1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA/TX-90/1225-1		

4. Title and Subtitle Guidelines for Planning, Designing and Operating Transit-Related Street Improvements: Survey of Current Practice	5. Report Date September 1989 6. Performing Organization Code
7. Author(s) Robert W. Stokes, Paul Luedtke & Thomas Urbanik II	8. Performing Organization Report No. Research Report 1225-1
9. Performing Organization Name and Address Texas Transportation Institute The Texas A&M University System College Station, Texas 77843	10. Work Unit No. 11. Contract or Grant No. Research Study No. 2-18-89-1225
12. Sponsoring Agency Name and Address Texas State Department of Highways and Public Transportation Transportation Planning Division P.O. Box 5051 Austin, Texas 78763	13. Type of Report and Period Covered Interim - September 1988 - September 1989 14. Sponsoring Agency Code

15. Supplementary Notes

Research performed in cooperation with Texas SDHPT, DOT, and FHWA.
Research Study Title: Preparation of a Texas Manual for Planning, Design, and Operation of Streets and Highways with Public Transportation Systems

16. Abstract

This report summarizes the results of a national survey of state DOTs and local transit agencies concerning current practice in the planning, design and operation of transit-related street improvements. The summary of current practices is divided into four subsections: 1) Bus service planning guidelines; 2) Bus facility design guidelines; 3) Bus service operating considerations; and 4) Light rail transit (LRT) services. The results of the study indicate that basic practices do not differ substantially between the agencies surveyed, though differences were found in the level of detail contained in the various guidelines. The survey results also suggest that the need for improved coordination and cooperation between transit and highway agencies is a major concern of local transit service providers. Subsequent phases of this study will focus on developing transit-related guidelines which can be incorporated into the state's roadway planning and design manuals.

17. Key Words	18. Distribution Statement
Bus service planning guidelines; Bus facility design; Bus service operations; Light rail transit; Transit-related street improvements; Interagency cooperation/coordination; Transit planning; Geometric design; Traffic control; Surface streets; Local streets.	No restrictions. This document is available to the public through the National Technical Information Service 5285 Port Royal Road Springfield, Virginia 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	92	

Form DOT F 1700.7 (8-69)

GUIDELINES FOR PLANNING, DESIGNING AND OPERATING TRANSIT-RELATED STREET IMPROVEMENTS: SURVEY OF CURRENT PRACTICE

by

Robert W. Stokes
Associate Research Planner

Paul Luedtke
Research Assistant

and

Thomas Urbanik II
Research Engineer

Research Report 1225-1

Research Study Number 2-18-89-1225

Sponsored By

Texas State Department of Highways and Public Transportation
in cooperation with the
U.S. Department of Transportation
Federal Highway Administration

Texas Transportation Institute
The Texas A&M University System
College Station, Texas 77843

September 1989

METRIC (SI*) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

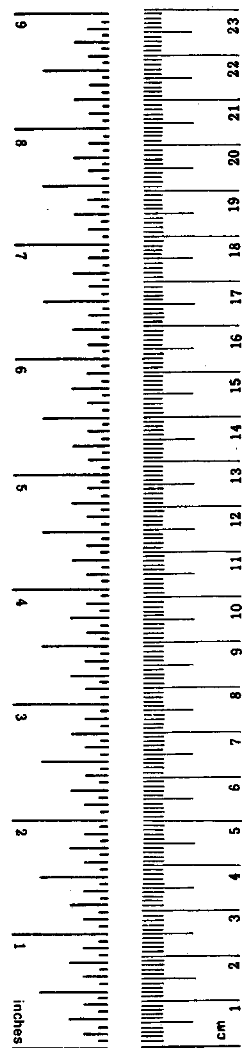
Symbol	When You Know	Multiply By	To Find	Symbol
	LENGTH			
in	inches	2.54	millimetres	mm
ft	feet	0.3048	metres	m
yd	yards	0.914	metres	m
mi	miles	1.61	kilometres	km
	AREA			
in^2	square inches	645.2	millimetres squared	mm^2
ft^2	square feet	0.0929	metres squared	m^2
yd^2	square yards	0.836	metres squared	m^2
mi^2	square miles	2.59	kilometres squared	km^2
ac	acres	0.395	hectares	ha
	MASS (weight)			
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
	VOLUME			
fl oz	fluid ounces	29.57	millilitres	mL
gal	gallons	3.785	litres	L
ft^3	cubic feet	0.0328	metres cubed	m^3
yd^3	cubic yards	0.0765	metres cubed	m^3

NOTE: Volumes greater than 1000 L shall be shown in m^3.

TEMPERATURE (exact)

°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

* SI is the symbol for the International System of Measurements

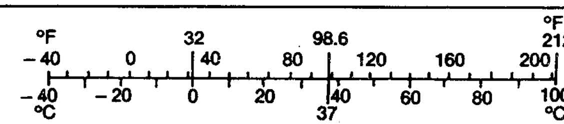


APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
	LENGTH			
mm	millimetres	0.039	inches	in
m	metres	3.28	feet	ft
m	metres	1.09	yards	yd
km	kilometres	0.621	miles	mi
	AREA			
mm^2	millimetres squared	0.0016	square inches	in^2
m^2	metres squared	10.764	square feet	ft^2
km^2	kilometres squared	0.39	square miles	mi^2
ha	hectores (10 000 m^2)	2.53	acres	ac
	MASS (weight)			
g	grams	0.0353	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams (1 000 kg)	1.103	short tons	T
	VOLUME			
mL	millilitres	0.034	fluid ounces	fl oz
L	litres	0.264	gallons	gal
m^3	metres cubed	35.315	cubic feet	ft^3
m^3	metres cubed	1.308	cubic yards	yd^3

TEMPERATURE (exact)

°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



These factors conform to the requirement of FHWA Order 5190.1A.

ABSTRACT

This report summarizes the results of a national survey of state DOTs and local transit agencies concerning current practice in the planning, design and operation of transit-related street improvements. The summary of current practices is divided into four subsections: 1) Bus service planning guidelines; 2) Bus facility design guidelines; 3) Bus service operating considerations; and 4) Light rail transit (LRT) services. The results of the study indicate that basic practices do not differ substantially between the agencies surveyed, though differences were found in the level of detail contained in the various guidelines. The survey results also suggest that the need for improved coordination and cooperation between transit and highway agencies is a major concern of local transit service providers. Subsequent phases of this study will focus on developing transit-related guidelines which can be incorporated into the state's roadway planning and design manuals.

Keywords: Bus service planning guidelines; Bus facility design; Bus service operations; Light rail transit; Transit-related street improvements; Interagency cooperation/coordination; Transit planning; Geometric design; Traffic control; Surface streets; Local streets.

IMPLEMENTATION STATEMENT

This report summarizes the results of a national survey of state DOTs and local transit agencies concerning current practice in the planning, design and operation of transit-related street improvements. The survey of current practice was performed as part of a larger study that will be directed at developing transit-related guidelines which can be incorporated into the Department's roadway planning and design manuals. The results of this survey should be useful to local, state, and federal transportation agencies in developing guidelines for transit-related street improvements.

DISCLAIMER

TABLE OF CONTENTS

CHAPTER 1
INTRODUCTION

1.1 Background and Study Objectives

In recent years, it has become increasingly evident that the economic and social vitality of many of the state's urban areas will be closely tied to the quality of their transportation systems. The transportation problems facing Texas cities, however, cannot be solved by simply building more streets and highways. Likewise, transit is not the solution to all urban transportation problems. A balanced transportation system, that makes the best use of the advantages of all available transportation modes, will be needed to efficiently serve the state's transportation needs.

The Texas State Department of Highways and Public Transportation (SDHPT) has responded to this need for a balanced transportation system by expanding beyond its traditional highway orientation to a role that now places increased emphasis on public transportation systems. The recent creation of a new division of public transportation within the SDHPT, and an increasing level of support for transit-related research, are clear indications of the Department's commitment to public transportation in Texas.

As a result of this expanded multimodal approach to transportation planning, there is a need to incorporate provisions for transit vehicles and services into the Department's roadway planning and design guidelines. Previous studies have addressed the planning, design and policy-related issues associated with transit operations on urban freeways (1, 2). Previous studies have also addressed the planning, design and operation of park-and-ride lots in Texas cities (3 - 5). This study is intended to supplement those previous studies by providing planning and design guidelines to facilitate transit operations on surface streets.

This report presents the results of a survey of current practices regarding the planning, design and operation of street improvements that incorporate provisions for transit operations. Subsequent phases of this study will focus on developing comparable guidelines for Texas.

The objectives of the **first year** of this study are:

1) Conduct a nationwide survey of current practices concerning the planning, design and operation of street improvements that incorporate provisions for transit services.

2) Prepare a report which summarizes the results of the survey of current practices.

The objectives of the **second year** of this study are:

3) Develop preliminary guidelines for planning, designing and operating transit-related street improvements in Texas.

4) Review these preliminary guidelines with SDHPT personnel at the district and division levels and revise/refine the guidelines if needed.

5) Prepare a Texas Manual of Guidelines for Planning, Designing, and Operating Transit-Related Street Improvements.

1.2 Study Method

The objectives of this phase of the study were accomplished through a national survey of state departments of transportation (DOTs) and thirty-two metropolitan transit authorities (MTAs). A mail-out questionnaire was used to solicit information from the individuals and agencies surveyed. The mail-out questionnaire was supplemented with telephone interviews and a literature review. The survey of transportation agencies and the literature review were used to compile information concerning current practices in the following aspects of transit-related street improvements:

1) Planning Criteria
   - Route Planning
   - Service Planning
   - Location of Transit Stops and Turnouts
   - Guidelines for Placement of Shelters

2) Design Criteria
   - Design Vehicles
   - Corner Radii
   - Lane Widths
   - Reserved Transit Lanes
   - Horizontal and Vertical Alignment
   - Clearances
   - Grades
   - Cross-Sections
   - Pavement Design
   - Bus/Light Rail Transit Stops
   - Transit Passenger Shelters
   - Park-and-Ride Lots

3) Operations
   - Signal Timing
   - Signing
   - Pavement Markings
   - Maintenance
   - Security/Enforcement

1.3 <u>The Need for Cooperative Transit Planning</u>

The urban transportation planning process plays an important role in efforts directed at meeting the transportation needs of our urban areas. This process, however, has become increasingly complex because it now includes a wide range of issues, impacts and alternatives, and an increasing number of participants representing a diverse range of interests. While planning for transit services is but one component in the overall transportation planning process, it has become an increasingly important one, particularly in those urban areas that are actively pursuing programs to restore (or maintain) acceptable levels of mobility to provide for continued economic growth and a better quality of life for their residents*.

In order to take full advantage of transit in serving the state's transportation needs, it will be necessary to develop a better understanding of the roles transit can serve and to consider these roles in the planning and implementation of roadway improvements. This will require increased levels of coordination between transit service providers, local and state highway agencies and private developers in planning roadway improvements.

The results of a recent survey (7) indicate that the lack of coordination between transit service providers and local and state highway agencies is one of the most important issues facing the transit industry in Texas. The survey respondents identified the following general areas where improvements in interagency cooperation and coordination are needed:

- The need for coordinated transportation planning at the state level (including short- and long-range state transportation plans);
- The need to consolidate all transportation-related functions (including regulation) under a single state agency;
- The need for improved coordination between local transit service providers and local and state highway agencies in planning roadway improvements;
- The need for policies/guidelines concerning the development of "transit friendly" roadways (e.g., sidewalks, street lights and other considerations concerning pedestrian access and safety);
- The need for policies/guidelines concerning use of transit sales tax revenues for street improvements; and

---

*See Bullard and Nungesser (6) for an excellent overview of the state-of-the-art in transit planning, management and operations. Their "Texas Transit Reference Manual" provides information on the roles of transit, and the operational and economic characteristics of the modes and technologies available to serve those roles.

- The need to consider transit in land use policy decisions.

Several large cities in Texas are currently implementing major transit improvement programs, and it appears that transit will become increasingly important in serving the state's transportation needs. However, there is more to good transit services than choosing the appropriate technology and providing high levels of service frequency and reliability. While the responsibility for providing safe, comfortable and reliable transit vehicles rests with the local transit agency, the means for assuring that transit vehicles can easily access major service areas and that patrons can safely walk to stops and wait comfortably for transit vehicles is generally beyond the control of the transit agency. The provision of quality transit services, then, requires a cooperative effort involving local transit service providers, local and state highway agencies and private developers. This study is intended to facilitate the development of a cooperative transit planning process in Texas by providing a review of current practices in the planning, design and operation of transit-related street improvements.

CHAPTER 2
SURVEY OF CURRENT PRACTICES

2.1 Overview

Table 1 presents a summary of survey responses by agency (state DOT or MTA) and indicates the availability of guidelines developed by these agencies for the planning, design and/or operation of transit-related street improvements. As expected, the majority of the guidelines have been developed by the MTAs.

The following sections of this report present a summary of typical guidelines developed by the agencies listed in Table 1, as well as representative guidelines identified in the literature review. The summary is intended to provide a review of "representative" guidelines, rather than an agency-by-agency review of current practice.

The summary of current practices concerning transit-related street improvements is divided into four subsections: 1) Bus service planning guidelines; 2) Bus facility design guidelines; 3) Bus service operating considerations; and 4) Light rail transit (LRT) services. The planning guidelines focus on policies and procedures for encouraging land use and development patterns which are conducive to efficient bus services, route and service planning considerations, and guidelines for locating bus service support facilities such as stops and passenger amenities. The review of planning guidelines is intended to acquaint SDHPT personnel with current transit planning practices. These guidelines should be of use to the Department in identifying roadway segments and travel corridors where street and highway designs should include provisions for transit services. The bus design guidelines address geometric and structural issues that should be considered in the design of roadways and support facilities to insure safe and efficient bus operations on surface streets. The subsection on bus operations summarizes policies and guidelines regarding signing, traffic signals, bus priority measures and maintenance for transit-related street improvements. The final subsection presents a summary of the physical and operating characteristics of light-rail transit vehicles and services that are pertinent to the design of

Table 1. Availability of Guidelines for Transit-Related Street Improvements

Agency	Written Guidelines Available: No	Written Guidelines Available: Yes	No Response
State of Alabama Highway Department	X		
Arizona Department of Transportation (City of Phoenix)		X	
California Department of Transportation		X	
Colorado Department of Highways	X		
Connecticut Department of Transportation	X		
Delaware Department of Transportation	X		
Washington D.C. Department of Public Works	X		
Florida Department of Transportation	X		
Georgia Department of Transportation	X		
Idaho Transportation Department	X		
Illinois Department of Transportation	X		
Indiana Department of Highways	X		
Iowa Department of Transportation	X		
Kansas Department of Transportation	X		
Kentucky Department of Highways	X		
Louisiana Department of Transportation and Development	X		
Maine Department of Transportation			X
Maryland Department of Transportation			X
Massachusetts Department of Public Works		X	
Michigan Department of Transportation	X		
Minnesota Department of Transportation		X	
Mississippi State Highway Department	X		
Missouri Highway and Transportation Department	X		
Montana Department of Highways	X		
Nebraska Department of Roads	X		
Nevada Department of Transportation	X		
New Hampshire Department of Public Works and Highways	X		
New Jersey State Department of Transportation	X		
New Mexico State Highway and Transportation Department	X		
New York Department of Transportation	X		
North Carolina Department of Transportation			X
North Dakota State Highway Department	X		
Oklahoma Department of Transportation	X		
Oregon Department of Transportation		X	
Pennsylvania Department of Transportation	X		
Puerto Rico Department of Transportation and Public Works			X
Rhode Island Department of Transportation		X	
South Carolina Department of Highways and Public Transportation		X	
South Dakota Department of Transportation			X
Tennessee Department of Transportation	X		
Utah Department of Transportation	X		
Vermont Agency of Transportation	X		
Virginia Department of Transportation	X		
Washington Department of Transportation		X	
West Virginia Department of Highways	X		
Wisconsin Department of Transportation	X		
Wyoming Highway Department	X		
Ontario Ministry of Transportation	X		
Quebec Ministry of Transportation	X		
Port Authority of New York and New Jersey			X
Ohio Department of Transportation		X	
Arkansas State Highway and Transportation Department	X		
Denver Regional Transportation District		X	
Orange County Transit District		X	
Cleveland Regional Transit Authority		X	
Southeastern Pennsylvania Transportation Authority		X	
Central Ohio Transit Authority		X	
Milwaukee County Transit System		X	

Table 1. Availability of Guidelines for Transit-Related Street Improvements (Cont.)

Agency	Written Guidelines Available: No	Written Guidelines Available: Yes	No Response
Dallas Area Rapid Transit		X	
Maryland Mass Transit Administration		X	
Houston Metro		X	
Miami Valley Transit Authority (OH)		X	
Kansas City Area Transportation Authority		X	
Bi-State Development Agency (St. Louis)		X	
Metro-Dade County Transit Agency		X	
Port Authority of Allegheny County	X		
Niagara Frontier Transportation Authority	X		
New York City Metro			X
Bay Area Rapid Transit	X		
Chicago Transit Authority	X		
Phoenix Regional Transportation Authority		X	
Ft. Worth Transportation Authority			X
Capital Metro (Austin)		X	
Southeastern Michigan Transportation Authority		X	
Indianapolis Public Transportation Authority			X
Massachusetts Bay Transit Authority			X
Metro Transit Commission (St. Paul)		X	
Metro Transit Development Board (San Diego)			X
New Orleans Regional Transit Authority	X		
Southern California Rapid Transit (Los Angeles)			X
Southwestern Ohio Transit Authority (Cincinnati)			X
Tri-County Metro (Portland)		X	
Washington DC Metro			X
Alameda-Contra Costa Transit District (Oakland)		X	
Municipality of Metro Seattle		X	

transit-related street improvements. The survey revealed very little specific information concerning design guidelines for on-street LRT operations. As a result, the LRT guidelines summarized in this report are very general in nature.

2.2 Bus Service Planning Guidelines

2.2.1 Service and Route Planning

Many of the MTAs in the survey have developed general service planning policies intended to encourage land use patterns and street networks which are conducive to efficient transit operations. Seattle Metro (8), for example, considers a number of factors in assessing whether a transit market exists and whether that market can be served by existing or proposed transit services. The factors considered in evaluating specific project developments include the following (8):

Relationship to Transit

- Is the site within a quarter mile of a bus route in urban areas, or within a half mile of a bus line in a suburban area?

- Can an existing bus line sufficiently serve the transportation needs of the development?

- Will the proposed development take advantage of nearby public transportation?

- Would potential users want to use transit to go there?

Orientation to Automobiles

- Is the development feasible without relying primarily on automobile access?

- Would the proposed development function in a manner that could be characterized as other than a primarily automobile oriented use? (Would parking requirements be compatible with transit/ridesharing?)

- Are the number of parking spaces provided greater than that required by the local jurisdiction?

- Are carpools and vanpools given priority parking spaces closest to the building entrance?

- If there is a charge for parking, is there a discount for HOVs (high occupancy vehicles)?

The Site Plan

- Does the site plan orient the development to the street?

- Does the site plan treat parking in a manner as to not separate the development from the street by parking?

- Are there passenger loading zones where carpools and vanpools can pick up riders?

