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16. Abstract

Transitways are defined as exclusive, physically separated, access controlled, high-occupancy vehicle priority treatment facilities which are typically located within existing freeway right(s)-of-way. Transitways are sometimes referred to as busways, high-occupancy vehicle (HOV) lanes, or authorized vehicle lanes (AVLs).

This revised manual is divided into two primary technical divisions: (1) Transitway mainlanes and connections; and (2) Transitway support facilities. Each of these technical divisions addresses transitway planning, design, and operational considerations. Information presented within this transitway manual should promote effective planning, uniformity of design, and operational efficiency for transitway facilities in Texas.

This revised manual was prepared for the Texas State Department of Highways and Public Transportation (SDHPT) to update guidelines and standards for the planning, design, and operation of transitway facilities. It follows the general style and format of the SDHPT Operations and Procedures Manual. This transitway manual has been prepared as an independent document under research study 2-10-84-339 to supplement previous information on transitway facilities given in Report 425-2, "Manual for Planning, Designing, and Operating Transitway Facilities in Texas" (September, 1985), and Report 425-2F, "Transitway Surveillance, Communications, and Control" (October, 1986).

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METRIC (SI*) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

LENGTH

Symbol	When You Know	Multiply By	To Find	Symbol
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

Symbol	When You Know	Multiply By	To Find	Symbol
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)

Symbol	When You Know	Multiply By	To Find	Symbol
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg

VOLUME

Symbol	When You Know	Multiply By	To Find	Symbol
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)

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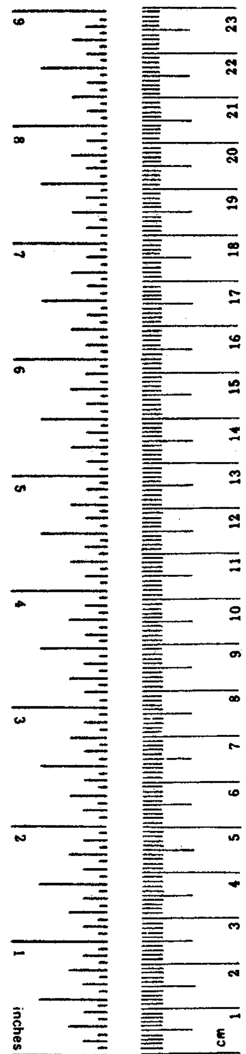
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

* SI is the symbol for the International System of Measurements



APPROXIMATE CONVERSIONS TO SI UNITS

LENGTH

Symbol	When You Know	Multiply By	To Find	Symbol
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

Symbol	When You Know	Multiply By	To Find	Symbol
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)

Symbol	When You Know	Multiply By	To Find	Symbol
g	grams	0.0353	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams (1 000 kg)	1.103	short tons	T

VOLUME

Symbol	When You Know	Multiply By	To Find	Symbol
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

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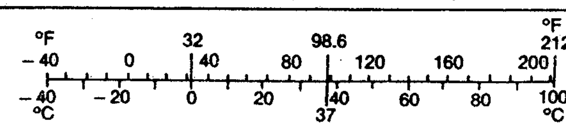

These factors conform to the requirement of FHWA Order 5190.1A.

REVISED
MANUAL FOR PLANNING, DESIGNING, AND OPERATING TRANSITWAY FACILITIES IN TEXAS

Research Study 2-10-84-339

Report 339-14

Prepared

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Texas State Department
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the
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ABSTRACT

Transitways are defined as exclusive, physically separated, access controlled, high-occupancy vehicle priority treatment facilities which are typically located within existing freeway right(s)-of-way. Transitways are sometimes referred to as busways, high -occupancy vehicle (HOV) lanes, or authorized vehicle lanes (AVLs).

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IMPLEMENTATION STATEMENT

This report was sponsored by the Texas State Department of Highways and Public Transportation as part of an overall study effort entitled "Improving Urban Mobility Through Application of High-Occupancy Vehicle Priority Treatments" (Research Study No. 2-10-84-339). An objective of this research is to assist the Department in the implementation and evaluation of high-occupancy vehicle priority treatment projects. This report updates previous guidelines for planning, designing, and operating transitways on Texas freeways.

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1. INTRODUCTION

1.1 BACKGROUND

Historically, the emphasis of highway planning has been to project travel demand and then identify a system of highway improvements capable of serving that demand. This approach has a major shortcoming when applied to plans for existing, congested urban freeways. Expansion of the freeway system is essential to help serve this demand. However, addition of more traffic lanes, by itself, cannot provide the capacity required to serve peak period travel demands.

As a result, consideration has been given to providing priority lanes designated for exclusive use by high-occupancy vehicles (HOVs) -- buses, vanpools, and carpools. Experience has shown that these priority lanes can be an effective means of moving large volumes of persons during peak periods (Table 1-1). During the peak hour, all the HOV facilities shown in Table 1-1 move the equivalent of approximately three or more general purpose (or freeway) traffic lanes. Obviously, the magnitude of person movement in the HOV lanes significantly impacts freeway corridor capacity. For the facilities shown in Table 1-2, all move at least 30 percent of the total movement on the freeway (1, 2).

The demonstrated ability of high-occupancy vehicles to move large volumes of commuters has led to the large commitment to HOV lanes (transitways) in Texas. Projections for transitway facilities being developed in Texas generally call for service of approximately 7,000 persons in the peak hour in 1995, essentially doubling the effective capacity of those freeways where transitways are introduced (1).

1.2 PURPOSE

Transitways, by utilizing high-occupancy vehicles, can increase person movement within certain intensively traveled urban arterial corridors.

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Table 1-1. Peak-Period, Peak-Direction Person Movement on Selected High-Occupancy Vehicle Projects

Transitway Project	Eligible Vehicle	Peak-Hour Volume		Peak-Period Volume	
		Vehicles	Persons	Vehicles	Persons
I-395 (Shirley), Washington D.C., Two-Lane, Reversible	Buses, 4+ Carpools	2,600	18,700	4,700	40,300[1]
I-66, Washington D.C., Two-Lane	Buses, 3+ Carpools	2,000	8,400	3,600	14,000[2]
I-10 (El Monte), Los Angeles, CA Two-Way	Buses, 3+ Carpools	1,100	6,500	2,600	15,800[3]
I-45 (North), Houston, TX One-Lane, Reversible	Buses, Vanpools	200	4,000	350	7,200[4]
I-10 (Katy), Houston, TX Buses, 2+ Carpools, One-Lane, Reversible	Buses, 2+	1,500	4,600	2,800	8,800

[1]6-9 A.M., 24-6 [2]4-6 P.M., [3]6-10 A.M., [4]6-8:45 A.M.

Source: Ref. (1, 2).

Table 1-2. High-Occupancy Vehicle Lane Volume as a Percent of Total Freeway Volume

Transitway Project	HOV Person Volume	Freeway Person Volume	Total
I-395 (Shirley), Washington, DC			
Peak Hour	18,700 (64%)	10,300 (36%)	29,000 (100%)
Peak Period	40,300 (57%)	30,600 (43%)	70,900 (100%)
I-10 (El Monte), Los Angeles			
Peak Hour	6,500 (38%)	10,400 (62%)	16,900 (100%)
Peak Period	15,800 (30%)	37,600 (70%)	53,400 (100%)
I-45 (North), Houston, TX			
Peak Hour	4,000 (40%)	6,200 (60%)	10,200 (100%)
Peak Period	7,200 (31%)	15,900 (69%)	23,100 (100%)
I-10 (Katy), Houston, TX			
Peak Hour	2,800 (35%)	5,300 (65%)	8,100 (100%)
Peak Period	8,800 (34%)	17,400 (66%)	26,200 (100%)

Source: Ref. (1, 2).

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Transitway facilities have been found to be technically and operationally feasible, and fiscally implementable in a relatively short time period when incorporated within or adjacent to a freeway cross section.

The purpose of this manual is to provide guidelines and standards for the planning, design and operation of transitway facilities. These criteria should promote uniformity of design and operational efficiency for transitway facilities in Texas.

1.3 SCOPE OF MANUAL

1.3.1 Definition

In this manual, transitways are defined as exclusive, physically separated, access controlled, high-occupancy vehicle priority treatment facilities. Transitways are typically located within existing freeway right(s)-of-way. Transitways are sometimes referred to as busways, HOV lanes, or authorized vehicle lanes (AVLs).

Transitways are intended to provide a high level of service for high-occupancy vehicles. This manual addresses facilities which may accommodate the following HOV types: (1) buses only, (2) buses and vanpools, and (3) buses, vanpools and carpools.

1.3.2 Classification

Depending upon the demand projected to utilize the transitway and the designated user-group(s), transitways may be classified as either one-way or two-way. Single lane transitways are one-way and reversible corresponding to the peak direction of travel. Multiple lane facilities may be either two-way or one-way reversible, depending on anticipated demand. Single lane and multiple lane transitways may be constructed at-grade, elevated, or depressed depending on cross-section constraints and adjacent land use. The geometric design of transitway facilities may resemble that of any other controlled access facility utilizing grade separations and special ramps for control of ingress and egress.

1.4 ORGANIZATION OF MANUAL

1.4.1 Format

This manual follows the general style and format of the Texas State Department of Highways and Public Transportation (SDHPT) Operations and Procedures Manual (3). This transitway manual has been prepared as an independent document which may replace existing SDHPT information on the design of high-occupancy vehicle facilities.

1.4.2 Content

The manual is divided into two primary technical divisions. These are: (1) Transitway Mainlanes and Connections; and (2) Transitway Support Facilities. Within each of these sections are presented planning guidelines, design criteria, and operational procedures.

1.4.3 Utilization

Every urban area has a unique system of transportation services and facilities. It would not be expedient to prepare a manual to address all of the many issues likely to confront the planner or engineer in developing an effective transitway system. Consequently, included herein are design standards and examples of application based upon the current state-of-the-art and accepted practice. Expansion and revision of this manual will, no doubt, be desirable as more experience is gained through the development of transitway systems in Texas. The information and guidelines should provide a common reference document and be useful to SDHPT personnel, city planners, transportation engineers, regional planning officials, and transit planners and managers.

1.5 REFERENCES

1. Alternative Mass Transit Technologies - Technical Data, Research Report 339-4, Texas Transportation Institute, July, 1985.

2. Ranft, S., Transitway Quarterly Summary, Texas Transportation Institute 1988.

3. Texas State Department of Highways and Public Transportation, Highway Design Division, Operations and Procedures Manual, 1981. Revised 1985.

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2. TRANSITWAY MAINLANES & CONNECTIONS

2.1 PLANNING GUIDELINES

2.1.1 General

Efficient utilization of urban transportation calls for maximizing person flow while minimizing overall person delay. One means of achieving this objective is to provide priority treatment for HOVs such as buses, vanpools, and carpools. Since it is not generally desirable to remove existing freeway lanes from general use during peak periods, at least in the peak direction of traffic flow, it may be necessary to develop new facilities intended exclusively for use by HOVs in certain high-travel demand corridors. Transitway facilities may be constructed at, above, or below grade, either in separate rights-of-way or within the existing freeway cross section.

While transitways may be designed to provide feeder service to rail transit lines or as bypasses of major congestion points, they are typically intended to provide line-haul express service to major urban activity centers. The basic purpose of transitway facilities is to promote higher vehicle occupancies by providing a higher level-of-service than competing general purpose highway facilities. The superior level-of-service afforded by transitways can benefit not only transitway users but other travelers in the corridor as well. Transitways can provide substantial benefits by reducing travel times, operating costs, energy consumption, and in altering a corridor's modal-split in favor of public transportation and ridesharing.

While individual transitways will differ in their specifics, there are certain basic considerations which are common to all facilities. The guidelines presented in this section are intended to assist the engineer in addressing the following basic considerations in transitway design:

1. Identification of corridors suitable for transitways;
2. Evaluation of transitway location and access;

3. Estimation of transitway demand; and
4. Assessment of cross-section requirements.

2.1.2 Determining Candidate Freeway Segments

Spielberg et al. (1) have suggested that, as a general rule-of-thumb, a perceived travel time savings of one minute per mile and a minimum total savings of 10 minutes per person is necessary to cause a significant shift to the utilization of HOV facilities. In order to accomplish this savings the maximum average travel speed in the non-priority lanes should not be greater than 25-30 mph. If speeds on the non-priority lanes exceed this threshold limit, HOV priority treatment is unlikely to prove effective in significantly increasing person throughput in the freeway corridor.

While an analysis of transitway demands is required to fully assess the potential effectiveness of transitway treatment in a particular corridor, the following guidelines should be useful in identifying candidate corridors:

1. Freeway segments or other corridors where average peak period operating speeds are less than 30 mph for at least one hour for a distance of 5 or more miles may lend themselves to transitway treatments;

2. Freeway segments or other corridors where average peak period operating speeds are less than 30 mph for at least one hour for a distance of less than 5 miles may be suitable for transitway treatment if segments on either end of the 30 mph segments have average peak period speeds below 40 mph for a total distance of 5 or more miles;

3. Freeway segments or other corridors where average peak period operation speeds are not below 30 mph for at least one hour but which experience cumulative delays of 10 or more minutes per person for a continuous segment of freeway may lend themselves to transitway treatment; and

4. Freeway travel patterns (i.e., the percent of peak period trips destined to major activity centers) should also be considered in determining freeway segments which may benefit from transitway treatment. Following the identification of candidate freeway segments, an analysis of travel patterns (origins/destinations) should always be performed. In general, approximately 6,000 peak hour work trips to a major employment center should occur on the facility; nearly 75% of these trips should be longer than 5 miles in length.

2.1.3 Location of Transitways

Experience in the United States has generally shown that urban freeways can be adapted to accommodate transitway facilities within freeway rights-of-way with little or no sacrifice in freeway capacity. Urban freeways that are characterized by peak period travel demand in excess of capacity are also likely to be cost-effective candidates for the location of transitways.

The design, construction and operation of transitways is sufficiently similar to controlled access highways so that transitways can be located anywhere a freeway or other arterial can be located. However, in mature urban areas where transitways are likely to be needed and can be cost-effective, acquiring the necessary continuous lengths of right-of-way can be very difficult and many times controversial. There is also an aversion to acquiring separate rights-of-way for transitways due to the slow process of acquiring right-of-way by eminent domain proceedings. Transitways are needed most where congestion is worst, and quick solutions are more popular than long-term ones, suggesting that locating transitways in shared rights-of-way has many practical aspects. Other places where transitways might be located include along railroads, and within utility and drainage easements, if the owners of these rights-of-way can be persuaded to share their property for transportation purposes.

However, for the reasons given above, many transitways, at least in Texas, will probably be located within freeway rights-of-way, and to that end this design manual is directed.

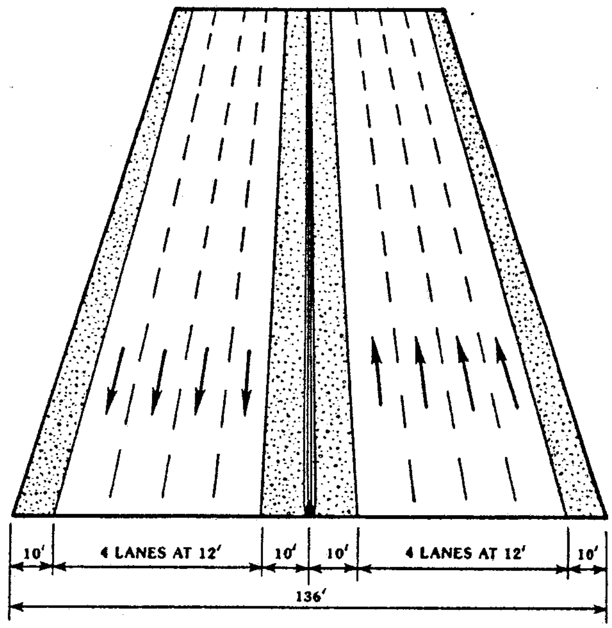
The location of transitways with respect to the freeway right-of-way depends upon the following:

1. Existing freeway geometry;
2. Required transitway cross section and alignment;
3. Accessibility to transitway and interchange spacing;
4. Passenger modes at access points;
5. Bus service requirements;
6. Adjacent land use and environmental impacts; and
7. Cost of implementation.

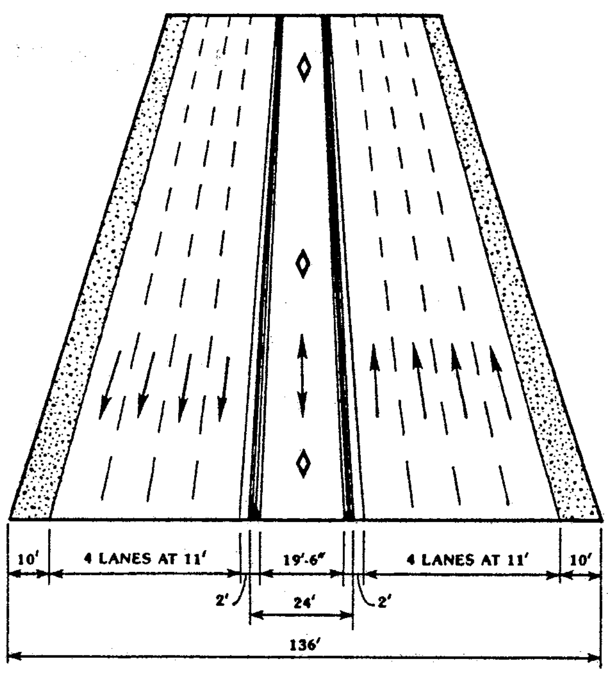
Transitways within existing freeway right(s)-of-way may be located within the outer separation of mainlanes and frontage roads, along one side of the freeway or within the freeway median. While space may exist in the outer separation or along one side, the frequent at-grade ramps common to urban freeways in Texas limit the application of these alignments.

Transitways located within a freeway median are preferable where existing freeway cross section is of sufficient width to accommodate the required transitway cross section. These treatments are relatively simple to implement, lend themselves to staged development, and have minimal impact on ramp or interchange geometry.

However, within many developed freeway corridors, the available right-of-way (especially in the median area) is limited and not sufficient to allow retrofit of a transitway without encroaching into the adjacent freeway cross section. This involves the reduction or possible elimination of the inside shoulders of the freeway, reduction of freeway mainlane widths, or the acquisition of additional right-of-way. Typical comparative "before and after" cross sections are shown in Figure 2-1. The modified freeway cross section resulting from the implementation of median transitways does not



FREEWAY MEDIAN WITHOUT TRANSITWAY



FREEWAY MEDIAN WITH TRANSITWAY

Figure 2-1. Typical Freeway Cross-Sections Before and After Implementation of Median Transitway

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imply that inside shoulders are not a desirable design feature with respect to both safety and operations. The intent is to maximize mobility along a freeway corridor by significantly increasing person movement capacity at low to moderate implementation costs in a reasonably short time period with minimum disruption to existing traffic. These definable benefits must be assessed relative to the presently undefined operational and safety benefits associated with the provision of inside shoulders.

Another consideration in transitway location is accessibility of the transitway to HOVs. Freeway corridors along which transitways may be needed are also likely to have congestion along the streets intersecting the freeway. If possible, access to the transitway should be provided from streets that do not provide direct service to the freeway.

2.1.4 Demand Estimation

2.1.4.1 General

The initial step in designing a transitway is to estimate the potential demand for the facility. The relationship between demand and facility design is essentially one of balancing demand and physical constraints. The physical constraints, (i.e., roadway space limitations) are typically the governing concerns. In balancing potential transitway demand against physical constraints, it may be necessary to manage the demand on the facility by establishing user authorization criteria which are consistent with the capacity (i.e., space) which can realistically be provided.

The basic characteristics which influence transitway demands are freeway operating conditions and peak-period travel patterns. If freeway peak-period operating speeds are on the order of 30 mph or less, transitway demands may be sufficient to produce a significant increase in freeway person throughput. Also, the existence of major activity centers which attract large numbers of peak-period commuters has substantial impact on transitway demands.

Since very few transitways are currently in operation, no widely accepted "standard" procedures for estimating transitway demand have been developed. Current procedures for estimating transitway demand are typically modified mode-choice models that generally do not account for the unique features of transitways. Additionally, few of the transitway demand estimation procedures currently in use have been rigorously validated to determine their accuracy or transferability. In short, the state-of-the-art in transitway demand estimation is not particularly sophisticated, and additional research in this area is clearly needed.

Section 2.1.4.2 presents a brief overview of the state-of-the-art in transitway demand estimation. The review discusses regional mode-choice models with HOV components (models typically implemented within the urban transportation planning system (UTPS) of urban travel demand models), and corridor level HOV models (simplified, "free-standing" models implemented outside the traditional UTPS framework). No step-by-step instructions for implementing these procedures are presented in the general state-of-the-art review. However, sufficient detail is given to allow the analyst to make an initial determination of the level of effort needed to implement them.

In addition to a general overview of transitway demand estimation procedures, Section 2.1.4.3 presents a detailed discussion of two corridor-level demand estimation procedures utilized by the Texas Transportation Institute (TTI) to estimate transitway demands in Houston. While these two procedures can be somewhat tedious to implement, the procedures appear to produce reasonable, planning-level estimates of potential transitway demands.

The demand estimation portion of the manual concludes with a brief summary of current TTI research efforts directed at developing regional and corridor-level transitway demand estimation models.

2.1.4.2 Overview of the State-of-the-Art in HOV Lane Demand Estimation

The Texas Transportation Institute has recently completed a nationwide survey of transportation agencies to assess the state-of-the-art in transitway demand estimation (2). Of the 17 agencies surveyed by TTI, 10 reported that they had developed demand estimation procedures. Three agencies reported they were in the process of developing demand estimation procedures, and four agencies reported they did not have any specific procedures for estimating demands (these four agencies also reported they had no HOV facilities in operation in their area).

Table 2-1 summarizes the demand estimation procedures identified through the TTI survey. As shown in Table 2-1, five of the procedures are mode-choice models in the regional travel demand modeling process, and five are corridor-level models.

The regional models are generally "traditional" mode-choice models that have been respecified to handle not only transit and drive alone modes, but shared ride two person, three or more person, and in one case, four or more person models. Other agencies use primary mode-choice models to initially estimate drive alone and shared ride mode splits. A secondary or sub mode choice model is then used to further estimate shared ride two-person occupancy, and shared ride three or more person occupancy mode splits. A few agencies also estimate four or more person occupancy modes.

The models utilized by the Los Angeles Regional Transportation Study (LARTS) are representative of the regional UTPS approach to HOV demand estimation. The LARTS model uses a combination of three models to compute the modal split of home-work trips. A binary mode choice model calibrated by Alan M. Voorhees and Associates, Inc. (AMV model) is used to determine the initial transit/auto mode split. A disaggregate modal choice model developed by Cambridge Systematics, Inc. (the CSI model) is used to estimate the number of shared ride person trips. Another mode-choice model, developed by Barton-Aschman Associates (the BAA model) is then used to estimate the split of shared ride person trips into two and three plus person carpools. The entire process is referred to as the "LARTS Coupled AMV-CSI Ad Hoc mode choice model."

Table 2-1. Summary of HOV Lane Demand Estimation Procedures

Urban Area/ HOV Facility	Agency Responsible for Demand Estimation	HOV Modes Modeled			Estimation Procedure		Description of Estimation Procedures
		Bus	Vanpool	Carpool	Regional Model	Free-Standing	
Houston, TX	Houston METRO (with assistance from TTI)						Manual procedures based on observed HOV lane/park-ride utilization and analysis of regional trip tables.
I-10W (Katy)		X	X	X(2+)		X	
I-45N (North)		X	X			X	
I-45S (Gulf)		X	X	X(2+)		X	
Los Angeles, CA	Caltrans, Southern California Association of Govt's (SCAG), Los Angeles Regional Transportation Study (LARTS)						Vorhees/Cambridge Systematics mode choice model. Part of UTPS-based LARTS regional model.
I-10 (El Monte)		X		X(2+,3+)	X		
Rte. 91		X		X(2+,3+)	X		
Orange Co., CA	Orange Co. Environmental Management Agency and Orange Co. Transit District						UTPS/Journey to Work Based Socioeconomic Growth Approach applied with a microcomputer spreadsheet and BASIC programs.
Rte. 55		X		X(3+)		X	
San Francisco/ Oakland, CA	Metropolitan Transportation Commission (MTC)						Part of the UTPS-based travel demand forecasting system. Makes use of 1985 release of UROAD for HOV forecasting.
Bay Bridge		X		X(3+)	X		
US 101		X		X(3+)	X		
Washington, D.C.	Metropolitan Washington Council of Governments (MWCOG)						Council of Governments/ Transportation Planning Board UTPS-based procedure. Utilizes MWCOG's MULTILOAD assignment procedure[a].
I-395 (Shirley)		X		X(4+)	X		
I-66				X(4+)	X		
Seattle, WA	Puget Sound Council of Governments						Modified mode choice regression model utilizing the UTPS-based regional modeling system.
I-5		X		X(4+)	X		
SR 520		X		X(4+)	X		

Table 2-1. Summary of HOV Lane Demand Estimation Procedures (Cont.)

