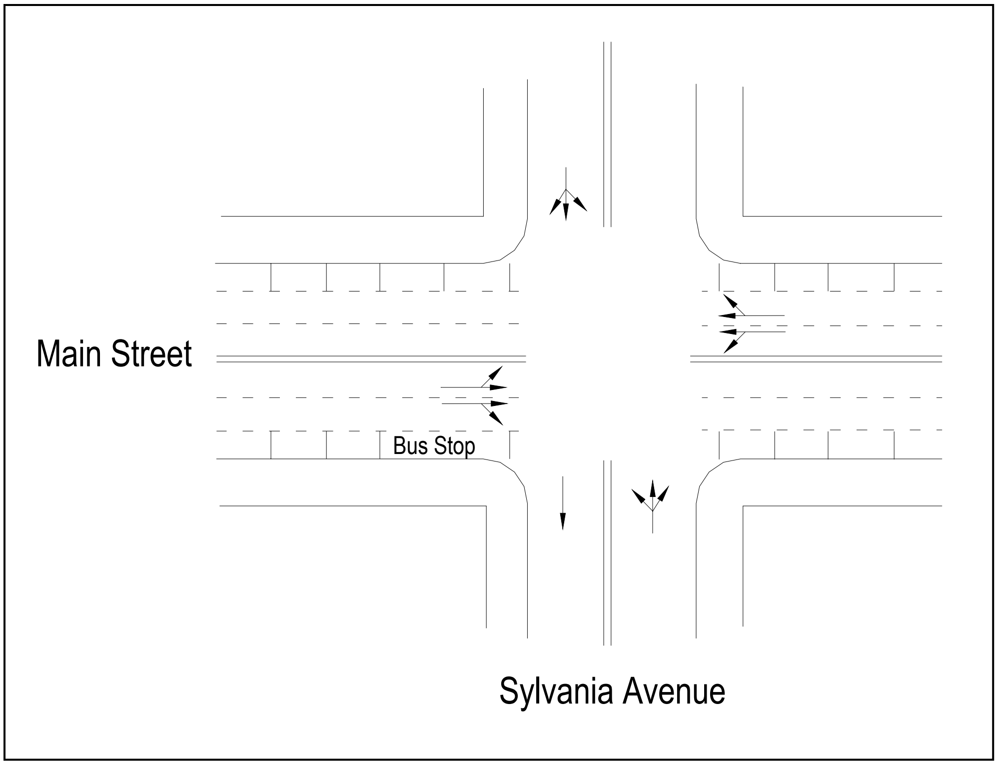


Figure 30. Geometry and Lane Configuration of Main Street and Sylvania Avenue.

Chapter VII

BUS BULB IMPACT ANALYSIS

Overview

Bus bulbs at a near-side bus-stop location can reduce the intersection's capacity by increasing the amount of time the travel lane is blocked by buses stopped in the travel lane and by eliminating the ability of right-turning vehicles from using the curb lane for right-turns. Bus bulbs also increase delays to through vehicles delayed behind the stopped bus. Although bus speed and travel time may improve as a result of not having to wait to reenter the travel lane, other vehicles on the roadway will experience some delay due to the stopped bus. To gain acceptance for installing bus bulbs, it is essential to demonstrate the impacts of bus bulbs on intersection operation and to quantify trade-offs between delays to all vehicles and savings in travel times to buses.

Based on evaluation methodology described in Chapter V and using the data collected and described in Chapter VI, further analysis of the impact of construction of bus bulbs was performed. Mainly, three parameters of traffic and bus characteristics were identified which impact the existing traffic and bus conditions due to construction of bus bulbs. These parameters include the bus travel time, bus re-entry delay, and signalized intersection control delay. The detail analysis and the results obtained from such analysis are presented in following sections.

Bus Travel Time

Bus bulbs in general reduce bus travel times as buses do not have to weave into and out of the parking lane and the re-entry delay is eliminated. For a segment of roadway approaching and departing a bus stop, the bus travel time (B_{TT}) includes the bus running time (B_{RT}), the time it takes for the bus to stop and pick up or discharge passengers (B_S), and the additional time as a result of other sources such as a traffic control device (B_C). The travel time can be expressed as:

$$\begin{aligned} B_{TTN} &= B_{RTN} + B_{SN} + B_{CN} \\ B_{TTC} &= B_{RTC} + B_{SC} + B_{CC} \end{aligned} \quad (1)$$

where:

B_{TTN} = Bus travel time for the bus bulb design (N).
B_{TTC} = Bus travel time for the curbside bus stop design (C).
B_{RTN} = Bus running time for the bus bulb design.
B_{RTC} = Bus running time for the curbside bus stop design.
B_{SN} = Bus stopping time for the bus bulb design.
B_{SC} = Bus stopping time for the curbside bus stop design.
B_{CN} = Control delay at downstream intersection with the bus bulb design.
B_{CN} = Control delay with curbside bus stop design.

Only slight differences exist between the bus running time for bus bulbs and for a curbside stop. The difference is due to the additional time required for buses to travel into and out of the curb lane with the curbside bus stop design. This additional distance is typically very small and therefore the running time for bus bulbs and for curbside bus stops is assumed to be equal in this analysis and:

$$B_{RTN} = B_{RTC} \tag{2}$$

Re-entry Delay

The time required for the bus to stop and pick up/discharge passengers includes the time to decelerate to the bus stop, the dwell time, the time to accelerate, and any re-entry delays. The following expresses this bus stop time:

$$\begin{aligned} B_{SN} &= D + L \\ B_{SC} &= D + L + d_{RD} \end{aligned} \tag{3}$$

where: D = dwell time (sec).
L = accel./decel. time for bus (sec/veh).
d_{RD} = re-entry delay (sec/veh).

The dwell time and acceleration/deceleration time is assumed to be equal for the bus bulb design and for the curbside design. The re-entry delay is present only for the curbside bus stop and estimating these delays are critical in assessing the travel time savings for buses at a bus bulb. The re-entry delay is a function of the volume and presence of queues in the adjacent lane to bus stop. The TCQSM estimates the re-entry delay as a function of the volume in the adjacent lane. The delays are based on the *Highway Capacity Manual*'s approach for estimating delay at a stop-controlled minor street right. Table 9 shows this delay, which assumes a critical gap of 7 seconds, random arrivals, and 12 buses per hour stopping at the bus stop.

The re-entry delays provided in Table 9 applies only to buses not waiting for a queue from a signal to clear before re-entering the roadway. This assumption limits the use of these re-entry delays for many near-side bus stop locations where queues extend from an upstream signal to the bus stop. When a queue is present from an upstream signal, the bus can be delayed by as much as the average vehicle delays due to the control device.

To account for these delays, the control delay from the signal at the downstream intersection could be included in the re-entry delay when a queue is present as follows:

$$d_{RD} = d_{gap} + d_{CC} \tag{4}$$

where:
d_{RD} = re-entry delay (sec/veh).
d_{gap} = gap-acceptance delay (sec/veh).
d_{CC} = control delay (sec/veh).

Table 9. Bus Re-Entry Delay.

Mixed Traffic Volume (Veh)	Average Re-Entry Delay (sec)[1]
100	0
200	1
300	2
400	3
500	4
600	5
700	7
800	9
900	11
1000	14

[1]Source: TCQSM, 1997

Table 10. Bus Gap-Acceptance Delay.

Mixed Traffic Volume (Veh)	HCM 2000 Delays (secs/veh)
100	8.9
200	9.5
300	10.3
400	11.1
500	12.2
600	13.4
700	14.8
800	16.5
900	18.5
1000	20.9

Using the assumptions of the TCQSM, the critical gap, which is the minimum time that allows intersection entry for one minor-stream vehicle, is assumed to be 7 seconds. The follow-up time, the time between the departure of one vehicle from the minor street and the departure of the next under a continuous queue condition for minor movement was taken as 3.3 seconds. The gap-acceptance delay for buses weaving out of the curbside stop was determined for a per lane roadway volume ranging from 100 to 1000 vehicles per lane and is shown in Table 10.