- Does the site plan provide weatherization improvements for pedestrians?

- Does the site plan provide for direct quality pedestrian access to transit?

- Does the site plan allow for pedestrian and transit amenities such as street trees and passenger shelters?

Trip Generation

- How many automobile trips will the proposed use generate both in the peak and off-peak hours?

- Is the developer proposing any incentive programs to reduce SOV (single occupant vehicle) trips generated by the development?

- What is the potential of the proposed development to generate transit/ridesharing trips in both peak and off-peak?

- What is the proposed development's potential to generate pedestrian trips?

Intensity of Use

- What is the proposed population/employment density of the proposal?

- Does the proposed development represent a high (15 or more dwelling units/acre), medium (7-14 dwelling units/acre), or low (less than 7 dwelling units/acre) intensity use of the site?

The Alameda-Contra Costa (AC) Transit District in Oakland uses the following general guidelines as indicators of whether a particular development is compatible with transit (9):

- Medium to high population densities are conducive to public transit use. This includes residential areas, office buildings and high intensity commercial activities.

- Intensification of development in built up areas and along existing transit corridors is compatible.

- Residential areas which provide good arterial and collector streets for circulation are compatible. Residential areas must, however, be designed to provide pedestrian access to these major streets in order to bring about this compatibility.

- Site plans which orient the building to the streets and bus stops rather than separate the building from the street by parking lots are more compatible.

- Developments with restricted parking are compatible with public transit. An alternative to this would be preferential treatment for public transit.

The AC Transit District has adopted service standards that are intended to promote these land use patterns and street networks that encourage efficient transit operations. The major considerations in these service standards are population densities and traffic generation potentials. The AC Transit District's population density service standards are intended to encourage higher densities along existing transit corridors and include the following (9):

- In areas where population density is equal to or greater than 10,500 persons per square mile, service with a midday base headway of 20 minutes or less will be provided within one-quarter mile of 95% of the population.

- In areas where population density is 6,500 to 10,499 persons per square mile, service with a midday base headway of 30 minutes or less will be provided within one-quarter mile of 90% of the population.

- In areas where population density is 2,500 to 6,499 persons per square mile, service with a midday base headway of 45 minutes or less will be provided within one-quarter mile of 90% of the population.

- In areas where population density is less than 2,500 persons per square mile, peak period service will be provided within one-half mile of 50% of the population.

In the case of major traffic generators such as shopping centers, sports facilities, airports and educational centers, AC Transit has established a cooperative planning process involving transit agency staff, developers, property owners and local government agencies to insure that the design of the development is transit-compatible.

The Baltimore Mass Transit Administration (10) has developed threshold criteria to evaluate the feasibility of providing transit services to new developments. These criteria are shown in Table 2.

Table 2. Threshold Criteria for New Transit Service, Baltimore

Land Use Type	Minimum Size
Residential	2400 dwelling units @ 6+ dwelling units/acre
Commercial	
Shopping Center	375,000 gross sq. feet of building area*
Office Buildings	150,000 gross sq. feet of building area or 2,500 employees
Industrial	1,400,000 gross sq. feet of building area or 3,000 employees

*Threshold represents minimum building area necessary to consider limited transit service during the day. (Individual projects not meeting these criteria may be considered together with other, nearby areas in meeting thresholds for new service.)

Source: Reference 10.

The Metropolitan Transit Authority of Harris County (Houston) has established a Service Implementation Team (SIT) Task Force to develop recommended transit-related improvements for projects funded in whole or part by the transit authority. In general, the types of transit-related improvements considered include (11):

- Sidewalks. Sidewalks should be constructed on both sides of the street to facilitate access to transit. People will be discouraged from riding the bus if they are not provided a safe and surfaced way to get to and wait for the bus.

- Consolidation of bus stops. Existing bus stop locations will be reviewed to see if some stops should be consolidated and/or eliminated. The consolidation and/or elimination of stops may increase bus speeds which, in turn, would improve efficiency.

- Bus Boarding Pads. Bus boarding pads should be installed at all proposed stops. Pads provide a larger surfaced area for patrons to wait for the bus and allow more sidewalk space for pedestrians. Bus shelters can be placed on top of a pad when boarding volumes at a stop meet the criteria for installing a shelter.

- Bus Turn-Out Bays. Turn-out bays will be requested at high boarding and alighting locations to prevent the buses from blocking traffic. They should be located on the farside of a signalized intersection to allow buses to merge back into traffic.

- Increased Corner Radius. The turning radii at locations where buses make right turns should be adequate to enable buses to make a proper turn. Due to the width of the road the bus is turning onto, or the angle of the intersection, a turning radius larger than that required by City standards may be needed so that the bus does not jump the curb or turn into the opposing lane of traffic.

- Median Openings. Median openings should be requested at locations where buses need to make a left-turn on a divided road.

- Left-Turn Lanes. Left-turn lanes should be constructed at locations where buses make left turns onto streets or into METRO facilities.

- Lighting. Street lights, or the ability to add lights at a later date, should be included in every project. The absence of lighting can discourage transit use at night.

The Milwaukee County Transit System (12) has developed route design guidelines to establish minimum or desirable standards for use in the planning of transit services in the Milwaukee area. These route design guidelines are used to evaluate proposals for service improvements on the basis of market potential, public benefit and the use of the transit system resources. Guidelines are included for (12):

- Service Classification
- Route Spacing
- Route Layout
- Frequency of Service
- Minimum Service Periods
- Market Potential

The Milwaukee route planning guidelines provide minimum route spacing standards for transit services operating on arterial and collector streets on the basis of the following population densities (12):

- Route spacing of 1/2 mile for medium and high density areas; where medium density = 1045 to 3135 dwelling units per gross square mile, and high density = 2957 to 7561 dwelling units per gross square mile.

- Route spacing of 1 mile for low density areas; where low density = 340 to 1070 dwelling units per gross square mile.

In addition to specifying service standards designed to encourage transit-oriented development patterns, several transit agencies have suggested specialized zoning techniques that can be adopted by local jurisdictions to bring about "transit friendly" land use development patterns. An easement for transit access purposes, for example, may be one such mechanism that the community, the transit agency and the developer can utilize to provide space for transit access and/or improvements. An easement is an authorization by a property owner for the use of a designated portion of his property by another entity for a specific purpose. Phone, gas and electric utilities typically utilize easements rather than fee-simple purchase for their transmission facilities. A similar easement mechanism can be utilized to reserve areas which may be, in the near future, strategic for providing access to the transit system. Easements can be reserved in commercial parking lots or yard areas for future park-and-ride lots, or for bus shelters, pedestrian access ways, or similar facilities. The major benefit in providing an easement is that it can reserve a strategic area or location and protect it from incompatible land uses until bus service is provided or the related improvements are constructed (8, 9).

2.2.2 Bus Stops and Turnouts

In transit service planning it is generally assumed that most patrons will not walk more than one-quarter mile to a transit stop. As a result, bus stops should be placed no more than one-quarter of a mile apart, as a general rule. In areas of high density development, transit stops may be necessary as frequently as every two blocks (one-eighth of a mile apart). This appears to be the standard within the industry.

The Denver Regional Transportation District (RTD), for example, recommends that for residential areas, local and express collection points should be a minimum of 600 feet apart (8 stops per mile) and a maximum of 1250 feet apart (4 stops per mile). In commercial areas, similar collection points should be a minimum of 500 feet apart (10 stops per mile). Limited service collection points should be a minimum of 2500 feet apart (2 stops per mile) and a maximum of 8000 feet apart (1 stop per 1 and 1/2 miles). A minimum of 500 feet may be used in cases of special high use facilities such as senior citizen housing or medical facilities (13).

The Milwaukee County Transit System uses the following guidelines to place bus stops (12):

- In residential areas, bus stops will be spaced at an average of eight per mile.

- For the various classes of transit service provided by the Milwaukee County Transit System, the passenger stop spacing/location guidelines shown in Table 3 are used.

Table 3. Transit Stop Spacing Guidelines, Milwaukee

Service Classification	Spacing/Location
Regular, schoolday and feeder service routes	660 feet standard spacings, but no more than 1250 feet
Express routes	At terminal areas, intersections with other transit routes, and at major traffic generators.
Freeway flyer	At terminal areas, one mile or more on linehaul.
Shuttlebus and contract service	As required to meet demand or purpose.

Source: Reference 12.

The recommended bus stop spacings used by the Baltimore MTA (10) are based on "catchment area" population densities, where the catchment area extends 1500 feet from each side of the bus route. The Baltimore bus stop spacing standards are shown in Table 4.

Table 4. Recommended Bus Stop Spacing, Baltimore

Catchment Area Density	Spacing Range
High (> 20 people/acre)	750-1000 feet
Medium (15-20 people/acre)	1000-1200 feet
Low (5-14 people/acre)	1500-1700 feet
Rural (< 5 people/acre)	*

*Rural portions of any routes shall be designated as flag stop areas.

Source: Reference 10.

The determination of the proper location of transit stops involves choosing between far-side, near-side, and mid-block stops. While there are no absolute rules or criteria for this choice, the following factors should be considered (9, 10, 14, 15):

- potential patronage
- passenger origin and destination
- pedestrian access
- adjacent land use and activities
- intersection geometrics
- parking restrictions and requirements
- traffic control devices
- physical roadside constraints (trees, poles, driveways, etc.)
- intersecting transit routes

The advantages of each type of bus stop are compared in Table 5. The far-side stops are generally preferable for the following reasons (9, 10, 14-17):

- Less likelihood of boarding and exiting passengers to cross in front of the bus.

- Automobile right turns can be accomplished with less conflict.

- Stopped buses do not obstruct sight lines to the left for vehicles entering the intersection from a side street.

- At signalized intersections, buses have a better chance of entering the traffic stream without interference due to gaps in traffic created by the signal.

A turnout is a specialized bus stop, where the transit vehicle can pick up and discharge passengers in an area completely separated from the travelled way. A turnout allows through traffic to flow freely without being impeded by stopped buses. Many transit planners and engineers believe the most appropriate use for bus turnouts is on roadways that experience high volumes of traffic. Although this appears to be an accurate assessment, frequently a bus turnout is counter-productive in high volume situations. Many

Table 5. Comparative Analysis of Bus Stop Locations

Near Side		Far Side		Mid-Block	
Advantages	Disadvantages	Advantages	Disadvantages	Advantages	Disadvantages
Minimizes interference when traffic is heavy on the far side of the intersection.	Conflicts with right turning vehicles are increased.	Minimizes conflicts between right turning vehicles and buses.	Intersections may be blocked during peak periods by queueing buses.	Minimizes sight distance problems for vehicles and pedestrians.	Requires additional distance for no-parking restrictions.
Passengers access buses closest to crosswalk.	Stopped buses obscure curbside traffic control devices and crossing pedestrians.	Provides additional intersection capacity by making curb lane available for traffic.	Sight distance is obscured for crossing vehicles stopped to the right.	Passenger waiting areas experience less pedestrian congestion.	Encourages patrons to cross street at mid-block (jaywalking).
	Sight distance is obscured for crossing vehicles stopped to the right of the intersection.	Minimizes sight distance problems on approaches to intersection.	Increases sight distance problems for crossing pedestrians.		Increases walking distance for patrons crossing at intersections.
	The through lane may be blocked during peak periods by queueing buses.	Encourages pedestrians to cross behind the bus.			
	Increases sight distance problems for crossing pedestrians.	Requires shorter acceleration and deceleration distances for buses.			
		Gaps in traffic flow are created for buses reentering the flow of traffic at signalized intersections.			

Source: Reference 10.

times, high traffic volumes will not allow sufficient gaps for the bus operator to safely and comfortably return the vehicle to the travelled way (10).

A recent study prepared for the City of Phoenix (14) concluded that bus bays (turnouts) are not generally desirable because of inconvenience to bus patrons resulting from delay of bus operations when reentering traffic. In many cases overall person-delay experienced by all people utilizing the street is greater when a bus bay is implemented. Bus bays are recommended only at locations where buses may be stopped for longer periods of time. According to guidelines used in Phoenix (14), the construction of a bus bay at any given location should only be considered under the following circumstances:

- End of bus trip layover or,

- Peak period average boarding exceeds 5 people per bus, or

- Average peak period dwell time exceeds 30 seconds per bus, or

- Five accidents involving buses occurred within the past year.

Generally turnouts should only be used on streets with speeds of 40 mph or over and only at signal-controlled intersections where the signal can create gaps in traffic (14). In addition, adequate deceleration and acceleration lanes should be provided to allow buses to leave and re-enter the traffic stream at a rate that is comfortable for the passengers (15).

The Orange County Transit District (17) suggests that bus turnouts should be constructed wherever the potential for auto/bus conflicts warrants separation of transit and passenger vehicles. Special consideration should be given to roadways that experience high traffic volumes or speeds where a bus stopping in a travel lane may be unsafe or impede the free flow of traffic. Bus turnouts should also be considered at locations with high bus or passenger volumes where a bus stopping in a travel lane may greatly impede traffic flow. Turnouts, like bus stops, are preferred at the far side of an intersection whenever possible. Bus turnouts should be considered when at least one of the following conditions is met (17):

- Bus parking in the curb lane is prohibited.
- Traffic in the curb lane exceeds 250 vehicles during the peak hour.
- Passenger volumes exceed 20 boardings an hour.
- Traffic speed is greater than 45 miles per hour.
- Accident patterns are recurrent.

When a bus bay is necessary, the far-side design is recommended (9, 10, 14, 15, 17), with exceptions sometimes necessary for site specific circumstances; i.e., a severe physical obstruction may necessitate a mid-block bus bay design, but this configuration is generally undesirable for bus operations. A far-side bay design is considered superior to the mid-block design because it reduces walking distances for bus transfers, encourages patrons to use the intersection crosswalk because the bus stops closer to it, and reduces right-of-way acquisition. Regardless of the design type, a 12-foot wide bay is highly recommended as this will reduce side-swipe accidents.

2.2.3 Waiting Areas and Shelters

Comfortable and secure passenger waiting areas need to be provided at all bus stops. These consist of spaces apart from the normal sidewalk for passengers to congregate, sit, and be protected from the weather. A paved landing area located immediately adjacent to the stopped bus for boarding and alighting passengers is also very important. In short, bus stops should work efficiently and provide passenger comfort, safety, and personal security (14, 15).

The passenger waiting area may include a range of improvements and amenities depending upon site specific needs. For example, the Regional Transit Authority of Phoenix recommends an eight-foot wide sidewalk extending at least 50 feet beyond each end of the shelter/accessory pad where the sidewalk is attached to the street curb. This will greatly reduce the potential for restricted sight visibility for vehicles exiting from driveways adjacent to bus stops. Under constrained right-of-way conditions the sidewalk should be a minimum of five feet in width (14).

The Orange County Transit District provides benches which seat three or more people at their bus stops. The following factors are considered in the design and placement of these benches (17):

- Benches should be constructed so as to be both comfortable and safe for passenger use.

- Materials should have high resistance to vandalism and weathering.

- Benches should be placed in such a way as to minimize obstruction of the public right-of-way and, if placed on the sidewalk, should provide at least 48 inches of clearance (on either the front or back side of the bench) for wheelchairs. In addition, benches should be placed no closer than four feet from the curb in order to allow passengers to move past people sitting on the bench.

Whenever possible, stops should be located near existing street lighting. If no street lighting is available, special lighting should be provided (10, 13, 15, 17).

A sheltered waiting area is important to the transit patron because it provides protection from the hot summer sun and rainy weather. However, it is recognized that the resources may not exist to provide a shelter at every bus stop. Therefore, many transit agencies have established guidelines to determine which bus stops should include shelters. These guidelines are generally based on the number of boarding and/or transferring passengers at each stop and the frequency of service at each stop.

In Phoenix (14), a passenger boarding level of 40 people per day is recommended as a threshold above which a passenger shelter should be seriously considered. When the expense of a shelter is not feasible, seating and shade protection by use of landscaping is generally included in the bus stop design. In Phoenix, a shelter/accessory pad is included as part of all improvements projects so that shelters may be constructed if the need arises in the future (14).

The guidelines used by the Milwaukee Transit System (12) in establishing priorities for the placement of shelters are shown in Table 6. The guidelines do not provide a minimum/threshold value for determining whether a shelter is warranted. The guidelines appear to be used only to "prioritize" potential shelter locations.

The Orange County Transit District recommends that, as a minimum, shelters should be considered at the following locations (17):

- Bus stops with high patronage (greater than ten passengers per hour) or at major activity centers.

- Bus stops at major transfer points.

Table 6. Warrants for Bus Passenger Shelters, Milwaukee County Transit System

Warrant	Value
Passenger Loadings	
25-74 passengers/day	10
75-149 passengers/day	20
150-299 passengers/day	30
300 or more passengers/day	40
Passenger Wait Time (1/2 midday headway)	
0-3 minutes	0
3.1 - 6 minutes	4
6.1 - 9 minutes	8
9.1 - 12 minutes	12
12.1 - 15 minutes	16
15.1 or more minutes	20
Bus Route Situation	
Transfer Point	10
On Line Stop	0
Exposure to Weather	
Minimum	5
Average	10
Full	20
Service from Special Location	
Housing for elderly	10
Recreation for elderly	10
Elderly nutritional site	10
Over 60 clinic	10
Handicapped destination	10
Hospital	10
School	10
College	10
High density residential	10
Commercial center	5
Industrial plant	5
Park	5
Other	5
(If more than one pertains, values are additive up to a maximum of 10 points.)	
TOTAL SCORE	_

Source: Reference 12.

- Bus stops located near schools, senior citizens' housing projects or community and recreation centers where large concentrations of school age children or senior citizens are expected.

The Baltimore MTA uses the following boarding thresholds to determine which stops should include shelters (10):

- A stop serviced by only one route with 25% of the peak direction boardings or a minimum of 100 daily boardings will be considered for a shelter.

- A stop served by two or more routes with 10% of the total peak direction boardings or a minimum of 100 daily boardings will be considered for a shelter.

The bus stop shelters currently available are manufactured in various sizes and shapes and may be constructed of many different types of material. However, the following general guidelines are typically used in selecting and locating shelters (9, 10, 15, 17):

- Passengers should be able to see approaching buses from within the shelter and be seen by passing traffic.

- The shelter should be enclosed to sufficiently protect passengers from inclement weather.

- A seating area should be provided inside the shelter.

- The shelter should be located near the front of the bus stop to provide quick access to the bus door.

- At least one entrance/exit should be oriented toward the street.

- The shelter should be accessible to the handicapped.

- Pedestrian and vehicular sight distance must not be impaired.

- If possible, the shelter should be lighted. If not, adequate street lighting is essential.

- Bus routing and scheduling information should be prominently displayed.

- The shelter should be close to the street, yet no closer than five feet from the edge of the pavement to avoid interference with passing vehicles.

- If the shelter is between the street and the sidewalk, it should be installed on a concrete landing pad with additional walkways connecting the sidewalk, shelter, and street.

In addition to these general guidelines, the needs of handicapped patrons deserve special consideration, and waiting areas should accommodate these needs. Important considerations in this regard include (18):

- Provision of ramps for wheelchair patrons.

- Locating stops close to the origins/destinations of handicapped patrons.