Urban Area/ HOV Facility	Agency Responsible for Demand Estimation	HOV Modes Modeled			Estimation Procedure		Description of Estimation Procedures
		Bus	Vanpool	Carpool	Regional Model	Free-Standing	
New York City, NY	New Jersey Transit, Port Authority of NY/NJ						Microcomputer based regression model. Forecasts travel among seven different modes (called "Trans-Hudson" Mode Choice Model).
NJ Rte. 495		X[b]				X X	
Pittsburgh, PA	Port Authority of Allegheny County						Utilizes relationship developed from Shirley Highway in Washington, D.C.
South Patway		X				X	
East Patway		X				X	
I-279[c]		X		X(3+)		X	
Boston, MA	Central Transportation Planning Staff (CTPS)						Bus estimates produced by CTPS using a manual procedure based on existing data. CTPS carpool estimates from the Bolling/Anacostia, MWCOG models and the FHWA procedure (4).
I-93		X		X(3+)		X	
Denver, CO[d]	Denver Regional Council of Governments (DRCOG)	X		X(3+)	X		Choice-based logit mode-choice model from the regional model system modified to estimate two-person and three + person carpools.
Minneapolis, MN	Metropolitan Council						UTPS-based logit model modified to estimate shared ride HOV modes.
I-394[e]		X		X(3+)	X		

Table 2-1. Summary of HOV Lane Demand Estimation Procedures (Cont.)

Urban Area/ HOV Facility	Agency Responsible for Demand Estimation	HOV Modes Modeled			Estimation Procedure		Description of Estimation Procedures
		Bus	Vanpool	Carpool	Regional Model	Free-Standing	
Austin, TX[d]	Capital Metropolitan Transit Authority	X		X(3+)	X		Part of regional model system being developed for transitway corridor alternative analyses project.
Dallas, TX[d]	North Central Texas Council of Governments	X		X(3+)	X		Developing new mode choice model which provides HOV estimates as part of the regional travel forecasting.

[a]Utilizes FHWA Shirley Highway Procedures for Bus Estimates.
[b]Trans-Hudson model provides estimates for auto, auto-to-bus, auto-to-rail, and 3 rail modes in addition to bus.
[c]To become operational 1989.
[d]Procedure currently in development stage.
[e]Interim facility.

Source: (1).

The Coupled AMV-CSI Ad Hoc Mode Choice Model requires four input networks: the transit network; the general highway network; a two occupancy, shared ride network; and a carpooling (three plus) network. The model provides the users with data regarding home to work transit, drive alone, two occupant and three plus occupant trips.

The regional models listed in Table 2-1 typically require the following peak period input data:

- Highway skim files (time and distance) for transitway and non-transitway paths;
- Transit skim files;
- Home-based work (HBW) person trip tables;
- Zonal data (parking costs, household income, auto occupancy, auto ownership, workers per household, transit availability, etc.); and
- Mode usage data and traffic counts (for model calibration/validation).

While most regional mode-choice models are very similar in their structure and specifications, these models generally are not directly transferable from one urban area to another. Therefore, a mode-choice model "borrowed" from another urban area will need to be recalibrated to reflect local conditions. Also, regional mode-choice models in general, and regional mode-choice models with components in particular, have not performed well in terms of their ability to predict mode-shares. Finally, the development and implementation of these models requires a substantial commitment of time and resources. It may require 18-24 months of intensive effort to develop a workable model.

A detailed discussion of regional mode-choice models, and their use in demand estimation, can be found elsewhere (2, 3).

The free-standing, corridor-level transitway models currently in use typically involve manually adjusting and assigning an existing trip table to

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a transitway network on the basis of some assumed relationships between travel time savings and mode splits. The trip tables used in the analyses are commonly UTPS generated tables or 1980 Census Journey-to-Work (JTW) trip tables. The mode splits needed in the analyses are generally based on rates observed on other, similar facilities. For example, Table 2-2 shows the factors used in Orange County (CA) to estimate person trips on HOV facilities.

Table 2-2. Factors Used in Estimating Transitway Person Trip Usage for Transitways and Commuter Lanes in Orange County California

Category of Travel Time Savings	% of Existing Trips Shifting to Transitways: Trips 7 Miles Or Less in Length	% of Existing Trips Shifting to Transitways: Trips Greater Than 7 Miles In Length	% Increase in HOV Formation For Trips Using Transitways
Less than 5 Minutes	No Shift	No Shift	No Increase
5-9 Minutes	No Shift	65-75%	20-30%
10-14 Minutes	No Shift	75-85%	30-40%
15 Minutes or Greater	No Shift	85-95%	40-50%

Source: Ref. (4).

A detailed example of a procedure that uses JTW data is presented in the following section.

2.1.4.3 Current Practices in Texas

In recent years, TTI has utilized the following four techniques to estimate the demand for transitway facilities in Houston: (1) the findings from a Federal Highway Administration (FHWA) study (5); (2) a mode-split analysis of home-based work trips (6, 7); (3) the findings from a recent TTI study that developed guidelines for sizing park-and-ride lots (8); and (4) an analogy to the contraflow lane operation on I-45N in Houston (9). Two of

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these approaches, the "park-and-ride" and "trip table" approaches, have been used extensively in recent years and appear to produce reasonable planning-level estimates of transitway demands. The park-and-ride procedures have been used to estimate transit and vanpool demands, and the trip table procedures have been applied to estimate carpool demands. Each of these procedures is described in the following subsections.

Use of Park-and-Ride Demand Estimation Procedures to Estimate Transit and Vanpool Demands

Utilizing data from 16 park-and-ride lots in Houston, Texas, TTI has developed a number of regression equations that can be used to estimate the demand (riders) for park-and-ride services. Separate models were developed for estimating ridership at lots with and without transitway services. The models developed for lots with transitway service are shown in equations 2.1 through 2.4 (8).

$$\text{Riders} = -4280.5 + 1675.75\text{ICI} + 0.23\text{CBDEMP} \quad (2.1)$$

$$\text{Riders} = -5351.3 + 1957.86\text{ICI} + 0.0156\text{MAPOP} \quad (2.2)$$

$$\text{Riders} = -4969.46 + 1866.33\text{ICI} + 0.0056\text{MAPOP} + 0.17\text{CBDEMP} \quad (2.3)$$

$$\text{Riders} = -3786.7 + 1326.79\text{ICI} + 8.75\text{MO} + 0.246\text{CBDEMP} \quad (2.4)$$

where:

Riders = Average daily ridership (round trips)
ICI = Average freeway congestion index
= (Delay (mins.)/10 mins.) + (AADT per lane/20,000)
MO = Number of months lot has been in operation
CBDEMP = Employees residing in the market area destined for the central business district (CBD)
MAPOP = Park-and-ride lot market area population (see Figure 2-2).

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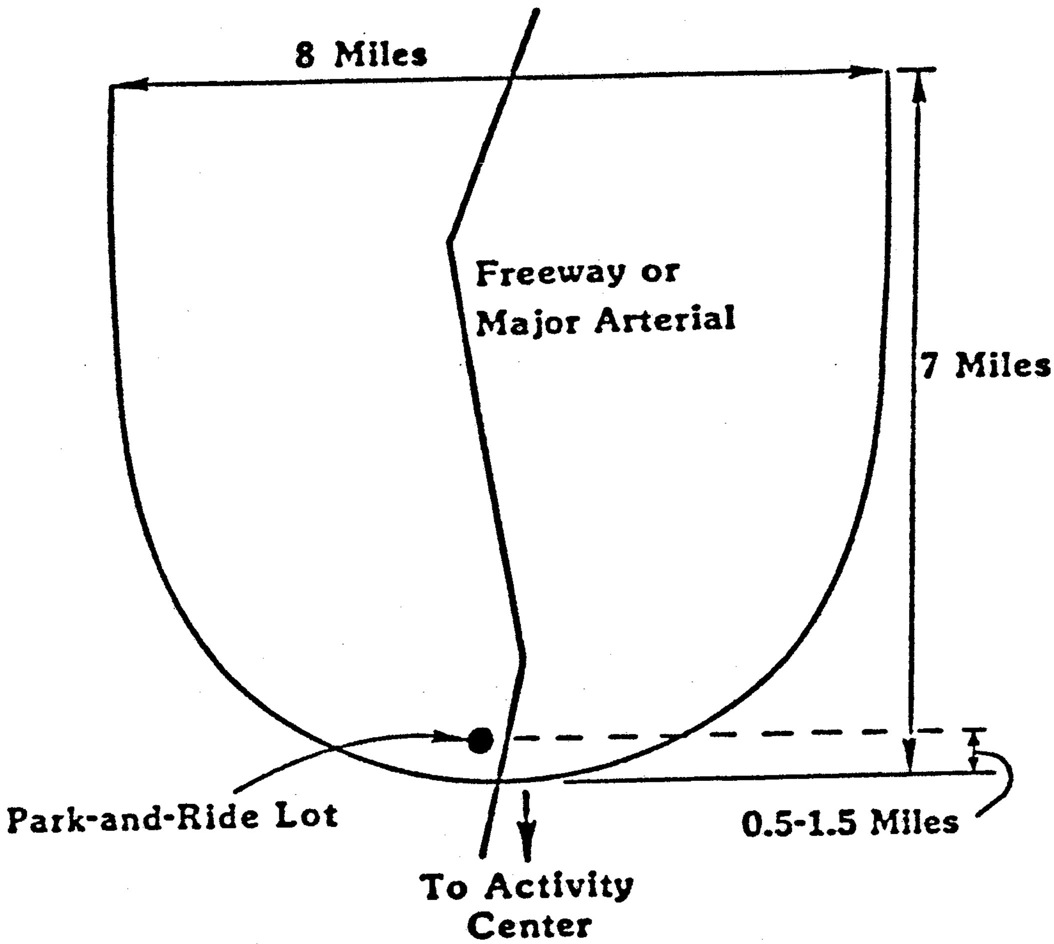

Source: Ref. (7)

Figure 2-2. General Shape of "Typical" Park-and-Ride Market Area for Houston Lots

In terms of the relative accuracy of the models, the models with the CBDEMP variable (eqs. 2.1, 2.3, and 2.4) perform better than the model without this variable (eq. 2.2). Therefore, if information on CBD employment is available, those models that incorporate this information should be used.

Carpool Demand Estimation Using Journey-To-Work Trip Tables

The park-and-ride demand estimation procedures described in the previous section have not been used to estimate carpool demands on transitway facilities. Experiences on Houston's Katy (I-10W) Transitway have shown that decisions concerning whether to allow carpools to use transitways, and, if so, what size carpools, can significantly affect transitway operations. Vehicle occupancy requirements should, therefore, be given careful consideration in transitway planning. In response to this issue, TTI is in the process of evaluating a number of carpool demand estimation procedures. A general description of one of these procedures is presented in this subsection. The procedure utilizes Census Journey-To-Work (JTW) data and has produced promising results in preliminary applications in the Katy (I-10W) corridor.

The basic procedure involves identifying the transitway market area (in terms of origin and destination census tracts), extracting this market area trip table from the Census JTW file, and splitting these trips between the modes available to serve these trips. Of course, a number of "adjustments" are necessary in the process of implementing this procedure. The following steps illustrate the basic procedure and provide some guidelines from Houston concerning the key assumptions necessary to implement the procedure:

Step 1: Define Transitway Market Area. This step involves identifying the census tracts representing the origins of commuters that could be expected to use the transitway to reach the major activity centers (destinations) served by the transitway. The result of this step is a matrix showing the origin and destination (O-D) census tracts served by the facility. The identification of destination (activity center) census tracts can be accomplished directly from census tract and urban area maps.

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Identification of origin census tracts requires a subjective assessment of those tracts that could be expected to use the roadways in the transitway corridor. In making this assessment, special consideration should be given to transitway access points. Since most commuters will not "backtrack" to gain access to a highway facility, identification of access points should be helpful in establishing reasonable boundaries for the market area.

Step 2: Compile Preliminary JTW Trip Table. Having identified the origin-destination census tracts in the corridor market area (Step 1), the JTW files can be used to tabulate the person-trip interchanges for these tracts. If the number of zones (tracts) involved is small, this tabulation can be performed manually. Simple computer programs could be developed to handle more extensive zone structures. The result of this step is a "preliminary" trip table. Step 3 outlines some adjustments that may need to be made to update the JTW trip table.

Step 3: Assess "Reasonableness" of JTW Trip Table. The preliminary trip table developed in Step 2 represents corridor trip interchanges. This preliminary table needs to be adjusted to account for travel that occurs on roadways other than the roadway where the transitway is, or will be, located. Also, the JTW data tends to over-estimate work trips because: (1) the data do not reflect absences from work due to travel, sickness, vacation, etc.; and (2) the data include weekend work trips. In comparing the JTW data with other travel data for Houston, TTI has found that the JTW data overestimates 1986 work trips by 7%-18% (7). In analyses that use the JTW data, TTI has used a multiplier of 0.9 (a 10% adjustment) to adjust the trip tables to reflect 1986 conditions in Houston.

Step 4: Compile Final Trip Table. In this step, the preliminary trip table (Step 2) is adjusted to reflect current conditions and to more precisely define the traffic market for the transitway. In the absence of local data, the factors developed for Houston (see Step 3) could be used.

Step 5: Estimate Carpool Mode-Splits. This step requires the analyst to develop estimates of carpool mode-splits for the activity centers served by the transitway. Unless local data is available (e.g., from an existing transitway facility), this data could be obtained from secondary sources. Table 2-3 shows mode splits for 2+ carpools for the activity centers served by the Katy (I-10W) Transitway in Houston. Table 2-3 also shows trip lengths, employment, and office space data for the activity centers. An examination of the data in Table 2-3 suggests that for large activity centers with employment densities in the range of 3000-3500 employees/million sq. ft. of office space and trip lengths on the order of 10 or more miles, mode splits of 20%-25% could be used in sketch planning applications. The 15% mode-split shown in Table 2-3 for the Texas Medical Center may be indicative of large activity centers that, due to the nature of their operations, may not be particularly conducive to ridesharing arrangements (The Texas Medical Center is a twenty-four-hour/day, seven-days-a-week facility with a high percentage of "professional" employees). As a first-cut approximation of 2+ carpool mode-splits, a uniform 20% mode split could be assumed for each activity center.

Table 2-3. Katy Transitway Carpool Mode-Splits and Activity Center Characteristics

Center	Trip Length[a] (miles)	Total Employment[b]	Square Feet Office Space[b] (millions)	Employees/ Million (sq. ft.)	Activity 2+ Carpool Mode-Split[c]
Downtown	13	178,300	51.8	3440	20%
City Post Oak	9	78,100	25.3	3090	25%
Greenway Plaza	13	34,200	12.1	2800	24%
Texas Medical Center	19	49,700	9.8	5100	15%

[a]Trip length refers to approximate distance from Beltway 8 entrance to Katy Transitway to activity center.
[b]Source: Houston-Galveston Area Council, 1985.
[c]Source: Ref. (7).

Mode-splits for "other" destinations also need to be considered. Data from the Katy Transitway in Houston show that 29% of the 2+ carpool trips are to destinations other than major activity centers.

Step 6: Estimate Carpool Trips. The mode-splits from Step 5, when applied to the trip table developed in Step 4, produce estimates of peak-

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period carpool person trip interchanges. If the mode splits developed for Houston are used (see Step 4), the estimates are for 2+ carpools. These estimates need to be adjusted to account for "other" destinations, as outlined in Step 5. If the Houston data are used, estimates of total 2+ carpools can be obtained by multiplying the activity center estimates by 1.4 (a 29% adjustment). As a first approximation of the origins of these other trips, the analyst could assume that they follow the same distribution as the major activity center origins.

The resulting person trips can be converted to vehicle trips on the basis of average occupancy rates (a factor of 2.2 has been used in Houston).

Step 7: Assign Carpool Vehicle Trips to Transitway. This assignment can be accomplished manually using the trip table (Step 6) and a map showing the transitway market area and highway network.

If the procedure outlined above is implemented using the various adjustment factors and mode-splits developed for Houston, the resulting estimates are 2+, peak-period, carpool vehicle demands. Also, these estimates assume that carpools need not be "authorized" to use the transitway (i.e., carpoolers are not required to undergo an initial orientation or training period). If analyses regarding other occupancy requirements and/or time periods are needed, the following conversion factors developed for Houston may be useful (7):

- To convert vehicle movement to person movement, multiply by 2.2.
- To convert from peak-period to peak-hour, multiply by 0.50.
- To convert from 2+ carpool demand to 3+ carpool demand, multiply by 0.20.
- To convert unauthorized carpool demand to authorized carpool demand, multiply by 0.60.

2.1.5 Design Concepts

Once the decision has been made to authorize specific high-occupancy vehicles to utilize the transitway and the demand for the facility estimated, the mainlane configuration and access connections must be selected. Various design concepts are possible with final implementation dependent upon factors of existing geometrics, available cross-section width, right-of-way constraints, adjacent land use, and cost. Each of these factors should be carefully considered.

2.1.5.1 Mainlane Configurations

Transitway mainlane configurations may be categorized as either single lane or multiple lane. Single lane transitways would normally be one-way, reversible facilities located within the median of a radial freeway corridor or possibly as a connection between major freeway systems on independent right-of-way. Single lane transitways may be placed at-grade or elevated, depending upon available cross-section width and the cost of aerial construction. Figure 2-3 illustrates an at-grade section of the single lane transitway mainlane configuration, and Figure 2-4 presents an elevated section.

Transitway facilities may also be multiple lane (i.e., two or more lanes). Operation on multiple lane transitways may be either one-way or two-way depending on demand. In many cases, the width required for multiple lane facilities prohibits at-grade construction. However, this must be compared with the construction cost for elevated implementation or the right-of-way cost for separate (off-freeway) implementation. Figure 2-5 depicts a sketch of a multiple lane transitway configuration.

2.1.5.2 Terminal Connections

The design of transitway connection depends on the decision of how to interface transitway vehicles with general purpose vehicles off the transitway. Two options are available. The first is to connect the