Control Delay

The last component of the bus travel time are delays including those from traffic control devices. The bus bulb impacts control delay in the additional time the approach lane to the intersection is blocked by the bus stopping in the travel lane and the reduction in intersection capacity due to the elimination of the curb lane for right-turn movements. Both of these impacts are accounted for in factors used in calculating the saturation flow rate at the intersection. The saturation flow rate is the maximum number of vehicles that can be discharged from the intersection lane group if the signal was always green. In calculating the saturation flow rate, bus stops are accounted for through the use of a bus blockage adjustment factor, f_{bb}. The factor accounts for buses blocking travel lanes when these buses stop within 250 feet upstream or downstream of the intersection. If the bus stops in the travel lane, the time the bus blocks the right-most lane, is determined as:

$$T_{LB} = \left(\frac{g}{C}\right)(D + L) \qquad (5)$$

where:

T_{LB}	=	time lost per bus, sec/bus.
D	=	dwell time per bus, sec.
L	=	accel/decel time per bus, usually 2-3 sec/bus.
g	=	effective green time for the lane group, sec.
C	=	cycle length, sec.

The bus blockage factor is then calculated as:

$$f_{bb} = \frac{1}{1 + P_{LB}(E_{LB} - 1)} \qquad E_{LB} = \frac{T_{LB}}{1.89} \qquad (6)$$

where:

E_{LB}	=	passenger car equivalent of one local bus;
P_{LB}	=	proportion of total lane group consisting of local buses, in decimal form (N_B/v).
v	=	adjusted flow rate for the lane group (veh/hr).

In addition to the impact of the bus blocking the travel lane, the bus bulb also impacts right-turning movements. At curbside bus stops located at the nearside of the intersection, right-turning vehicles may use this curbside lane when a bus is not present. For bus bulbs, the right travel lane operates as a shared lane, used by both right-turning and through movements, and the right-turn adjustment factor is calculated as follows:

$$f_{RT} = 1.0 - (0.15)P_{RT} \qquad (7)$$

where: P_{RT} = proportion of right-turns in the lane group.

Treating the curb lane at a curbside bus stop as an exclusive right-turn lane may overestimate the capacity at some approaches where a right and through movement cannot be made simultaneously. At these locations, the impact of the bus bulb can be accounted for through the use of the lane width adjustment factor. In this condition, for curbside bus stops, the right travel lane width includes the width of the adjacent parking lane. For bus bulbs, this lane width is reduced by the width of the parking lane. The lane width adjustment factor in the *Highway Capacity Manual* is calculated as:

$$f_w = 1 + \frac{(w - 12)}{30} \quad (8)$$

where:

fw	=	lane width adjustment factor.
w	=	lane width (feet).

The maximum value that can be used for the lane width, w, is 16 feet. Lane widths greater than 16 feet should be treated as two lanes.

A comparison of control delay with a curbside stop to the delay with a bus bulb was determined for a two-lane intersection approach with volumes ranging from 100 to 1000 vehicles per hour per lane (vphpl). Figure 31 shows the delays with and without the bus bulb. The figure demonstrates that for volumes below 500 vphpl, there is little difference between the delays at the intersection for a bus bulb condition or a curbside bus stop. After this volume, there are higher delays at intersections with bus bulbs when compared to curbside bus stops.

A second comparison was also performed of bus delays with a bus bulb and a curbside bus stop. For the bus bulb, the bus delays include just the delays at the signalized intersection. For the curbside bus stop, the bus delays include the re-entry delay and the delays at the signalized intersection. Figure 32 shows the bus delays with and without the bus bulb. The figure shows that for volume conditions lower than 500 vphpl, the bus delays are lower for bus bulbs. After this volume, the bus delays are significantly greater for bus bulbs. Both figures demonstrate that bus bulbs may be best suited for locations with volumes less than 500 vphpl. At very low volumes, however, the bus travel time savings may also not be sufficient to warrant the inclusion of a bus bulb.

Bus Travel Time Savings

Using the expressions developed for estimating the bus travel time, the difference between the bus travel time with a curbside bus stop design and the bus travel time with a bus bulb, or the travel time savings expected with the bus bulb design, can be determined as follows:

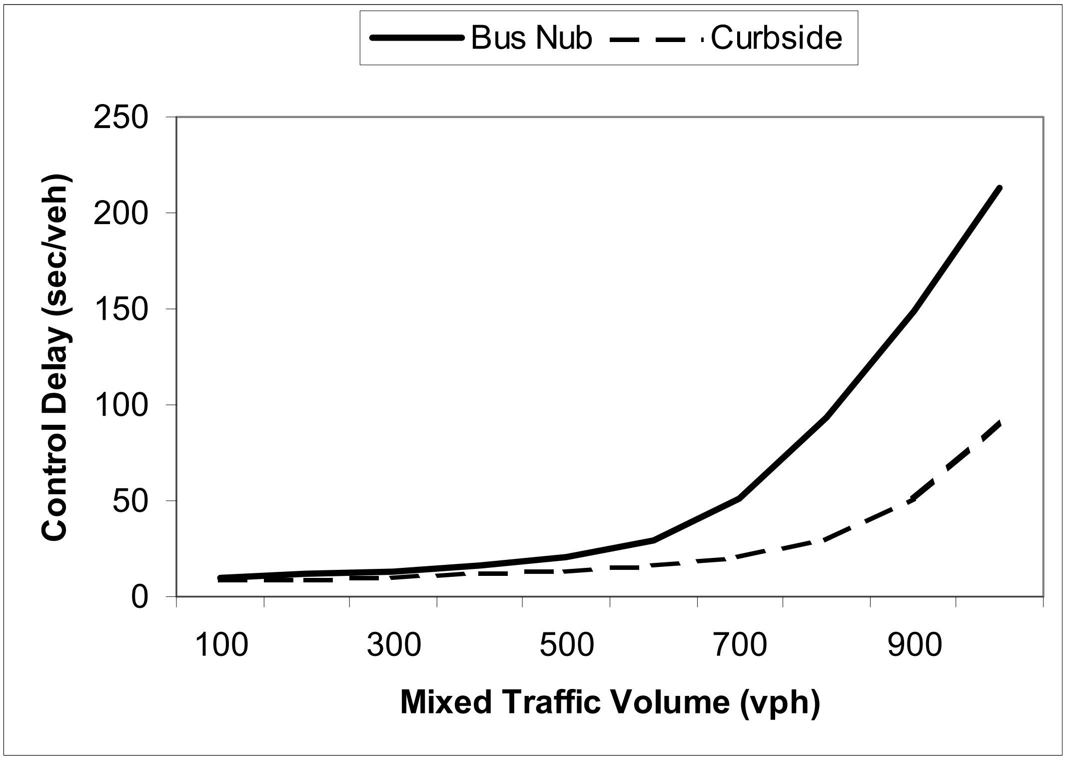


Figure 31. Intersection Control for Bus Bulb and Curbside Bus Stop.

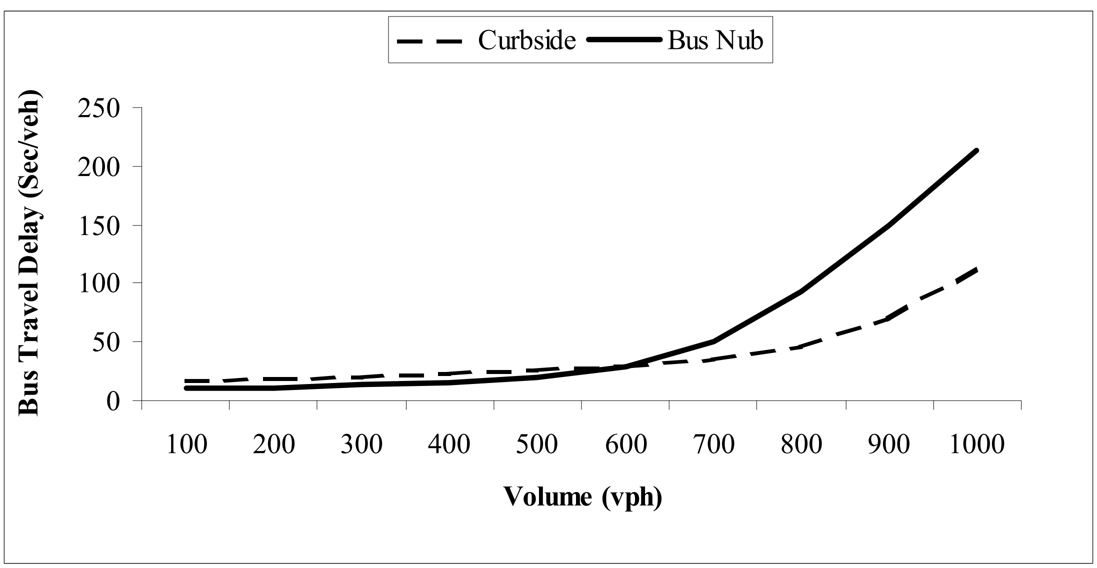


Figure 32. Bus Delays for Bus bulbs and Curbside Stops.

$$
\begin{aligned}
&\text{Bus Travel Time Savings} = B_{TTC} - B_{TTN} \\
&= B_{RTC} + B_{SC} + B_{CC} - (B_{RTN} + B_{SN} + B_{CN}) \\
&= D + L + d_{RD} + d_{CC} - (D + L + d_{CN}) \\
&= d_{CC} + d_{RD} - d_{CN} \\
&= d_{RD} - (d_{CN} - d_{CC})
\end{aligned} \tag{9}
$$

The above equations show that the expected bus travel time savings from a bus bulb is the re-entry delay minus the increase in intersection delay after the bus bulb is constructed. The expression demonstrates the trade-offs between reduced bus travel time savings and increases in intersection delays that must be considered to determine whether a bus bulb is appropriate for a particular location.