- Positioning telephones, information signs and traffic signal pedestrian push-buttons so they are accessible to handicapped patrons.

- Provision of preferential parking for handicapped patrons.

- Sizing loading areas to accommodate increased loading time requirements of wheelchair patrons.

2.2.4 Pedestrian Access

One of the factors affecting transit use is accessibility. Land use activities should be arranged to facilitate the movement of people from their origins (residence) to local transit services and back again. This can be achieved through pedestrian walkways (accessways) between transit stops and adjacent land uses.

Some residential subdivisions, for example, are very restrictive of passenger access to bus stops. A long continuous wall surrounding the length of the development often forces potential transit passengers living in close proximity to bus stops to walk several blocks to exit the development and then several more blocks to reach the bus stop. It would be desirable to provide an occasional break in the wall between properties to provide a walkway from bus stops to the development (14).

Similar problems also exist at commercial sites, where the main entrance is often located away from the street, perhaps facing a parking garage in the back. In some instances a large "sea" of parking separates the street from the buildings on site. In both instances it is difficult for pedestrians from the bus stop to access these buildings because of the long walking distances and sometimes hostile pedestrian environment (14).

Good site design for access to the bus system requires buildings to be set closer to the street. Also, shaded walkways protected from automobile traffic enhance the pedestrian environment.

The primary considerations relative to maximizing accessibility to transit services are (10, 14-17):

- Accessways should be direct and should minimize unnecessary meandering.

- Accessways should be paved, wheelchair accessible and, whenever possible, lighted.

- Accessways should extend from the development to the bus stop, to avoid bus passengers walking through landscaping or parking lots to access buses.

2.2.5 Summary

The general planning guidelines reviewed in the preceding sections of this report suggest that the following service planning guidelines are representative of current practice in the United States (19):

- Service Criteria. Bus service should be provided where 1) population density exceeds 2000 people/sq. mile and 2) ridership exceeds 20 to 25 passengers per bus hour on weekdays, 15 on Saturdays, and 10 on Sundays. Route continuity and transfer requirements may lower these factors.

- Service Area. The service area is normally defined by legislation. Where population density within this area exceeds 4000 people/sq. mile, or three dwelling units per acre, 90 percent of the residences should be within 0.25 mile of a bus line. Where population density ranges from 2000 to 4000 people/sq. mile, 50 to 75 percent of the population should be within 0.5 mile of a bus line.

- Route Structure and Spacing. Bus routes should fit major street patterns. Basic grid systems are appropriate where streets are in a grid pattern; radial or radial-circumferential systems are applicable where radial or irregular street patterns exist. Bus routes should be spaced at approximately 0.5 mile intervals in urban areas and 1 mile intervals in low-density suburban areas. Closer spacing should be provided where terrain inhibits walking.

- Route Directness and Length. Circuitous routings should be avoided: a route not more than 20 percent longer than the comparable trip by car is desirable. Route deviation should not exceed 8 minutes per round trip (based on at least 10 customers per round trip). Routes should be as short as possible to serve their markets, and generally should not exceed 25 miles or 2 hours per round trip.

- Bus Stops. Bus stop frequency should be approximately 10 to 12/mile in central areas, 6 to 8/mile in urban areas, and 2 to 5/mile in suburban areas. Express service stop frequency should be 2 to 4/mile in suburban pickup areas.

- Route Planning Procedures. Key steps in planning route changes include: 1) a review of characteristics of the service area, including physical feasibility for bus operations; 2) an estimate of ridership (often by comparison with similar areas); 3) an estimate of revenues; 4) a simulation of travel times by car, considering bus requirements; 5) schedule preparation; 6) an estimate of costs; and 7) an assessment of economic performance.

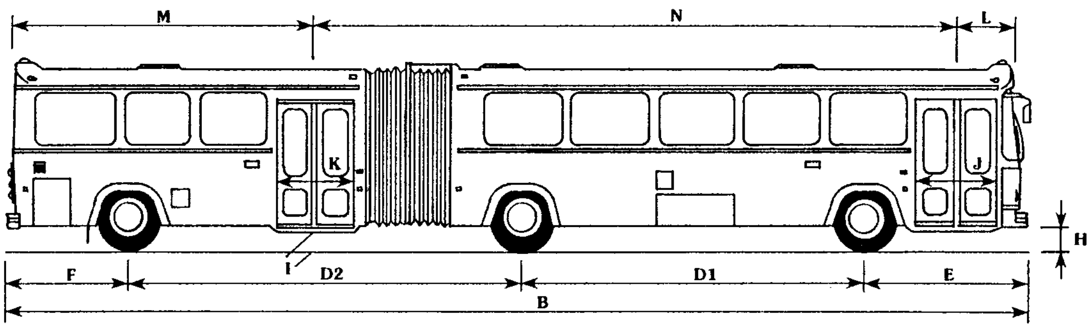
These same basic factors should be useful to local and state highway agencies in identifying roadway segments and travel corridors where street and highway designs should include provisions for transit vehicles and service support facilities. However, it should be clear that many of the factors affecting the efficiency of transit services are beyond the control of local transit and highway agencies. As a result, the provision of quality transit services will not only require cooperation between transit and highway agencies, but should include private developers and local agencies responsible for land use and development policies as well.

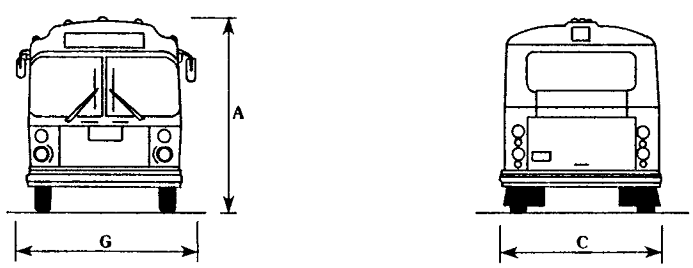
2.3 Bus Facility Design Guidelines

2.3.1 Vehicle Specifications and Turning Radii

For the purpose of designing facilities for buses, it is useful to define a design vehicle, which represents a compilation of critical dimensions from those vehicles currently in operation. The following two basic bus types are commonly used by transit service providers in North America (1, 10, 11, 14, 17, 20, 21): 1) 60-foot articulated coach; and 2) 40-foot "standard" coach. Figures 1 and 2 show typical design vehicle dimensions and weights for these two basic bus sizes.

The standard 40-foot coach and the 60-foot articulated coach are generally the largest vehicles in a transit fleet and represent the most common design cases. Key



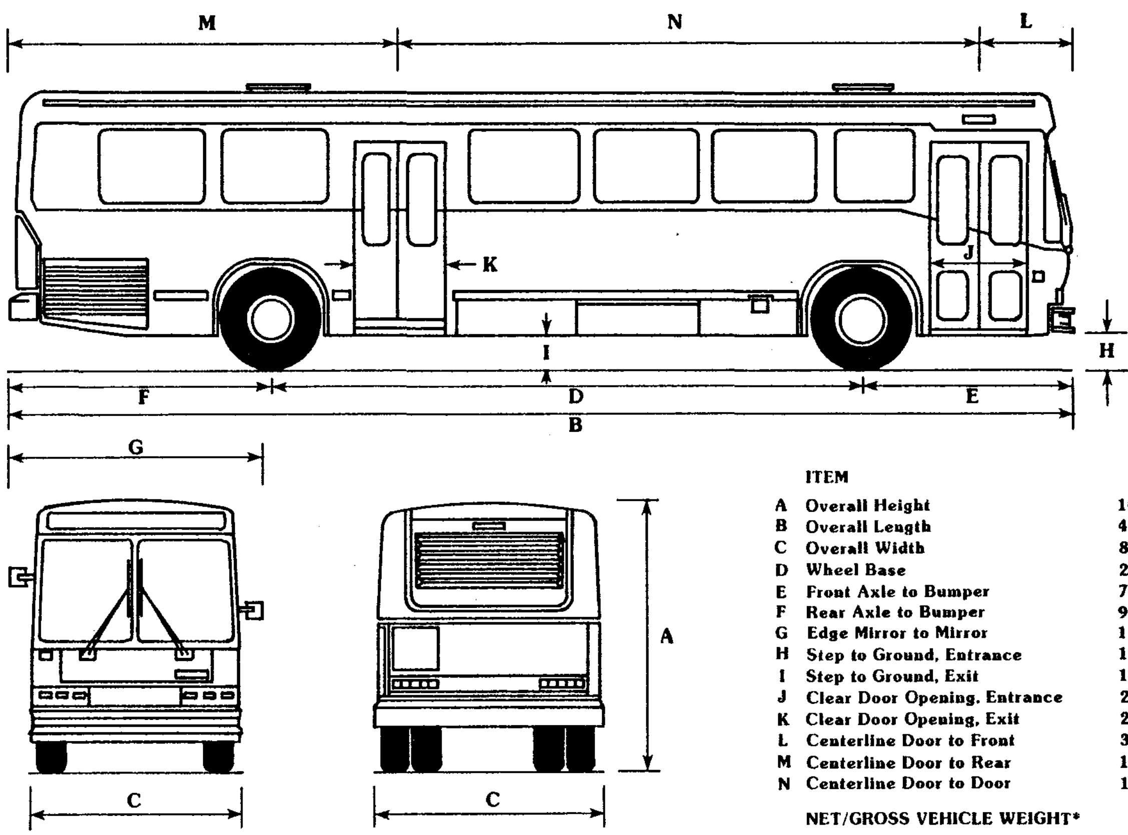


ITEM		
A	Overall Height	10'4"
B	Overall Length	59'10"
C	Overall Width	8'6"
D	Wheel Base (D1/D2)	18'7"/24'0"
E	Front Axle to Bumper	8'8"
F	Rear Axle to Bumper	8'8"
G	Edge Mirror to Mirror	10'6"
H	Step to Ground, Entrance	1'2"
I	Step to Ground, Exit	1'2"
J	Clear Door Opening, Entrance	3'8"
K	Clear Door Opening, Exit	3'6"
L	Centerline Door to Front	3'6"
M	Centerline Door to Rear	21'4"
N	Centerline Door to Door	35'0"
	NET/GROSS VEHICLE WEIGHT*	
	Front Axle	11,800/16,420
	Rear Axle	12,130/16,420
	Center Axle	14,970/24,250
	MAXIMUM BEND ANGLE	
	Horizontal	± 36 deg
	Vertical	± 11 deg
	Seating Capacity	70

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

Source: Reference 20.

Figure 1. Articulated Design Vehicle Dimensions and Weight



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

NET/GROSS VEHICLE WEIGHT*

Front Axle	7,420/11,980
Rear Axle	18,060/24,660
Seating Capacity	51
Standing Capacity	25

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

Source: Reference 20.

Figure 2. "Standard" 40-Foot Design Vehicle Dimensions and Weight

roadway design features such as lane and shoulder widths, lateral and vertical clearances, vehicle storage dimensions, and minimum turning radii are typically based on the standard 40-foot coach. The articulated bus, while longer than the single unit bus, has a "hinge" near the center of the vehicle which allows maneuverability comparable to the single unit bus (1). Design templates for minimum turning paths for single unit (40-foot) and articulated buses are shown in Figures 3 and 4, respectively.

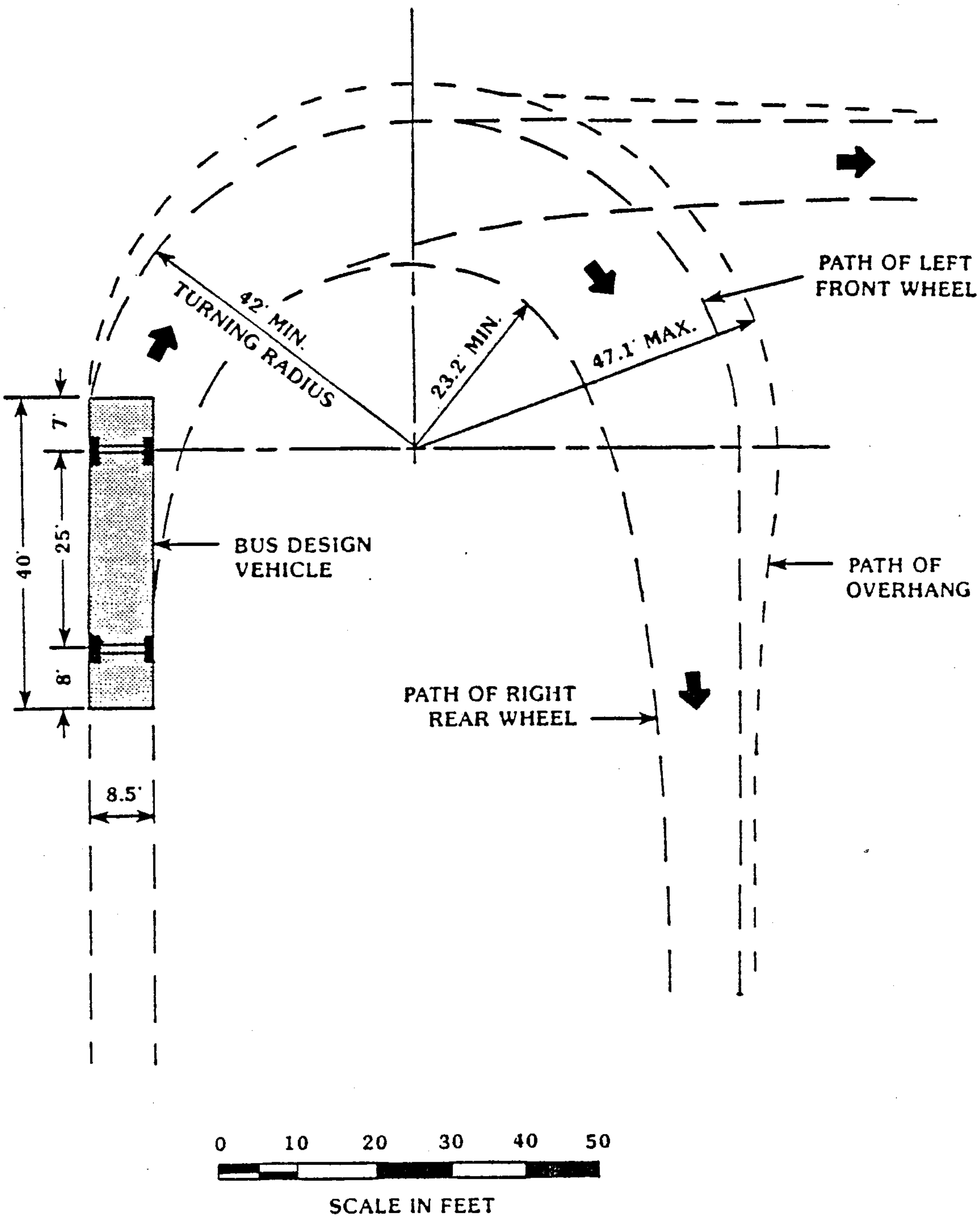
The single unit bus is also typically used as the design vehicle for design criteria affected by acceleration and deceleration, such as vertical alignment and speed transition lanes. The nominal acceleration rate is 2.0 mph/second and the nominal deceleration rate is 2.5 mph/second, which assumes standing passengers (1).

2.3.2 Clearances, Lane Widths and Grades

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

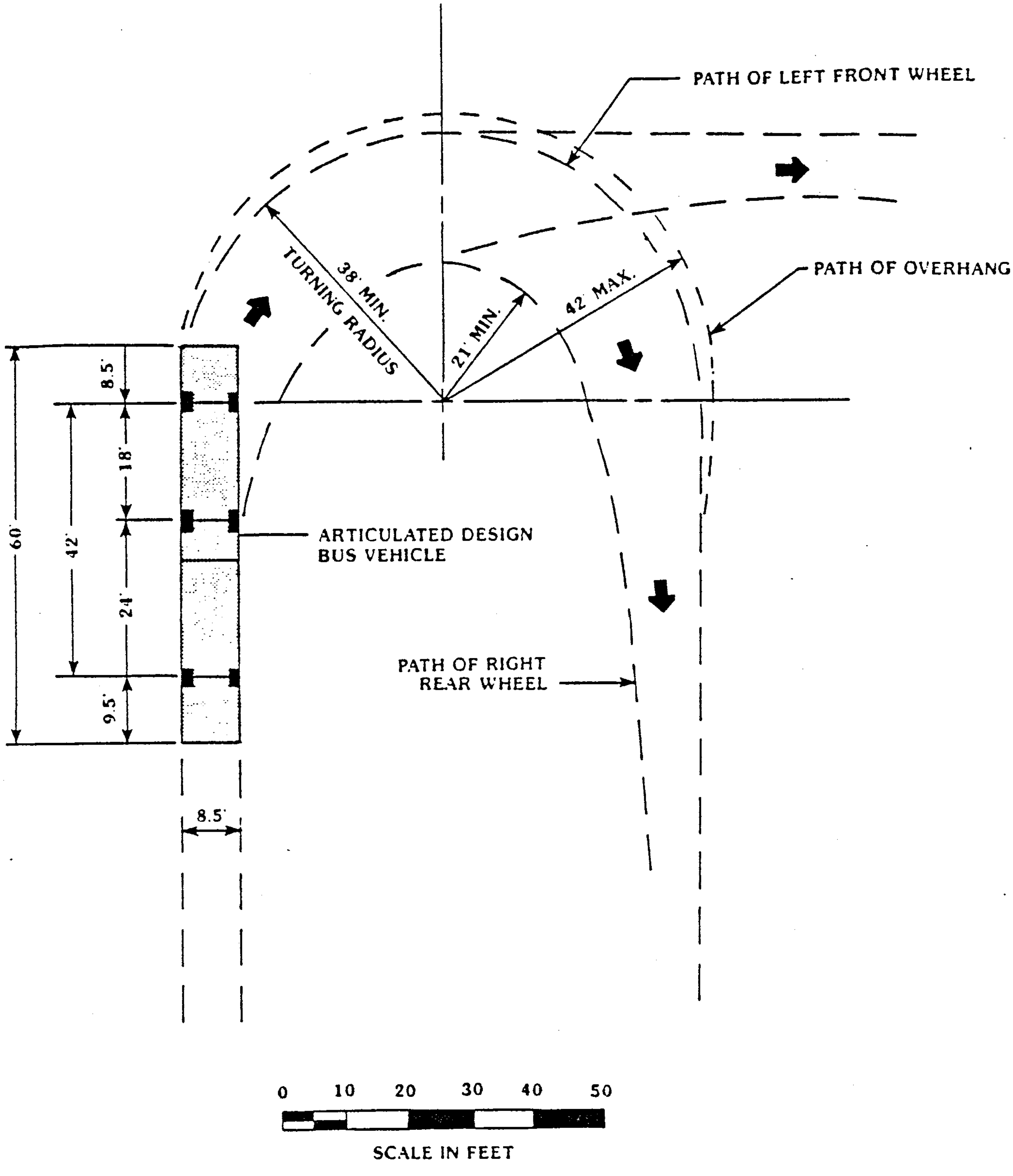
Overhead clearance should be provided so that damage to tall vehicles and overhead structures is avoided. The amount of clearance required on a roadway is usually a function of the type of roadway. AASHTO (22) recommends an absolute minimum clearance of 14.5 feet and a desirable minimum clearance of 16.5 feet for freeways and arterial streets. These minimum clearance values, are based on the maximum allowable vehicle height plus 1 foot, and future resurfacing. Collector streets and local streets are not required to maintain such high clearances; however, it is desirable to maintain these clearances since collectors do experience some truck traffic, as do local streets (21).