Figure 2-3. At-Grade Transitway Mainlane Configuration

Figure 2-4. Elevated Transitway Mainlane Configuration

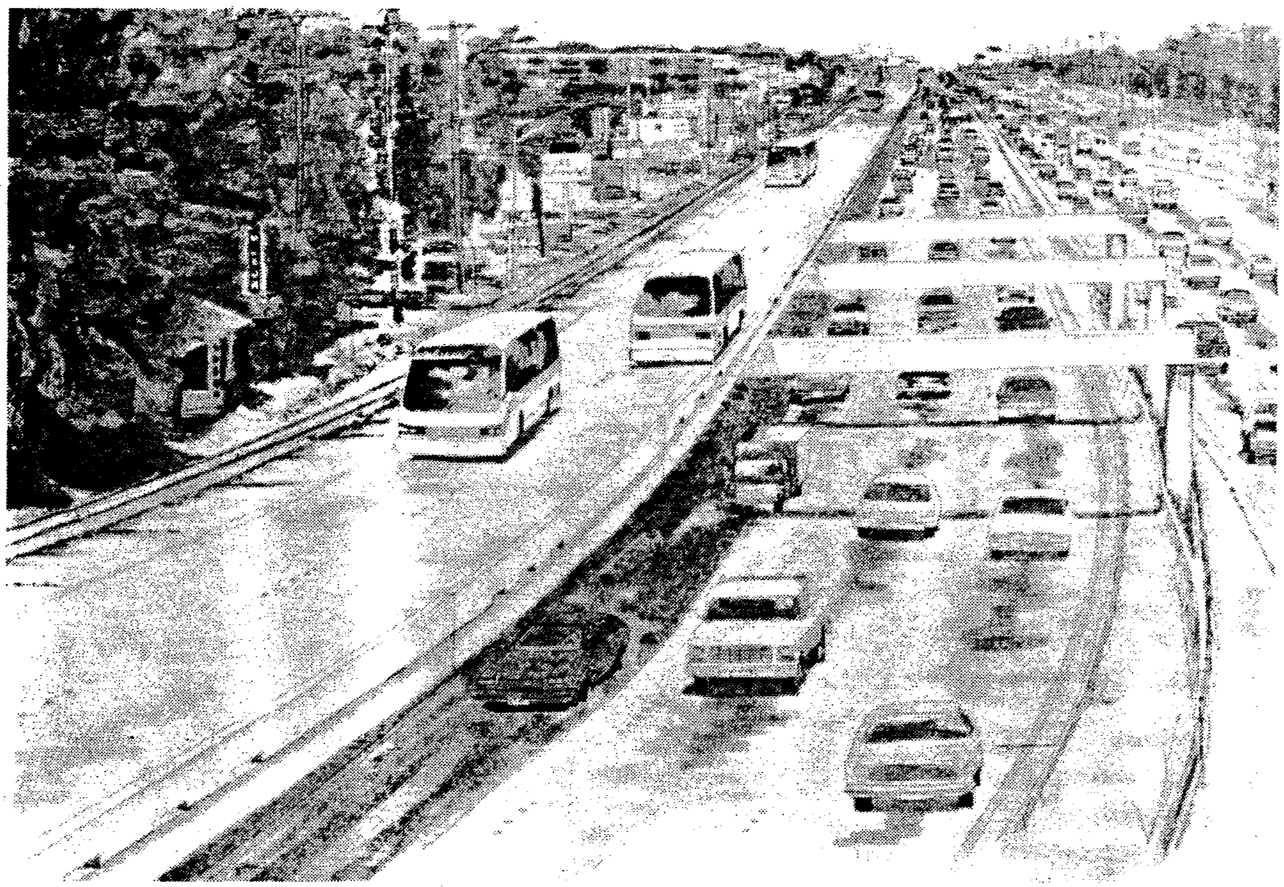

Figure 2-5. Artist's Rendention of a Multiple Lane Transitway Configuration

Figure 2-6. Terminal Slip Ramp Connection

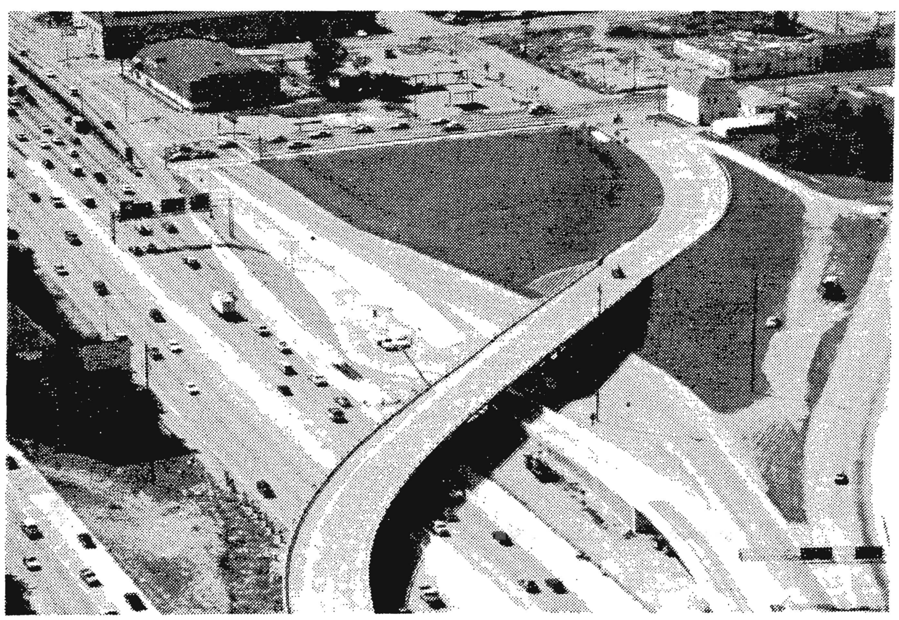

Figure 2-7. Terminal Flyover Connection to Surface Street System

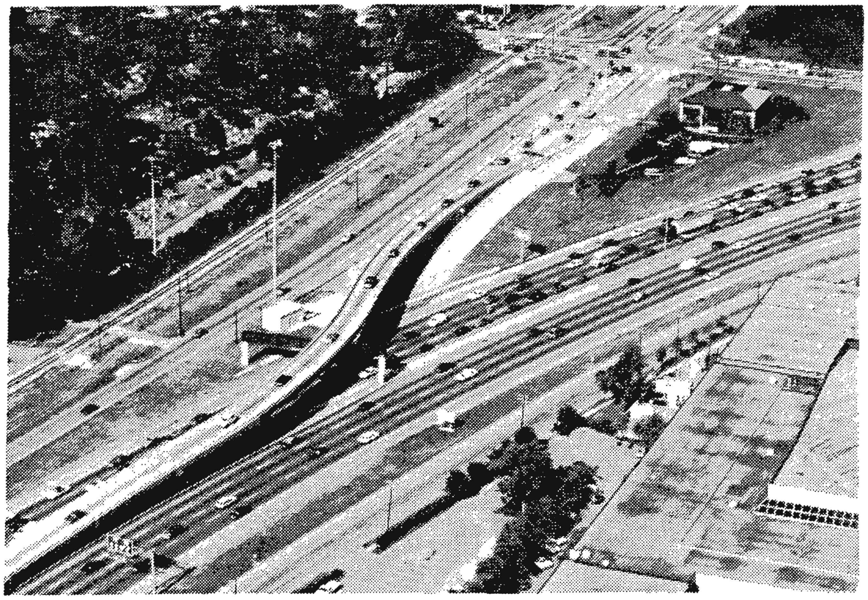

Figure 2-8. Terminal Flyover Connection to Surface Street System

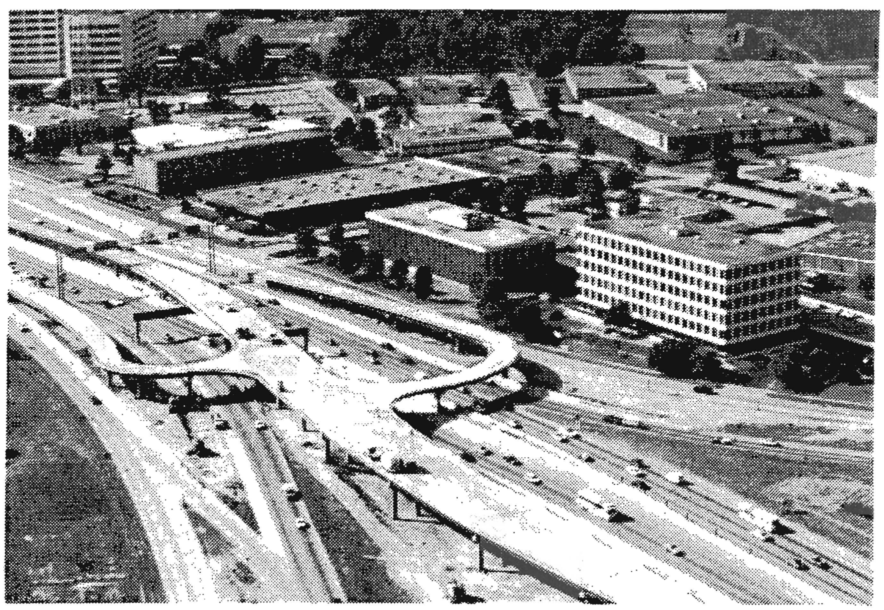

Figure 2-9. Terminal Flyover Connection to Frontage Road

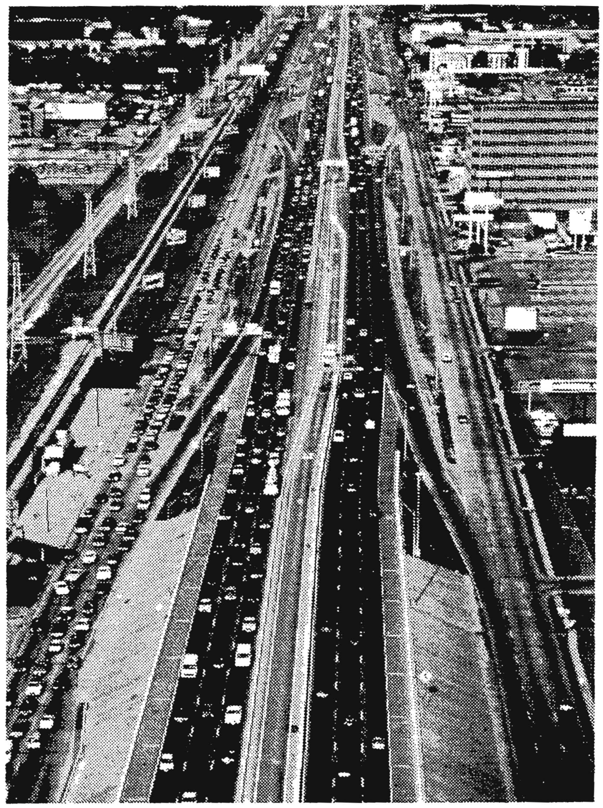

Figure 2-10. Intermediate Slip Ramp Connection to Freeway Mainlanes

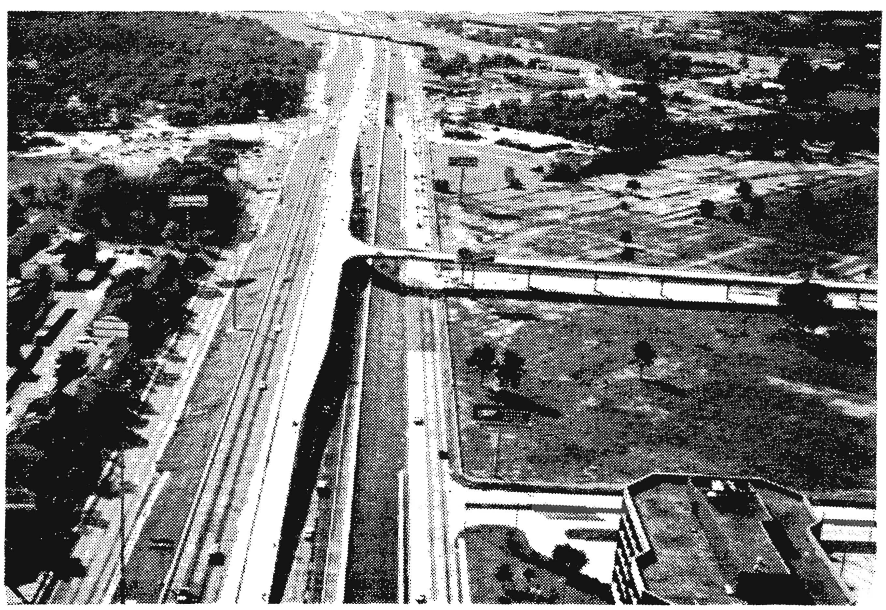

Figure 2-11. Example of Intermediate Connection by Grade Separated "Tee" Interchange

transitway must also use freeway ramps in close proximity to the transitway access points.

Intermediate access provided by grade separated interchanges are, in effect, aerial intersections with ramp connections. These interchanges may be operated one-way or two-way and may provide access from only one side of the freeway (a "Tee" design) or from both sides of the freeway (a "Cruciform" design). The structure must be wide enough and long enough to provide transitional acceleration and deceleration movements to and from the transitway mainlanes. Examples of design are shown in Figure 2-11, Figure 12, and Figure 2-13. Figure 2-13 is currently operating as a "Tee" interchange but will eventually be converted to a "Cruciform" interchange.

2.2 DESIGN CRITERIA

2.2.1 General

Design criteria for transitways are dependent upon a number of factors. The desired level-of-service influences both horizontal and vertical alignment. The class of authorized vehicles to be accommodated determines turning radii and allowable gradients. Transitways should be designed to accommodate all potential future vehicles, including buses, vans, and passenger vehicles. The projected facility demand establishes cross section by number of lanes required, as does the type of operation (one-way or two-way) and the provision for passing disabled vehicles (shoulder width). Available space also determines whether a facility may be located in the existing freeway median or within the freeway outer separation area; and whether transitways should be constructed on an elevated structure or at-grade adjacent to freeway mainlanes. Cost, aesthetics, adjacent land use, available right-of-way, and public perception of environmental degradation all influence transitways. Design criteria are dependent upon decisions relative to all these factors.

Design criteria for transitways are presented at two levels: (1) desirable; and (2) usual minimum. Values indicated as desirable are

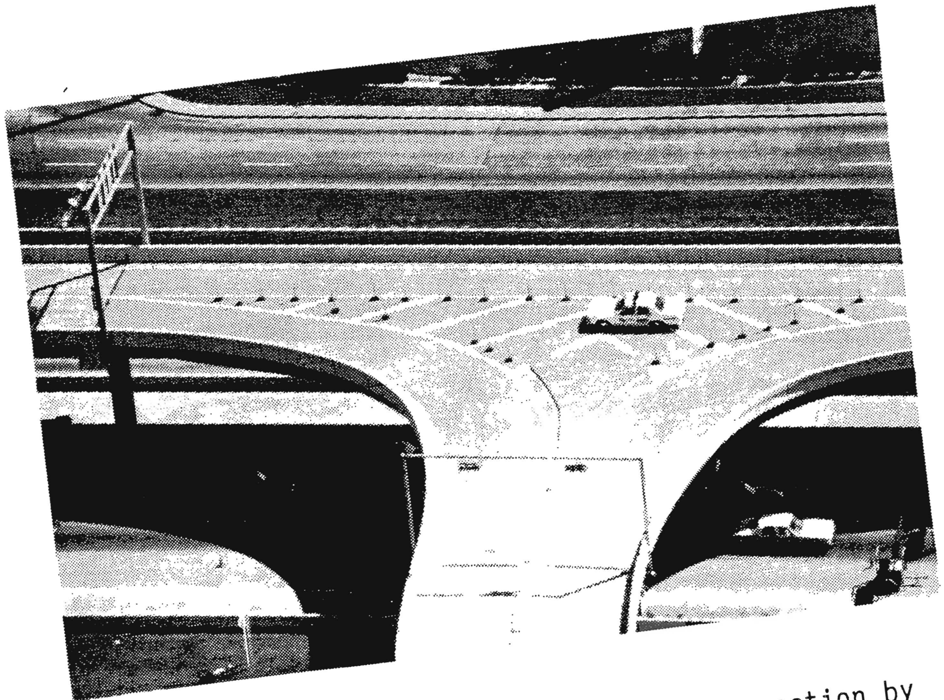

Figure 2-12. Example of Intermediate Connection by Grade Separated "Tee" Interchange

Figure 2-13. Example of Intermediate Connection by Grade Separated "Tee" Interchange

recommended for design to insure acceptable operations. Values shown as usual minimum, while safe, are to be used under conditions of extreme geometric or right-of-way constraint as long-term transitway operations may be adversely affected. Values less than those recommended as the usual minimum are to be employed in transitway design only in a temporary state (during construction phasing) or for limited segments (less than 2000 feet). Permanent operations, under these criteria, are generally undesirable.

2.2.2 Level-of-Service

Success in implementing and operating a transitway will depend, in great part, on the selection of design criteria which will assure a higher level-of-service (LOS) than experienced on congested freeway mainlanes. Location of the transitway, as well as the geometry of transitway access ramps, will influence level-of-service. Transitway cross-sections should be selected to accommodate a desirable level-of-service for the estimated demand of authorized vehicles in the design year.

In establishing the capacity which can be accommodated on a transitway at a specified level-of-service, consideration must be given to the differences in physical and operational capabilities of the high-occupancy vehicles which will use the facility. Experience on HOV facilities (12) indicates a LOS "A" capacity of 1200 passenger car equivalents per lane per hour (pce/lane/hr) (with one bus and one van each equal to 2.0 pce) as desirable. A LOS "C" capacity (1500 pce/lane/hr) may be accepted as the usual minimum for transitways with bus, vanpool, and carpool as authorized vehicles. Recent experience in Texas indicates demands of 1400 vehicles with 4500 passengers accommodated on a single lane transitway during the peak hour (13).

2.2.3 Design Speed

Design of transitway facilities should maximize travel time savings and trip time reliability as incentives for motorists to utilize high-occupancy vehicle modes of travel. Operating speed for express through movements

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should be no less than 50 mph and at the optimal for all interchanging or transitional movements. The corresponding design speeds needed to achieve this level of operations may be categorized by transitway mainlane(s) and connecting ramps, or intersections.

Desirably, design speed for transitway mainlane(s) should be in the 50-60 mph range. Under conditions of special or short-term operation, design speeds for transitway mainlane(s) should be a usual minimum of 40 mph. All design criteria should be commensurate with selected design speeds.

Transitway ramp connections should desirably be designed at approximately 0.70 mainlane design speed or nominally in the 30-40 mph range. This criterion would be applicable to both intermediate and terminal elevated "flyover" type ramps and at-grade "slip" ramps.

Other types of transitway ramp connections which are associated with grade separated interchanges with transitway mainlanes will require lower design speeds for turning maneuvers. Elevated "Tee" ramps may require radii with design speeds in the range of 15-20 mph. Adequate acceleration and deceleration lane lengths should be incorporated at these intersections for transitional maneuvering.

Lower ramp design speeds may also be appropriate where conditions of restrictive geometry or right-of-way exist for connections. These situations should be avoided where possible, as travel time savings associated with use of the transitway facilities are reduced.

2.2.4 Design Vehicles (HOV)

The physical and operating characteristics of authorized high-occupancy vehicles control various transitway design criteria. Four classes of authorized vehicles are considered -- passenger cars "P", vans "V", single unit buses "B", and articulated buses "A-B".

Dimensions representing vehicles within the general classes applicable to transitway design are shown in Table 2-4 (14). The dimensions of these design vehicles take into account dimensional trends in manufacture and represent a composite of those vehicles currently in operation. The design vehicle dimensions are values critical to geometric design and are greater than nearly all vehicles belonging to each corresponding vehicle class.

Table 2-4. Design Vehicle Dimensions

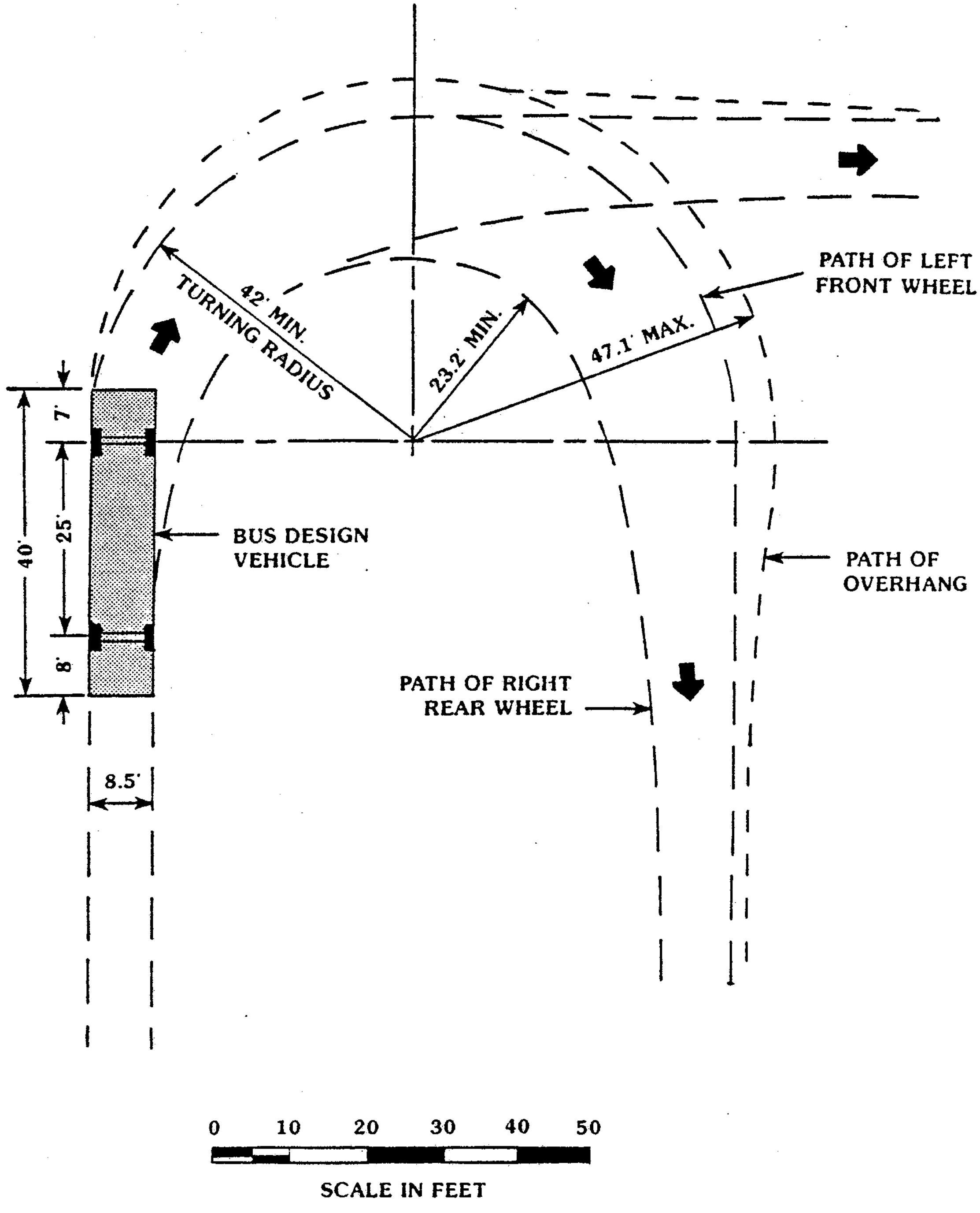
Design Vehicle Type	Symbol " "	Height (ft)	Width (ft)	Length (ft)	Overhang		Wheel Base (ft)
					Front (ft)	Rear (ft)	
Passenger Car	"P"	4.25	7.0	19	3	5	11
Van	"V"	6.5	7.5	17	2.5	4	10.5
Single Unit Bus	"BUS"	13.5	8.5	40	7	8	25
Articulated Bus*	"A-BUS"	10.5	8.5	60	8.5	9.5	18

*Segmented bus that has the rear portion flexibly but permanently connected to the forward portion.

Source: Ref. (14).

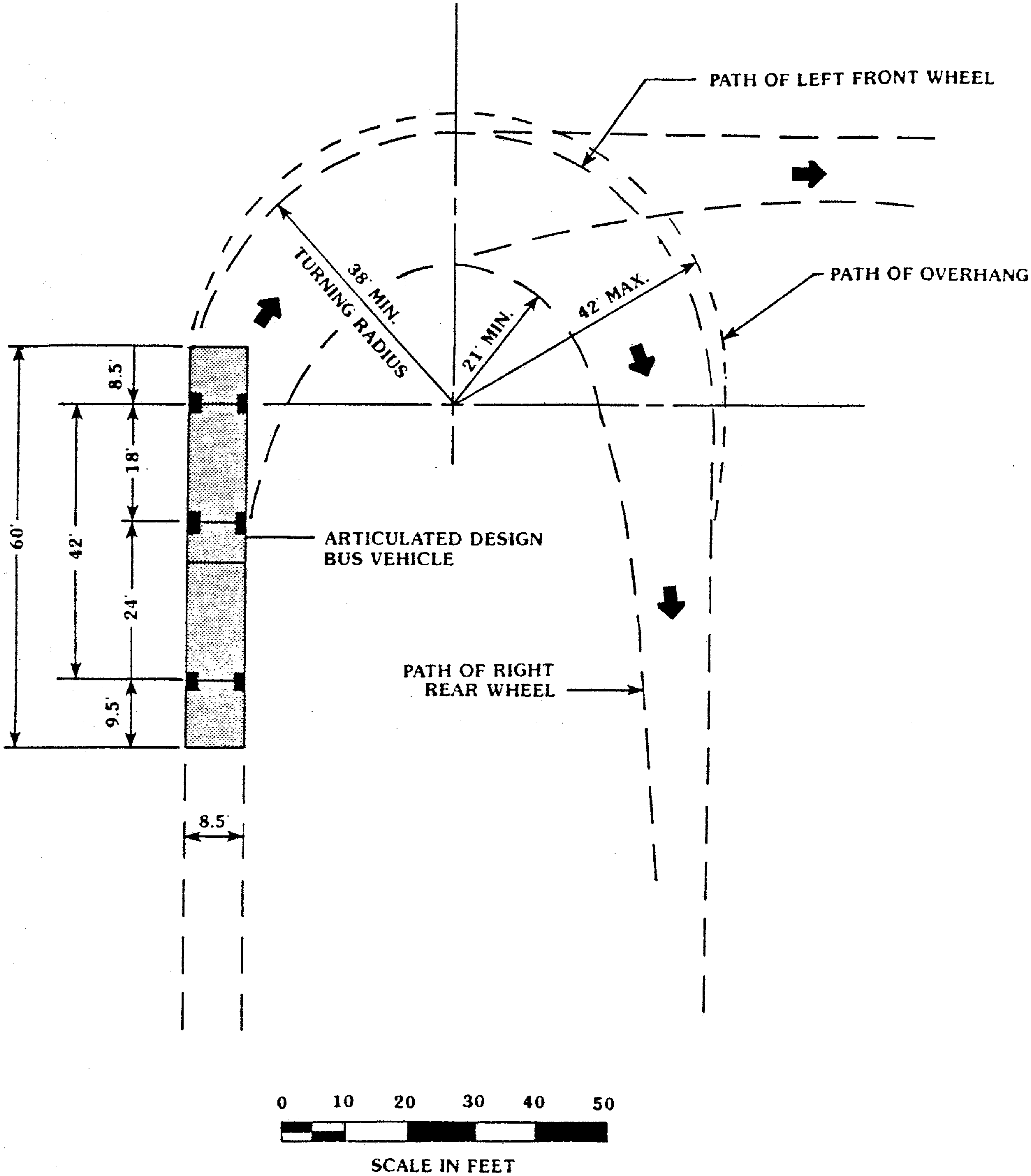
The single unit and articulated buses are the largest vehicles to utilize transitway facilities, and, therefore, must be considered in dimensioning transitway geometrics. Lane and shoulder widths, lateral and vertical clearances, storage distances, and minimum turning radii are controlled by the single unit bus. The articulated bus, while longer than the single unit bus, has a permanent hinge near the center which allows greater maneuverability. Design templates for minimum turning path of both the "BUS" and "A-BUS" design vehicles are shown in Figures 2-14 and 2-15.

The single unit bus is also the controlling vehicle for transitway 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



Source: Ref. (14)

Figure 2-14. Minimum Turning Path Design Template for "BUS" Design Vehicle



Source: Ref. (14)

Figure 2-15. Minimum Turning Path Design Template for "A-BUS" Design Vehicle standing bus passengers. Figure 2-16 illustrates bus acceleration characteristics measured during a series of demonstration tests (15). Figure 2-17 illustrates transit bus speed related to distance as determined from recent studies conducted in Texas (16).

The passenger car, with eye height at 3.5 feet and object height 0.5 feet, should be the controlling design vehicle to establish stopping sight distances on transitways. It is recognized that a transitway facility may operate with only buses and vanpools with higher eye heights which reduce the calculated stopping distance. However, the provision for future changes in vehicle authorization precludes the elimination of passenger cars as the critical transitway vehicle for this design criterion.

Table 2-5 presents both desirable and usual minimum stopping sight distances for a range (30-60 mph) of transitway design speeds. The deceleration associated with those values shown as desirable will be acceptable for buses with standees. Both tolerable and desirable stopping sight distance values are also applicable for calculation of horizontal curvature where line of sight is 2.0 feet in height.

Table 2-5. Transitway Stopping Sight Distance Values

Transitway Design Speed (mph)	Minimum Stopping Sight Distance (feet)
30	200
40	275
50	400
60	525

Source: Ref. (14).