Results

Table 11 shows the operational analysis for the intersection approach with and without the bus bulb. Overall, these approaches perform at good levels of service with minimal delays. The analysis shows that installing a bus bulb would result in the reduction in the approach capacity between 8 and 11 percent and an increase in control delay from between 7 and 16 percent. Table 12 also shows the bus travel time savings for each of the bus stops analyzed. Bus travel time savings as a result of the bus bulbs ranges between 15 and 30 seconds per bus stop. The bus travel time savings are reported per bus stop and suggests that for significant bus travel time savings to be achieved for the route, several bus bulbs would be warranted.

Table 11. Operational Analysis of Bus Stop Approaches With and Without Bus Bulb.

Lane Group	Capacity (vph)	Adj. Saturation Flow Rate (vph)	v/c	g/C	Delay (sec/veh)	LOS
CS Ferry Street EB	712	1356	0.69	0.525	19.60	B
BN Ferry Street EB	646	1230	0.76	0.525	23.32	C
CS Ferry Street WB	728	1386	0.60	0.525	16.79	B
BN Ferry Street WB	648	1233	0.67	0.525	19.48	B
CS Bloomfield Ave	1998	2994	0.44	0.67	5.42	A
BN Bloomfield Ave	1833	2750	0.48	0.67	5.79	A
CS Cedar Lane-Elm EB	2222	3333	0.42	0.67	5.20	A
BN Cedar Lane-Elm EB	2018	3027	0.46	0.67	5.56	A
CS Cedar Lane-Elm WB	2206	3309	0.35	0.67	4.79	A
BN Cedar Lane-Elm WB	1956	2934	0.40	0.67	5.13	A
CS Cedar Lane-Garrison EB	1591	3330	0.56	0.48	18.13	B
BN Cedar Lane-Garrison EB	1494	3128	0.60	0.48	18.86	B
CS Cedar Lane-Garrison WB	1284	3303	0.56	0.39	23.32	C
BN Cedar Lane-Garrison WB	1213	3121	0.60	0.39	24.05	C

CS - Curbside Bus Stop
BN - Bus Bulb

Table 12. Bus Travel Time Savings.

Location	Re-Entry Delay (sec/veh)	Δ dc (sec/veh)	Bus TT Savings (sec)
Ferry Street EB	27.67	7.74	19.93
Ferry Street WB	28.30	2.69	25.61
Bloomfield Ave	16.97	0.37	16.60
Cedar Lane-Elm EB	17.04	0.37	16.67
Cedar Lane-Elm WB	15.87	0.34	15.53
Cedar Lane-Garrison EB	29.75	0.73	29.02
Cedar Lane-Garrison WB	34.160	0.73	33.43

Chapter VIII

MEASUREMENT OF RE-ENTRY DELAYS

Overview

The TCQSM's estimate of the re-entry delay is a function solely of the volume in the adjacent lane. The re-entry delay, though, is a function of additional parameters including: the bus stop geometry that may require the bus driver to make complex maneuvering into or out of the bus stop zone; the presence of illegal parking in the bus stop zone; low passenger volumes boarding or exiting at the stop; whether the bus is on-time or behind schedule; and whether there is another bus in the bus zone. In an attempt to measure the bus re-entry delay and to better understand the relationship of the factors that impact the bus re-entry delay, field visits were made to bus stops in New Jersey.

Study Locations

The locations studied included Central Avenue, adjacent to New Jersey Institute of Technology (NJIT), and at locations identified by NJ Transit field supervisors as locations where buses have problems re-entering the traffic stream. The location adjacent to NJIT was selected because it allowed the use of video cameras to capture several factors related to re-entry delays. Table 13 shows the locations identified by NJ Transit as locations where buses experience re-entry delays. All of the locations visited were in Jersey City which is known for areas of high vehicular volume and bus patronage. Locations in Paterson, Teterboro and Rutherford were not visited based on prior knowledge of these areas as not appropriate for collecting re-entry delays. The following describes each of the locations studied and the observations made from field visits.

Central Avenue Location

Re-entry delays were measured at two mid-block bus stops on Central Avenue, between the intersections of Central Avenue and MLK Boulevard and Central Avenue and Lock Street. Both bus stops are mid-block stops. Central Avenue is an urban principal arterial with two lanes in each direction and parking allowed on both sides of the roadway. As previously mentioned, the bus stops are located adjacent to NJIT and within a commercial district. The stop serves the NJIT campus as well as nearby residences and Rutgers University.

Field observations showed that buses generally pulled into the curb when picking up or discharging passengers. On some occasions, however, parked cars encroached into the bus zone forcing bus drivers to stop in the travel lane.

Table 13. Bus Stops Identified as Trouble Spots.

City	Location	Route Number
Jersey City	Westside and Communipaw Ave.	80
Jersey City	595 Newark Ave.	80, 84
Jersey City	Sip & Corbin Aves.	1
Jersey City	Palisades & Newark Aves	86
Jersey City	Bergen and Montgomery Ave.	80, 87
Paterson	Broadway & Washington	161
Paterson	Market St. Across from City Hall	161
Teterboro	Teterboro Airport & Fred Wehran Dr.	161
Rutherford	Route 3 East & Grove St	191

Westside Avenue and Communipaw Avenue

The intersection of Westside Avenue at Communipaw Avenue is located in Jersey City. Figure 33 shows a diagram of the intersection with the adjacent bus stop. Westside Avenue is a two-way roadway with two lanes in each direction and a parking lane. The bus stop is located in a commercial district with several stores located adjacent to the intersection. Westside Avenue and Communipaw Avenue are quite congested during the evening peak period, with a high bus patronage using Route 80 which serves this location.

Field visits indicated that northbound buses on Westside Avenue pull over to the curb to serve bus passengers. One possible reason for buses pulling into the curb may be because the bus stop is located on the farside of the intersection and has sufficient room for the bus driver to weave into and out of the travel lane. During the evening peak period, buses arriving at the same time often bunch together at the bus stop causing buses to stop in the travel lane. When buses do not pull into the curb at this location, vehicles are forced to wait behind the bus and can queue into the intersection. This creates congestion in the bus stop zone and queuing in the intersection upstream of the bus stop. The adjacent business activities also result in passenger vehicles encroaching in the bus stop and contributing to the bus not pulling into the bus zone.