Overhead clearances recommended by transit agencies are generally lower than the AASHTO standards. For example, Phoenix (14) suggests that overhead obstructions should be a minimum of 12 feet above the street surface and, to avoid being struck by a bus mirror, no obstruction should be located within two feet of the street curb. Because the maximum bus width (including mirrors) is about 10.5 feet, a traffic lane used by buses should be large enough to permit adequate distances from obstructions and be no narrower



Source: Reference 1.

Figure 3. Minimum Turning Path Design Template for 40-Foot Bus



Source: Reference 1.

Figure 4. Minimum Turning Path Design Template for Articulated Bus

than 12 feet in width (10, 13, 14, 17, 20, 21). The lane widths recommended by most transit agencies are consistent with the preferred lane widths recommended by AASHTO (22) for various urban street classifications (see Table 7).

Table 7. Recommended Urban Street Lane Widths, AASHTO

Road Classification	Lane Width (ft)	Additional Auto Parking Width (ft) (As Needed)
Local	11 (Minimum) 12 (Preferred)	7 (Residential Areas)* 9 (Commercial & Industrial Areas)**
Urban Collector	11 (Minimum) 12 (Preferred)	7-10 (Residential Areas)* 8-10 (Commercial & Industrial Areas)**
Urban Arterial	12	Restricted

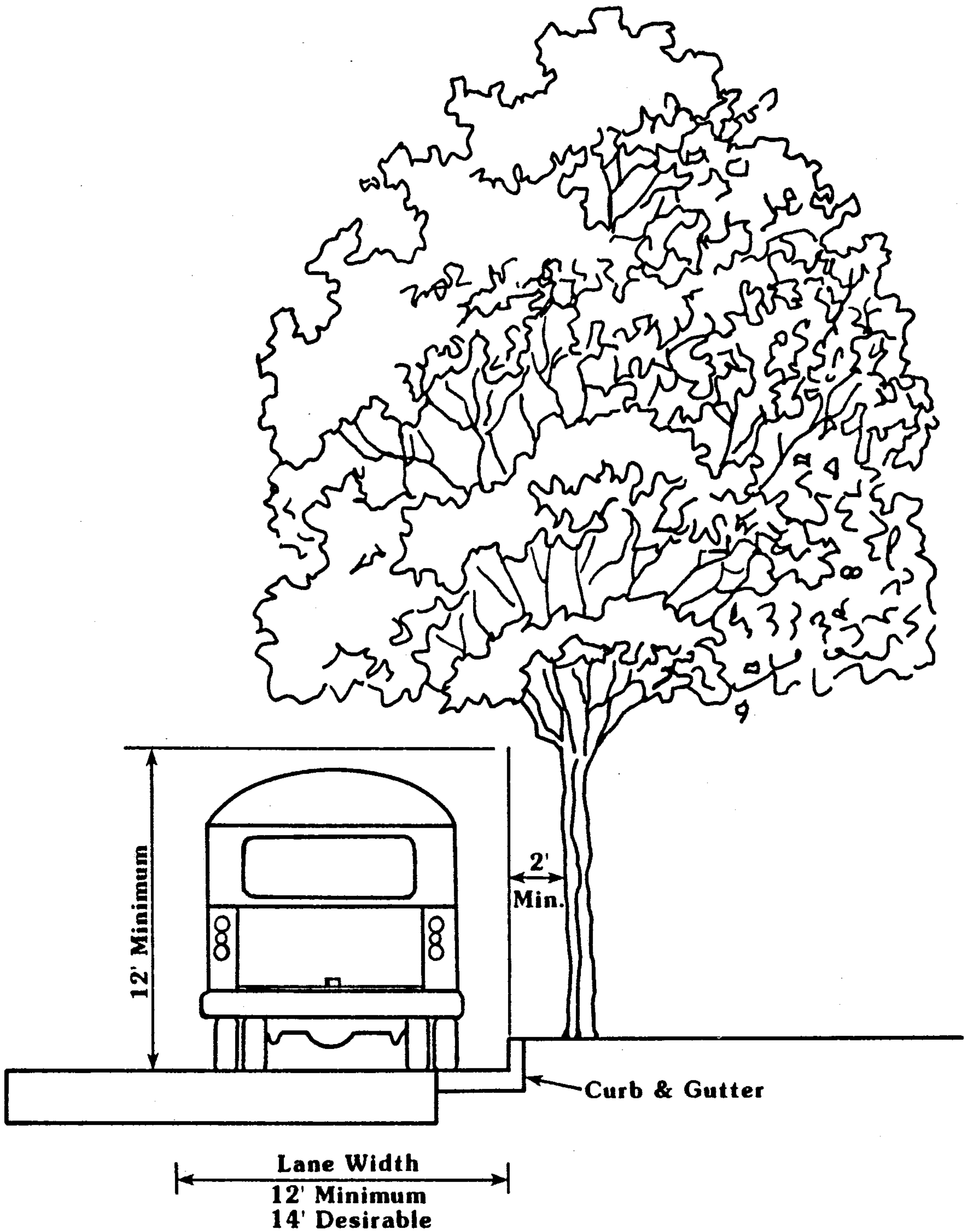
*Provided as needed on one or both sides of roadway.
**Usually provided on both sides of roadway.

Source: Reference 22.

Desirably, the curb lane width (including the gutter) should be 14 feet to allow buses freedom of movement and to avoid sideswipe accidents (14). Representative clearance requirements for buses using a curb lane are shown in Figure 5.

Roadway grades should be selected to provide uniform operation throughout. Determination of roadway grade is related to topography and the potential to balance quantities of cut and fill material, while still providing a roadway that can be traversed safely and economically (10).

The Orange County Transit District (17) recommends that in an uphill direction, the maximum sustained grade for roadways designated for 40-foot buses should not exceed 6 percent. For the downhill direction, the roadway should be designed with a maximum 12 percent grade. In some cases where the roadway is steep, a climbing lane for buses and trucks will be needed. In addition, abrupt changes in grade should be avoided, due to bus overhangs and ground clearance requirements.



Source: Reference 14.

Figure 5. Representative Clearance Requirements for Buses Using a Curb Lane

The Maryland DOT (10) recommends roadway grades as a function of posted speeds and roadway classification (Table 8). Typically the desirable grades recommended for 40 foot buses are in the range of 6% to 8% (1, 10, 14, 17, 20, 21).

Table 8. Recommended Roadway Grades for 40 Foot Buses, Baltimore

Roadway Classification	Maximum Grade	Desirable Grade
Collector	7%	6%
Local 40 MPH (Posted)	8%	6%
Local 30 MPH (Posted)	9%	7%

Source: Reference 10.

The maximum grade for driveways is determined by the clearance of the vehicle undercarriage and the wheelbase length. It is therefore the change in grade which is critical and not simply the grade of the driveway. If this change in grade is too steep, the front bumper, rear bumper or midsection may scrape the pavement, causing damage to the bus, the pavement, or both (15).

2.3.3 Intersection and Driveway Design

The corner radius at street intersections is a common transit related design problem. Some of the advantages of a properly designed corner curb radius are (10, 14, 15, 17, 20, 21, 23):

- Less bus/auto conflict at heavily used intersections
- Higher bus operating speeds and reduced travel time
- Improved bus rider comfort

The design of intersection radii should be based on the following elements (10, 14, 15, 17, 20, 21, 23):

- Bus turning radius
- On street parking

- Right-of-way/building restrictions
- Allowable bus encroachment into other traffic lanes
- Angle of intersection
- Width and number of lanes on the intersecting street
- Operating speed and speed reductions
- Pedestrians

Generally, curb return radii are determined from the effective width of the departing and entering roadway. The effective width of the departing roadway is determined by measuring the distance from the outside edge of the right-most lane that the bus can turn right from to the curb face. The effective width of the entering roadway is determined by measuring the distance from the left-most point that the bus is allowed to reach to the right-most portion of the traveled way.

Table 9 shows recommended radii at intersections for four types of parking arrangements frequently encountered. Use of radii less than the recommended minimums shown in Table 9 could result in transit vehicles encroaching into adjoining lanes or transit vehicles mounting adjacent curbs. Additionally, if parking is allowed on either the approach street or the cross street, certain parking restrictions should be enforced to avoid conflicts and facilitate bus turning movements. On the approach, parking should be prohibited a minimum of 15 feet from the point of curve of the radius. On the cross street, parking should be prohibited a minimum of 40 feet from the point of tangent of the curb radius (10).

Table 9. Typical Intersection Curb Radii for Buses

Parking Configuration	Radii (ft)	
	Minimum	Desirable
No On-Street Parking	40	50
On Street Parking Before the Turn	25	35
On-Street Parking After the Turn	35	40
On-Street Parking Before and After the Turn	25	25

Sources: References 10, 14, 15, 17, 20, 21, 23.

It is important to note that as the intersection radii increases, the pedestrian crossing distance also increases. The increased pedestrian walking time should be allowed for at signalized intersections with the larger radii (23).

The design of entrance radii is similar to that of street intersections, but lower traffic and pedestrian volumes afford greater bus encroachment allowances. Figure 6 shows typical entrance radii for several conditions with respect to parking, entrance widths and encroachment (15).

Although most streets form 90 degree intersections, there are many intersections that are skewed. Figure 7 shows curb return radii for skewed intersections used by the Alameda-Contra Costa Transit District.

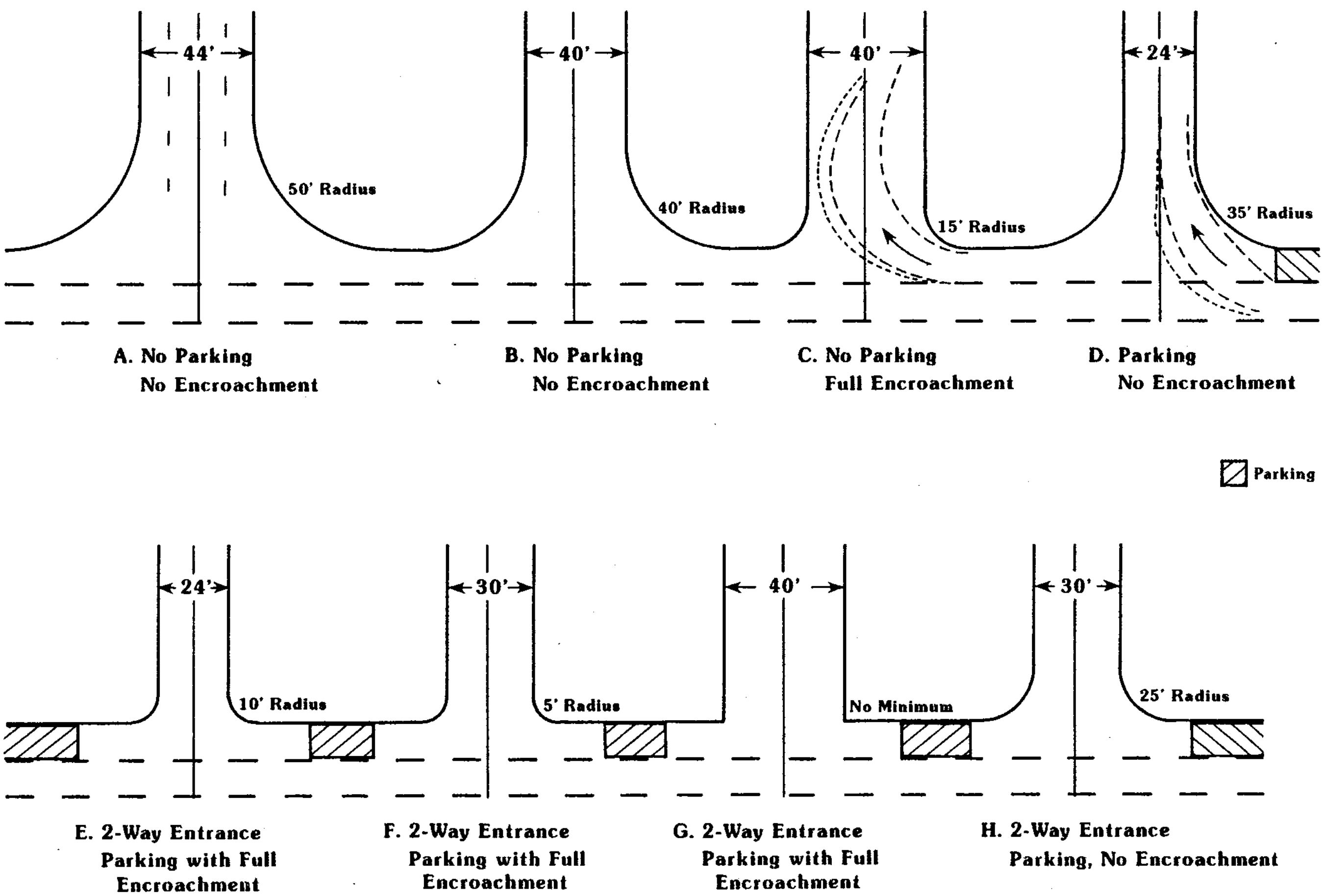
An alternative to the simple curb return radii outlined above is the compound radius. Examples of compound curb radii are shown in Figure 8.

2.3.4 Pavement Design

The pavement design for roadways used by buses is similar to normal pavement design. The following factors are important in designing an adequate pavement structural section (10, 14, 15, 21):

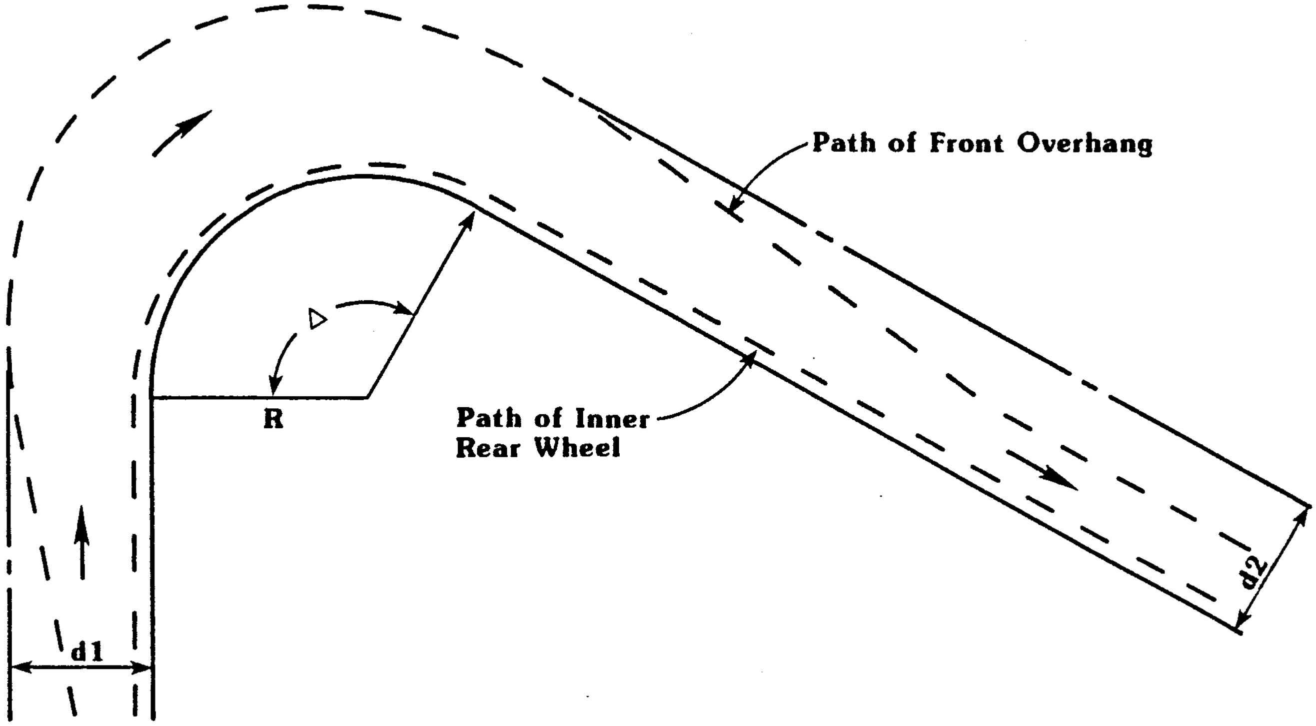
- Bus axle weights
- Projected bus volumes
- Pavement material strengths
- Subgrade soil conditions

Roadway pavements used by buses need to be of sufficient depth to accommodate bus axle loads approaching 25,000 pounds (14, 15, 22). The detailed design of pavement sections will depend upon site specific soil conditions and should follow local pavement design practices.



Source: Reference 15.

Figure 6. Typical Entrance/Driveway Radii for Buses



Occupied Width of Cross Street

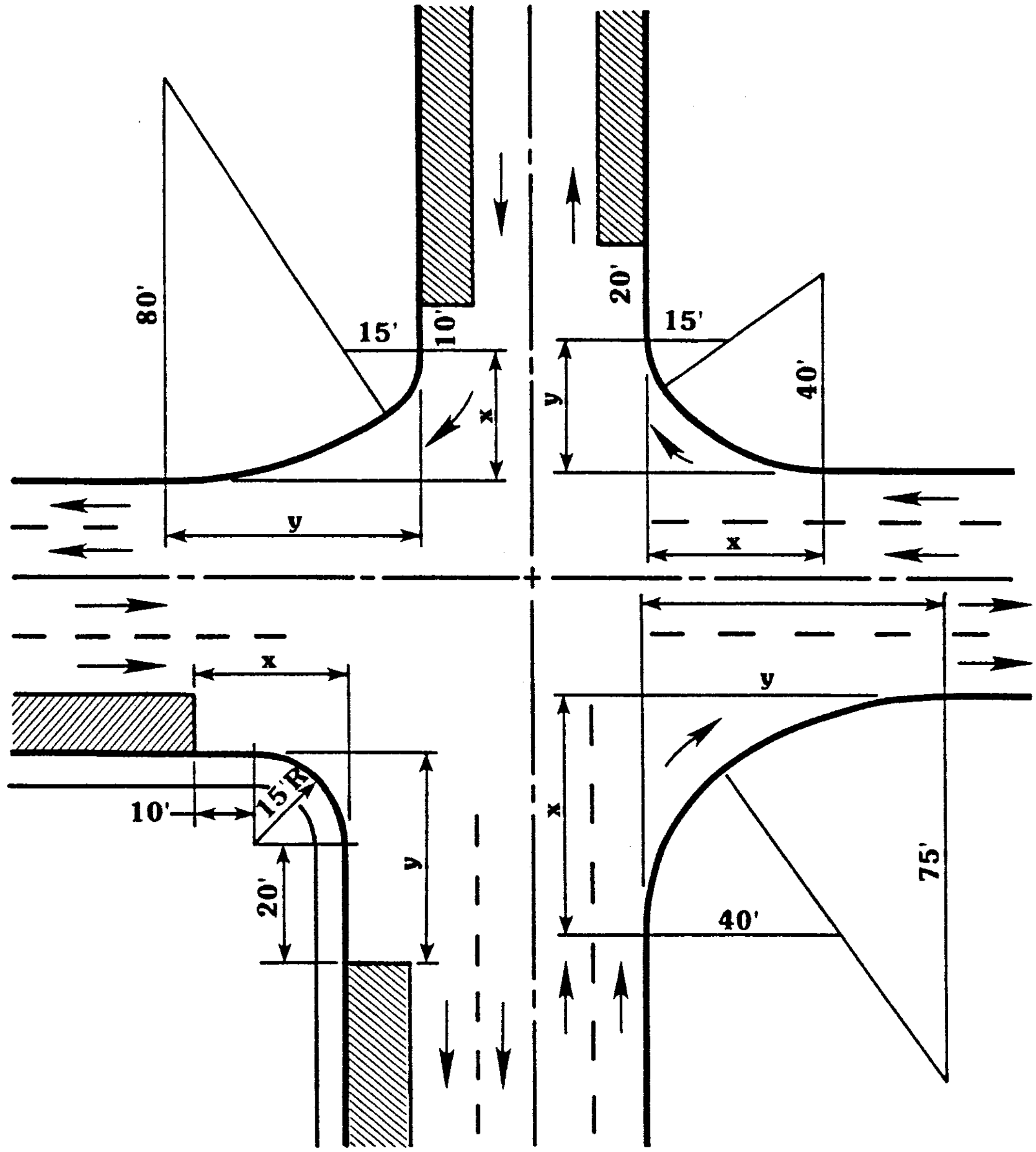
Angles	d2 when d1 = 12'				
	R = 15'	R = 20'	R = 25'	R = 30'	R = 40'
30°	22	19	19	19	18
60°	28	26	24	23	22
90°	38	33	30	25	21
120°	46	40	32	26	19
150°	48	40	32	22	17

Occupied Width of Main and Cross Street

Angles	d1 = d2				
	R = 15'	R = 20'	R = 25'	R = 30'	R = 40'
30°	17	17	17	17	17
60°	21	20	20	19	18
90°	23	22	22	21	18
120°	28	25	23	19	18
150°	28	25	23	18	16

Source: Reference 23.