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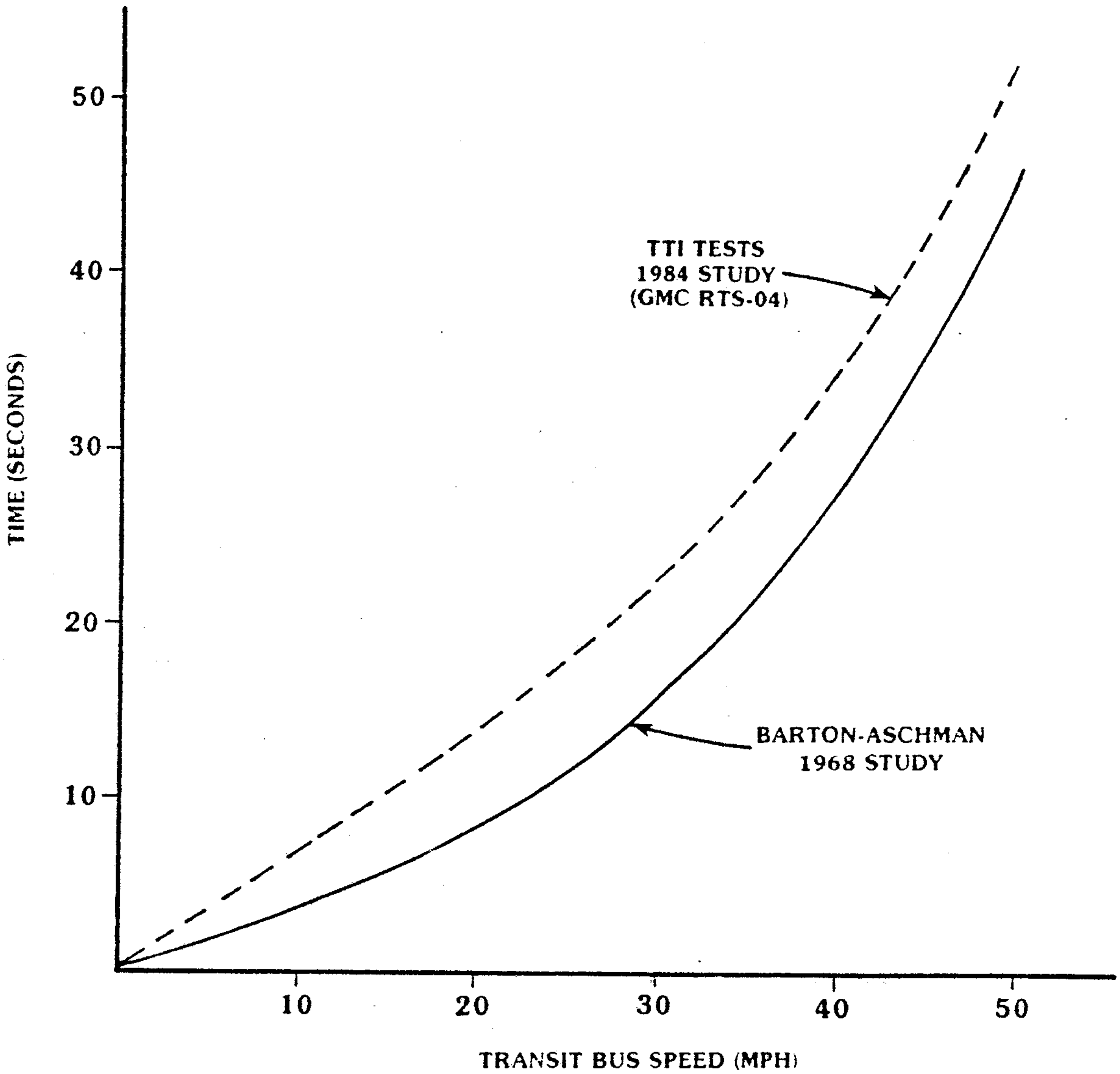
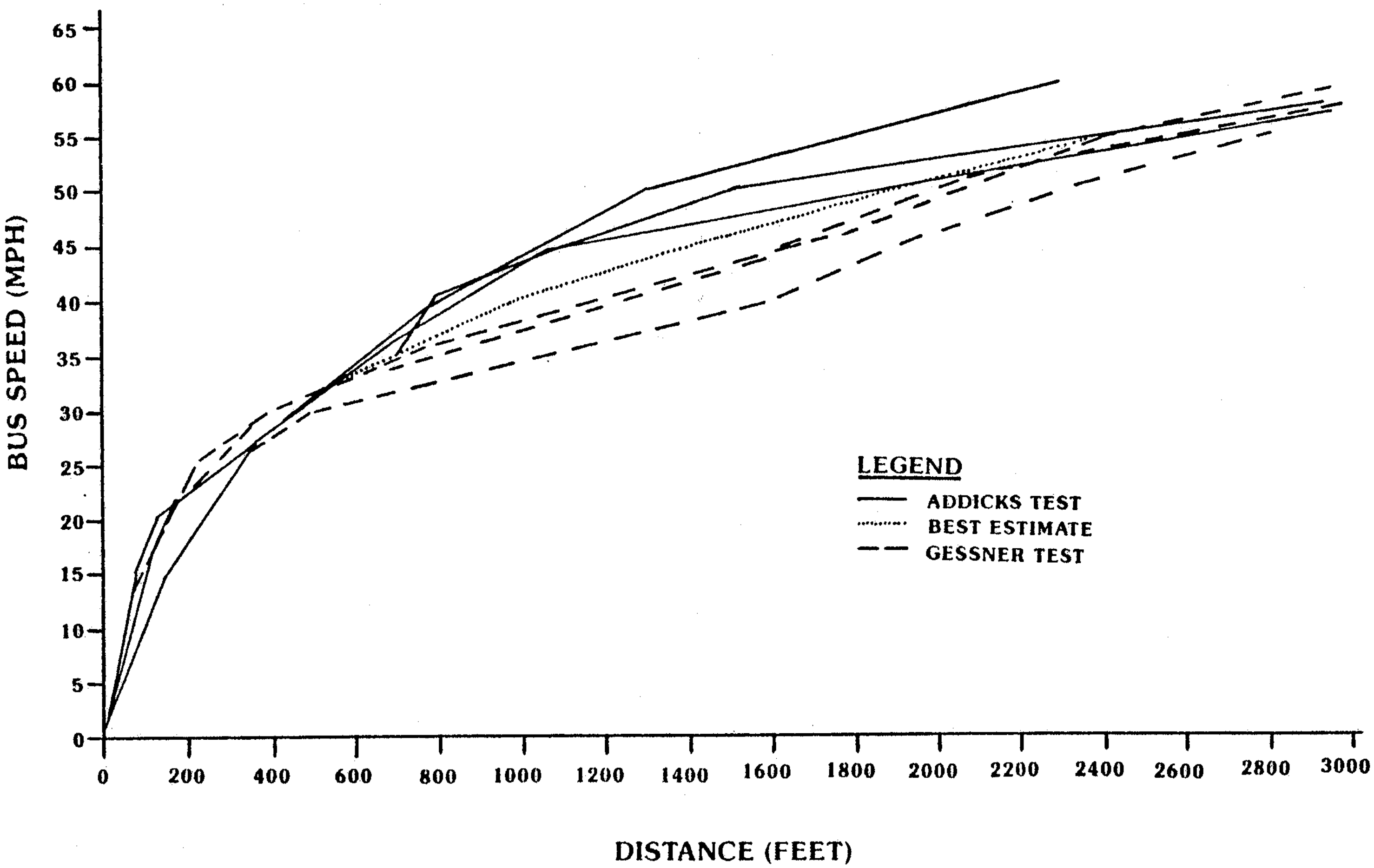


Source: Ref. (14)

Figure 2-16. Bus Acceleration Characteristics, Speed versus Time



Source: Ref. (16)

Figure 2-17. Transit Bus Relationships, Speed Versus Distance

2.2.5 Alignment

2.2.5.1 General

Transitway alignment should conform to American Association of State Highway and Transportation Officials (AASHTO) (14) practice recommended for high-type freeway facilities. At-grade transitways incorporated into freeway medians will follow the existing alignment controls. Alignment of independent (separate right-of-way) transitways will be controlled by the stopping sight distance criteria presented in Table 2-5. Only under special conditions of geometric constraints, and after careful regard to safety and vehicle capabilities, should reduced values be considered for design of transitways.

2.2.5.2 Superelevation

Superelevation rates on transitway mainlanes must be applicable to curvature over a range of design speeds. Consideration must be given to the higher center of gravity exhibited by buses and vans which will result in superelevation rates slightly higher than otherwise justified. Table 2-6 presents recommended values for superelevation rates on transitways.

Table 2-6. Recommended Transitway Superelevation Rates

Transitway Design Speed (mph)	Maximum Superelevation e (ft/ft)
40-50	0.04-0.06
50-60	0.06-0.08

Source: Ref. (14).

2.2.5.3 Horizontal Curvature

Horizontal curvature on transitways is dependent upon the joint relationship between design speed, pavement side friction, and superelevation

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to effect safe, smooth, and comfortable travel. Table 2-7 presents recommended values for maximum degree of curvature (minimum radius). Selection of values for radii of horizontal curvature less than recommended should only be considered where costs of providing the recommended radii are inconsistent with benefits.

Table 2-7. Recommended Maximum Degree of Curvature (Minimum Radius) for Horizontal Curvature on Transitways

Design Speed (mph)	Curvature for Typical ^{e} Max (ft/ft)		
	0.04	0.06	0.08
40	$10^{o}00'$ (575'R)	$11^{o}15'$ (510'R)	----
50	$6^{o}00'$ (950'R)	$6^{o}45'$ (850'R)	$7^{o}30'$ (765'R)
60	NR NR	$4^{o}15'$ (1350'R)	$4^{o}45'$ (1200'R)

NR - Not Recommended

Source: Ref. (<u>14</u>).

2.2.5.4 Vertical Curvature

The length of crest vertical curves on transitways is dependent on the requirements for stopping sight distance as previously discussed. The length of sag vertical curves is dependent on comfort level and headlight sight distance. Transitways introduced into the median of freeways will typically adhere to the existing vertical curvature. For the design of transitways independent of freeway vertical alignment, K-values should be utilized to calculate the recommended minimum length of vertical curvature. For crest vertical curves, these calculations assume a driver eye height of 3.5 feet (passenger car being the most critical), an object height of 0.5 feet, parabolic curvature, and the presence of fixed source lighting for an urban

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environment. For sag vertical curves, the calculations assume that the light beam distance is nearly the same as the stopping sight distance, the headlight height is 2.0 feet, and the upward divergence of the light beam is 1^{0} from the longitudinal axis of the vehicle. Table 2-8 indicates the recommended K-values for the length of transitway vertical curves over a range of design speeds for both crest and sag conditions.

Table 2-8. Transitway Vertical Curve Criteria (K-Factors)

Design Speed (mph)	Minimum K-Factors*	
	Crest (stopping)	Sag (stopping)
60	190	120
50	110	90
40	60	60
30	30	40

*Ft/ft change in algebraic difference in gradients

Source: Ref. (14).

2.2.6 Gradients

2.2.6.1 General

Recommended gradients should reflect current AASHTO (14) practice to insure both safety and uniformity of operation in concert with the capabilities of the transitway design vehicles. Consideration must be given to both maximum and minimum grades.

2.2.6.2 Maximum Grades

Table 2-9 shows recommended maximum grades for transitway mainlanes and ramps. On existing freeways with transitway retrofit, existing grades should be utilized. Values exceeding the recommended maximum may be considered in special or extreme situations only. The designer can enhance operation of authorized vehicles by providing flatter grades of adequate length at starting and stopping locations.

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The maximum length of grade should be such that authorized vehicles are not slowed by more than 10 mph, considering the length and percent of grade. Figure 2-18 illustrates speed degradation for a standard transit bus ("B") with an average weight to horsepower ratio of approximately 175 (17). As can be seen, long grades at or near the maximum should be avoided wherever possible due to this effect on operations.

Table 2-9. Recommended Grades on Transitways

Transitway	Segment Maximum Grade (%)
Mainlane (50-60 mph)	6
Ramp (30-40 mph)	8

Source: Ref. (18).

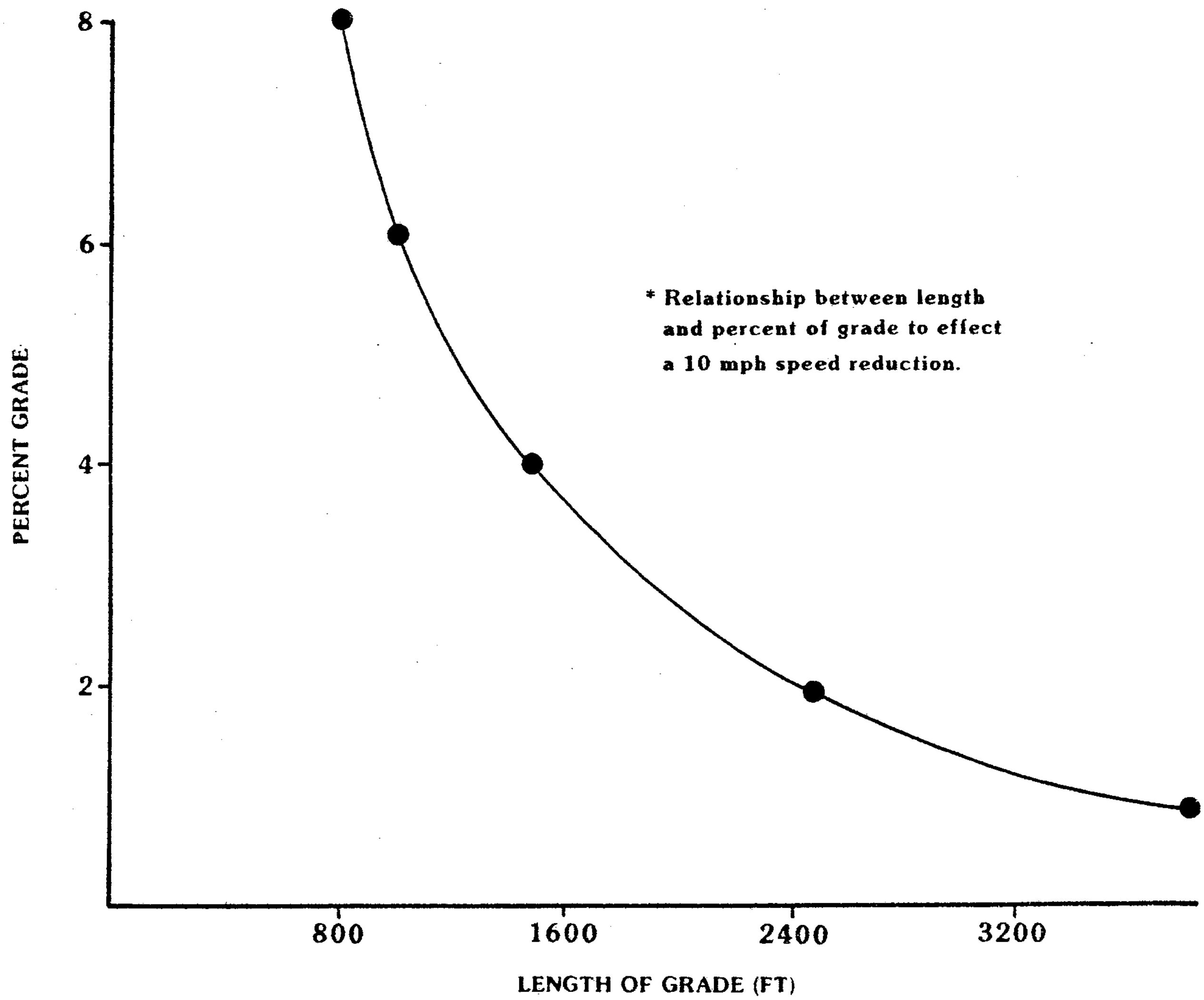
2.2.6.3 Minimum Grades

A minimum longitudinal grade of 0.35% is controlled by the need to provide adequate drainage and to prevent long periods of water retention (ponding) on the transitway surface. For median, retrofitted, at-grade facilities minimum grade will follow the existing freeway gradient.

2.2.7 Clearances

2.2.7.1 General

Both vertical and lateral clearances must be accommodated in transitway design and should be consistent with current AASHTO practice (14). Vertical clearances should be determined by the height of the most critical authorized vehicle to use the facility (i.e., transit buses). Lateral clearance tolerances must be considered as applied to continuous obstructions (i.e.,



*Assumed typical transit bus (GMC TDH 5307 RTSO 6V92TA) with average weight/horsepower ratio of 175 and entry speed of 55 MPH

Figure 2-18. Bus Speed Degradation Curves the concrete barrier physically separating the transitway). Figure 2-19 illustrates both vertical and lateral clearance envelope dimensions.

2.2.7.2 Vertical Clearance

Vertical clearance to structures passing over the transitway should desirably be 16.5 feet. While this is more than sufficient allowance for the maximum height of a transit bus (13.5 ft), it does allow for the possibility of emergency or future use by other types of vehicles (trucks, rail cars, etc.). In situations of restricted vertical clearance, a minimum (usual) of 14.5 feet is acceptable. This includes an allowance of 6 inches in anticipation of future resurfacing.

2.2.7.3 Lateral Clearances

The incorporation of transitways into existing freeway medians or outer separations may occur, many times, within restricted rights-of-way. Under these conditions, depending upon the required cross section and operations, lateral clearance should be a usual minimum of 2.00 feet from the edge of the travel lane to the face of the barrier or physical obstruction. Only in special temporary or construction situations, or for limited distance, should lateral clearance values less than the usual minimum be used in transitway design.

2.2.8 <u>Cross Section</u>

2.2.8.1 General

Transitway cross section widths may be categorized as either single lane (one-way reversible) or multiple lane (one-way or two-way, reversible or non-reversible). In addition, consideration relative to available space for location and cost effectiveness will determine whether a transitway facility is constructed at-grade or elevated. Cross-section width will also vary based upon whether the design segment of the transitway is a mainlane or a connection ramp.

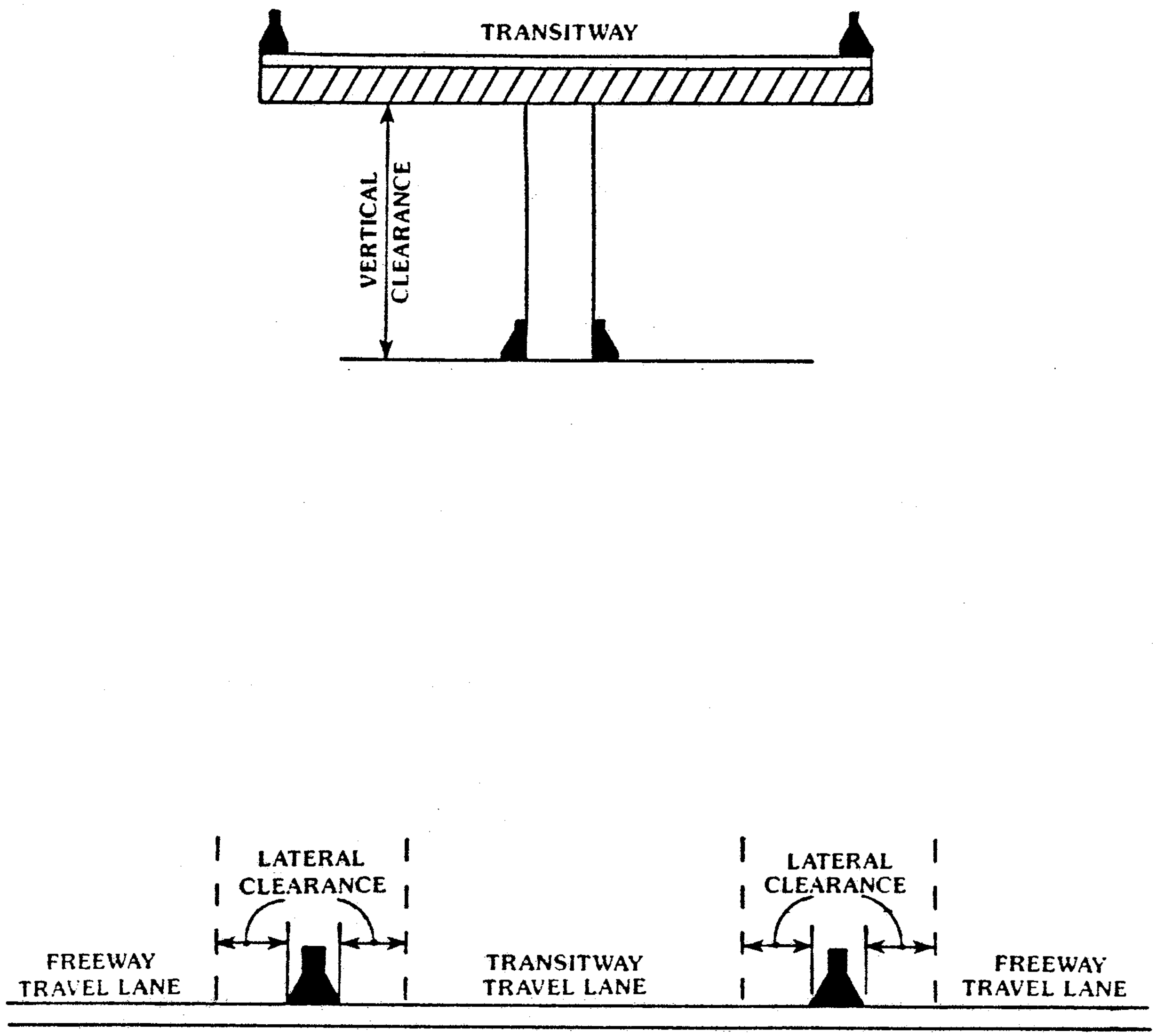


Figure 2-19. Vertical/Lateral Clearance Envelopes

2.2.8.2 Pavement Width

However classified or located, the requirements for the combined pavement and shoulder width (or lateral clearance) must include provision for passing a stalled or stopped vehicle. The results of a study (15) conducted to establish minimum total transitway pavement widths which maintain acceptable operations under conditions of passing stalled vehicles have been incorporated into the following recommendations for transitway cross section.

Transitway travel lanes are recommended to be 12 feet wide. Transitway mainlane widths less than the recommended may be acceptable in extreme cases, but only if used on tangent sections in conjunction with sufficient center shoulder separation or outer lateral clearance width.

Ramp lane widths are recommended to be 13 feet wide (19). Ramp lane widths less than the recommended should be used only in extreme cases and for relatively short distances. Shoulders should be included in total design width for transitway ramps, wherever possible, to provide for passing of stalled vehicles and facilitate passenger unloading of buses and vanpools from the right side of the vehicle.

Most urban transit buses are designed with a minimum turning radius (inner rear wheel path) of 20 to 25 feet and an outer front wheel radius of 38 to 42 feet. The center radius decreases as the inner radius increases, but is still a significant factor. Transitway mainlane pavement widening on curves provides additional lateral width for maneuvering and for the overhang of various parts of the transitway vehicle. Table 2-10 shows recommended pavement widening for transitway mainlanes for various horizontal curve radii and design speeds.

Table 2-10. Pavement Widening Recommended for Horizontal Curvature On Transitway Mainlanes

Design Speed (mph)	Pavement Widening (ft) for Curve with Radius (ft)		
	500	750	1000
30	1.5	1.0	0.5
40	2.0	1.0	1.0
50	---	1.5	1.0
60	---	---	1.0

Source: Ref. (19).

Likewise, curved ramp pavement widths must also be sufficient to accommodate the bus wheel path and allow passing of stalled vehicles. Recommended total ramp pavement widths are given for both single and multiple lane operation and varying ramp radii in Table 2-11.

Table 2-11. Recommended Widths for Transitway Ramps

Transitway Ramp Operation	Pavement Width (ft) for Inner Pavement Edge Radius (ft)			
	100	250	500	1000
Single lane, one-way	30	28	26	24
Multiple lane, two-way	40	38	37	36

Source: Ref. (19).

As stated previously, it is necessary to provide sufficient total width, barrier to barrier, to provide for through movements on the transitway around stalled vehicles. The difference in total cross-section width and travel lane width functions essentially as a "breakdown shoulder."

On single lane transitways, this shoulder space is the sum of lateral separation on each side of the center travel lane. As a usual minimum, this separation on each side should be 3.75 feet. Desirably, the separation on each side of the mainlane to the barrier should be 8.0 feet, to allow for

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possible future expansion to two 12-foot mainlanes with 2-foot minimum clearance offsets to the barrier on each side.