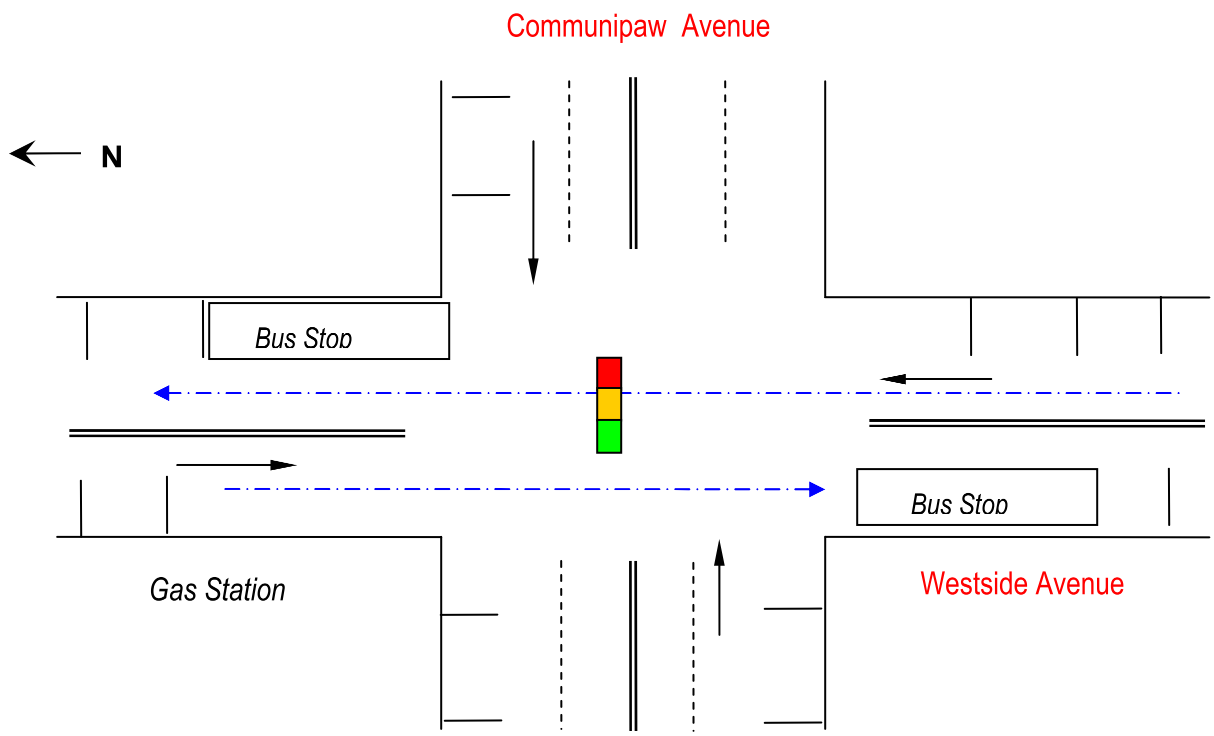


Figure 33. Westside Avenue and Communipaw Avenue.

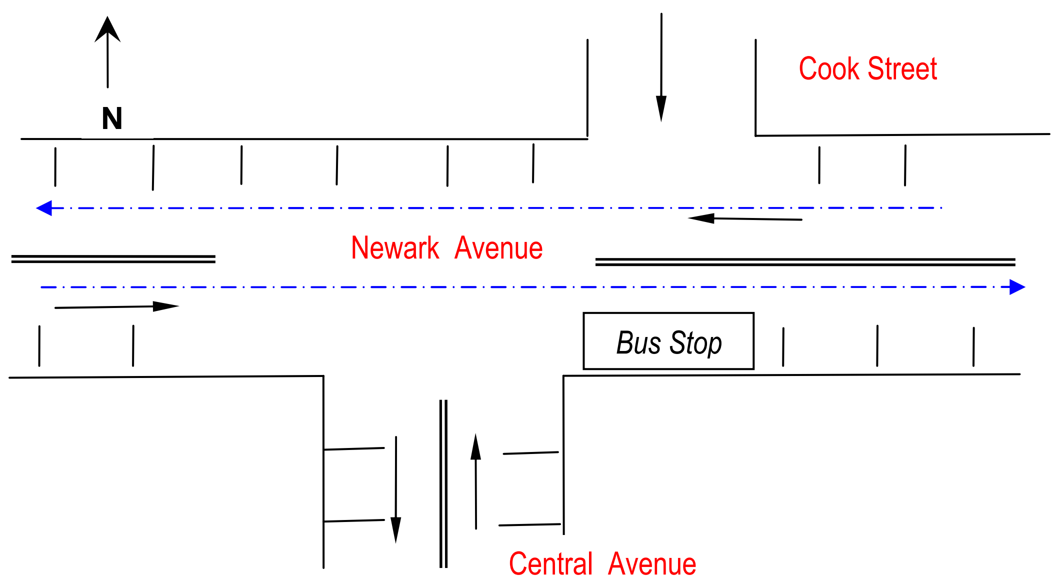


Figure 34. Newark Avenue and Central Avenue.

Newark Avenue and Central Avenue

The intersection of Newark and Central Avenue is located in Jersey City. The bus stop serving eastbound buses was studied to determine whether re-entry delays existed at this location. As shown in Figure 34, the bus stop is a farside bus stop. The intersection of Central and Newark Avenue is unsignalized with two lanes in each direction on Newark Avenue and parking allowed on both sides of the roadway. Newark Avenue is a narrow roadway with a pavement width of 30 feet. The bus stop is located adjacent to the Jersey City Court House and, as a result, the area is very congested during business hours.

Field visits made to the site indicated that most buses stopping at this location do not pull into the curb. When the bus stops in the travel lane, or partially pulls into the curb, vehicles behind the bus cannot pass resulting in severely congested conditions. Passenger vehicles were also seen to occupy the bus zone at many times.

Sip and Corbin Avenue

The intersection of Sip Avenue and Corbin Avenue, as shown in Figure 35, is located in Jersey City. The nearside bus stop servicing buses on the westbound approach of Sip Avenue was studied for measuring re-entry delays. Sip Avenue is a major arterial that is two-way with one travel lane and one parking lane in each direction. The bus stop is located in a residential area. Corbin Avenue is a minor roadway providing access to the residences in the area.

Field visits showed that buses pull into the curb to serve bus patrons. After pulling into the curb and picking up/discharging passengers, the bus is then forced to pull into the left lane to make a left-turn on to Westside Avenue. The short distance between the bus stop and the left-turn bay, makes this a difficult maneuver. The weaving maneuver out of the bus stop results in re-entry delays that differs from the delays under study. For this reason, this location was not considered for measuring re-entry delays.

Palisades Avenue and Newark Avenue

The intersection of Palisades Avenue and Newark Avenue is a T-intersection located in Jersey City. The bus stop under study, as shown in Figure 36, is a nearside bus stop located on the southbound approach of Palisades Avenue. Palisades has two travel lanes in both directions with no curbside parking allowed. The southbound direction of Palisades at the location of the bus stop has a slight downgrade. Field visits showed that buses make a right turn on to Newark Avenue after picking up and discharging passengers at the bus stop. For this reason buses do not have a re-entry problem and this location is not suitable for data collection.

Bergen Avenue and Montgomery Avenue

Bergen Avenue and Montgomery Avenue is located in Jersey City. The bus stop under study, as shown in Figure 37, is located southbound on Bergen Avenue mid-block between the intersections of Bergen and Montgomery and Bergen and Glenwood. On-street parking is allowed at this location. Field visits showed that parked vehicles occupied the bus zone on many occasions. For this reason, buses do not pull into the curb on most occasions. This location is not suitable for collecting bus re-entry delays.