Figure 7. Curb Return Radii for Skewed Intersections



		Distance from P.I.*	
		X	Y
A	PARKING - Approach	25'	50'
B	PARKING - Away	35'	24'
C	PARKING - Approach & Away	25'	35'
D	NO PARKING	48'	61'

* P.I. = point of intersection between x and y

▨ Parking

Source: Reference 17.

Figure 8. Typical Compound Curb Return Radii

Pavements in bus stop areas, especially in areas of high bus volumes, should be given special consideration. While pavements at bus stop areas can be either asphalt or concrete, a concrete pad has the advantage of resistance to shoving, rutting, and petroleum deterioration. The disadvantage of concrete pads is the higher initial construction cost (15).

2.3.5 Bus Stops, Turnouts and Turnarounds

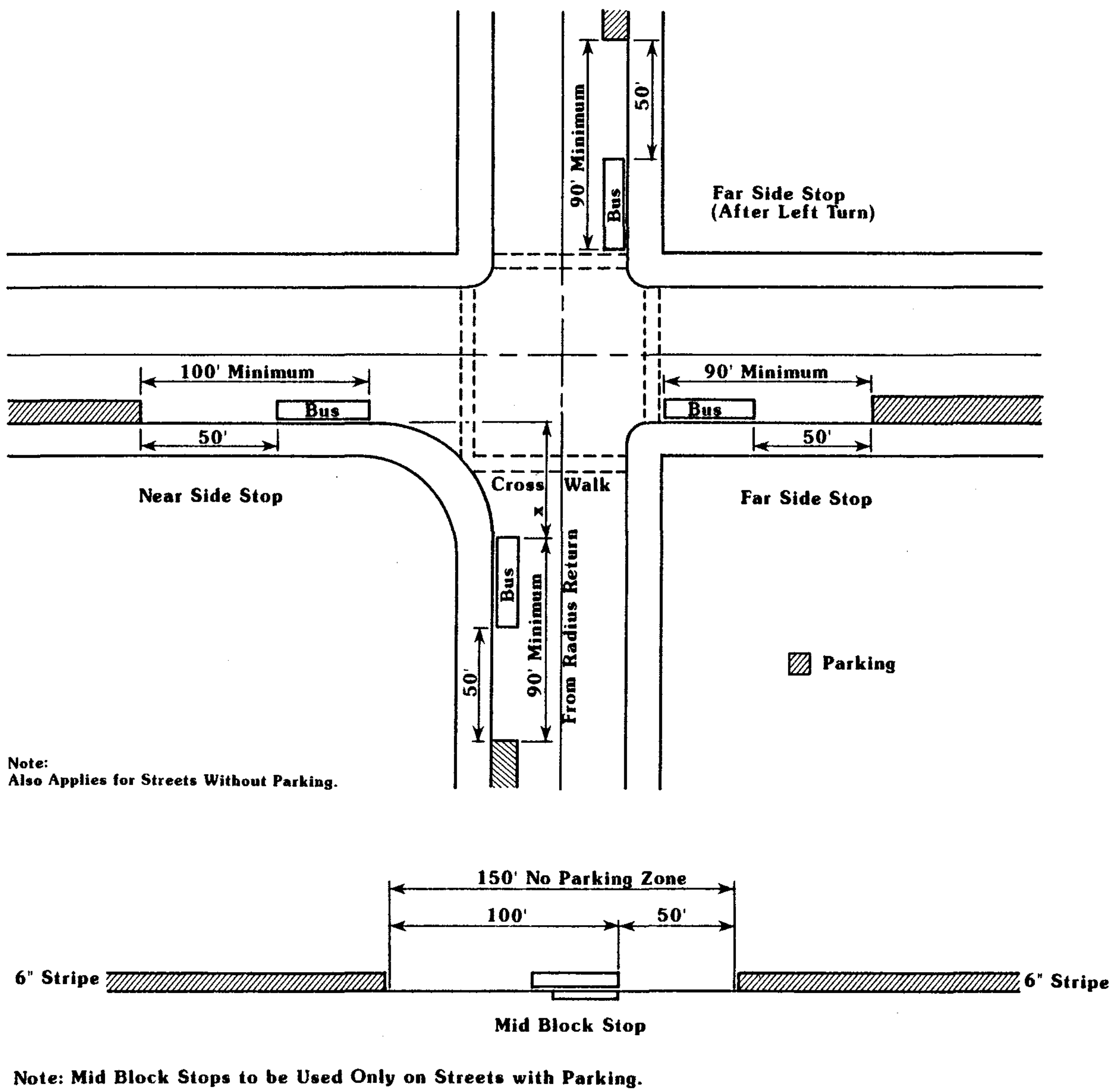
Bus stops are intended to facilitate passenger loading and unloading adjacent to the street curb. While bus stops can be located at near-side, far-side, or mid-block locations, the far-side location is generally preferred (see Section 2.2.2).

Although a range of values for bus stop lengths was found in the survey of transit agencies (Table 10), most agencies suggested that for 40-foot transit vehicles, bus stop zones for near-side and far-side stops should be a minimum of 115 feet long and preferably 160 feet long. Bus stop zones for mid-block stops should be a minimum of 130 feet long and preferably 170 feet long. Sidewalks and wheelchair access ramps should be provided at all stops. For articulated bus stop zones, the bus berth position should be 70 feet long (as compared to 50 feet for the 40-foot vehicle), thereby increasing the overall length of the zone by 20 feet. Representative dimensions for bus stop zones are illustrated in Figure 9 (15, 17).

Table 10. Range of Bus Stop Lengths Identified from Survey of Transit Agencies

Bus Stop Location	Bus Stop Length (Range)
Midblock	130' - 200'
Nearside	90' - 160'
Farside	80' - 115'
Farside after Right Turn	90' - 135'
Farside after Left Turn	90' - 115'

At some bus stops, more than one bus may be at the stop at a given time. The number of bus loading positions required depends upon 1) the rate of bus arrivals, and 2) passenger service time at the stop (23). Table 11 presents suggested bus stop capacity requirements based on a range of bus flow rates and passenger service times.



Source: Reference 15.

Figure 9. Typical Dimensions for On-Street Bus Stops

Table 11. Suggested Bus Stop Bay Requirements

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

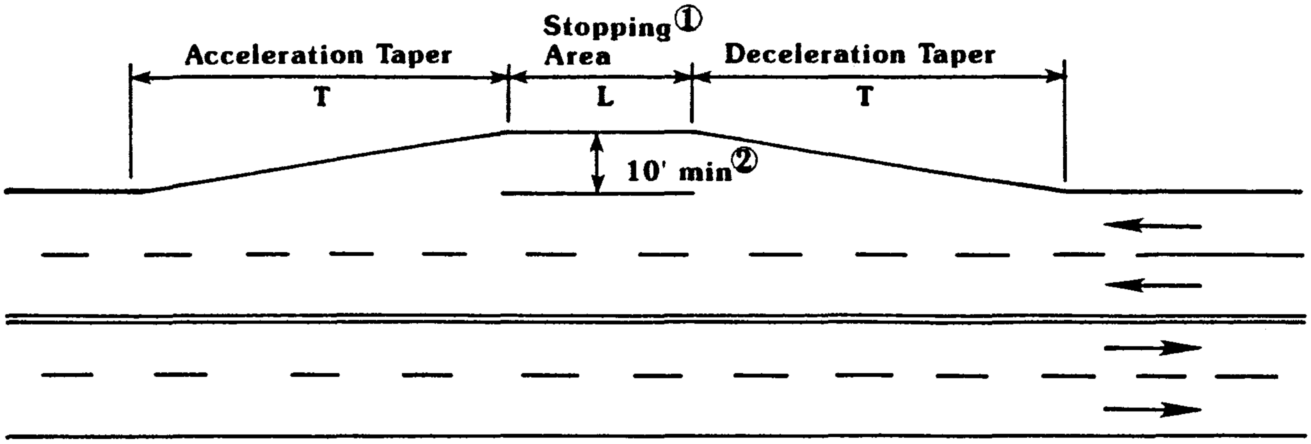
Source: Reference 23.

A bus turnout is defined as a specially constructed area off the normal roadway section, provided for bus loading and unloading. Turnouts are provided primarily on high volume or high speed roadways to provide for safe, efficient operation of bus stops. Additionally, bus turnouts are frequently constructed in heavily congested downtown and shopping areas where large numbers of passengers may board and disembark (23).

The basic requirement for a bus turnout is that the deceleration, standing, and acceleration of buses be accomplished on pavement areas clear of and separated from the through traffic lanes (15, 17, 23).

The speed-change sections should be long enough to enable the bus to leave and enter the through traffic lanes at approximately the average running speed of the roadway without undue discomfort (sidesway) to passengers. The length of acceleration lanes for bus turnouts should be well above the normal minimum values, as the buses start from a standing position and the loaded bus has a lower acceleration capability than passenger cars. Normal length deceleration areas are suitable. Table 12 shows typical bus turnout design speeds for various street classifications. Typical bus turnout dimensions are shown in Figure 10.

A turnaround is a roadway designed for use as a transit vehicle layover area and for transit vehicles to reverse direction (turn-around) at the end of a route. The Metropoli-



① L = 50B + 20A, A = No. of articulated buses, B = No. of buses which will simultaneously be at the stop.

② Does not Include Gutter Width. For Speeds Over 30 mph, a 12' Minimum is Recommended

Design Speed	Taper Length, T	
	Minimum	Recommended
<20	50'	150'
20-30	50'	150'
30	100'	220'
35		300'
40		400'
45		500'
50		620'
55		750'

Figure 10. Typical Bus Turnout Dimensions

Table 12. Suggested Bus Turnout Design Speeds

Street Classification	Non-Peak Hour Approach Speed (MPH)	Design Speed (MPH)
Local (urban area)	1 to 20 MPH	30
Minor Arterial	20 to 30 MPH	35
Major Arterial	20 to 30 MPH	40-50
Expressway	30 to 40 MPH	45 and over

Source: Reference 15.

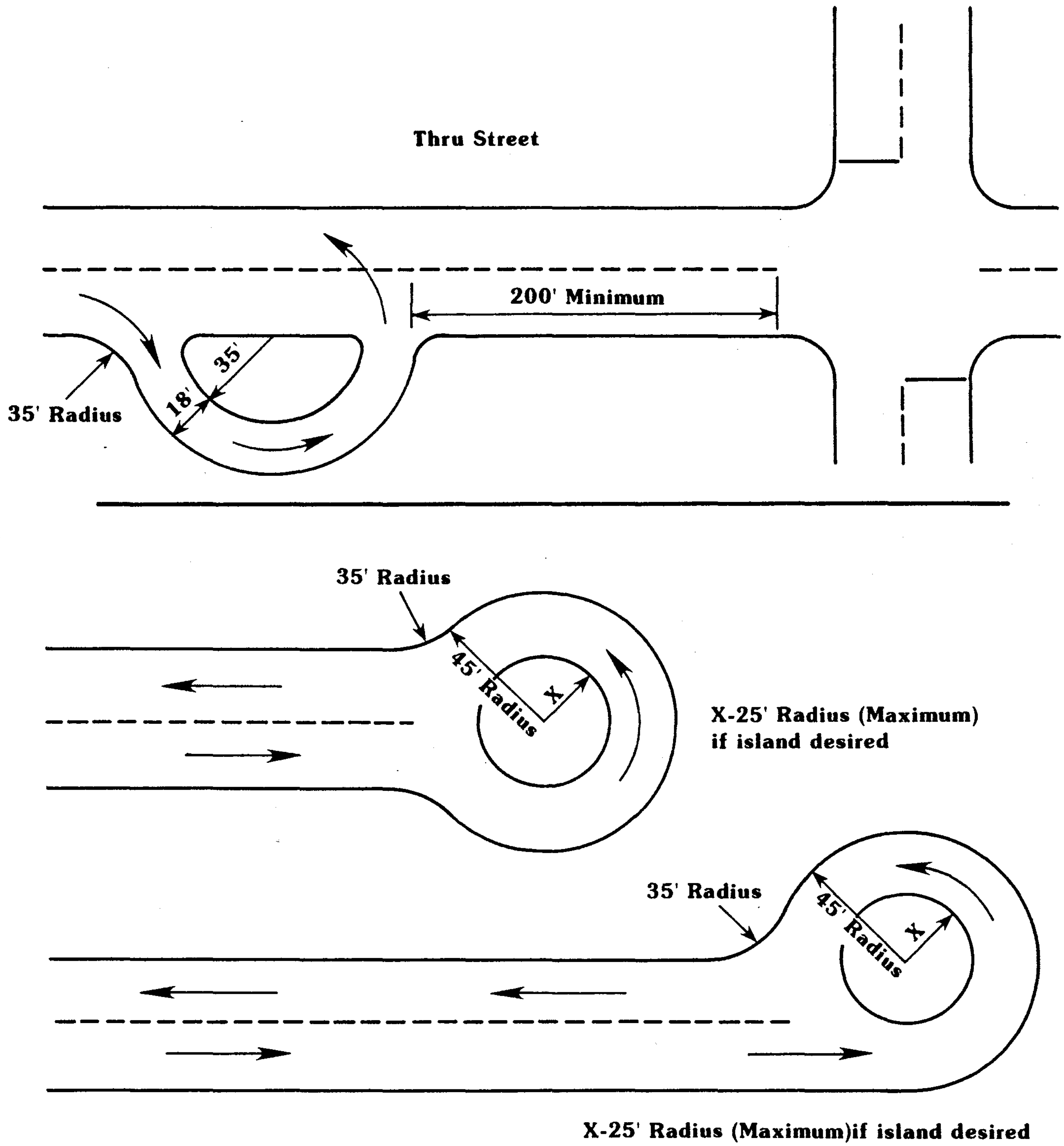
tan Transit Commission of St. Paul suggests the following situations where turnarounds should be considered (18):

- On-street layovers cannot be tolerated because the roadway does not allow for vehicle parking.
- The intersecting minor streets cannot accommodate the axle weights of a bus.
- The neighboring environment is sensitive to bus operations.
- The on-street routing necessary for the bus to reverse directions would require an unacceptable amount of unproductive mileage.
- The current layover or route reversal maneuver, though once acceptable, has become hazardous due to increases in traffic or due to other changes which have been made in the roadway system.

Transit vehicle turnarounds should be designed to discourage use by non-transit vehicles and should be wide enough to permit transit vehicles to safely pass a stalled vehicle. Typical bus turnaround configurations are shown in Figure 11.

2.3.6 Summary

The preceding sections of this report have presented a review of policies and guidelines for the design of transit related roadway improvements. Table 13 presents a



Source: Reference 24.

Figure 11. Typical Bus Turnaround Configurations

summary of typical values for the principal bus facility design guidelines reviewed in this section of the report.

Because the guidelines presented in this section of the report relate directly to roadway design, they should be of particular interest to the Department. However, it is important to note that these guidelines are intended primarily as representative values that may need to be modified to reflect local conditions and practices. The MTAs that responded to the survey were quick to point out that the guidelines are intended to provide guidance in developing transit facility designs rather than as specific engineering designs of the various facilities. Many of the MTAs indicated that the guidelines were developed to encourage the inclusion of transit related facilities with other street improvement projects undertaken by the State, cities, counties, and private developers.

Table 13. Summary of Typical Bus Facility Design Guidelines

Design Element	Typical Values
Bus Design Vehicle Dimensions	
Height	11 feet
Width (including mirrors)	10 feet 6 inches
Length	60 feet
Heaviest Axle Weight	25,000 pounds
Bus Turning Radius	
Exterior	55 feet (outside body overhang)
Interior	30 feet
Curb Radius	50 feet for buses turning into single traffic lane without encroachment. 30 feet desirable when turning into two or more traffic lanes.
Bus Clearance Requirements	Overhead obstructions - 12 foot minimum above street surface. No obstructions 2 feet from edge of street. Curb lane width - 12 foot minimum, 14 foot desirable.
Grades	6% to 8%

2.4 Bus Service Operations

2.4.1 Capacity

The percentage of buses (and other heavy vehicles) in the traffic stream is an important parameter in designing highways. Vehicles of different sizes and weights have different operating characteristics which must be considered in highway design. Besides being heavier, buses generally are slower, occupy more roadway space, and consequently impose a greater traffic effect on the highway than do passenger vehicles. The overall effect on traffic operations of one bus is often equivalent to several passenger cars. Thus, the larger the proportion of buses in a traffic stream, the higher the traffic load and the greater the highway capacity required (22). Current practice is to adjust for the presence of buses in the traffic stream using the procedures and factors presented in the Highway Capacity Manual (25). The basic transit capacity considerations presented in the Highway Capacity Manual are outlined below.