On multiple lane transitways, the breakdown shoulder may be located in the center to separate each lane with two-way operation. Desirably, this shoulder should be 10.0 feet wide and, as a usual minimum, 8.0 feet wide. Multiple lane transitways on unrestricted rights-of-way may place shoulders of comparable width on either side of the mainlanes.

Transitway ramps should also be provided with additional total width to function as a breakdown shoulder and allow passing of stalled vehicles. A usual minimum of 8.0 feet and desirable of 10.0 feet of added total width is recommended for either one-lane one-way, or two-lane two-way ramp operation.

Schematics of transitway mainlane total widths are given in Figures 2-20 to 2-23. Both desirable and usual minimum dimensions are shown for single lane versus multiple lane and at-grade versus elevated transitway facilities. Figure 2-24 and 2-25 also illustrate the difference in total width for unrestricted right-of-way, two-way, or one-way, reversible operation and for restricted right-of-way, one-way operation or low volume (1200 pcephpl), two-way operation.

2.2.8.3 Acceleration/Deceleration Lanes

Speed change lanes should be provided on the transitway at all locations where access points and mainlanes interface. This interface may occur either at-grade or at elevated intersections; or between terminal or intermediate ramp connections. It is desirable for vehicles entering the transitway to achieve speeds within 10 mph of through mainlane transitway vehicles (16).

Table 2-12 summarizes recommended deceleration and acceleration lane lengths for various combinations of transitway mainlane design speeds and ramp exit/entrance design speeds. Usual minimum taper lengths to allow lane transition are included in the total recommended speed change distances (L_d, L_a).

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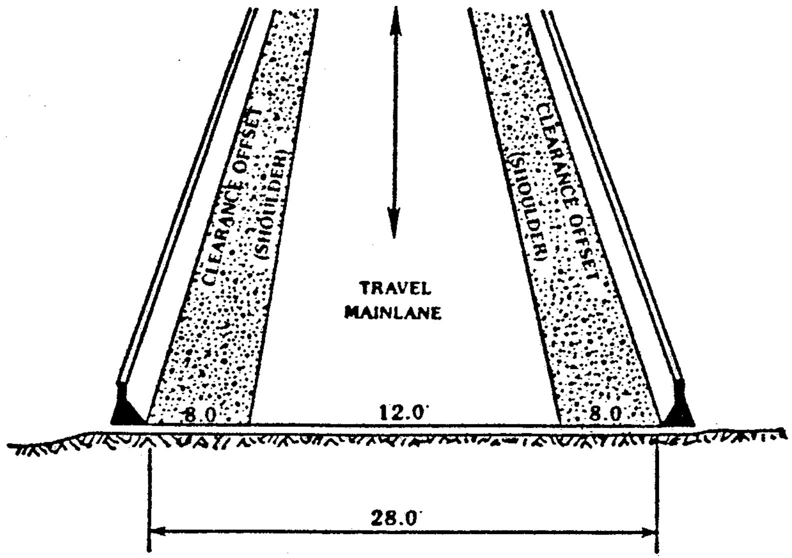
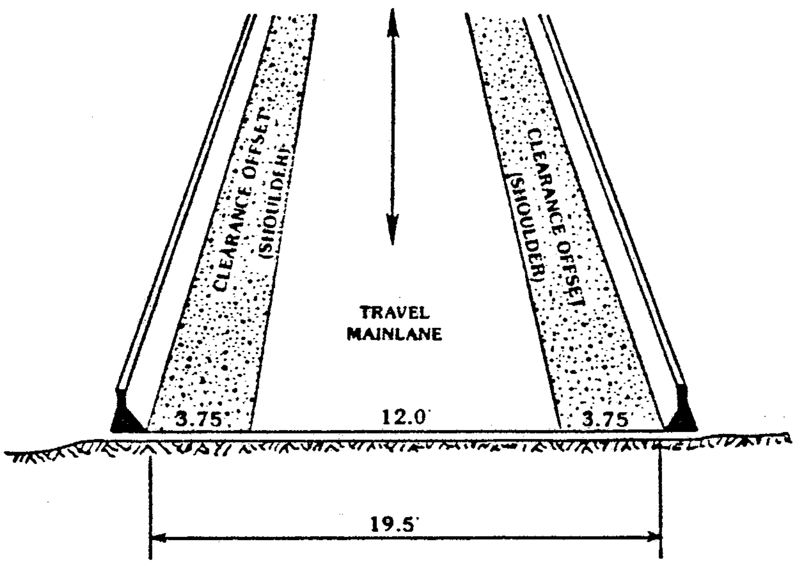


a) Desirable



b) Usual Minimum

Figure 2-20. Transitway Cross Section,
Single Lane At-Grade, One-Way

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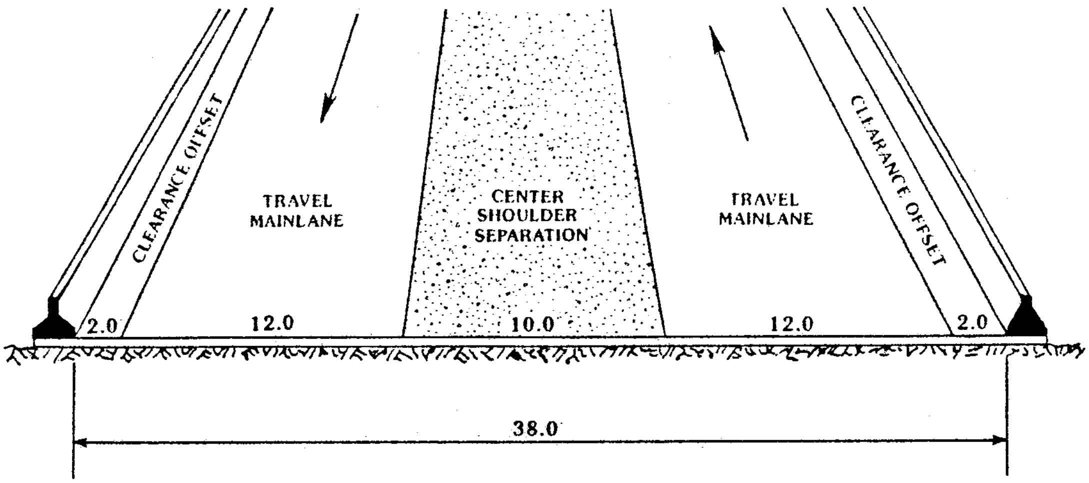
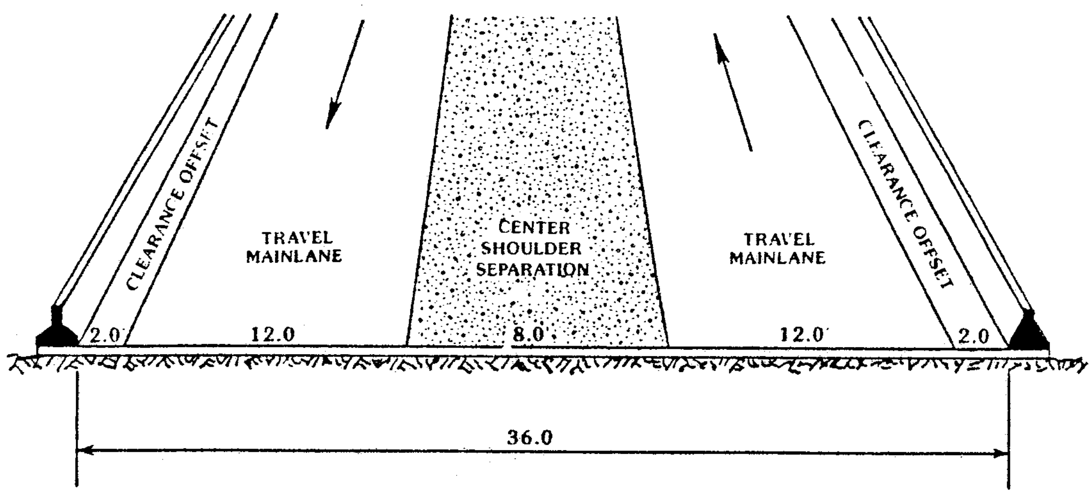


a) Desirable



b) Usual Minimum

Figure 2-21. Transitway Cross Section, Multiple Lane At-Grade, One-Way

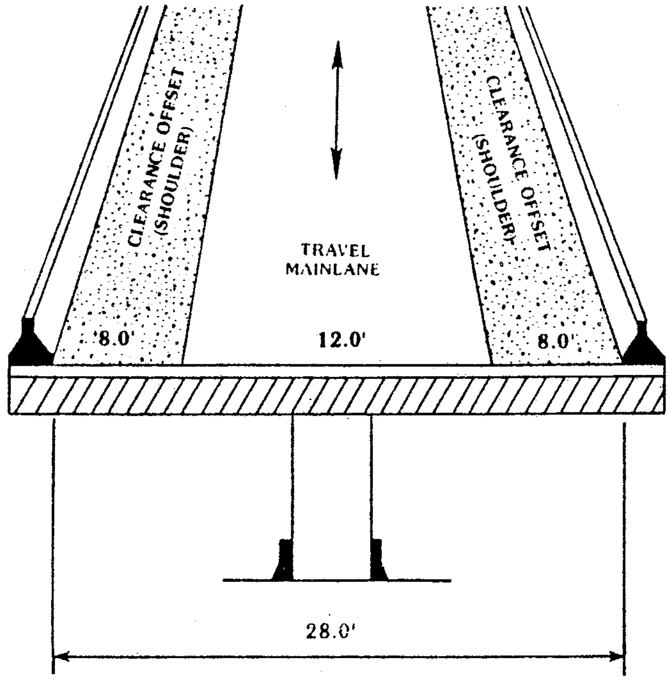


Figure 2-22. Recommended Transitway Cross Section, Single Lane Elevated, One-Way

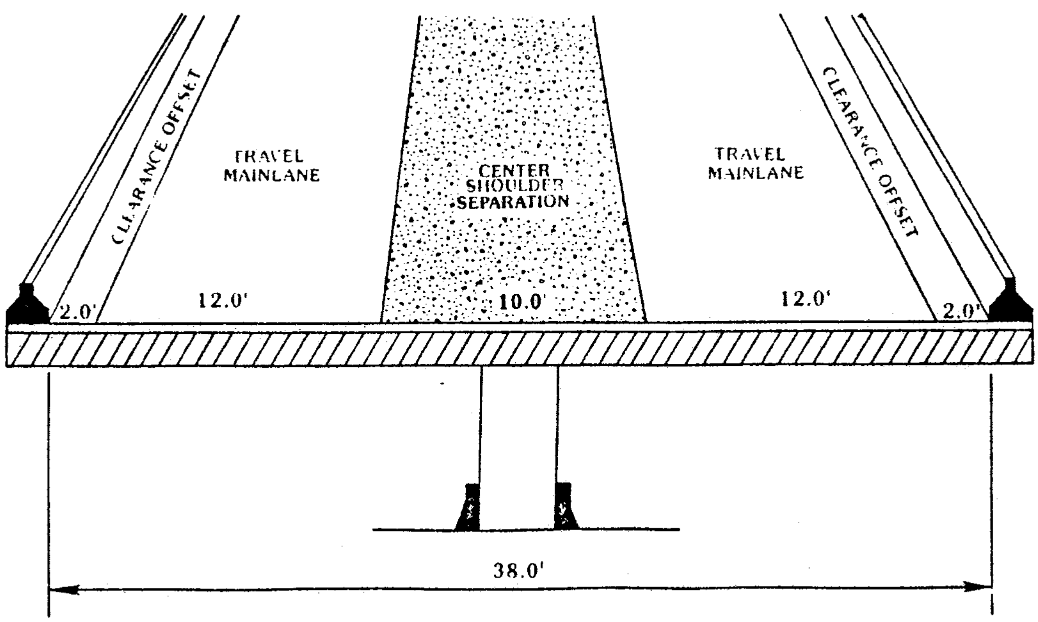


Figure 2-23. Recommended Transitway Cross Section, Multiple Lane Elevated, One-Way or Two-Way

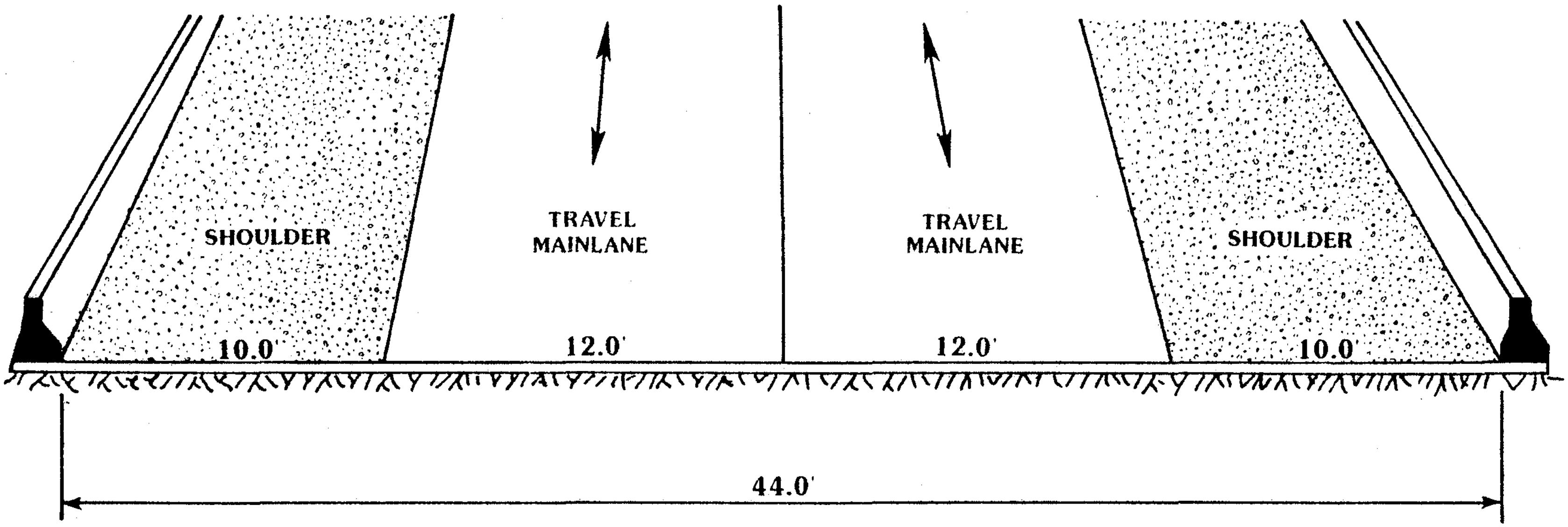


Figure 2-24. Recommended Transitway Cross Section,
Unrestricted Right-of-Way, Two-Way, or One-Way, Reversible Operation

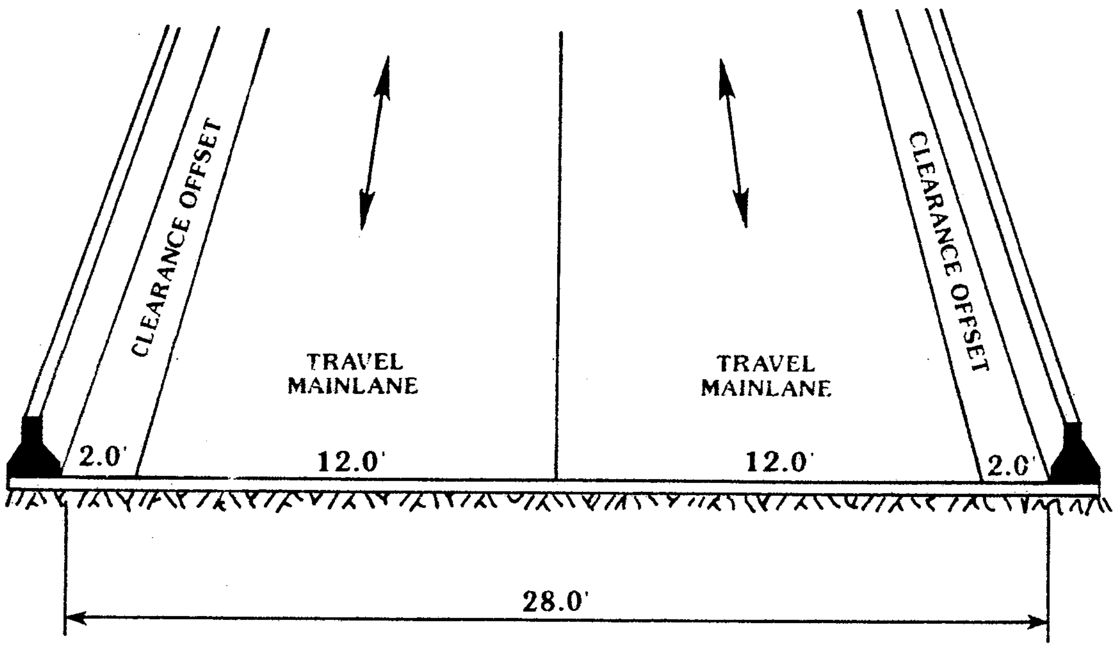


Figure 2-25. Recommended Transitway Cross Section, Restricted Right-of-Way, One-Way Operation or Low Volume (1200 pceph), Two-Way Operation.

Table 2-12. Recommended Acceleration/Deceleration Lane Lengths

Transitway Mainlane Thru Speed (mph)	Transitway Intersection Entering Speed [1] (mph)	Length of Acceleration/ Deceleration Lane (ft)	Length of Taper [2] (ft)	Recommended Total Length (ft)
35	25	250	170	420
40	30	400	190	590
45	35	700	210	910
50	40	975	230	1205
55	45	1400	250	1650
60	50	1900	270	2170
65	55	2400	280	2680
70	60	3000	290	3290

[1] Bus Speed at end of taper
[2] Usual minimum Taper - 20:1, Desirable Taper - 50:1

Source: Ref. (16)

The recommended length of these acceleration or deceleration lanes is based upon the previously specified nominal rates for single unit buses (acceleration of 2.0 mph/second, deceleration of 2.5 mph/second) and the performance curves given in Figures 2-16 and 2-17. Limits of the lane length and taper length are illustrated in Figure 2-26.

The values shown represent acceleration and deceleration on a level (0%) grade. For the critical design HOV (single unit buses) these lengths may be reduced when incorporated with a grade separated interchange. The effective reduction for the length of a deceleration lane on an upgrade is approximately 5% for every 1% positive grade. The effective reduction for the length of acceleration lane on a downgrade is approximately 10% for every 1% negative grade. These guidelines are restricted to gradients 6% or less and lengths of grade of 1000 feet or less.

2.2.8.4 Cross Slope

The recommended cross slope on transitway mainlanes and ramps to insure adequate drainage is 0.020 feet/foot of pavement. This value applies to all transitway pavement designs.

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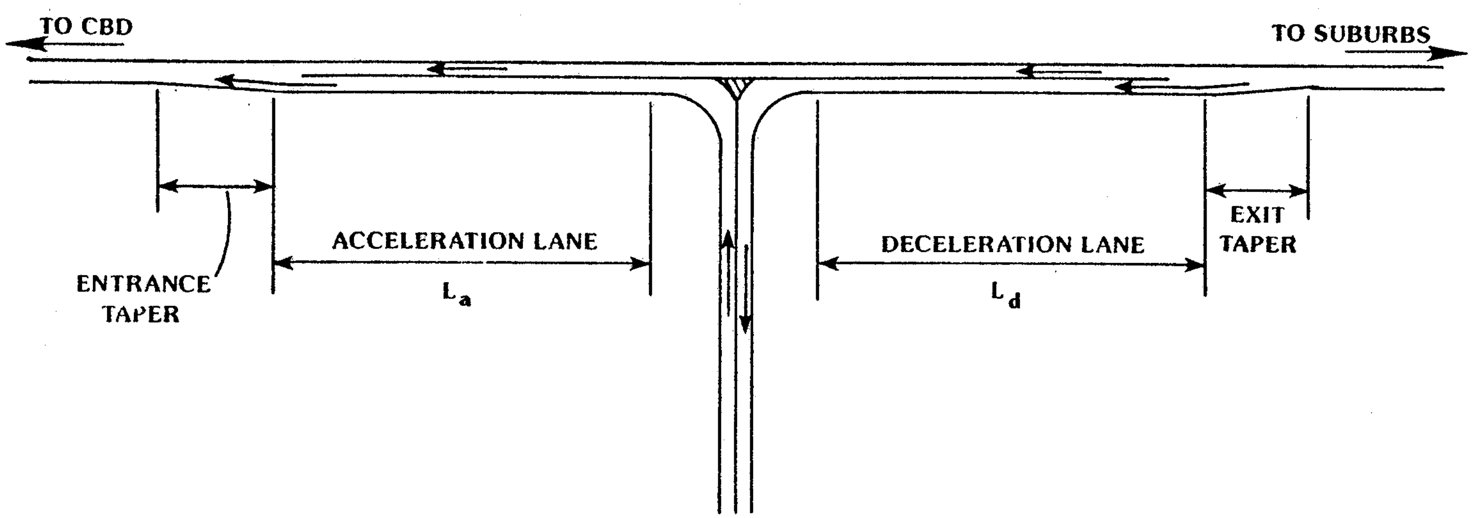

Figure 2-26. Limits of the Lane Length and Taper Length Distances

2.2.9 Special Features

2.2.9.1 Median Slip Ramps

Where access is required from freeway mainlanes to an at-grade median transitway facility at some intermediate location, a slip ramp connection may be provided. This slip ramp consists of an opening in the transitway separation barrier sufficient to allow a lane change maneuver by the high-occupancy vehicle from the inside freeway mainlane into the transitway. At an operating speed of 50 mph, this maneuver by a transit bus will require 4.0-5.0 seconds. Therefore, this intermediate slip ramp opening should be desirably 400 feet and a usual minimum of 300 feet long. Figure 2-27 illustrates a typical design layout.

2.2.9.2 Intermediate Elevated Intersection (Interchanges)

Connections with either at-grade or elevated transitway mainlanes may be facilitated at intermediate access points through elevated intersecting ramps. These ramps may terminate directly into transit support facilities or tie into the frontage road or surface streets for authorized vehicle collection or distribution. The interchange may be either a "Tee" or "Cruciform" configuration with an approximate 90-degree angle between transitway mainlanes and ramps. Typical layouts are shown in Figures 2-28 and 2-29. These intermediate interchanges function similar to an intersection joined with acceleration and deceleration lanes for entrance/exit movements with the transitway. Sufficient structure width must be provided for separation of through movements from turning movements, and appropriate lengths of speed change lanes are necessary for safe and efficient merge and diverge.