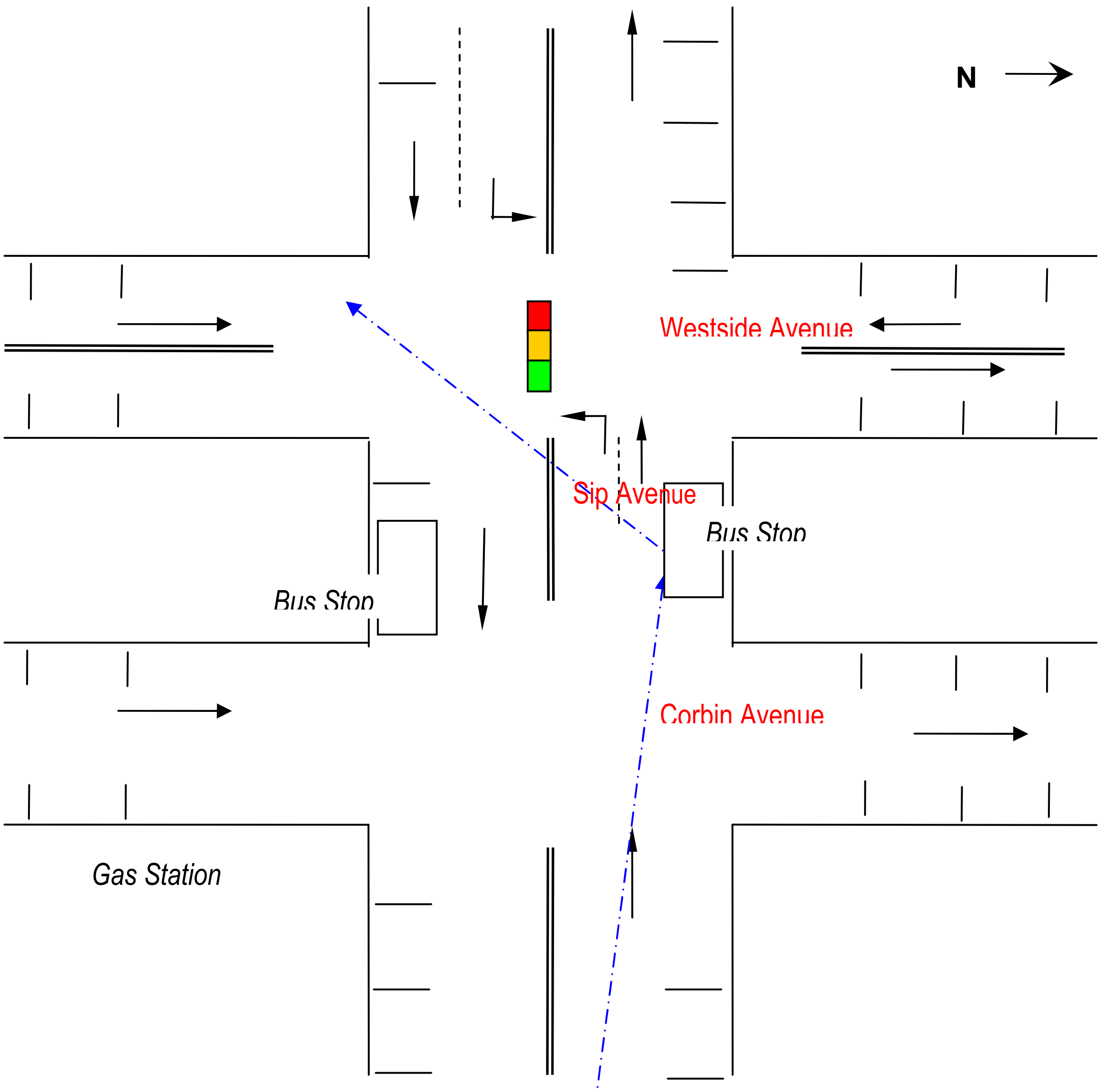


Figure 35. Sip Avenue and Corbin Avenue.

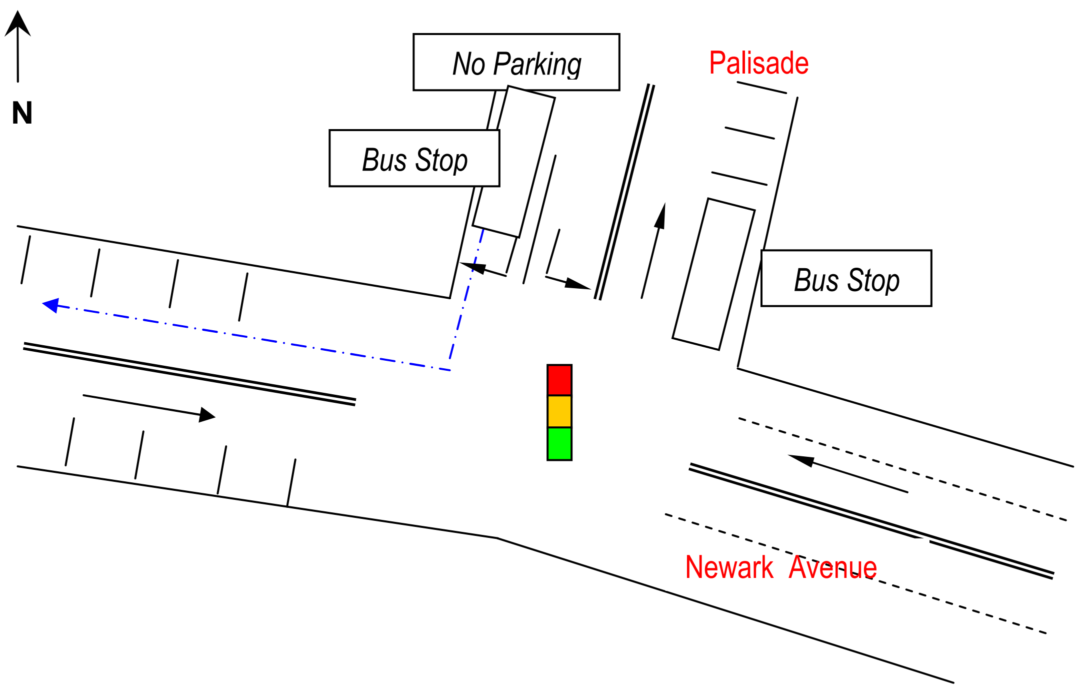


Figure 36. Palisades Avenue and Newark Avenue.

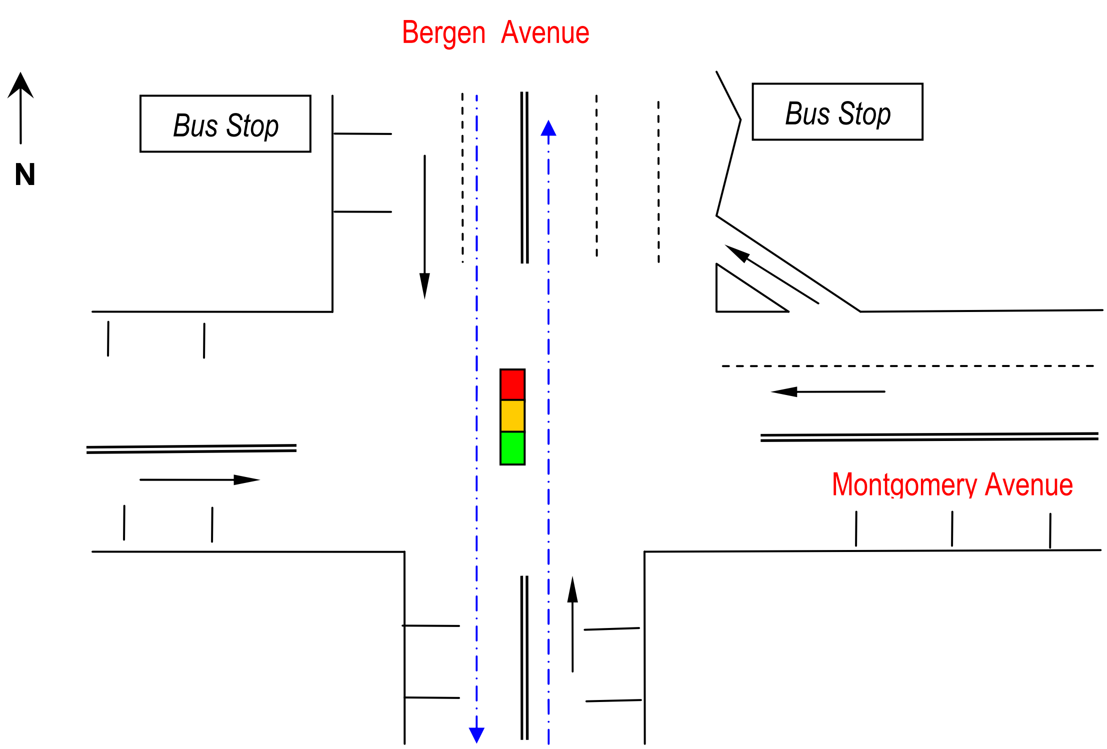


Figure 37. Bergen Avenue and Montgomery Avenue.

Table 14. Study Locations for Measuring Re-Entry Delays.