> The reductive effect of buses on vehicular capacity varies according to the method of operation. The time available for other vehicles generally will be reduced by the time preempted by buses. This time loss depends on the number of buses in the traffic flow and their service time requirements at stops (25).
>
> For uninterrupted flow, buses are the equivalent of 1.5 passenger car units in the lane where they operate. At bus stops, buses have a greater reductive effect because of the time involved in discharging and receiving passengers. The equivalency factors for these conditions depend on the specific duration of the bus stop and its reductive effect on arterial street green time (25).
>
> The reductive effects of local transit buses on other vehicles in an arterial street lane can be estimated as follows (25):

1. Where the buses stop in a lane that is not used by moving traffic (e.g., in a curb parking lane), the time loss to other vehicles is approximately

3 to 4 sec per bus. For this case, buses would either accelerate or decelerate across the intersection, thereby reducing the impeditive effects to other traffic.

2. Where buses stop in a normal traffic lane, the time loss involves the dwell time* for buses plus a time loss for stopping and starting, and the associated queuing effects on other traffic. The time loss can be estimated from the following equation for the lane in which the buses operate.

$$T_L = (g/C) \times N \times (D + L)$$

where:

T_L = time loss, in sec per hr;
g/C = green time/cycle time ratio;
N = buses per hour that stop;
D = average dwell time, in sec; and
L = additional time loss due to stopping, starting, and queuing, in sec (L = 6 to 8 sec, assuming average conditions)

Equivalent passenger car units derived from this equation for various rates of vehicle flow, dwell times, g/C ratios, and bus volumes are given in Table 14. Alternatively, the (effective) green for the lane in which the buses operate can be obtained by deducting the time loss. The data are precise for near side bus stops and a reasonable approximation for far side stops (25).

Suggested arterial street bus capacity ranges based on actual operating experience are given in Table 15. This table gives representative service volumes for downtown streets and arterial streets leading to the city center for each level of service. Where stops are not heavily patronized, as along outlying arterial streets, volumes could be increased by about 25 percent (25).

---

*Dwell Time is the time, in seconds, that a transit vehicle is stopped for the purpose of serving passengers. It includes the total passenger service time plus the time needed to open and close doors (25).

Table 14. Passenger Car Equivalency of Urban Buses at Signalized Intersections
(Applies Where Buses Block Cars)

Duration of Stop (Seconds)	Percent Green Time on Street With Buses			
	30%	40%	50%	60%
5	2	2	3	3
10	2	3	4	5
15	3	4	5	6
20	4	5	7	8
25	5	6	8	9
30	5	7	9	11
45	8	10	13	15
60	10	13	19	20

Note: Computations are based on the following relationship: Pass. car equivalent per bus = $(g/C)\ [(D+6)/h]$
where:

h = 2 seconds per car;
g/c = green time/cycle ratio;
6 = additional time loss due to starting, stopping, and queuing, seconds; and
D = dwell time per bus, seconds.

Source: Reference 25.

Table 15. Suggested Bus Flow Service Volumes for Planning Purposes[a]
(Flow Rates for Exclusive or Near-Exclusive Lane)

Level of Service	Description	Buses/Lane/Hour	MidValue
Arterial Streets			
A	Free Flow	25 or less	15
B	Stable Flow, Unconstrained	26 to 45	35
C	Stable Flow Interference	46 to 75	60
D	Stable Flow Some Platooning	76 to 105	90
E	Unstable Flow, Queuing	106 to 135	120
F[b]	Forced Flow, Poor Operation	over 135[c]	150c
Main CBD Street			
A	Free Flow	20 or less	15
B	Stable Flow, Unconstrained	21 to 40	30
C	Stable Flow, Interference	41 to 60	50
D	Stable Flow, Some Platooning	61 to 80	70
E	Unstable Flow, Queuing	81 to 100	90
F[b]	Forced Flow, Poor Operation	over 100[c]	110[c]

[a]These service volumes may be used for planning purposes. More precise values for operations and design purposes should be computed from the capacity relationships and procedures set forth in Chapter 12 of the Highway Capacity Manual (25).

[b]The values for level of service F should not be used for planning or design. They are merely given for comparative purposes (25).

[c]Results in more than one-lane operation.

Source: Reference 25.

2.4.2 Bus Priority Measures

Bus priority measures can be effective in improving service to specific activity centers by reducing traffic delays. A vast body of literature exists concerning the state of the art, planning guidelines, and operational experiences of various arterial street bus priority measures (e.g., see References 19, 25-28). Hence, only a brief overview of these measures is presented in this report.

Table 16 provides examples of the types of bus priority treatments that have been implemented on arterial streets. General planning guidelines for assessing the applicability of those treatments are also outlined in Table 16.

Planning and implementing bus priority measures require a reasonable concentration of bus services, a high degree of bus and auto congestion, and community willingness to support public transport. Planning calls for a realistic assessment of demands, costs, benefits, and impacts. Measures should be applied that (19):

- Alleviate existing bus service deficiencies,
- Achieve attractive and reliable bus service,
- Serve demonstrated existing demands,
- Provide reserve capacity for future growth in bus trips,
- Attract auto drivers, and
- Relate to long-range transit improvement and downtown development programs.

Key factors include the intensity and growth prospects of the city center; the historic and potential future reliance on public transport; street width, configuration, continuity, and congestion; the suitability of existing streets and expressways for express bus service; bus operating speeds and service reliability in the city center; availability of alternative routes for displaced auto traffic; locations of major employment centers in relation to bus routes; goods and service vehicle loading requirements; express and local bus routing patterns; bus passenger loading requirements along curbs; and community attitudes and resources (19).

Table 16. Applicability of Arterial Bus Priority Treatments

Type of Treatment	General Applicability To: Local Bus	Limited-Express Bus	Planning Period (Years)	Design-Year Conditions: One-Way Peak-Hr Bus Volumes	One-Way Peak-Hr Bus Passenger Volumes	Related Land-Use and Transportation Factors
Bus streets	X	X	5-10	20-30	800-1200	Commercially oriented frontage
CBD curb bus lanes, main street	X		5	20-30	800-1200	Commercially oriented frontage
Curb bus lanes	X		5	30-40	1200-1600	At least 2 lanes available for other traffic in same direction
Median bus lanes	X	X	5	60-90	2400-3600	At least 2 lanes available for other traffic in same direction; ability to separate vehicular turn conflicts from buses.
Contra-flow bus lanes, short segments	X		5	20-30	800-1200	
Contra-flow bus lanes, extended	X	X	5	40-60	1000-2400	At least 2 lanes available for other traffic in opposite direction. Signal spacing greater than 500-ft intervals.
Bus turnouts	X		5	10-15	400-600	Points of major passenger loadings on streets with more than 500 peak-hour autos using curb lane.
Bus preemption of traffic signals[a]	X		1-5	10-15	400-600	Wherever not constrained by pedestrian clearance or signal network constraints.
Special bus signals and signal phases, bus-actuated[a]	X		1-5	5-10	200-400	At access points to bus lanes, busways, or terminals; or where special bus turning movements must be accommodated.
Special bus turn provisions	X		1-5	5-10	200-900	Wherever vehicular turn prohibitions are located along bus routes.

[a]Also see Section 2.4.4 of this report.

Source: Adapted from Reference 19.

2.4.3 Signs and Pavement Markings

Proper signs at transit facilities is an important element of good transit service. Signs serve as a source of information to the patrons and operators regarding the location of bus stops, park and rides, etc., and is an excellent marketing tool to promote transit use (10).

While the signs used by the individual transit agencies differ in terms of color, logo and message content, the typical transit sign is reflectorized for nighttime visibility and double faced for visibility in both directions leading to the bus stop. The standard sign identifies the location as a bus stop and includes the name and number of the bus route(s) using the stop and the transit information telephone number. The sign may include on the front-side a standard (but smaller in size) "no parking" symbol (14). While the bus stop sign is generally not a traffic sign (it is not displayed to regulate, warn or inform motorists), this is not always the case. The Texas Manual on Uniform Traffic Control Devices (29), for example, includes a "no parking" sign (a traffic sign) with the words "Bus Stop."

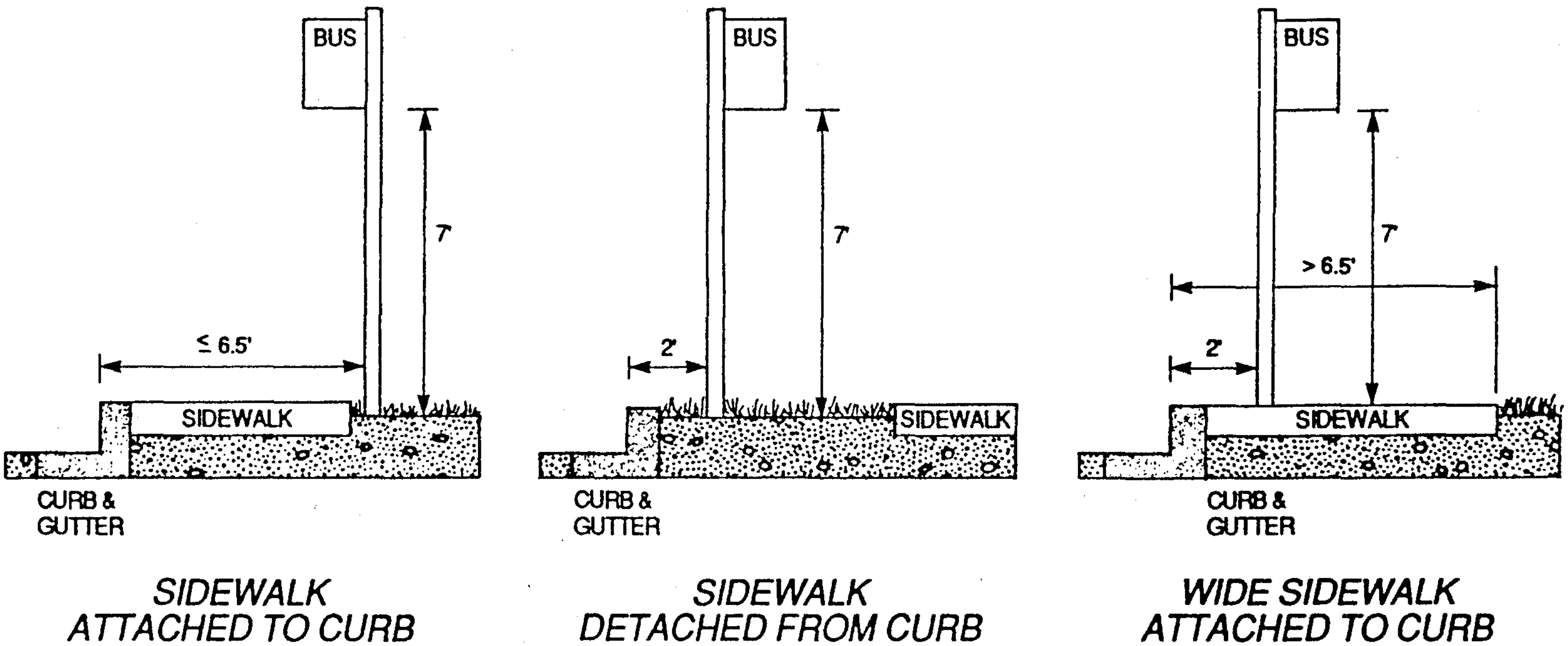
Bus stop signs should be placed at the location where people will board the front door of the bus. The bus stop sign indicates the area where passengers should stand while waiting for the bus and serves as a guide for the bus operator in positioning the vehicle at the stop.

Bus stop signs should be installed with their own sign post and should not be obstructed by trees, buildings or other signs (10, 14, 15, 17). The bottom of the sign should be at least 7 feet above ground level and should not be located closer than 2 feet from the curb face (14, 17, 23). Figure 12 shows typical bus stop sign placement standards.

Pavement markings associated with bus stops are generally installed and maintained by local authorities. The most common is the yellow painted curb at bus stops. Stop lines and/or crosswalks are also desirable, as most bus stop locations are at intersections. Pavement markings for priority lanes, such as for high occupancy vehicles or buses, should be installed by local authorities (18).

2.4.4 Traffic Signals

Bus stops are frequently located at signalized intersections. Generally, the intersections are of two major streets with the potential for transfers of passengers between buses or for larger accumulations of passengers. Traffic signal design should accommodate



Source: Reference 14.

Figure 12. Guidelines for Bus Stop Sign Placement

buses and bus passengers. The Metropolitan Transit Commission (St. Paul, MN) recommends the following guidelines concerning traffic signals and transit operations (18):

- Location of bus stops should be coordinated with traffic signal pole and head location. Bus stops should be located so that buses do not totally restrict visibility of traffic signals from other vehicles. [As noted in Section 2.2.2, these problems can be effectively addressed by using far-side bus stops.]

- All bus passengers become pedestrians upon leaving the bus. It is very desirable that WALK and DON'T WALK indications be in place at signalized intersections at bus stops.

- When traffic actuated signals are installed, pedestrian push buttons should also be installed to activate the WALK and DON'T WALK lights. Without push buttons, pedestrians are totally dependent upon vehicles for actuating the signal. Push buttons should be mounted on signal poles and pedestals or on separate push button stations convenient to cross walks and the bus stop locations.

- Near side stop areas often are between the advance detectors for a traffic signal and the crosswalk. Location of a detector at the bus stop will enable the bus to actuate the detector and the signal controller to obtain or extend the green light. Lack of a detector will force a bus to wait until other traffic approaching from the same direction actuates the signal controller.

- Timing of traffic signals should also reflect the specific needs of buses. Clearance intervals should be designed to reflect the deceleration characteristics of loaded buses as well as trucks and passenger vehicles. Longer clearance intervals may be required on higher speed roadways with significant bus traffic. Vehicle passage times must provide adequate time for a bus to accelerate from the bus stop into the intersection. Intersections adjacent to railroad tracks should have timing and detection that reflect the need for buses to stop at the railroad crossings.

- Preemption of traffic signals by buses is technically possible. The buses may either call for a green light for its direction of approach or may extend the green light to enable the bus to proceed through without stopping.

Because a significant amount of delay in urban areas is caused by traffic signals, a variety of schemes to give buses priority at traffic signals have been proposed. Urbanik (30) defines two types of priority treatments for buses at traffic signals, passive priority and active priority. Passive priority entails globally altering the timing patterns of all intersections in the signal system to acknowledge the presence of buses in the network. No changes are made on a cycle by cycle basis due to the presence or absence of buses at any point in time. Active priority or preemption of traffic signals occurs when a signal from a bus overrides the existing pattern and substitutes a new signal pattern benefitting the bus.

Traffic signal preemption can be further divided into two subsets, unconditional and conditional preemption. Unconditional preemption results if preemption is granted whenever a bus requests it, subject only to clearance intervals (pedestrian and vehicle) required for safety. On the other hand, conditional preemption results if other factors (e.g., progression, or time since last preemption) are also considered to determine when or if a preemption will be granted (30).

These schemes to give buses priority at traffic signals can have a significant impact on intersection operations. Consequently, they must be carefully coordinated and designed with the authorities responsible for signal operation.

General guidelines for assessing the potential applicability of traffic signal priority measures were outlined in Table 16 (Section 2.4.2). Specific considerations concerning the implementation of traffic signal priority schemes for buses can be found in References 28 and 30.

2.4.5 Maintenance

Regular maintenance of bus stops is extremely important to the image of the transit system. Shelters or other components of the waiting area that have been damaged should be tended to immediately. A clean and neat bus stop creates a positive impression for transit patrons and the general public.

A typical maintenance visit with frequency of not less than once a week should include a full wash down of the shelter and accessories, removal of all dirt, graffiti and posted material, cleaning of glass surfaces, removal of trash bag and contents, replacement of trash bag, litter pickup at the curb and around shelters up to a distance of ten feet beyond the dimension of the shelter and accessories, removal of other debris that detract from the neat appearance of the general area, manual or chemical removal of weeds, pruning of obstructing tree growth, and touching up of scratches with paint (14).

The majority of bus stops are at sidewalk areas within the public roadway section. Maintenance of these areas is generally the responsibility of the agency responsible for the roadway unless a separate maintenance agreement between the highway and transit agencies is instituted. Maintenance for those areas on private property, such as shopping centers, hospitals, schools, etc., would be the responsibility of the property owner unless a separate maintenance agreement between the property owner and the transit agency is arranged prior to initiation of transit service. Maintenance of passenger shelters is generally the responsibility of the agency that owns the shelter.

In general, the agency responsible for maintenance at bus stop areas is as indicated below (15):

Item	Responsible Agency
Area surrounding bus stop	Local roadway jurisdiction
Bus stop signs	Transit agency
Repainting of painted surfaces	Local roadway jurisdiction
Passenger shelter and pad	Transit agency (or property owner)
Landscaped areas	Property owner

Maintenance for transit-related street improvements generally consists of the following:

- Maintenance of pavement surfaces
- Repainting stop areas
- Snow removal/sanding of roadway and bus turnouts
- Cleaning, repair and replacement of parking control signs
- Cleaning, repair and replacement of bus stop signs.

Routine maintenance of roadways (sanding, sweeping, etc.) and pavement repairs are provided by the agency responsible for the roadway, and maintenance of stop areas, turnouts and turnarounds should be included in that agency's maintenance program. The maintenance of parking control signs should also be provided by the agency responsible for the roadway (15).

2.4.6 Summary

This section of the report has summarized the effects of transit vehicles on roadway capacity and outlined policies, guidelines and strategies for increasing the efficiency of transit operations on surface streets. The review suggests that perhaps the most promising strategies for improving bus services are those relating to priority treatments for transit vehicles. These strategies include reserved bus lanes and priority treatment for transit vehicles at traffic signals.

The planning and implementation of these bus priority treatments requires a high concentration of bus services, high levels of traffic congestion, and community support for transit services. Consequently, to be successful, they must be carefully coordinated with the transportation agencies responsible for traffic control and general roadway planning and operations.

2.5 Light Rail Transit Services

2.5.1 Overview

Light rail transit (LRT) is an electrically-powered vehicle, or train of vehicles, operating over and guided by steel rails. Light rail transit operations range from high-speed, totally grade-separated operations to operations at the city street level in mixed traffic. The LRT vehicle is powered from an overhead wire, and fare collection is typically accomplished on board the vehicle. Access to vehicles may be from ground level or from high-level platforms. Light rail transit provides a wide range of passenger capacities and performance characteristics.

Modern LRT operations have the following general characteristics (31):

- Predominately reserved, but not necessarily grade-separated, rights-of-way.
- Overhead electrical power distribution.
- Single or dual-directional rolling stock.
- Low or dual-level passenger loading platforms at stations or stops.
- Single vehicle operation during off-peak periods with multiple vehicle (train) operation during peak periods.

The following subsections of this report present a summary of the physical and operating characteristics of LRT vehicles and services that are pertinent to the design of transit related street improvements. The information presented is representative of the dimensions and characteristics of LRT vehicles and services currently in operation and is intended to serve as a guide in preliminary studies. Site-specific evaluations should be based on the characteristics and specifications of the LRT vehicle(s) selected for a particular transit system.

This section of the report has been divided into the following subsections: 1) LRT right-of-way categories; 2) Physical and operating characteristics of LRT vehicles; 3) LRT stations; and 4) LRT traffic control strategies. Much of the material in this section has been extracted from previous TTI rail transit studies (31-33), and the reader is referred to these earlier studies for more detailed information on fixed-guideway transit technologies and operations.