2.2.9.3 Terminal Connections

Access at a terminal connection to an at-grade median transitway may be provided by a slip ramp design. Figure 2-30 presents an example of this concept. As can be seen, the terminal openings are flared and widened for

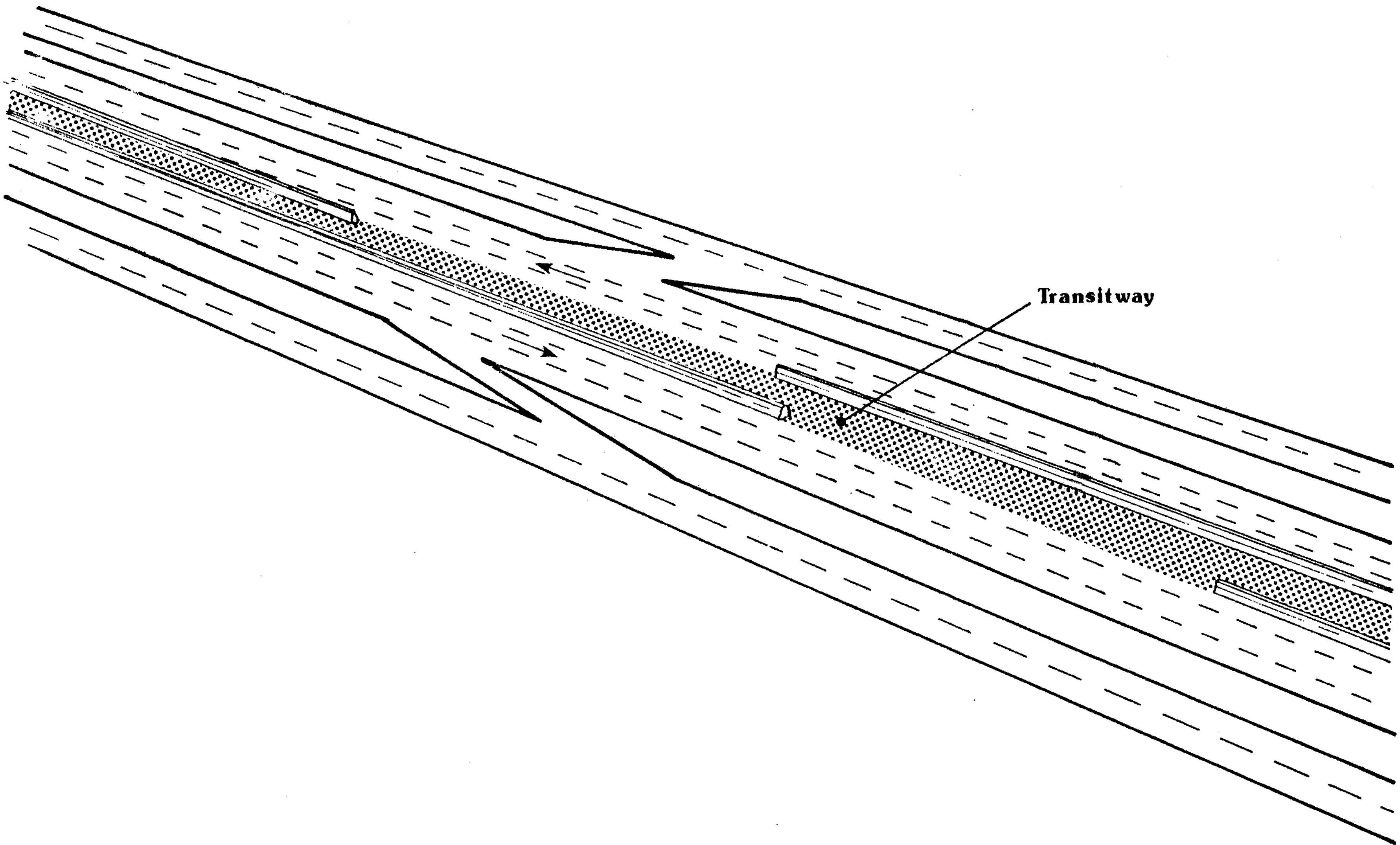

Figure 2-27. Conceptual Layout of a Typical Intermediate Slip Ramp

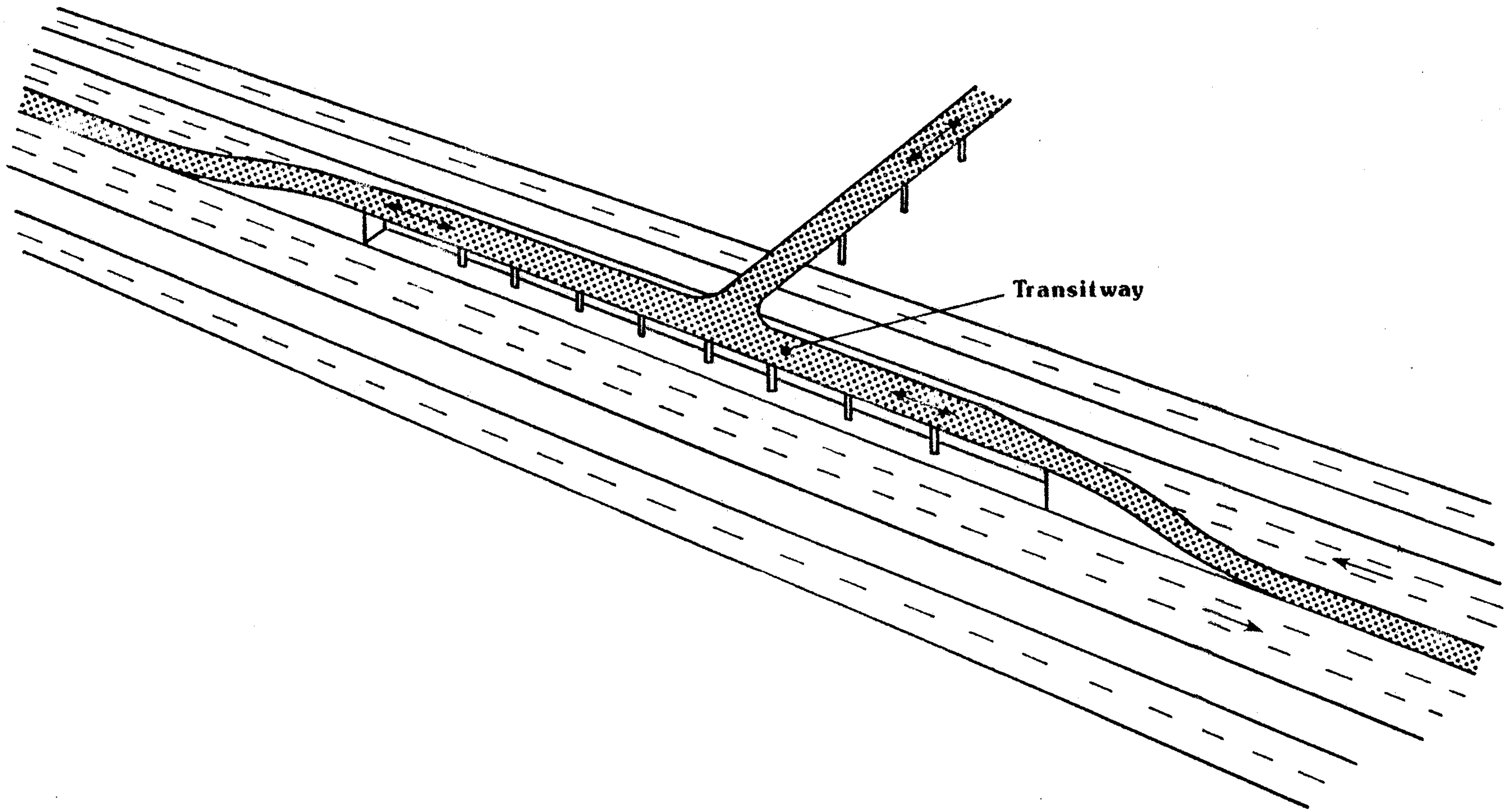

Figure 2-28. Conceptual Layout of a Typical Elevated "Tee" Interchange

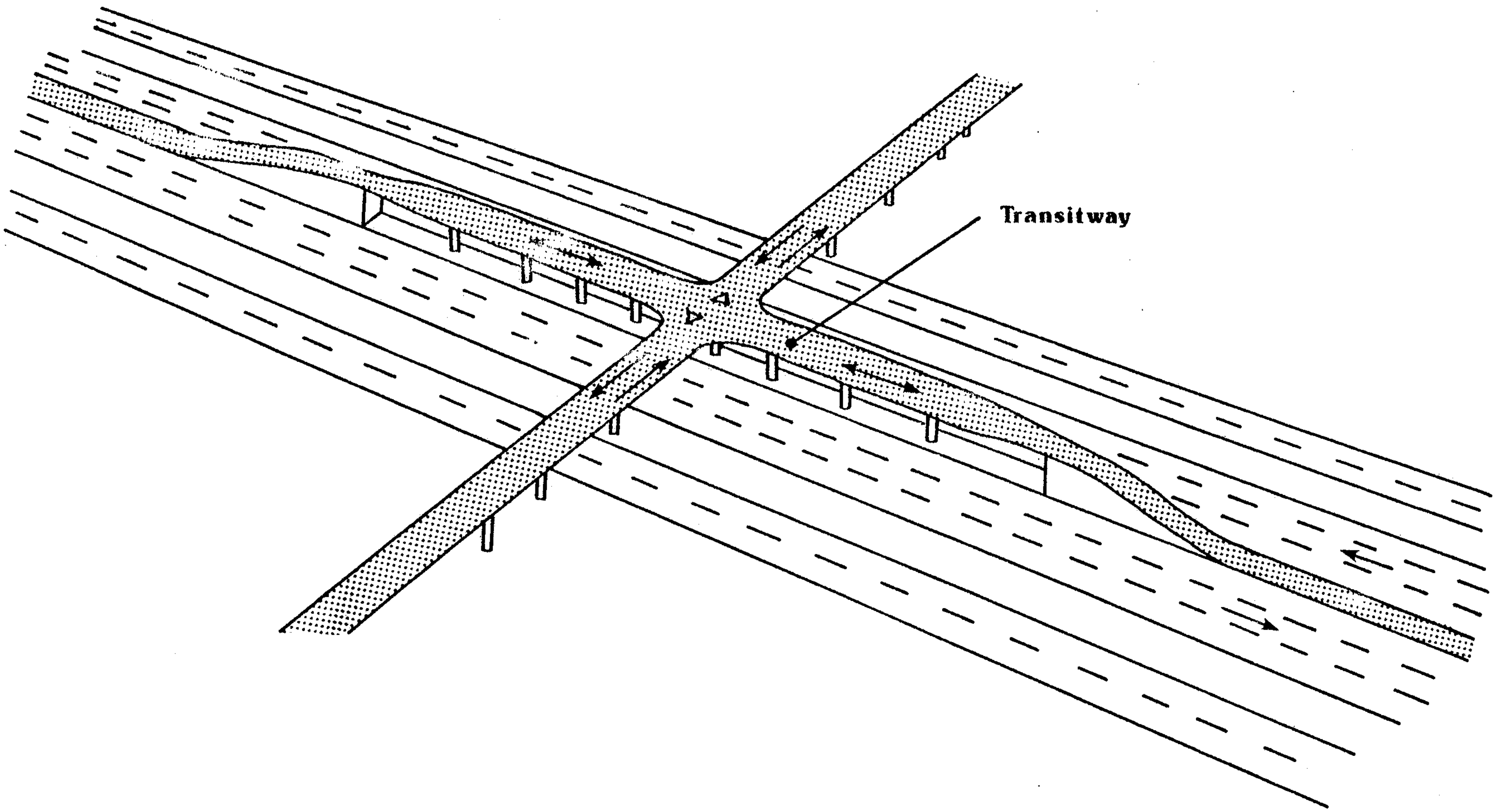

Figure 2-29. Conceptual Layout of a Typical Elevated "Cruciform" Interchange

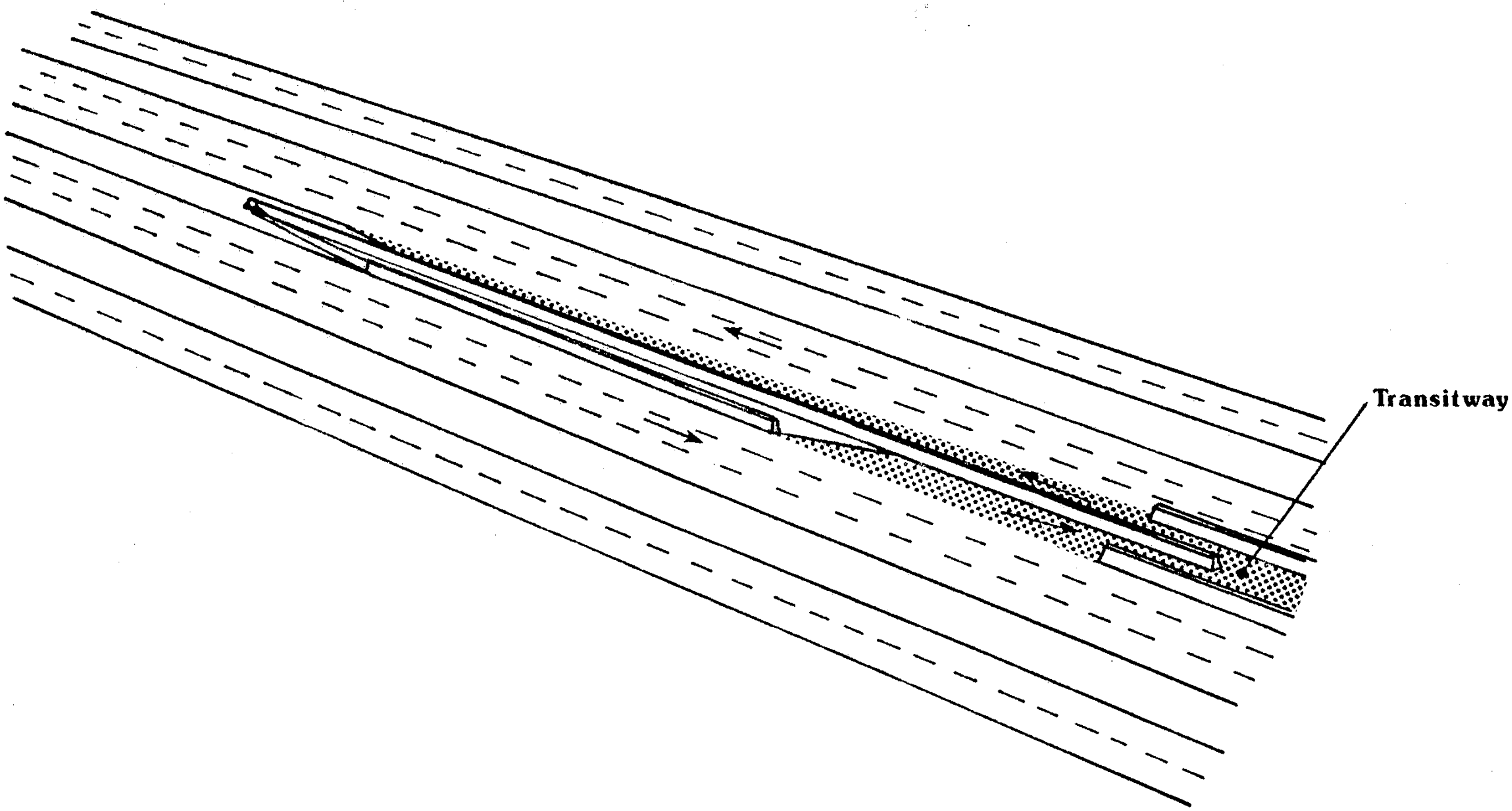

Figure 2-30. Conceptual Layout of a Typical Terminal Slip Ramp

both ingress and egress movement by authorized transitway vehicles. Transition lane lengths and tapers as previously specified are recommended for the corresponding diverge and merge maneuvers with freeway mainlane traffic.

Transitway terminal connections may also be accomplished with elevated ramp structures which "flyover" the at-grade freeway from median transitway mainlanes. High-occupancy vehicles enter and exit the transitway directionally from support facilities, frontage roads, or surface streets, depending on demand, geometric requirement, and route patterns. Appropriate grades and lengths of grades as previously recommended must be applied for safe and efficient operations. Adequate vertical clearance must also be maintained over freeway and at-grade transitway sections. Figures 2-31 and 2-32 illustrate two designs for terminal elevated ramp terminal connections.

2.2.9.4 Emergency Opening Access

Experience with the early Texas transitways indicated the need for emergency access located between the usual access points. Emergency access of this type is needed to assist in the removal of non-operating vehicles from the transitway. The current design for Emergency Opening Systems (EOS) is a 30-foot opening in the concrete median barrier, bridged by a guardrail assembly to prevent unauthorized access. Both ends of the EOS are hinged so that access may be obtained from either direction in the transitway. One man can open and close the EOS. Crash tests (20) have demonstrated that it will safely redirect errant vehicles and prevent them from entering the transitway.

2.2.10 Summary

Table 2-13 summarizes the recommended criteria for transitway design. Reference should be made to the text for detailed discussion. It should be noted that each potential transitway project must be considered site specific. It should also be emphasized that both the minimum and desirable standards presented must be qualified. In extreme cases, values less than

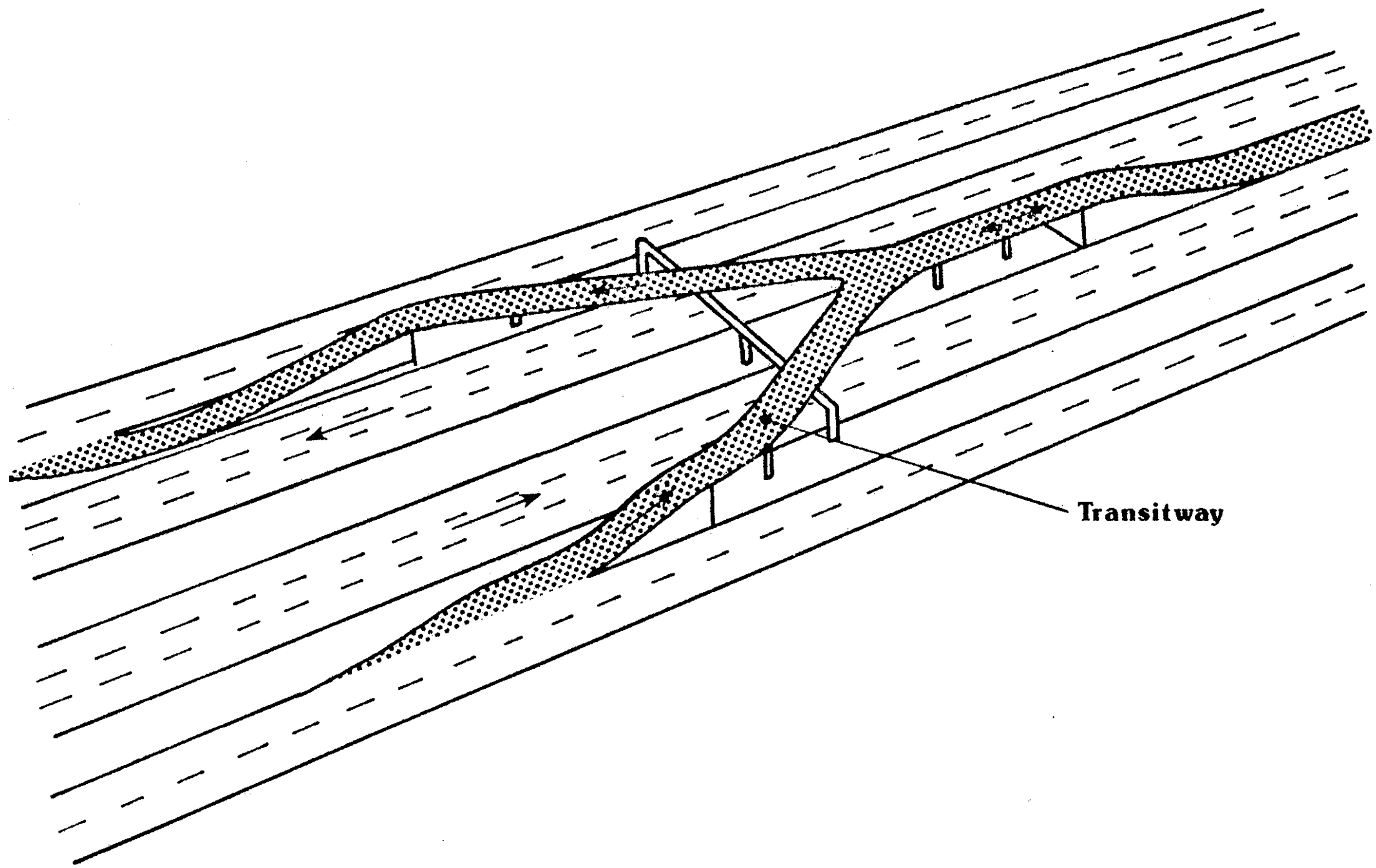

Figure 2-31. Conceptual Layout of a Typical Flyover Terminal to Frontage Road

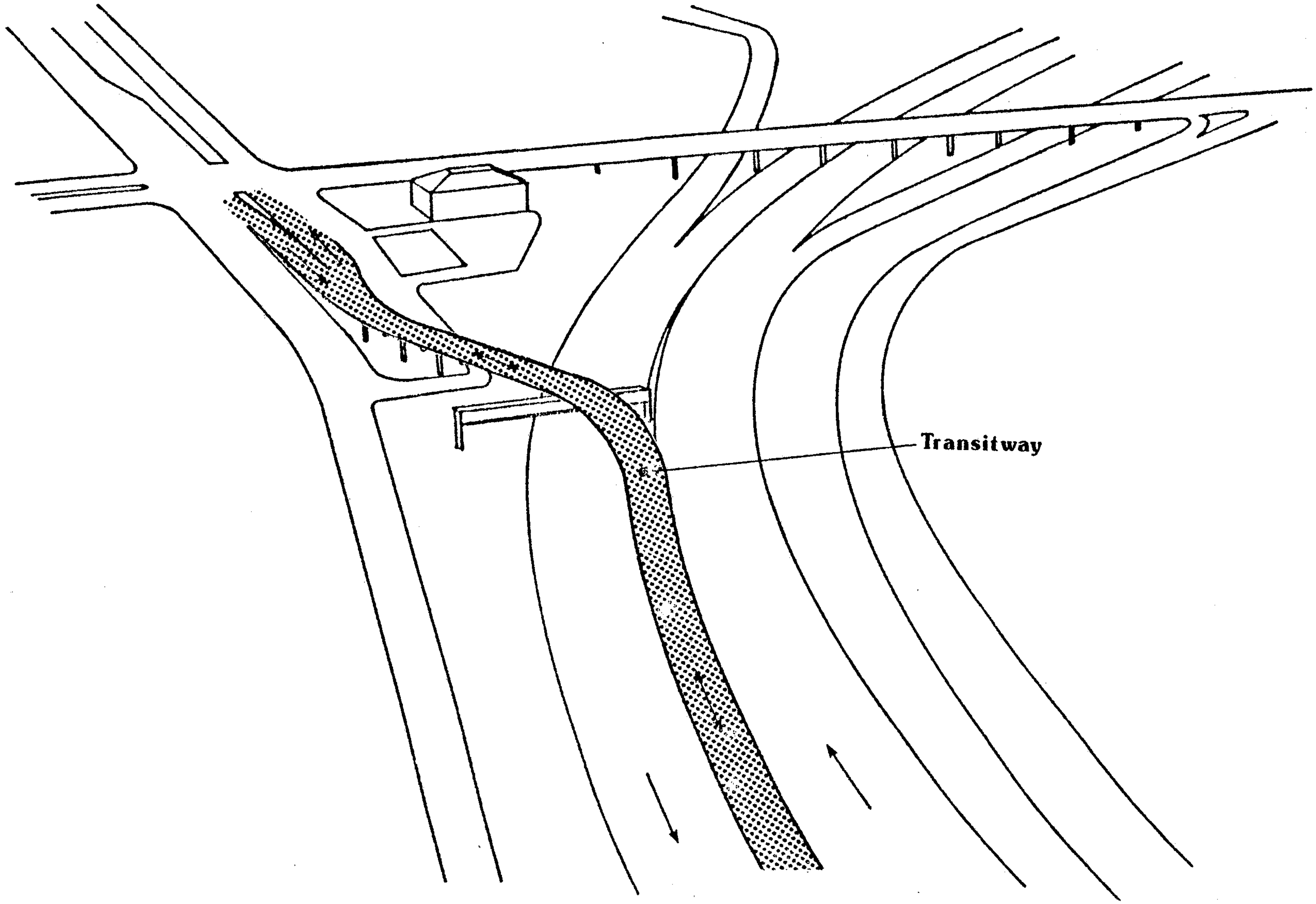

Figure 2-32. Conceptual Layout of a Typical Flyover Terminal to Surface Street

Table 2-13. Summary of Recommended Criteria for Transitway Design

Criteria (Minimum or Maximum)	Mainlane		Ramp	
	Usual	Desirable	Usual	Desirable
Design Speed (mph)	40	60	30	40
Alignment				
Stoppng Distance (ft)	275	525	200	275
Horizontal Curvature (ft)	——	1350	——	575
Superelevation (ft/ft)	0.08	0.06	0.06	0.04
Vertical Curvature (K-Factor)	K=60 crest K=60 sag	K=190 crest K=120 sag	K=30 crest K=40 sag	K=60 crest K=60 sag
Gradients				
Maximum (%)	8	6	——	8
Minimum (%)	0.35	0.35	0.35	0.35
Length (ft)	750	1250	——	750
Clearance				
Vertical (ft)	14.5	16.5	14.5	16.5
Lateral (ft)	2.00	8.00	2.00	8.00
Pavement Width				
Travel Lanes (ft)	12	12	13	13
Shoulder Lanes (ft)				
Single	3.75	8.00	2.00	8.00
Multiple	8.00	10.00	8.00	10.00
Total Combined Width				
Single-At-grade (ft)	19.5	28.0	24.0	24-30
Multiple-At-grade (ft)	36.0	38.0	36.0	36-40
Single - Elevated (ft)	28.0	28.0	24.0	24-30
Multiple - Elevated (ft)	38.0	38.0	36.0	36-40
Transition Lanes				
Acceleration (ft)	400	1600	——	——
Deceleration (ft)	320	720	——	——
Tapers (ratio)	20:1 (exit) 20:1 (entr)	30:1 (exit) 50:1 (entr)	—— ——	—— ——
Cross Slope (ft/ft)				
Maximum	0.020	0.020	0.020	0.020

the usual minimum may be approved as a temporary condition or for limited segments of a transitway. Likewise, where more than sufficient right-of-way is available, or considering the incremental costs of expanding an elevated transitway, optimal cross-sections exceeding those stated as desirable may provide additional operational benefits. Various justifiable factors must be considered which may influence the planning or design decision to deviate from either the minimum or desirable guidelines for transitways.