Main Street	Cross St	Bus Stop Location	Through Lanes	Dir.	Time Periods
Bloomfield Ave	Park Street	Near-side	2	EB	4-6 PM
Ferry St	Van Buren St	Near-Side	1	EB	4-6 PM
Central Ave	MLK/Lock	Mid-block	1	EB	8-9 AM,4-6 PM
Central Ave	MLK/Lock	Mid-block	1	WB	8-9 AM,4-6 PM
Westside Ave	Communipaw	Far-Side	1	SB	4-6 PM
Bloomfield Ave	Park St	Near-side	2	EB	4-6 PM
Cedar Lane	Garrison St	Near-Side	2	EB	4-6 PM
Cedar Lane	Garrison St	Near-Side	2	WB	4-6 PM
Cedar Lane	Elm St	Near-Side	2	EB	4-6 PM
Cedar Lane	Elm St	Far-side	2	WB	4-6 PM

Data Collection

Based on the observations of the initial field studies, re-entry delays were measured at the locations shown in Table 14 using both video cameras and stopwatches. Data were also collected at the three locations at Bloomfield and Park, Ferry Street and Van Buren and Cedar Lane and Elm where the bus travel time savings were estimated. The data collected included bus arrival and departure times, volume in adjacent lane(s), and the number of queued vehicles behind the stopped bus. Re-entry delays were determined using two approaches. In the first approach, the re-entry delay was taken as the time when the bus closed its doors to the time when the vehicle entered into the travel lane. In a second approach the re-entry delay was measured as the time from the time the door closed to the time that the bus re-entered. In the second approach the dwell time was not measured. Field measurements were performed during peak as well as off peak hours for different lane configurations and bus stop types.

Field observations identified four cases to describe conditions when a bus stops at a curbside bus stop. These conditions are shown in Figure 38. In the first case, the bus completely pulls into the curb area and vehicles in the travel lane are not impacted by the stopped bus. This case is referred to as Case A. Under this case, re-entry delays are possible and a function of the volume in the adjacent lane during the time that the bus is stopped. In Case B the bus partially pulls into the curb lane, allowing vehicles behind the bus to pass. Field observations showed that under this case vehicles pass the stopped bus using the adjacent travel lane. In Case C the bus stops in the travel lane partially blocking the lane. Under this condition, vehicles either wait behind the bus, or attempt to go around the stopped bus. Finally, in Case D, the bus fully blocks the travel lane and vehicles must wait behind the stopped bus and do not attempt to go around the bus. Under this case, there are no re-entry delays.

Tables 15 through 18 shows the re-entry delays collected using a video camera at the Central Avenue locations. Additional data gathered include the dwell time and number of vehicles passing the stopped bus. The number of vehicles passing the stopped bus is adjusted to an hourly flow rate. Tables 19 through 22 shows the re-entry delays collected at other locations.

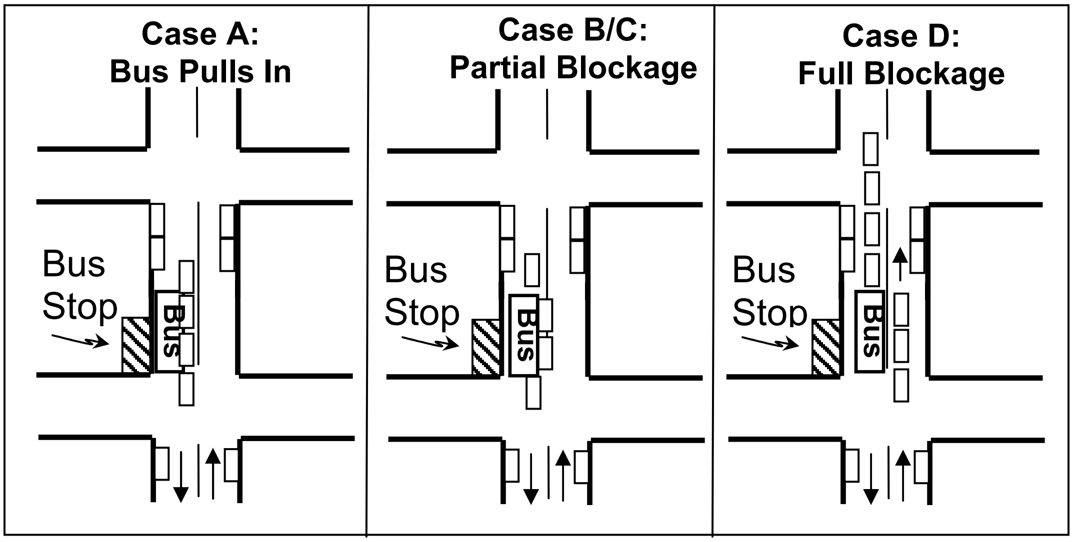


Figure 38. Re-Entry Delay Measurement Cases

Table 15. Re-Entry Delays For Case A (Bus Pulls in).

Arrival Time	Time Door Closed	Departure Time	No. of Passing Vehicles	Direction	Dwell Time (sec)	Re-entry Delay (sec)	Passby Flow Rate (vph)
4:48:52 PM	4:49:05 PM	4:49:05 PM	3	WB	12	0	900
4:09:51 PM	4:10:01 PM	4:10:01 PM	0	WB	10	0	0
4:27:14 PM	4:27:32 PM	4:27:59 PM	14	WB	45	27	1120
4:27:43 PM	4:28:01 PM	4:28:01 PM	5	WB	18	0	1000
4:59:09 PM	4:59:20 PM	4:59:20 PM	2	WB	11	0	655
5:27:57 PM	5:28:14 PM	5:28:16 PM	1	WB	19	2	189
5:29:38 PM	5:29:51 PM	5:29:51 PM	1	WB	13	0	277
5:31:15 PM	5:31:30 PM	5:31:30 PM	3	WB	15	0	720
5:37:15 PM	5:37:25 PM	5:37:28 PM	3	WB	13	3	831
8:36:47 AM	8:36:58 AM	8:36:58 AM	3	WB	11	0	982
8:51:37 AM	8:51:45 AM	8:51:47 AM	1	WB	10	2	360
8:57:09 AM	8:57:29 AM	8:57:29 AM	0	WB	20	0	0

Table 16. Re-Entry Delays for Case B (Partial Pull-In).

Arrival Time	Time Door Closed	Departure Time	No. of Passing Vehicles	Direction	Dwell Time (sec)	Re-entry Delay (sec)	Passby Flow Rate (vph)
4:37:38 PM	4:37:45 PM	4:37:52 PM	2	WB	14	7	514
4:37:41 PM	4:37:52 PM	4:37:52 PM	2	WB	11	0	655
4:39:13 PM	4:39:20 PM	4:39:22 PM	3	WB	9	2	1200
4:45:12 PM	4:45:26 PM	4:45:26 PM	4	WB	14	0	1029
4:51:40 PM	4:51:50 PM	4:51:51 PM	1	WB	11	1	327
4:54:34 PM	4:54:42 PM	4:54:43 PM	4	WB	9	1	1600
5:43:44 PM	5:44:01 PM	5:44:01 PM	5	WB	17	0	1059
4:10:08 PM	4:10:22 PM	4:10:25 PM	2	EB	17	3	424
4:12:47 PM	4:12:53 PM	4:12:53 PM	0	EB	6	0	0
4:49:34 PM	4:50:09 PM	4:50:11 PM	3	EB	37	2	292
5:05:25 PM	5:05:43 PM	5:05:56 PM	5	EB	31	13	581
5:17:32 PM	5:17:47 PM	5:17:47 PM	0	EB	15	0	0
5:18:02 PM	5:18:15 PM	5:18:15 PM	4	EB	13	0	1108
5:37:32 PM	5:37:56 PM	5:37:56 PM	1	EB	24	0	150
9:15:20 AM	9:15:31 AM	9:15:31 AM	0	WB	11	0	0
9:19:57 AM	9:20:07 AM	9:20:07 AM	2	WB	10	0	720
9:28:38 AM	9:28:48 AM	9:28:48 AM	0	WB	10	0	0
8:34:27 AM	8:35:05 AM	8:35:05 AM	3	EB	38	0	284
9:02:39 AM	9:03:01 AM	9:03:01 AM	4	EB	22	0	655
9:15:28 AM	9:16:02 AM	9:16:02 AM	3	EB	34	0	318
9:25:54 AM	9:26:22 AM	9:26:22 AM	0	EB	28	0	0

Table 17. Re-Entry Delays for Case C (Partial Blockage).