2.5.2 LRT Right-of-Way Categories

The broad spectrum of rights-of-way that are normally used by light rail transit distinguishes it from heavy rail. Typically, rail transit rights-of-way may be classified into three categories (31):

- Category A. Exclusive, fully controlled right-of-way with grade separation of vehicular and pedestrian traffic (all heavy rail systems and some portions of light rail systems operate in this category).

- Category B. Semi-exclusive, partially controlled rights-of-way separated from other traffic except at grade crossings (typical of light rail systems).

- Category C. A non-exclusive, shared right-of-way condition (typical of street cars, trolley buses and other buses operating in mixed-flow with automobiles).

Light rail transit systems are characteristically of Category B operation but may employ segments of all three categories. Where Category A rights-of-way are used, light rail transit operation is essentially the same as heavy rail operation in terms of vehicle speed and service.

In terms of the objectives of this study, LRT operations in right-of-way categories B and C are of particular concern. Within these two right-of-way categories, the following four alignment options are the most commonly used (31-38).

Mixed Traffic Operations

The performance and service quality of light rail vehicles operating on paved trackage in mixed street traffic may be significantly affected by the same handicaps that affect urban transit motor bus operations, but with the additional disadvantage of lower maneuverability which results in even greater delays. In the design of new light rail systems, mixed traffic operation that requires the guideway to be shared with rubber-tired vehicles should be minimized. Although several North American cities, including Boston, Portland, New Orleans, Philadelphia, Pittsburgh, San Francisco, and Toronto, currently operate on-street LRT lines, there is very little information on the operating strategies of these systems or on the potential for improving their performance (35).

Reserved LRT Lanes

In areas where restricted street widths dictate a need for continuous access across the guideway for driveway or emergency access, paved track may be utilized that is restricted to light rail vehicles. Common treatments include solid striping separating the track zone from other lanes, diagonal striping across the track zone, or mountable concrete or asphalt medians on which the track is located. Such medians are typically raised several inches above the adjacent street pavement.

Dedicated Street Right-of-Way

The alignment configuration most frequently associated with the light rail mode is the reserved right-of-way located in the center of a street, avenue, or boulevard. This may be accomplished by the use of full curbs with a raised or lowered median area, or by separation of the track and street areas with bushes or other greenery, fencing, or concrete barriers. Sufficient width must also be provided in the median area for stations. Dedicated street rights-of-way offer opportunities for improved operating speeds over those offered by mixed traffic and reserved lane operation since traffic interference and safety hazards are reduced.

Pedestrian Malls

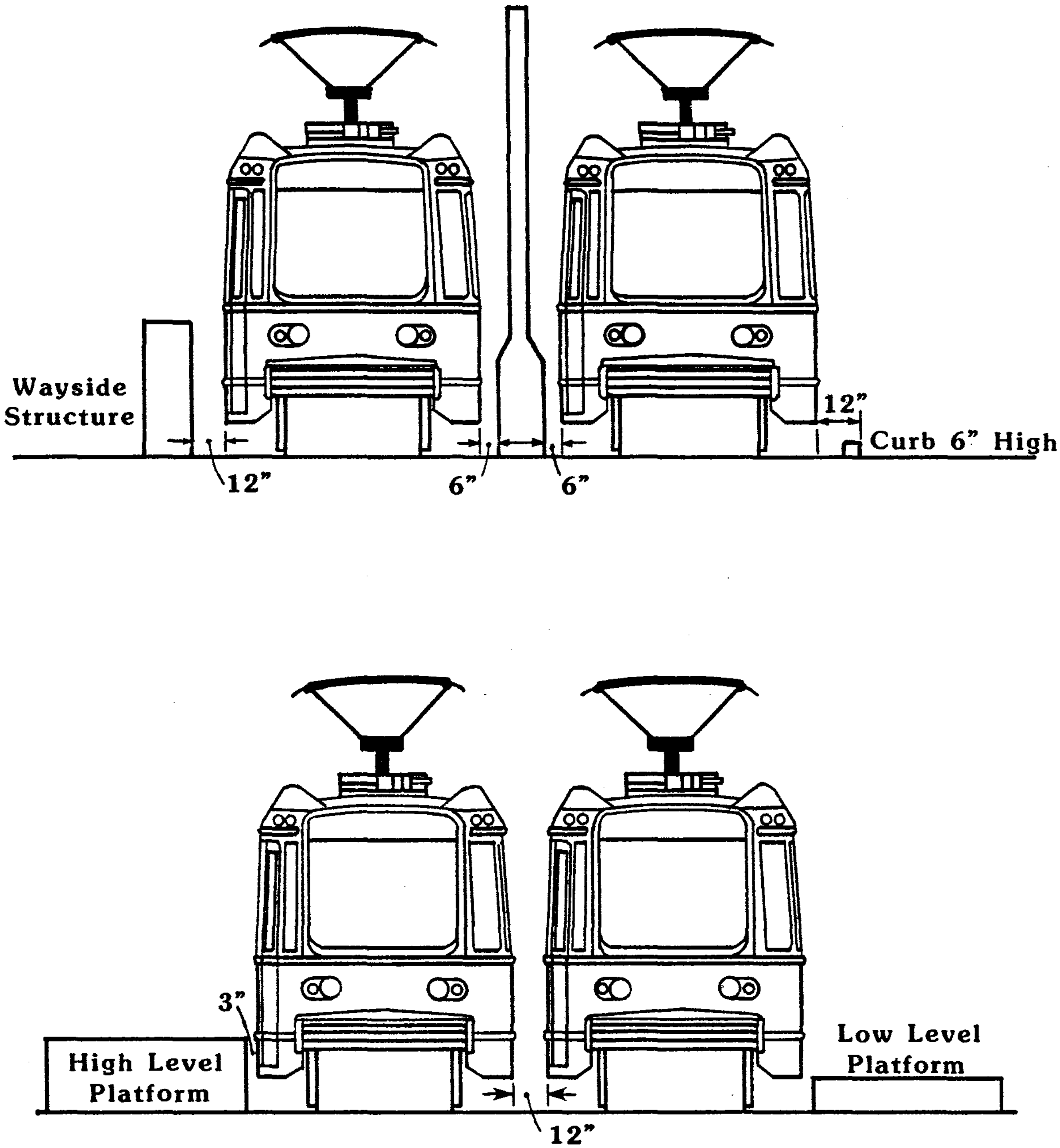
In many Western European countries, it is popular to use a major shopping street in a downtown area as a pedestrian and light rail transit thoroughfare. Track zones are typically delineated by either curbs, striping, or different-colored concrete blocks or slabs. Such transit malls facilitate light rail operation by removing motor vehicle interference and allowing ready access to the system, in spite of the comparatively low maximum speeds that must be observed for safety reasons.

An important consideration in the utilization of streets for light rail guideways is the retention of ample motor vehicle capacity. If implementation of reserved lanes or median areas is considered, the remaining street right-of-way should be sufficient to allow at least two driving lanes in each direction. Since most light rail routes tend to be located on high-volume streets, this may necessitate the elimination of parking to obtain this extra lane capacity (34).

The right-of-way envelope for LRT operations is a function of the design vehicle and vertical and horizontal clearance dimensions. Figure 13 illustrates the minimum lateral clearances, based upon design vehicle width, for typical light rail system conditions. Table 17 presents lateral clearance dimensions for use in assessing right-of-way requirements.

2.5.3 Physical and Operating Characteristics of LRT Vehicles

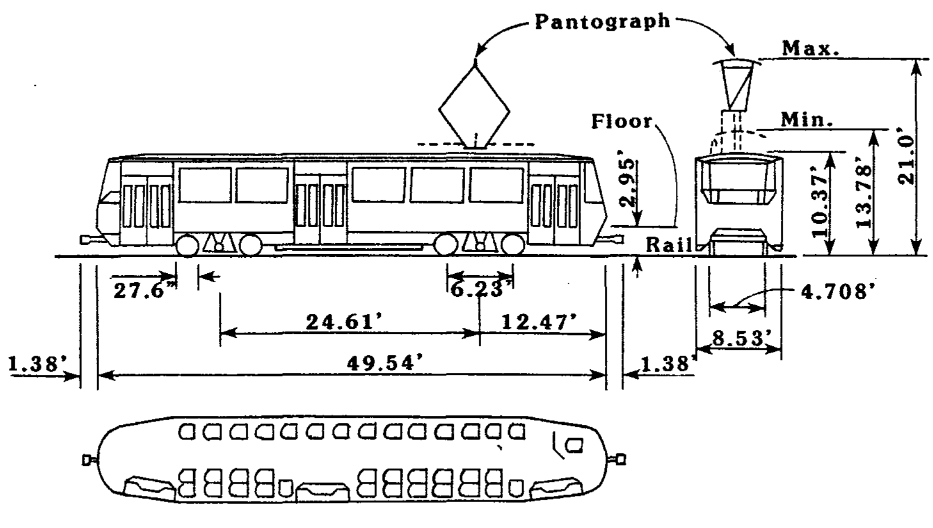
The typical light rail vehicle has three basic body configurations: a nonarticulated car, a single-articulated car, and a double-articulated car. Articulation allows the vehicle to "bend" on joints usually supported by one or more two-axle nonpowered trucks when traversing both horizontal and vertical curves. Such design permits a single vehicle to possess a large seating capacity and yet to both traverse and retain a narrow profile on sharp curves, thus reducing engineering standards for the fixed guideway facilities and potential clearance and safety conflicts (34). Figure 14 shows two examples of typical LRT vehicles.



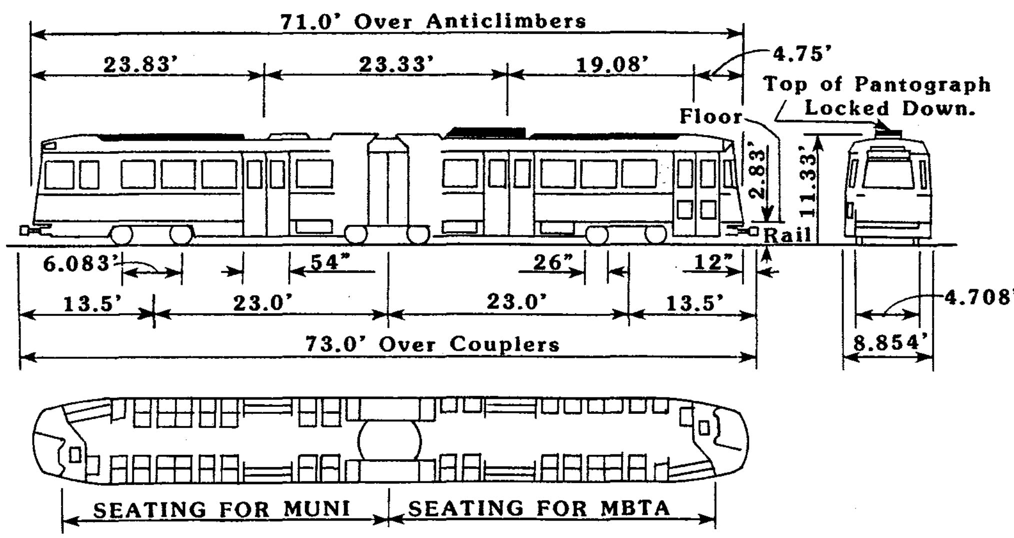
Source: Reference 31.

Note: Low level platform may extend beneath a LRT vehicle provided the minimum horizontal and vertical clearances for the given vehicle are maintained.

Figure 13. Minimum Lateral Clearances for Various Light Rail Transit Conditions



TATRA T5B



S.L.R.V. ARTICULATED

Source: Reference 31.

Figure 14. Two Examples of Light Rail Vehicle Dimensions

Table 17. Minimum Right-of-Way Widths for Light Rail Transit Vehicles

Vehicle Width	Single Track	Double Track
7'-0"	9'-0"	17'-0"
7'-4"	9'-4"	17'-8"
7'-8"	9'-8"	18'-4"
8'-0"	10'-0"	19'-0"
8'-4"	10'-4"	19'-8"
8'-8"	10'-8"	20'-4"
9'-0"	11'-0"	21'-0"

Notes: 1. Minimum widths shown are for tangent track sections without superelevation.

2. All minimum widths provide for 12 inches of lateral clearance between rail vehicle(s) and structures; for double track, clearances also provide 12 inches between vehicles.

3. Vehicle widths, ranging from 7 feet to 9 feet in 4 inch increments, are intended to represent the variety of designs available.

4. Additional width will be required for poles, barriers, stations, spirals and/or curves.

Source: Reference 31.

The general physical and operating characteristics of LRT vehicles are summarized in Table 18. The values shown in Table 18 are representative values which, for planning purposes, can be used in preliminary design. Data for the specific LRT vehicle to be used for individual systems should be used in final system design.

The acceleration/deceleration rates shown in Table 18 are typical for passenger comfort and, for planning purposes, can be used in preliminary design. Modern LRT vehicles are capable of the maximum speeds shown in the table; however, track geometry and operational constraints frequently limit the running speed (31).

Vehicle design characteristics (i.e., truck spacing) govern minimum radii for track curvature. Usually, trains of coupled vehicles have the same turning characteristics as the basic unit comprised of a single vehicle or a married pair. Maximum vertical up-grades are limited by vehicle power, desired performance and wheel-rail traction. Braking capability, influenced by train length and loading, is the principle consideration for down-grades (31).

Figure 15 shows typical vehicle displacement for LRT vehicles on curves having 45 to 1400 feet radii. The "inswing" and "outswing" are based upon the vehicle dimensions shown in Table 18.

Table 18. Typical Light Rail Vehicle Characteristics

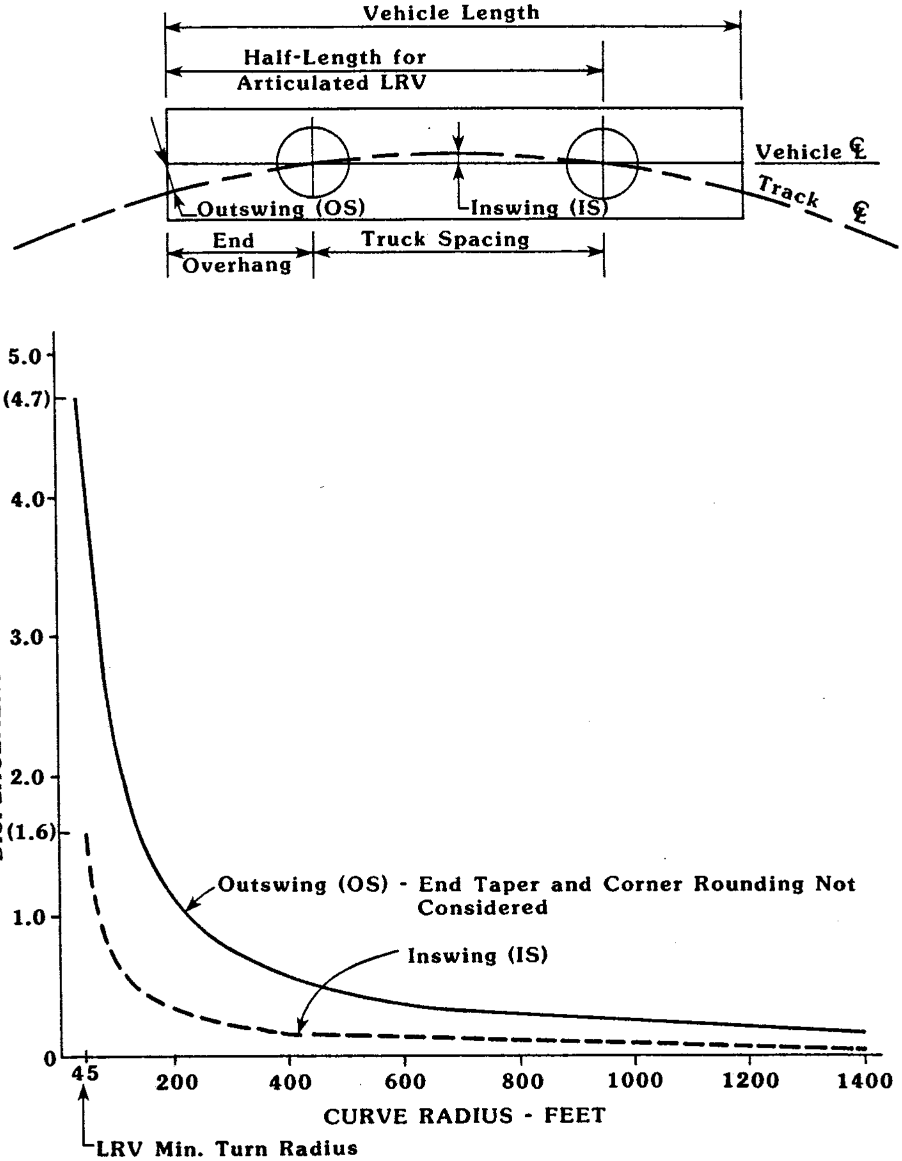
Characteristic	LRT Vehicle Length 50-ft. Class	70 to 75-ft Class
Dimensions		
Length Over Couplers	51 ft	73 ft
Body Length	49 ft	71 ft
Body Width	8.67 ft	8.67 ft
Truck Spacing	24 ft	23.0 ft
End Overhang	12.5 ft	12.5 ft
Wheel Base	6.0 ft	6.0 ft
Wheel Diameter	26 inches	26 inches
Height (Rail to Roof)	11.5 ft	11.5 ft
Height (Rail to Floor)	34 inches	34 inches
Height (Rail to Pantograph)	15 ft	15 ft
Performance		
Maximum Speed	50 mph	50 mph
Accel/Decel Rates	3.0 mph/sec	3.0 mph/sec
Emergency Decel Rate	6.7 mph/sec	6.7 mph/sec
Min. Horiz. Turn Radius	45 ft	45 ft
Min. Vert. Curve Radius	900 ft	500 ft
Maximum Grade	+ 6%, - 8%	+ 6%, - 8%
Capacity		
Number of Seats	38	52
Standees (Design)	90	83
Standees (Crush)	135	160
Total (Crush)	173	212
Weight		
Vehicle (Empty)	42,000 lb	65,000 lb
Passengers (Crush)	26,000 lb	32,000 lb
Vehicle (Gross)	68,000 lb	97,000 lb
Electrical		
Line Voltage	750 VDC	750 VDC
Power Collection	Overhead	Overhead

Notes: 1. The 70 to 75-ft. class light rail vehicle is articulated.
2. Standee Design allows 2.7 sq. ft. per person.
3. Standee Crush allows 1.4 sq. ft. per person.

Source: Reference 31.

2.5.4 LRT Stations

Light rail stations are typically spaced at 0.2 to 0.5 mile intervals (31, 34) and basically fall into two categories: those at grade and those with controlled access. Because the light rail mode frequently uses on-board or self-service fare collection procedures, only simple facilities are used for at-grade stations at low-volume locations and on right-of-way widths that are constricted, such as where the guideway is situated in reserved street lanes or in street medians. Such stations are relatively simple, generally consisting of the



Source: Reference 31.

Note: Plotted Values based upon LRT vehicle classes and dimensions shown in Table 18.

Figure 15. Typical LRT Vehicle Displacement on Horizontal Curves

platform, signing, lighting, a small amount of shelter, and proper pedestrian access. Many of the basic planning and design guidelines for bus stops, shelters and signing discussed in previous sections of this report are also applicable to LRT station design.