2.3 OPERATIONAL CONSIDERATIONS

2.3.1 General

Transitways are a special application of high speed, limited access roadway design. High person-volumes are achieved with low volumes of vehicles. The transitway has control of access through the geometric design and vehicle authorization procedures. The type of operation and, in many applications, the restriction in design width places greater emphasis on the need for an active traffic operations management system.

Management of transitway operations may be accomplished by a range of technological and manpower means. Minimal control may be exercised with on-site personnel and passive signing/delineation. Maximum control may be applied with sophisticated surveillance, vehicle detection with computer integration and dynamic, real-time signing/delineation. The level of control would depend upon the user demand and size of the transitway system. Operational control may evolve from low to high level as the transitway system is implemented in stages to achieve the final configuration.

This section of the manual presents operational considerations relative to transitway implementation under various levels of control. Surveillance, communication and control on transitways will be discussed with issues relating to access authorization. Enforcement requirements, incident response, and motorist information techniques applicable to transitways will also be addressed.

The importance of coordinating operational considerations into both the planning and design processes for transitways cannot be overstated. Operation of a transitway is critical and should be considered when making implementation decisions.

2.3.2 Surveillance, Communication and Control

2.3.2.1 General

Surveillance, Communications and Control (SC&C) refers to automated electronic systems which safely and efficiently manage and control traffic operations on high speed limited access facilities such as transitways. The collection and processing of data by detectors and the visual verification of operations by closed circuit television are the major elements of traffic surveillance. The presentation of operational information to the motorists through signs, delineation, signals and/or auditory means is the communications component. The application of traffic restraints on direction of flow by signs, barrier gates, and signals constitutes traffic control.

A typical SC&C system for a transitway consists of the following: on-site personnel with radio communication and electronic sensors in the pavement connected by communication cable to a central computer provide information on traffic conditions to the central control operators. The operators communicate with users and control transitway movement with devices placed over the transitway and at access ramps. These devices, which include programmable changeable message signs, lane control signals, ramp metering signals, barrier gates, traffic signals, and dynamic signs are computer controlled. Verification of SC&C system operations may be accomplished with on-site personnel or with a closed circuit television system (CCTV) from the central control.

2.3.2.2 Purpose and Justification

SC&C systems are designed to provide the authorized users of a transitway with information on traffic and roadway conditions. More importantly, SC&C systems are designed to detect and respond to disabled vehicles, wrong-way operations and unauthorized vehicles (21).

A partial or full blockage of a transitway in a narrow cross section can occur as a result of mechanical failures or an accident. The length of time the transitway is blocked is critical to both the efficiency and safety of the lane. For each minute that the transitway is blocked, the amount of person delay time increases. As shown in Figure 2-33, a lane carrying 6000 persons per hour will accumulate 50 person minutes of delay for the first minute the lane is blocked. The second minute of delay will add an additional 150 person minutes and for the fifth minute of the delay, 450 person minutes.

2.3.2.3 System Design

The development of an SC&C system design should first focus on the individual transitway facilities serving separate transportation corridors. A design hierarchy begins with manual control of individual field components for a single transitway, followed by a collective remote control (satellite) facility of the individual field components for a single transitway. As other transitways develop into a network, the SC&C system at the satellite can be interconnected to a central control facility, bringing all area transitways under one SC&C system management. Each stage of this SC&C hierarchy should be configured to provide operational backup for the succeeding system design.

This hierarchical development strategy for system design provides the maximum flexibility for SC&C system implementation. System design can accommodate the operating characteristics of individual transitway facilities and allow for the integration of a future transitway network operations control system. This approach results in better utilization of manpower, a more coordinated incident response and a more efficient transitway operation.

Length of time lane blocked in minutes	Additional delay in each time interval in person-minutes	Cummulative delay in each time blocked in person-minutes
0	0	0
1	50	50
2	150	200
5	450	1250
15	1450	11250

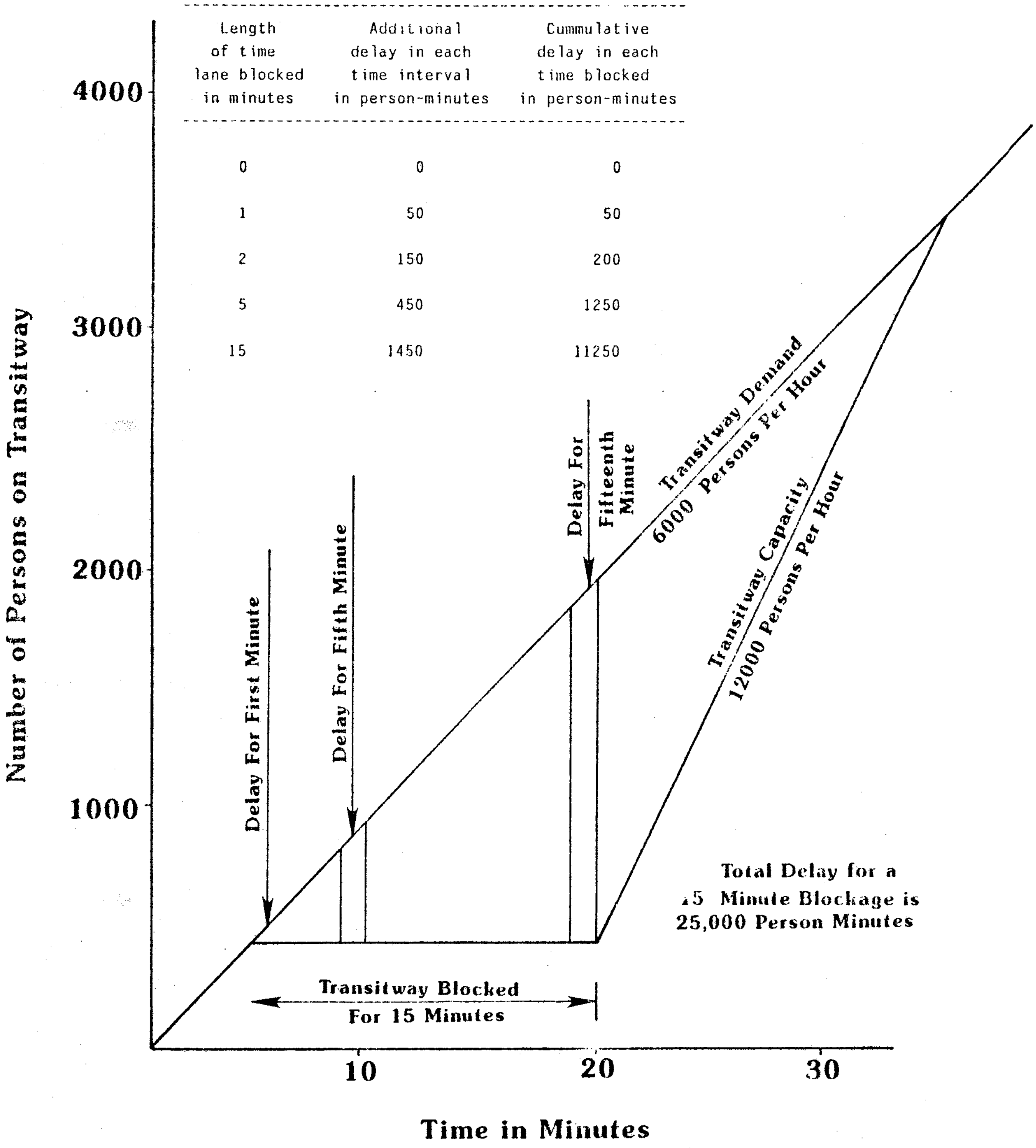

Figure 2-33. Transitway Delay Plot

Manual Control

Communication and control devices (changeable message signs, lane control signals, etc.) can be operated individually by field personnel from a control panel (see Figure 2-34) located within or near the field device's field controller cabinet. This level of system control is used to allow transitway operations to begin prior to the integration of the field components, via communication cable, to a satellite control facility computer. This level of SC&C design does not provide any capability for surveillance, incident detection, or real time response to the devices.

Manpower requirements to operate a transitway are high with a manually controlled system. This manual operation level can serve as a backup to the satellite control in the event of a computer or communication cable failure.

Satellite Control

The next higher level of SC&C design is the satellite control. The satellite control facility will be located adjacent to the transitway and will house the computer and communication equipment used to control SC&C field equipment via a dedicated communication cable. From this facility, operators can monitor transitway traffic operation, detect incidents and remotely control all SC&C field equipment.

Data collected from field devices are processed by satellite control computers prior to being transmitted to a central control center. If equipment or communication failure were to occur at the central control center, operations could continue from the satellite control facilities.

Satellite facilities can be designed as a manned facility for a single transitway SC&C operation or as a backup to a central control center controlling several transitways (see Figure 2-35).

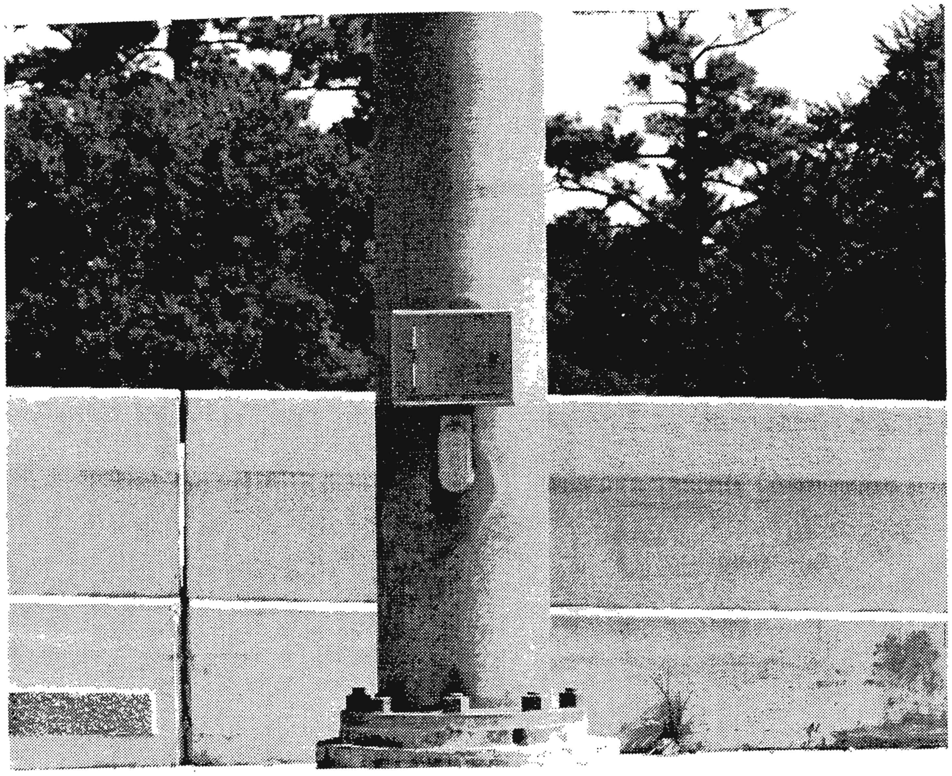

Figure 2-34. Field Controller Cabinet

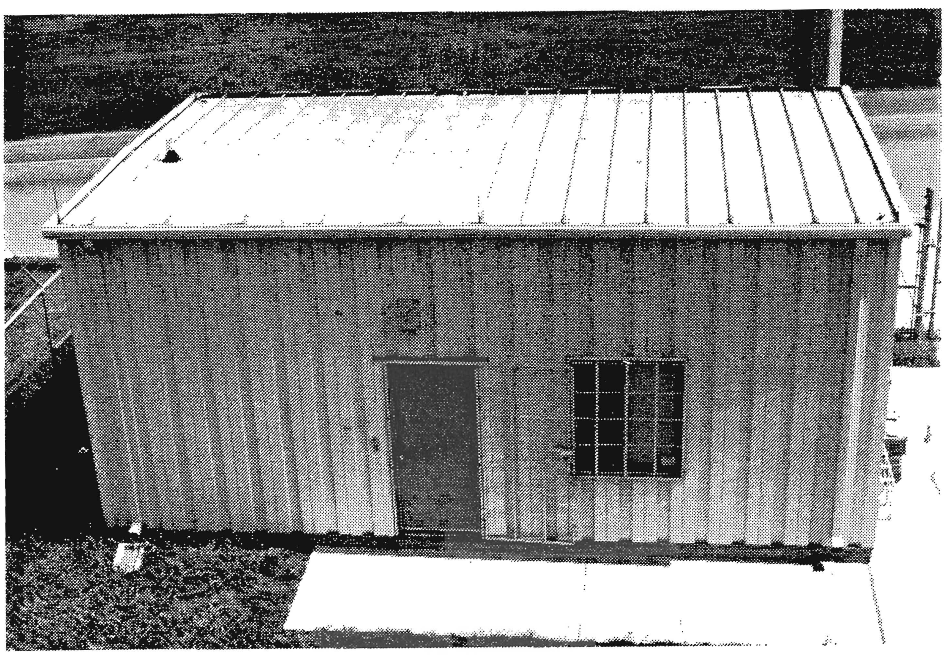

Figure 2-35. Satellite Control Center

Central Control

The final level in the hierarchial design of the SC&C system is central control. The central control center (CCC) provides a single location, from which SC&C system operations for all transitways can be conducted. Data from each field device will be collected and processed by satellite control center computers, then transmitted to central control computers for monitoring by CCC personnel.

The operational functions of the satellite control center and the central control center are practically identical. From either location, remote control of SC&C field equipment and collection of surveillance data is possible. The determining criteria as to which installation is warranted depends upon the number and physical locations of transitways. A single transitway would require a satellite control center for operations. A network of transitways, serving different geographic sections of a metropolitan area, would require a central control center to consolidate operations and to reduce personnel requirements.

From the CCC, operators monitor the operations of several transitways. Real time traffic operations can be viewed on closed circuit television and operation status information can be displayed on dynamic maps or on computer interactive graphics systems.

SC&C system design incorporates computer software programs that respond automatically to traffic conditions sensed by electronic surveillance devices. From the CCC, operators can monitor actions taken by the computer system and determine if these actions are appropriate. Visual and electronic surveillance equipment can be used to confirm and evaluate the programmed response. The operators can supplement or override automatic control responses implemented by the computer programs by inputting different operation parameters to modify the operational evaluation criteria or by disengaging the automatic response programs and transmitting direct control commands to individual field devices. However, software programs prevent operators from giving erroneous commands to the system. For example, an

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operator could not command the one-way reversible transitway to operate simultaneously in both directions.

The system can be designed to provide a historical record of all daily activities. Computer programs log instructions executed by the system, whether given by an operator or automatically by the system's software. Video recordings obtained from the CCTV system component can record incidents, activities of field personnel, and general operating conditions of the transitway. This information can be used to evaluate operational performance of the SC&C system, operating personnel, and transitway usage.

To promote system efficiency, the CCC computer can monitor and diagnose the operating conditions of electronic equipment in the field, satellite center facility, and central control center. Operators can quickly note any failed component in the system and take the necessary action to address the problem. This capability enhances the SC&C system reliability, a necessity for effective transitway operations.

2.3.3 Field Equipment

Development of an SC&C system for transitway operations must begin with the identification of the necessary field equipment, their functions, and physical placement. To provide a comprehensive system design, the following SC&C system equipment components should be considered.

2.3.3.1 Surveillance

Loop Detection. The purposes of pavement imbedded loop detectors are to provide remote sensing of traffic volume, flow conditions, and operating direction. A vehicle is detected as it passes over the loop and causes a change of inductance in the wire coil. The time the vehicle is within the detection area of the loop can be measured.

For a reversible single lane transitway, 3 vehicle detection loops, each 6 foot square and spaced at 30 feet, center to center, are located at one

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mile intervals. Additional loop detectors are installed at all entry and exit locations along the transitway facility. Data is transmitted by the loop detectors to a nearby field cabinet where a microprocessor compiles the data and transmits it to a control center. This information is then processed by the satellite computer, and the results are used by the operators to monitor operating conditions and detect incidents.

Closed Circuit Television. Closed Circuit Television (CCTV) is used for surveillance of the transitway to observe operations and confirm incidents. This system should be designed to provide total visual coverage of the transitway. The maximum optical range of a camera with a 15 mm to 180 mm zoom lens is approximately 1 to 1.5 miles. Camera poles should be at least 30 to 40 feet in height, with good access for maintenance (see Figure 2-36).

The CCTV cameras can be either solid state or tube design, but current technological advances in solid state video chip design make the solid state cameras the preferred choice. These cameras can provide black and white or color images. However, color cameras provide better image detail, enhance the viewer's attention span, and reduce eye strain.

Each camera installation must have a weather-proof housing and controls for pan, zoom and tilt functions to allow operators to remotely adjust the cameras for 350 degrees area coverage. Other camera control features such as remote focus and iris control should be included in the design.

A large communication bandwidth is required to transmit video signals. The most common mediums for transmitting video signals are coaxial cable, fiber optic cable and/or microwave.

2.3.3.2 Communication

Changeable Message Signs. Changeable Message Signs (CMS) may be employed at the termini of a transitway and at specific intermediate locations to convey to the transitway users the status of operations (i.e., open, closed, congested, accident, etc.). These devices use 7 by 5 dot

Figure 2-36. Transitway Camera Pole

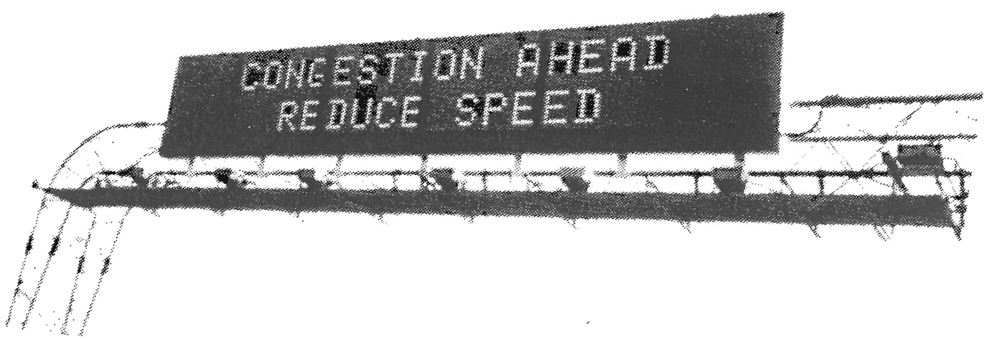

Figure 2-37. Transitway Changeable Message Sign

matrix characters arranged in a two- or three-line configuration (see Figure 2-37). Signs may use bulb lamps, reflective disks or fiber optic lenses to display each character. The CMS's are controlled by a microprocessor located in an adjacent field controller cabinet. The CMS field controllers are connected to the control center master controller by a modem operating in a dedicated communications cable. Messages can be displayed on the signs by operators in the control center or from the field controller cabinet.

Highway Advisory Radio. Highway Advisory Radio (HAR) is a low power AM band transmitter used for communicating with motorists concerning transitway conditions and operations. These transmitters have a limited broadcasting range of approximately 2.5 to 3 miles. Frequencies designated for broadcast are 530 mhz and 1610 mhz of the AM band. Each transmitter can operate as a single broadcast station or several transmitters can be synchronized to broadcast as a single station. This latter technique eliminates signal echo as motorists drive from one transmitter broadcast area to the next.

HAR can be operated from a central location over telephone leased lines or dedicated communication cable. The HAR operators can transmit pre-recorded messages or live broadcast. HAR can be used in conjunction with CMS signs or static message signs to provide a network of transitway user communications.

2.3.3.3 Control

Lane Control Signals. Lane control signals (LCS) should be utilized along a transitway. LCS should be located at each terminus and at approximately one mile spacings along the transitway. Each LCS installation should have displays facing each direction of travel. These signals confirm to the transitway users that they are traveling in the correct direction (steady downward green arrow); that the lane is closed (red X); that they are traveling in the wrong direction (flashing red X); or that there is an accident ahead (flashing downward yellow arrow) (see Figure 2-38).

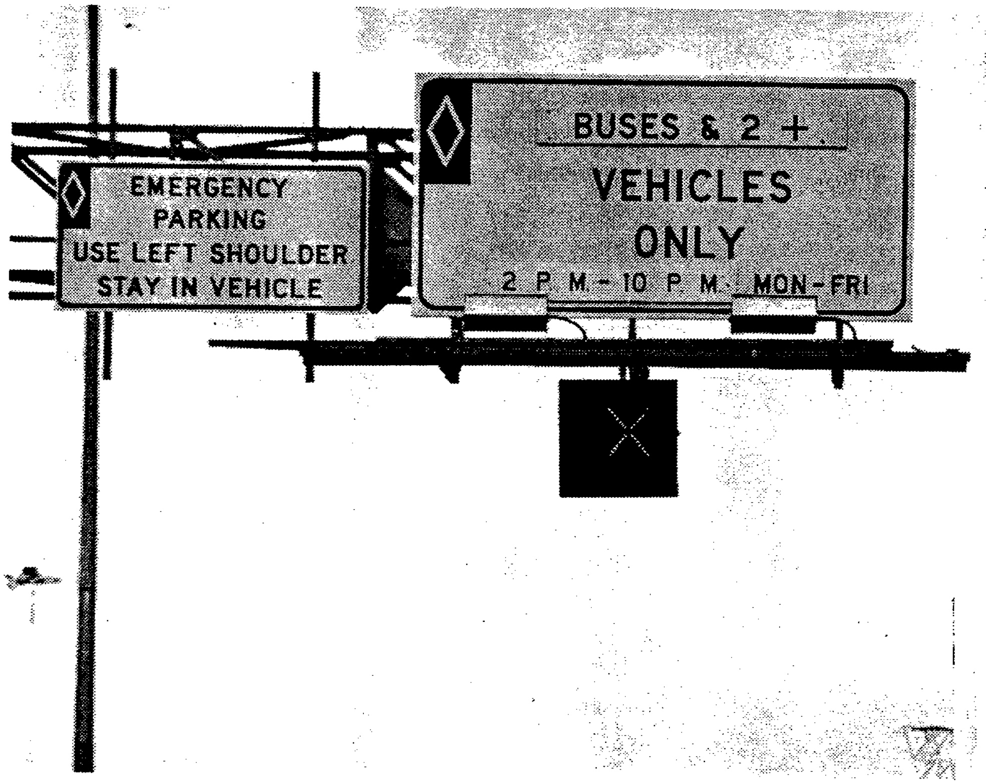

Figure 2-38. Transitway Lane Control Signal

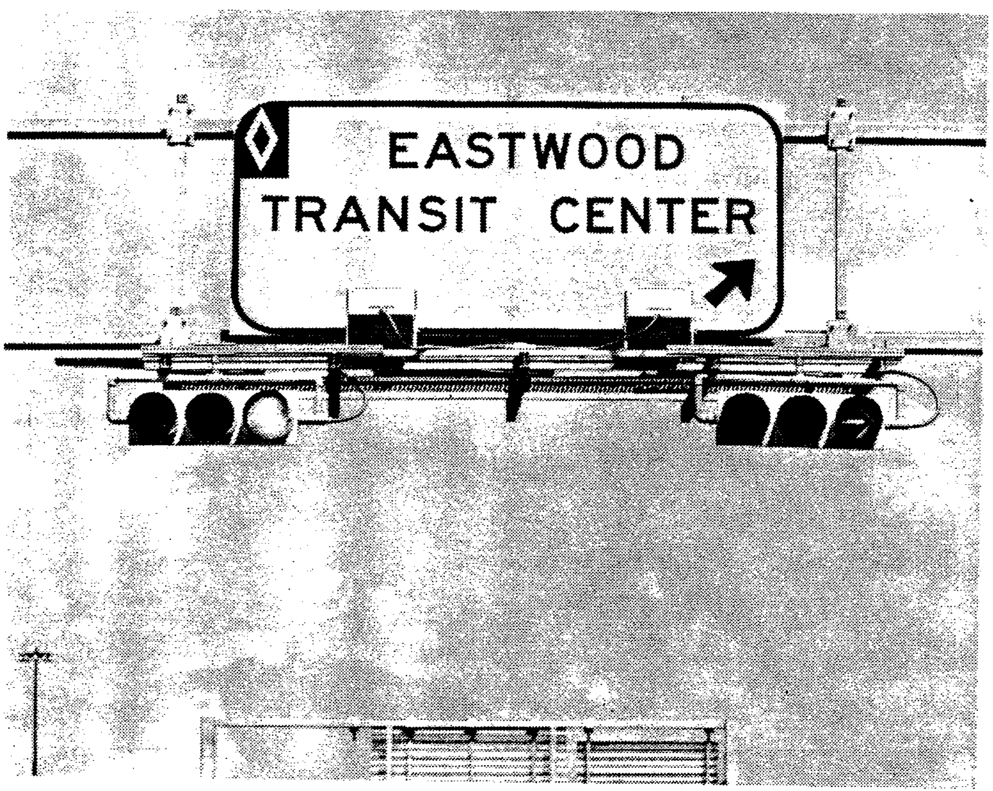

Figure 2-39. Transitway Control Signals

The lane control signals can be operated remotely from the control center via communications cable. Manual control of the LCS can be provided at the field control cabinets.