Arrival Time	Time Door Closed	Departure Time	No. of Passing Vehicles	Direction	Dwell Time (sec)	Re-entry Delay (sec)	Passby Flow Rate (vph)
3:51:12 PM	3:51:28 PM	3:51:30 PM	5	WB	18	2	1000
5:07:46 PM	5:08:12 PM	5:08:12 PM	4	WB	26	0	554
3:49:41 PM	3:49:50 PM	3:49:50 PM	7	EB	9	0	2800
3:50:18 PM	3:50:35 PM	3:50:45 PM	11	EB	27	10	1467
4:11:20 PM	4:12:10 PM	4:12:10 PM	2	EB	50	0	144
4:24:50 PM	4:25:01 PM	4:25:01 PM	2	EB	11	0	655
5:49:31 PM	5:49:53 PM	5:49:53 PM	0	EB	22	0	0
5:27:49 PM	5:28:03 PM	5:28:03 PM	2	EB	14	0	514
5:41:21 PM	5:41:58 PM	5:41:58 PM	9	EB	37	0	876
8:37:58 AM	8:38:13 AM	8:38:13 AM	0	EB	15	0	0
8:49:45 AM	8:49:56 AM	8:49:56 AM	0	EB	11	0	0
8:50:52 AM	8:51:21 AM	8:51:21 AM	11	EB	29	0	1366
9:07:14 AM	9:07:26 AM	9:07:32 AM	5	EB	18	6	1000
9:14:51 AM	9:15:00 AM	9:15:02 AM	2	EB	11	2	655

Table 18. Re-Entry Delays for Case D (Full Blockage).

Arrival Time	Time Door Closed	Departure Time	No. of Passing Vehicles	Direction	Dwell Time (sec)	Re-entry Delay (sec)	Passby Flow Rate (vph)
3:55:55 PM	3:56:00 PM	3:56:00 PM	0	WB	5	0	0
4:09:55 PM	4:10:12 PM	4:10:12 PM	0	WB	17	0	0
4:53:52 PM	4:54:07 PM	4:54:07 PM	0	WB	15	0	0
5:29:56 PM	5:30:15 PM	5:30:15 PM	0	WB	19	0	0
4:52:04 PM	4:52:12 PM	4:52:12 PM	0	EB	8	0	0
9:10:41 AM	9:10:53 AM	9:10:53 AM	0	WB	12	0	0
9:05:36 AM	9:05:46 AM	9:05:46 AM	0	EB	10	0	0

Table 19. Re-Entry Delays Measured at Bloomfield Ave and Park Street.

Re-entry Delay (secs)	Passing Vehs Lane1	Lane 2	Direction	Case	Passby Flow Rate (vph)
12.06	0	0	*EB*	B	0
8.31	0	5	*EB*	D	2166
12.19	0	0	*EB*	D	0
6.88	0	1	*EB*	B	523
7.46	0	3	*EB*	D	1448
13.57	1	4	*EB*	A	1326
12.67	1	3	*EB*	A	1137
7.69	1	1	*EB*	A	936
7.38	0	2	*EB*	D	976
6.83	1	0	*EB*	B	527
7.94	0	2	*EB*	D	907
13.62	0	2	EB	D	529

Table 20. Re-Entry Delays Measured at Cedar lane and Elm Street.

Re-entry Delay (secs)	Passing Vehs Lane1	Lane 2	Direction	Case	Passby Flow Rate (vph)
5.34	0	0	*WB*	A	0
9.41	2	3	*WB*	A	1913
5.41	0	2	*WB*	A	1331
5.65	0	0	*EB*	B	0
6.84	0	0	*WB*	A	0
7.23	0	1	*EB*	A	498
15.56	1	5	*WB*	A	1388
9.31	3	5	*WB*	A	3093
5.51	0	2	*WB*	A	1307
4.75	0	3	*WB*	D	2274
5.66	0	0	*WB*	A	0
4.22	0	2	EB	A	1706
5.01	0	2	EB	B	1437
5.98	2	3	WB	A	3010
6.34	1	4	WB	A	2839
5.72	2	4	WB	A	3776

Table 21. Re-Entry Delays Measured at Cedar lane and Garrison Street.

Re-entry Delay (secs)	Passing Vehs Lane1	Lane 2	Direction	Case	Passby Flow Rate (vph)
0	0	4	*EB*	D	0
0	0	3	*WB*	D	0
0	0	2	*WB*	D	0
7.34	1	4	*WB*	B	2452
0	0	3	*WB*	D	0
0	0	4	*EB*	D	0
7.62	1	3	*WB*	A	1890
8.33	1	3	*WB*	B	1729
0	0	5	*EB*	D	0

Table 22. Re-Entry Delays Measured at Westside and Communipaw Avenue.

Re-entry Delay (secs)	Passing Vehs Lane1	Lane 2	Direction	Case	Passby Flow Rate (vph)
0	0		SB	*D*	0
0	0		SB	*D*	0
0	0		SB	*D*	0
0	0		SB	*D*	0
0	0		SB	*D*	0
0	0		SB	*D*	0
3.66	2		SB	*A*	1967
3.15	1		SB	*A*	1143
4.8	1		SB	*A*	750
0	0		SB	*D*	0
0	0		SB	*D*	0
0	0		SB	*D*	0
0	0		SB	*D*	0
0	0		SB	*D*	0
0	0		SB	*D*	0
4.21	1		SB	*A*	855
0	0		SB	D	0

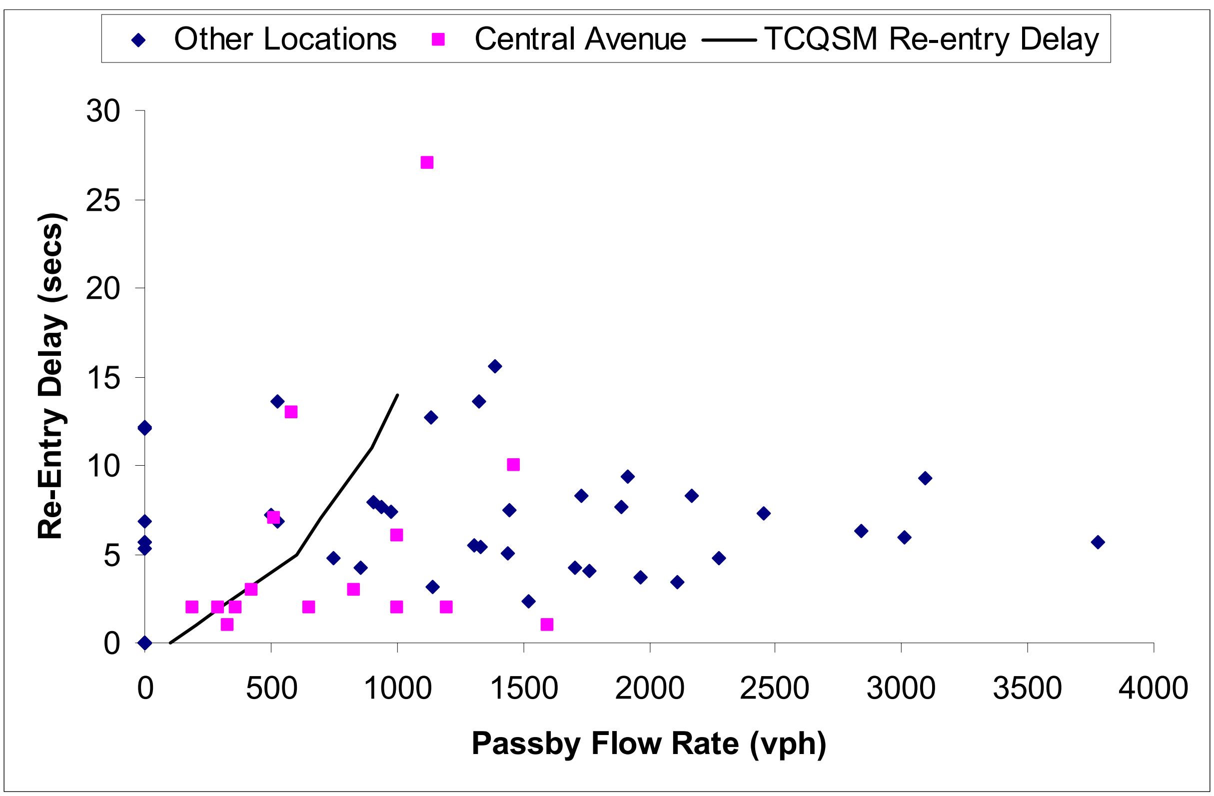


Figure 39. Re-Entry Delay vs. Passby Flow Rate.