Platform length should be able to accommodate the longest light rail trains, with typical lengths ranging from 100 to 330 feet (31, 34). Platform widths vary between 6 and 12 feet. In high demand areas where either large volumes of riders are expected or several light rail routes share the same track, station and platforms may have to be designed for simultaneous loading of more than one train or vehicle.

In designing a light rail system, an important decision is whether to use high-level, low-level, or dual-level loading, since platform height affects not only the station design, but also vehicle design, system performance, and rider accessibility. High-level loading and unloading offers the advantages of shorter station dwell times and ready access for the elderly and handicapped, assuming that ramps are used for platform access instead of steps. Although high-level loading involves a greater initial investment than does low-level loading, the difference may be able to be offset by the cost of the less complex vehicles that will be required since stepwells or movable steps are not needed (34).

The design of stations or stops for light rail guideways located on a public street right-of-way deserves special attention because of the potential impacts on motor vehicle and pedestrian traffic. Where a median already exists, this median may need to be widened, and where the guideway is located in reserved lanes, a safety island must be installed both to physically protect people boarding or alighting from the transit vehicles and to prevent delays to motor vehicle traffic. Where heavy volumes of left-turn traffic are expected, either a special left-turn lane can be installed or the boarding island can be placed on the far side of the intersection. These actions presume the dedication of either driving or parking lanes to light rail usage near stations and intersections. In special cases, the left-turn movements may be allowed from the track lane. Where the median area is of sufficient width, the guideway can be placed on a reverse curve through the intersection to gain space for the platforms. Turnaround loops, layover tracks, and stations at major transfer points are typically located on off-street parcels. It should be apparent that any light rail guideway designed for use on street right-of-way will require detailed traffic engineering studies so that any impacts on pedestrian and motor vehicle traffic resulting from land or intersection modification can be appropriately treated (34, 35, 39, 40). A summary of basic traffic engineering and control strategies that can be employed to improve LRT operations and safety is presented in the following subsection.

2.5.5 LRT Traffic Control Strategies

The at-grade operation of LRT introduces potential conflicts with motor vehicles and pedestrians at intersections, in streets between intersections, and at mid-block crossings. These conflicts are a source of delay and accidents for LRT vehicles. There are four basic strategies available to the traffic engineer to eliminate or reduce LRT conflict points at intersections or mid-block crossings: at-grade separation of traffic flows in space, vertical separation of traffic flows in space, separation of traffic flows in time, and reduction in the number of traffic approaches (39).

Traffic flows can be separated at grade by developing separate traffic lanes for each movement, by developing medians, or by prohibiting or diverting certain movements. Development of special lanes, such as through lanes or right-turn lanes, serves to compartmentalize the traffic movements, thereby reducing potential conflicts at a given intersection approach. A more positive means of separating LRT from motor vehicle traffic would be to separate the two movements by using a median. Such a treatment, which is found in most LRT systems, would restrict crossings to specific locations, and special design measures can be undertaken at these locations to safely separate the movements. Such a median would provide opportunities for landscaping, placement of traffic signs and signals, platforms, a refuge area for crossing pedestrians, and space for left-turn lanes (39).

Prohibition of certain traffic movements can also result in a reduction in the number of conflicts. Examples of this would be prohibition of left turns or through movements from a cross street. Such prohibitions could also apply to a pedestrian crossing (39).

Traffic flows can be separated vertically so that conflicts are totally eliminated. Examples of this treatment are pedestrian overpasses and underpasses and railroad or highway grade separations. When the LRT is separated from all motor vehicle and pedestrian conflict, it becomes a rapid transit system. This approach, however, is the most costly conflict control strategy and is generally used only when other traffic engineering measures have failed (34, 39).

The separation of traffic flows in time is one of the most widely used traffic engineering techniques, usually accomplished by the use of traffic-control signs or traffic signals (34, 35, 39-42). Modification of existing traffic control systems is a popular option, as it can be implemented in a variety of ways. Typical examples include the following (34, 39):

- At locations with a relatively low volume of traffic, stop or yield signs are used to define the right-of-way of specific movements. This technique may be adequate at the outer ends of LRT lines, where cross-street traffic may be low (less than 5000 vehicles/day) and the LRT headway high (greater than 5 minutes). At higher volume intersections or crossings, traffic signal control can be used to positively assign right-of-way to conflicting movements. Standard traffic-signal warrants must be met before installation of such a device is considered.

- Standard traffic signals with fixed-time cycles and special phases for light rail transit movements may be utilized. The signals may show white arrows providing priority in one or more directions. Faster and safer transit movements are allowed, although the intersection's total capacity is reduced because of the additional phases.

- Traffic signals can be equipped with special phases such that light rail movements can actuate either additional leading green time or additional lagging green time as part of the signal cycle. Such an arrangement assures a higher probability of light rail vehicles reaching an intersection during a green phase.

- Signal preemption can be used to eliminate all cross traffic delays for light rail, but this will disrupt other traffic. While this option may not be desirable at intersections where cross traffic and turning traffic volume-to-capacity ratios are high, it may be viable for minor street crossings (also see Section 2.4.4 of this report).

- Full preemption with barriers or gates to more fully protect against motor vehicle conflicts will increase driver compliance and safety. These barriers are similar in physical appearance to typical railway crossing gates. Street capacity will be affected when the barriers are actuated. On new light rail segments that are on or adjacent to active railway rights-of-way, this type of protection may be incorporated into the crossing protection already in place at the railway grade crossing.

Table 19 lists the types of traffic control devices used in four cities with new LRT lines. The information in the table illustrates the range of traffic control devices that can be used for LRT operations.

A reduction in the number of approaches to an intersection or mid-block crossing can be achieved by converting one or both of the crossing streets to one-way operation or by closing one or more of the approach legs. For example, conversion of a two-way cross street to one-way operation cuts the number of potential conflicts at the intersection almost in half. Conversion of two-way streets to one-way operation is easiest to accomplish where there is a grid street pattern. In such locations, one-way couplets can be established, and access to private property is usually not seriously affected. Another significant benefit of converting to one-way operation is that the traffic-signal phasing at such intersections is simplified. The smaller the number of phases used to control a given intersection, the greater the throughput capacity of that intersection (39).

2.5.6 Summary

The service guidelines summarized in the preceding section suggest that the principal factors affecting the design of roadways that will accommodate LRT vehicles are

Table 19. Types of Traffic Control Devices Used with Light Rail Transit

Traffic Control Device	San Diego	Portland	Sacramento	San Jose
RR crossbuck and warning signs	X	X	X	
Crossing gates and flashers	X	X	X	
RR flashers but no gates			X	
Painted reservations	X		X	
Median island reservations		X		X
Curbside reservations	X	X	X	X
Transit streets	X		X	X
Turn prohibition signs in streets	X			
Turn prohibition signs		X	X	
"Left Turns Yield to Trolleys" sign			X	
Circular railroad warning sign			X	
"Trolley Crossing" warning sign				X
STOP signs			X	
Blank-out "No Left Turn" sign		X		X
Blank-out "Train" sign		X		
Traffic signal pre-emption	X	X	X	X
"T" for trolley phase	X		X	X
"Bar" signal for trolley phase		X		
3-indication "T" display				X
Red arrows for conflicting turns			X	X
"Inverted doghouse" signal head			X	

Source: Reference 42.

those relating to right-of-way widths and location, clearances (vertical and lateral) and intersection design (radii, signalization, and markings). In terms of overall operations and safety, application of the appropriate conflict-control strategy is perhaps the most important consideration in designing streets to accommodate LRT operations. The at-grade operation of LRT introduces potential conflicts with motor vehicles and pedestrians at intersections, in streets between intersections, and at mid-block crossings. These conflicts are a source of delay and accidents for LRT vehicles.

An analyses of on-street LRT vehicle delays in Toronto revealed that delays caused by boarding passengers and by traffic signals accounted for 90 percent of all delays incurred by LRT vehicles (35). Boarding delays accounted for 40 percent of the total delay, and traffic signals accounted for the remaining 50 percent (35). Planning and design guidelines for at-grade LRT operations on local streets should pay special attention to these two major sources of delay.

CHAPTER 3
SUMMARY AND RECOMMENDATIONS

3.1 Summary

This report summarizes the results of a national survey of state DOTs and local transit agencies concerning current practice in the planning, design and operation of transit-related street improvements. The results of the survey indicate that very few state DOTs have incorporated specific provisions for transit services into their roadway design standards.

The general planning guidelines reviewed in this report suggest that population densities, trip generation potentials (i.e., land uses) and characteristics of the street network are the primary factors considered by transit agencies in planning new or improved services. These same basic factors should be useful to local and state highway agencies in identifying roadway segments and travel corridors where street and highway designs should include provisions for transit vehicles and service support facilities. However, it should be clear that many of the factors affecting the efficiency of transit services are beyond the control of local transit and highway agencies. As a result, the provision of quality transit services will not only require cooperation between transit and highway agencies, but should include private developers and local agencies responsible for land use and development policies as well.

The sections of this report which review policies and guidelines for the design of transit related roadway improvements should be of particular interest to the Department. However, it is important to note that these guidelines are intended primarily as representative values that may need to be modified to reflect local conditions and practices. The MTAs that responded to the survey were quick to point out that the guidelines are intended to provide guidance in developing transit facility designs rather than as specific engineering designs of the various facilities. Many of the MTAs indicated that the guidelines were developed to "encourage" the inclusion of transit related facilities with other street improvement projects undertaken by the State, cities, counties, and private developers.

The review of current practice in the area of bus service operations summarized the effects of buses on roadway capacity and outlined policies, guidelines and strategies for increasing the efficiency of transit operations on surface streets. The review suggests that perhaps the most promising strategies for improving bus services are those relating to priority treatments for transit vehicles. These strategies include reserved bus lanes and priority treatment for transit vehicles at traffic signals. Successful implementation of these priority measures will require a cooperative effort involving local transit service providers and local and state highway agencies.

The results of this study suggest that the principal factors affecting the design of roadways that will accommodate LRT vehicles are those relating to right-of-way widths and location, clearances (vertical and lateral) and intersection design (radii, signalization, and markings). In terms of overall operations and safety, application of the appropriate conflict-control strategy is perhaps the most important consideration in designing streets to accommodate LRT operations. The at-grade operation of LRT introduces potential conflicts with motor vehicles and pedestrians at intersections, in streets between intersections, and at mid-block crossings. These conflicts are a source of delay and accidents for LRT vehicles. Effective intersection control and traffic interface design appear to be the key elements in successful at-grade LRT design. However, experience in this field appears to be limited.

3.2 Recommendations

The objective of this phase of the study was to compile a summary of current practice concerning the planning, design and operation of transit-related street improvements. Subsequent phases of the study will focus on developing comparable guidelines which can be incorporated into the Department's roadway planning and design manuals.

The results of this study indicate that basic practices do not differ substantially between the agencies surveyed, though differences were observed in the level of detail of the various guidelines. As a result, subsequent study efforts will be largely a matter of identifying those guidelines the Department considers most important in the roadway design process and presenting those guidelines in a format and level of detail consistent with other sections of the Department's roadway planning and design manuals. In this regard, it would be useful if, as part of the Department's review process, the guidelines presented in this report could be prioritized in terms of their relative importance in roadway planning and design.

Because the primary objective of this study is to develop guidelines that can be incorporated into the Department's design manuals, and because the material in this report is not in a format suitable for that purpose, it may be useful to consider the following three basic reports for documenting the final study results:

1. A Technical Report which documents the state-of-the-art;

2. A Summary Report which illustrates the range of factors commonly considered in transit-related roadway improvements; and

3. The development of Typical Design Details for incorporation into the Department's design manuals.

This three-tiered reporting strategy would provide concise summaries of key planning and design factors, as well as detailed documentation of the basis for their development.

The results of this study also indicate that the need for improved coordination and cooperation between transit and highway agencies is a major concern of transit service providers. The results of a recent TTI study (7) show that the need for improved coordination between transit agencies and state and local highway authorities is a major concern of the transit industry in Texas. Based on these considerations, it may be appropriate to consider expanding the focus of this study to include an examination of mechanisms for fostering more effective interagency cooperation and coordination. An initial step in this direction might be to include representatives from the transit industry, local transportation agencies, and related SDHPT divisions/districts in subsequent phases of this study.

REFERENCES

1. Mounce, J.M., H.G. Hawkins, R.W. Stokes and H.S. Payne. Revised Manual for Planning, Designing and Operating Transitway Facilities in Texas. Research Report 339-14. Texas Transportation Institute, College Station, TX. August 1988.

2. Bullard, D.L. Planning and Policy Issues Associated With Developing Mass Transportation Improvements in Urban Freeway Corridors. Technical Report 1095-1F. Texas Transportation Institute, College Station, TX. August 1988.

3. Nordstrom, J. and D.L. Christiansen. Guidelines for Estimating Park-and-Ride Demand. Technical Report 1064-1F. Texas Transportation Institute, College Station, TX. July 1981.

4. Bullard, D.L. and D.L. Christiansen. Guidelines for Planning, Designing and Operating Park-and-Ride Lots in Texas. Research Report 205-22F. Texas Transportation Institute, College Station, TX. October 1983.

5. Nungesser, L.G. and N.P. Ledbetter. Procedures for Estimating Park-and-Ride Demand in Large Texas Cities. Research Report 339-7. Texas Transportation Institute, College Station, TX. February 1987.

6. Bullard, D.L. and L.G. Nungesser. Texas Public Transit Reference Manual. Technical Report 1082-1F. Texas Transportation Institute, College Station, TX. November 1985.

7. Stokes, R.W. Transit Study Needs in Texas. Technical Report 2004-1F. Texas Transportation Institute, College Station, TX. August 1989 (Draft).

8. Municipality of Metropolitan Seattle. Encouraging Public Transportation Through Effective Land Use Actions. Report No. DOT-1-87-35. Prepared for U.S. DOT. May 1987.

9. Alameda-Contra Costa Transit District. Guide for Including Public Transit in Land Use Planning. Oakland, CA. April 1983.

10. Maryland Department of Transportation, Mass Transit Administration. Access by Design: Transit's Role in Land Development. Baltimore, MD. September 1988.

11. Metropolitan Transit Authority of Harris County. S.I.T. Review of Joint and General Mobility Projects. Houston, TX. March 1988.

12. Milwaukee County Transit System. Route Design Guidelines. Milwaukee, WI. (undated).

13. Regional Transportation District. Transit Facilities Design Guidelines. Denver, CO. September 1987.

14. Regional Public Transportation Authority. Bus Passenger Facilities: Street Improvement Guidelines. Phoenix, AZ. March 1989 (Draft).

15. Tri-Met Planning and Development Division. Transit Facilities Design and Maintenance Standards. Portland, OR. 1980.

16. Greater Cleveland Regional Transit Authority. Planning for Transit and Land Use Compatibility: A Manual of Standards and Design Guidelines for Bus-Related Street Improvements. Cleveland, OH. November 1981.

17. Orange County Transit District. Design Guidelines for Bus Facilities. Garden Grove, CA. November 1987.

18. Metropolitan Transit Commission. Guidelines for the Design of Transit Related Roadway Improvements. St. Paul, MN. May 1983.

19. Transportation Research Board. Bus Route and Schedule Planning Guidelines. NCHRP Synthesis of Highway Practice 69. Washington, DC. May 1980.

20. Southeastern Michigan Transportation Authority. Designing for Transit: A Transit Design Criteria and Standards Manual. Detroit, MI. April 1982.

21. Capital Metropolitan Transportation Authority. Transit Facility Design Guide. Austin, TX. June 1988.

22. American Association of State Highway and Transportation Officials. A Policy on the Geometric Design of Highways and Streets. Washington, DC. 1984.

23. Alameda-Contra Costa Transit District. Transit Facilities Standards Manual. Oakland, CA. March 1983.

24. Mid-Ohio Regional Planning Commission. The Development and Transit Connection: A Design Manual. Columbus, OH. December 1983.

25. Transportation Research Board. Highway Capacity Manual. TRB Special Report 209. Washington, DC. 1985.

26. Levinson, H.S., C.L. Adams and W.F. Hoey. Bus Use of Highways: Planning and Design Guidelines. NCHRP Report 155. Washington, DC. 1975.

27. Levinson, H.S., et al. Bus Use of Highways: State of the Art. NCHRP Report 143. Washington, DC. 1973.

28. Urbanik, T., II and R.W. Holder. Evaluation of Priority Techniques for High-Occupancy Vehicles on Arterial Streets. Research Report 205-5. Texas Transportation Institute, College Station, TX. July 1977.

29. Texas State Department of Highways and Public Transportation. Texas Manual on Uniform Traffic Control Devices for Streets and Highways. Austin, TX. 1980.

30. Urbanik, T., II. Priority Treatment of Buses at Traffic Signals. ITE Journal. November 1977.

31. Peterson, R.L., R.W. Stokes and J.M. Mounce. Transitway Conversion to Rail Transit Guideways. Research Report 425-2F (Supplement). Texas Transportation Institute, College Station, TX. August 1986.

32. Peterson, R.L., C.J. Porterfield and H.C. Petersen. Feasibility of Utilizing Existing Railroad Rights-of-Way for Transit Corridors in Urban Areas. Technical Report 1074-1F. Texas Transportation Institute, College Station, TX. May 1984.

33. Cline, J.C., T. Urbanik II and B. Rymer. Delay at Light Rail Transit Grade Crossings. Research Report 339-10. Texas Transportation Institute, College Station, TX. September 1987.

34. Southeastern Wisconsin Regional Planning Commission. State-of-the-Art of Primary Transit System Technology. Waukesha, WI. February 1981.

35. Taber, J. and J. Lutin. Investigating the Potential for Street Operation of Light-Rail Transit. In Light-Rail Transit: Planning and Technology. TRB Special Report 182. Washington, DC. 1978.

36. Bates, M. and L. Lee. At-Grade or Not At-Grade: The Early Traffic Question in Light Rail Transit Route Planning. In Light Rail Transit: New System Successes at Affordable Prices. TRB Special Report 221. Washington, DC. 1988.

37. Fox, G.D. Designing At-Grade Light Rail Transit. In Light Rail Transit: New System Successes at Affordable Prices. TRB Special Report 221. Washington, DC. 1988.

38. Fehon, K.J., W.A. Tighe and P.L. Coffey. Operational Analysis of At-Grade Light Rail Transit. In Light Rail Transit: New System Successes at Affordable Prices. TRB Special Report 221. Washington, DC. 1988.

39. Korve, H.W. Traffic Engineering for Light-Rail Transit. In Light-Rail Transit: Planning and Technology. TRB Special Report 182. Washington, DC. 1978.

40. Burgin, E.A. Light-Rail Transit Signaling. In Light-Rail Transit: Planning and Technology. TRB Special Report 182. Washington, DC. 1978.

41. Stone, T.J. and W.A. Wild. Design Consideration for LRT in Existing Medians: Developing Warrants for Priority Treatments. In Light Rail Transit: Planning, Design and Implementation. TRB Special Report 195. Washington, DC. 1982.

42. Hoey, W.F. Traffic Controls for Light Rail Transit. Compendium of Technical Papers, 41st Annual Meeting, District 6 ITE. Colorado Springs, CO. 1988.