Figure 39 shows a plot of the re-entry delay versus the passby flow rate. Included in the plot are the re-entry delays measured as well as the re-entry delays from the Transit Capacity and Quality of Service Manual (TCQSM). The plot shows that the measured re-entry delays show significant variability and spread with a minimum re-entry delay measured of 1 second and a maximum re-entry delay of 27 seconds. The plot also demonstrates that the measured re-entry differ from the delays provided in the TCQSM. The TCQSM re-entry delays increase with increasing volume. Although difficult to see a trend in the measured re-entry delays, the delays appear to not be correlated to the adjacent volume only.

Chapter IX

CONCLUSIONS AND RECOMMENDATIONS

OVERVIEW

This report summarized the results of the work performed under the project *Effectiveness of Bus bulbs for Bus Stops*. The research attempted to evaluate the effectiveness for bus bulbs for New Jersey conditions. The intent of the original study was to construct the bus bulbs and evaluate their effectiveness. This intent could not be realized, but instead the effectiveness of bus bulbs was studied by evaluating conditions that are required for bus bulbs to be effective with a procedure developed to estimate the bus travel time savings with bus bulbs.

Research Summary

Bus bulbs are recommended at locations with high bus patronage and high pedestrian activity. In urban locations, however, these locations are associated with high bus and vehicular volumes and can result in increased delays for buses if a bus bulb is installed. The need for bus bulbs to be installed in locations with on-street parking also becomes problematic for urban areas as parking is often eliminated directly upstream and downstream of bus stops in urban areas to improve intersection capacity.

The geometric design of bus bulbs varies by location and depends on the specific objectives of the bulb and the existing conditions at the intersection. Based on conditions found in New Jersey, the recommended length and width for bus bulbs is 45 feet (13.7 m) long, based on the length of a typical New Jersey Transit bus, with a width of 6 feet. A double 10 ft radii design for curb extension is also recommended. This curb radii allows for mechanical street cleaning and requires a 14-1/2 foot curb transition length for a 6 ft wide bus bulb.

A review of geometric conditions and bus activity resulted in eight sites investigated for the installation of a bus bulb. These sites included: Ferry Street, Newark; Broad Street, Newark; Route 506 (Bloomfield Avenue), Montclair; Route 7 (Washington Avenue), Belleville; Route 501 (JFK Boulevard), Jersey City; Paterson, Passaic County; Route 27 (Nassau Street), Princeton; Route 71 (Main Street), Avon-By-The-Sea; Cedar Lane and Elm Street, Teaneck; and Cedar Lane and Garrison, Teaneck. The locations were identified as being able to be benefited by bus bulbs include: Ferry Street, Newark; Bloomfield Avenue, Montclair; and Cedar Lane, Teaneck. Streetscapes Projects resulted in the installation of bus bulbs on Route 71 and Cedar Lane. The installation was performed independent to this project. The data collected included: vehicular volumes, pedestrian volumes, bus travel times, and bus speed profiles.

The impacts of bus bulbs on roadway operations include that at a near-side bus-stop, the adjacent intersection's capacity can be reduced by increasing the amount of time the travel lane is blocked by buses stopped in the travel lane. The bus bulb also eliminates the ability of right-turning vehicles from using the curb lane for right-turns. Bus bulbs also increase delays to through vehicles delayed behind the stopped bus. Although bus speed and travel time may improve as a result of not having to wait to reenter the travel lane, other vehicles on the roadway will experience some delay due to the stopped bus.

The expected bus travel time savings from a bus bulb can be shown to be the re-entry delay minus the increase in intersection delay after the bus bulb is constructed. The expression demonstrates that reduction in bus travel time savings from the bus bulbs must be weighed against increases in intersection delays when a bus bulb is considered for installation. An estimate of potential bus travel time savings at three locatiosn showed that installing a bus bulb would result in the reduction in the approach capacity between 8 and 11 percent and an increase in control delay from between 7 and 16 percent. Bus travel time savings as a result of the bus bulbs ranges between 15 and 25 seconds per bus stop.

Guidelines

Bus bulbs should be installed in locations in New Jersey that have the greatest potential to achieve the benefits associated with their installation. These benefits include:

1. Reduce bus delays through the elimination of bus weaving maneuvers into and out of the curb lane;

2. Provide additional sidewalk area for bus patrons to wait;

3. Remove fewer parking spaces than a traditional curb-side bus stop; and

4. Decrease the walking distance for pedestrians crossing the roadway.

To achieve these benefits, bus bulbs should be considered at locations when the following factors are present:

- Bus re-entry delays exist,

- Roadway volume in the lane adjacent to the curb lane exceeds 500 vehicles during the peak hour,

- 24-hour parking is available both upstream and downstream of the bus bulb,

- Vehicle speed on the roadway is less than 35 mph,

- Bus volumes are 20 or more per peak hour on the roadway,
- Passenger volumes exceed 20 to 40 boardings an hour,
- Average peak-period dwell time exceeds 30 seconds per bus,
- Pedestrian volumes exceed 30 pedestrians per hour,
- Level-of-Service for the intersection approach adjacent to the bus bulb is C or better,
- Right turns represent no more than 5 percent of through volume.

The research further determined that roadway volume, bus volume, bus patronage and adjacent pedestrian activity, play a critical role in determining the suitability of a location for the installation of bus bulbs. Table 23 attempts to identify combination of these factors that indicate whether bus bulbs should or should not be installed.

Table 23. Criteria for Installing Bus Nubs in New Jersey

				Roadway Volume								
				Low			Med			High		
				Bus Patronage			Bus Patronage			Bus Patronage		
				Low	Med	High	Low	Med	High	Low	Med	High
Bus Volume	Low	Pedestrian. Activity	Low	•	•	•	•	•	•	•	✓	✓
			Med	•	•	✓	•	•	✓	•	✓	✓
			High	•	✓	✓	✓	✓	✓	✓	✓	✓
	Med	Pedestrian. Activity	Low	•	•	•	•	✓	✓	✓	✓	✓
			Med	•	✓	✓	•	✓	✓	✓	✓	✓
			High	✓	✓	✓	✓	✓	✓	✓	✓	✓
	High	Pedestrian. Activity	Low	•	•	✓	✓	✓	✓	•	•	•
			Med	✓	✓	✓	✓	✓	✓	•	•	•
			High	✓	✓	✓	✓	✓	✓	•	•	•

✓ - Bus bulb should be considered for installation.
• - Bus bulb should not be considered for installation.

Ranges	Low	Med	High
Roadway Volume	≤ 500 vph	> 500 – 700 vph	≥ 700 vph
Bus Volume	≤ 10 bus/hr	> 10 – 20 bus/hr	≥ 20 bus/hr
Bus Patronage	≤ 20 boardings/hr	> 20 – 30 boardings/hr	≥ 30 boardings/hr
Pedestrian Activity	≤ 20 pedestrians/hr	> 20 – 30 pedestrians/hr	≥ 30 pedestrians

Conclusions

The research demonstrates that bus bulbs can be an effective alternative to curbside bus stops with the potential to reduce bus re-entry delays, increase bus speeds, decrease the walking distance for pedestrians, and provide additional sidewalk area for bus patrons. The research also demonstrates that achieving these benefits requires careful consideration of conditions at the bus stop prior to installation of the bus bulb. In urban areas, consideration must also be made to the impact of the bus bulb on the operation of the adjacent intersection.

In many of the Urban Centers of New Jersey, bus bulbs may not entirely be appropriate because of the high vehicular volumes and bus patrons which may exacerbate already congested conditions. In many of these locations, however, to avoid significant re-entry delays, bus drivers currently do not pull into the curb to pick-up and discharge passengers. In these locations, bus bulbs may improve safety to bus patrons who would no longer have to enter the street to board buses stopping in the travel lane.

The construction of bus bulbs bus bulbs at Avon-by-the-Sea, New Jersey and at Teaneck, New Jersey show that this bus treatment will be used by municipalities in New Jersey. The guidelines provided in this research on the design, placement, and evaluation procedure will help these municipalities in using bus bulbs in a safe and efficient manner.

Recommendations

The research attempted to measure re-entry delays at locations in New Jersey. The findings showed re-entry delay did not have a correlation with adjacent roadway volumes. The ability to accurately estimate the re-entry delay is critical, though, to determine the potential travel time savings resulting from bus bulbs. For this reason the recommendation of the research is for further data collection on re-entry delays, identifying the factors that contribute to re-entry delay. Bus bulbs are recommended for use in New Jersey. Given good design, with projections of travel time saving, bus bulbs will prove to be acceptable for road users and bus patrons.

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