Transitway Control Signals. Transitway control signals provide traffic control for intermediate access ramps to the transitway. These control signals resemble standard intersection traffic signals (see Figure 2-39). Their function is to alert users to the directional operation of the ramp. Transitway control signals can be operated manually from a nearby control cabinet or remotely from a control facility.

Barrier Gates. Barrier gates to the transitway serve two important functions. First, when the transitway is not in operation, the barrier gates secure the transitway from any unauthorized use. Secondly, entrance and exit ramps have specific open/closed positions, depending upon the operational direction of the one-lane transitway. Barrier gates are used to properly direct users on to the transitway. These gates can be controlled remotely from the control center via a dedicated communication cable or manually by field personnel.

2.3.3.4 Data Communication

All field devices are controlled and monitored from a central location by computers through a data communication network. This network may use coaxial cable, fiber optic cable, microwave, twisted wire pair, or a combination of these technologies. Leased telephone lines may be used. However, for large-scale SC&C systems with CCTV, a dedicated communication plant is recommended.

The data communication network is the most critical and complex component of the SC&C system. Design criteria for the communication system are predicated upon:

- Data transmission rates
- Frequency band width requirements

- Number of communication channels required
- Service and maintainability

Failure to provide a secure, expertly engineered, and craftsmanlike installation of a communication plant will result in a substandard operational capability.

2.3.4 <u>Control Center Equipment</u>

The equipment normally found in control centers consists of the computer and its related peripheral equipment, operator control consoles, display components, and communication equipment for dispatching emergency and maintenance vehicles to problem locations. Figure 2-40 illustrates an example of a control center layout. Table 2-14 lists the required equipment discussed in the following text.

2.3.4.1 Computer System

The computer system receives data from all system components except the CCTV system and the voice communications. The computer processes the data and performs the following functions:

1) <u>Monitors Status of Traffic Operations</u>. The center's computer will present the status of traffic volumes classification, and speeds of vehicles using the transitway. This information can be presented graphically and/or using a numeric format.

2) <u>Activates Incident Alarm System</u>. The computer monitors the loop detector system for incidents (accidents, disabled vehicles, etc.) that may affect operations and/or safety. If an incident is detected, the computer activates controls to display warnings to the transitway users, activates the alarm system to alert the operator, and provides traffic operations status reports. The operator can use the CCTV system, or radio communications with field personnel to verify the incident. Upon verification, the operator can determine the necessary course of action to return the transitway to normal

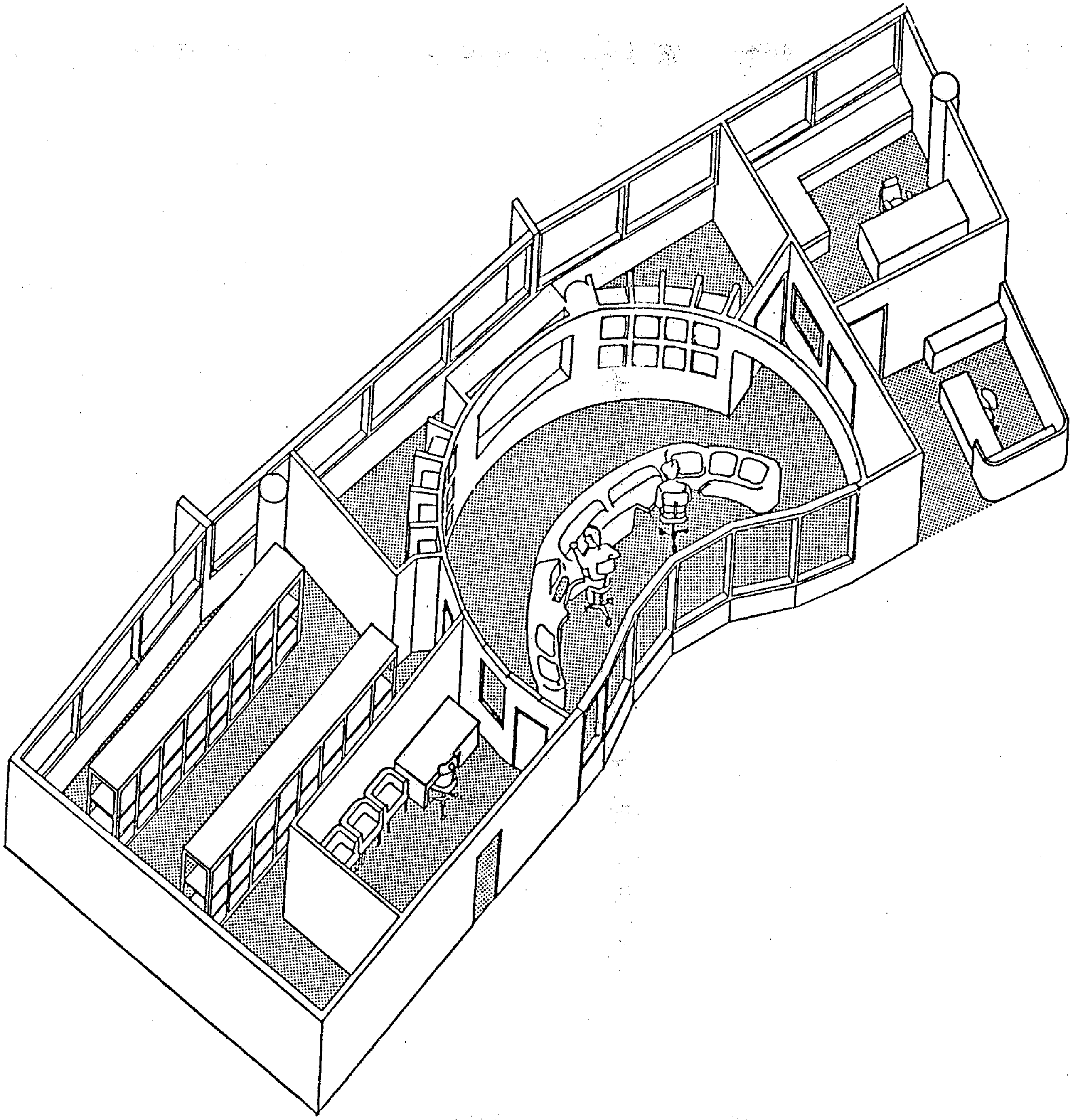

Figure 2-40. Control Center Layout

Table 2-14. Required Control Center Equipment

Computer	Closed Circuit Television	Dynamic Display Map	Control Panel	Communications	
				Data	Voice
Computer color graphics CRT's	17" monitors (wall display)	Graphic display of system	Control keyboard for SC&C devices	Digital data modems	Telephone headsets
CRT's with keyboards	14" monitors (console display)	Electronic display for SC&C device conditions	Control keyboard for display map	Computer interface equipment	Radio systems
Disc drive	Camera control systems with AVL switching system		Control keyboard for computer reports		
Tape drive	Video cassette recorders		Alarm for monitoring traffic conditions		
Line printers					
Character printers					

operations. After the incident is removed, the operator (using the computer) can cancel the operation warnings to users.

3) Activates Wrong Way Movement Alarm. The computer can detect and respond to a vehicles inadvertently accessing the reversible transitway in the wrong operating direction. After a wrong way vehicle is detected, the computer automatically activates warning devices (lane control signals and changeable message signs) to alert transitway users. The alarm system is activated in the control center to alert the operator to the situation. The operator verifies the situation using the CCTV system and takes the appropriate action to respond to the situation.

4) Monitors Status of Field Equipment. All electronic equipment in the field will be monitored for proper operation. When a malfunction is detected, the operators will be alerted by computer graphic display and/or computer printout. All malfunctions will be recorded on the daily operation log computer print out. Operators can use this information to issue repair work orders.

5) Controls Message Signs and Signals. All signs and signals can be controlled remotely. All messages and signal indications can be preprogrammed and activated automatically by the computer or manually by operator execution.

6) Controls Access to Transitway. Access to the transitway by ramps that serve facilities (park-and-ride lots, transfer centers, etc.) or that interface the street system can be controlled with automatic security gates and/or ramp metering signals. The operators can remotely activate these devices, or the computer programs can automatically operate them in accordance with established operating procedures.

2.3.4.2 Closed Circuit Television

The closed circuit television (CCTV) system receives video signals from cameras placed on poles adjacent to the transitway. Any camera can be accessed through a switching system operated by personnel from the control room. Pictures from several different cameras can be displayed simultaneously on video monitors. The pan, tilt and lens functions of the cameras can be operated from the console using remote control. Video cassette recorders can be used to record the video signals from any camera.

CCTV is an important element of the surveillance system. Its primary function is to provide visual observation of transitway operations, so that the following tasks can be accomplished:

1) Verification of Electronic Detection. Incident detection algorithms used to detect the full or partial blockages of the transitway are subject to error because of the spacing of detectors, the malfunction of detectors, and the variations of traffic conditions. CCTV permits the detection algorithms to be biased in favor of incident detection with a higher error rate of false calls rather than detection with a lower error rate of false calls in order to lower the probability of an incident going undetected. Warning calls of incidents can easily be confirmed by visual surveillance.

2) Confirmation of Equipment Operation. The SC&C system will have the capability to confirm the sending and the receiving of commands to signs and signals. The CCTV provides an additional check on the proper operation of field devices. Also, the operation of automatic gates, the position of manually operated gates, and the operation of vehicle sensors can be monitored by an operator from the control room.

3) Evaluation of Incidents. After an incident on the transitway has been detected, located and verified, the CCTV system can provide the operator with information for determining the actions to be taken. In many cases, the type of emergency vehicles to be dispatched and the appropriate routes to be followed can be determined from the CCTV system.

4) Control of a Transitway. Traffic, pavement, and environmental conditions undetected by electronic surveillance may dictate an emergency closing of a transitway. The operator with visual surveillance of a

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transitway will be able to assess the situation or assist field personnel in assessing the situation.

5) Operation of a Transitway. In addition to traffic incidents and wrong way operations, there are operational regulations to be considered on the transitway. Some of these are unauthorized use of the lane, speeding, minimum headways, no passing, and unsafe operations. The CCTV system can be used to monitor for these occurrences and assist the field crews in identifying unsafe drivers.

6) Training Transitway Users and Operators. Videotapes can be made of transitway operations and incident management can be used to train operating and enforcement personnel. Additionally, videotapes can be used to instruct authorized drivers on proper transitway operations.

2.3.4.3 Dynamic Display Map/Computer Graphics Monitor

The dynamic display map and/or computer graphics monitor can provide a graphic representation of the transitways with the location and status of SC&C devices. Computer driven lamps or CRT graphics can be used to display traffic volumes, speeds, and percent of occupancy (roadway density) at various thresholds.

The map or CRT monitor can provide the operator with real time operational information in an easily recognizable format for an entire transitway network. Problem areas can be quickly identified, equipment failures can be displayed, and transitway operations can be continuously monitored.

2.3.4.4 Control Keyboard

The control keyboard provides the operator with direct input to the computer. Simplified coded inputs reduce the time to make control commands by operators. The control keyboard will permit operators to:

1) Request reports to be displayed on a CRT or to be printed.

2) Activate the display map and/or computer graphics monitor.

3) Control the signs, signals and gates in the field.

4) Control the visual and audible alarms for various operations, such as incidents, wrong-way travel, unauthorized entry, and failed equipment.

Another technology providing direct input into the computer system is called "touch screens." The operator inputs commands by using a light pen to touch a specific point on the computer screen. This point is identified by software and gives a specific instruction to the computer. This method can reduce time to input control commands.

2.3.4.5 Electronic Support and Processing Equipment

A complement of electronic equipment will be required in the CCC to provide the interface between the computer, video, and audio systems. This equipment should be placed in a separate environmentally controlled room to prevent equipment overheating and prevent noise generated by the equipment from entering the operator work area.

2.3.5 <u>Infrastructure</u>

Infrastructure for the SC&C system must be provided for the installation of field equipment. Elements of a SC&C infrastructure are:

- Conduits
- Pull boxes
- Structures for changeable message signs, cameras, and lane control signals

2.3.5.1 Conduit

Proper installation of the communication cable (coaxial, fiber optic, twisted wire pair, etc.) is critical to the successful implementation of a SC&C system.

The conduit system serves two purposes: One, it provides an effective means to install the communication cable with a minimal possibility of damage. Two, it's a defense against possible damage to the cable from future construction activities adjacent to the transitway facility.

Conduits can be manufactured of various materials: PVC, ridged metal, HDP, etc. To provide maximum protection, all conduits should be concrete encased. Repairs to a damaged communication cable can be expensive. As an example, splicing costs for fiber optics is estimated at $1000 per fiber pair. Repair of a 6-pair fiber cable, including conduit replacement, cable testing, time and materials may be as much as $20,000. This cost figure does not include lost operating time, data loss, and possible disruption to transitway operations.

The number of conduit runs for the SC&C communication plant should be a minimum of three; one for the initial installation of cable, a second for electrical power, and a third to serve as a spare. In the event that cable repairs are necessary, the spare conduit can be used to install a "by-pass" cable without disabling the system. The spare conduit can also be used for future expansion of the system.

Accommodating the maximum tensile (pulling) strength of the communication cable to prevent damage during installation is the primary consideration for the SC&C conduit system design. Corrugated coaxial cable appears to require the most care during installation. Specifications for an 1/2-inch corrugated coaxial cable installation calls for: the pulling tension not to exceed 200 pounds per square inch, a maximum bending radius of six inches, and a cable pull length through no more than two consecutive 90-degree bends.

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Other considerations for conduit design are:

- Conduit diameter
- Conduit material (drag coefficient)
- Bend radius

Conduit size (diameter) is dependent upon the size (diameter) of the communication cable. Typically, a cable with an outside diameter of 5/8 inch to 7/8 inch can be accommodated with a 3 inch diameter conduit with bend radius of 36 inches.

2.3.5.2 Pull Boxes

Pull boxes provide access into the conduit system. These boxes may be located in the roadway, under bridge decks, and along the outside shoulders of the roadway.

The critical design consideration for pull boxes is their dimensions. Pull boxes should be large enough for easy installation of the communication cable. Type of communication cable specified for the SC&C system will directly impact sizing requirements for the pull boxes. A cable that is more flexible (smaller bending radius) can be accommodated with a smaller pull box.

Placement of pull boxes should be evenly distributed along the conduit system. The distance between pull box locations is dependent upon the type of communication cable specified for the system. The higher the tensile strength of the cable, the further apart boxes may be located. Likewise, the numbers and locations of field equipment will influence the locations of pull boxes.

2.3.5.3 Structures

Various field equipment for the SC&C system must be mounted on support structures. These structures can range from a simple camera pole to a large changeable message sign support.

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It is preferable that the installation of these structures is incorporated into the construction of the roadway. This minimizes the costs for additional traffic control during installation and for disruption to the transitway users. All structures must have direct access to the conduit system for the interconnection of field equipment to computers located at a control facility. Some structures (CMS, LCS, etc.) will require small access cabinets for the installation of manual control panels. These panels will be used by personnel to operate the equipment in the field in the event of communication or computer control failure.

The proper design and installation of the infrastructure to support a SC&C system is critical. The design of the infrastructure should be conducted parallel with the detail design of the system.

2.3.6 SC&C Benefits

The benefits of implementing an automated SC&C system are more efficient operation and the reduction of operating costs associated with transitway operations.

2.3.6.1 Operating Efficiency

The reduction of user travel time is the most used measure for assessing the benefits of transitway operation and its associated SC&C system. A disabled vehicle situation can be anticipated to occur approximately every 40,000 vehicle miles traveled. A disabled vehicle will cause a decrease in traveling speeds or in extreme cases, a total blockage of the facility. As depicted in Figure 2-33, this blockage will result in the compound growth of travel time delay for transitway users. A transitway operation without a SC&C system must rely on area traffic bulletins, police reports, or bus operator communications to locate and remove the incident. With the SC&C system, loop detectors and CCTV provide operators with real-time operating status. An incident can be located in seconds. It is this reduction of time in locating a disabled vehicle and its subsequent removal that provides the travel time savings to the transitway users in the event of an incident. And

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like any freeway operation, the greater the traffic volumes, the more delay associated with the increasing number of incidents.

2.3.6.2 Operation Costs Reduction

The most significant category of operating cost associated with transitway operation is manpower. Manpower requirements include supervisors, system operators, response field personnel, and police. The amount of manpower needed to operate a transitway is inversely proportional to the level of SC&C automation. The more the system is designed for automatic control and monitoring, the less manpower is required. For an example to demonstrate this point, the level of manpower required to staff the transitway system of metropolitan Houston is presented below:

The Houston transitway system consists of five radial transitways totalling approximately 71 miles (Figure 2-41). Manpower estimates are based upon the level of SC&C automation.

Manual Control - Under this SC&C configuration, automation is at a minimum. All devices (CMS, LCS, Barrier Gate, etc.) are manually operated by field personnel. There is no automatic detection (loop and cameras). All incidents are located by moving patrols, police, or by bus operators.

Satellite Control - This level of automation provides remote control of all field devices and automatic detection devices (loops and cameras). Each transitway has a separate operating control facility.

Central Control - This is the highest level of automated control. Through a central control facility, all individual satellite control facilities are interconnected. All operational activities are controlled from one location.

The Table 2-15 shows the number of estimated personnel and associated complement of operating vehicles necessary to operate the transitway system

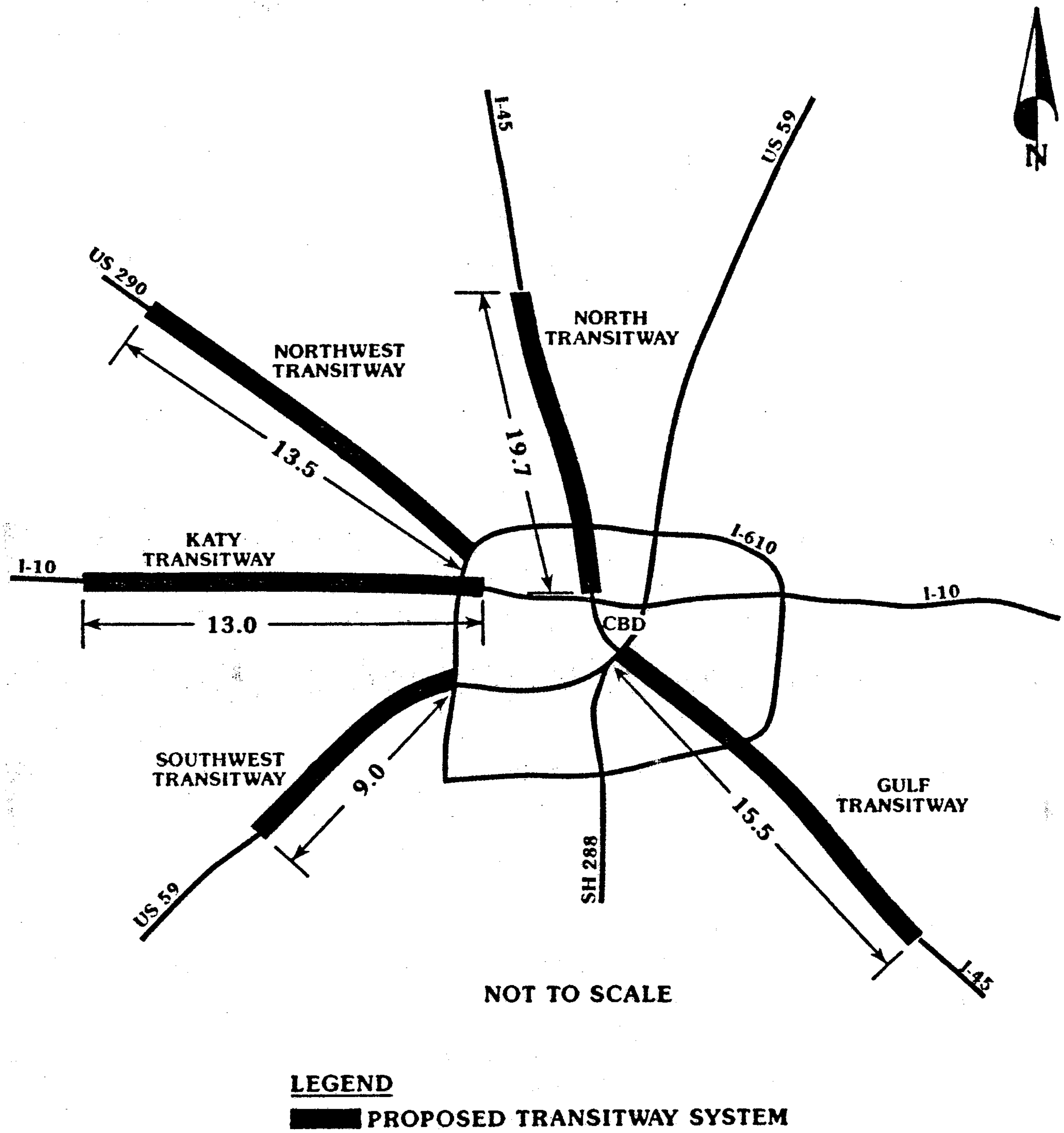


Figure 2-41. Houston Transitway System

(22). This table dramatically demonstrates the manpower savings that can be obtained by implementing an SC&C system.

Table 2-15. Houston Transitway Program - SC&C System Staffing and Vehicle Requirement

	Manual Control	Satellite Control	Central Control
Manpower Staffing			
Superintendent	2	2	2
Supervisors	5	10	2
Operators	5	10	2
Field Crew	20	10	10
METRO Police	20	10	10
TOTAL	52	42	26
Vehicles			
Auto-Managers	6	6	1
Auto-Police	10	5	5
Truck-Crew	5	0	0
Wrecker-Crew	5	5	5
TOTAL	26	16	11

Note: Assumes 16 hours operating per day - 2-8 hour shifts - Monday through Friday.

Source: Ref. (22)

2.3.6.3 Capital Costs

The capital cost for the SC&C system is predicated upon many factors:

- Length of the transitways
- Number of entrance and exit points
- Whether design includes a central control center and/or satellite facilities
- Communication medium technology
- Number and spacing of field equipment, etc.

These numerous design and operating variants make it difficult to develop a useful capital cost estimate in advance of system conceptual design. Presently, planned SC&C systems range in estimated capital costs of \$20 million for a 12-mile two-lane reversible HOV facility in Norfolk, Virginia (23) to $27 million for approximately 71 miles of single reversible lane transitways in Houston, Texas (22).

Because most SC&C systems are built in long-range incremental phases, it is important to recognize that the initial implementation phase of a system may have a disproportional amount of total system costs. This results from having to build centralized control facilities and the acquiring of central control equipment that must accommodate future expansion requirements.

2.3.7 Summary

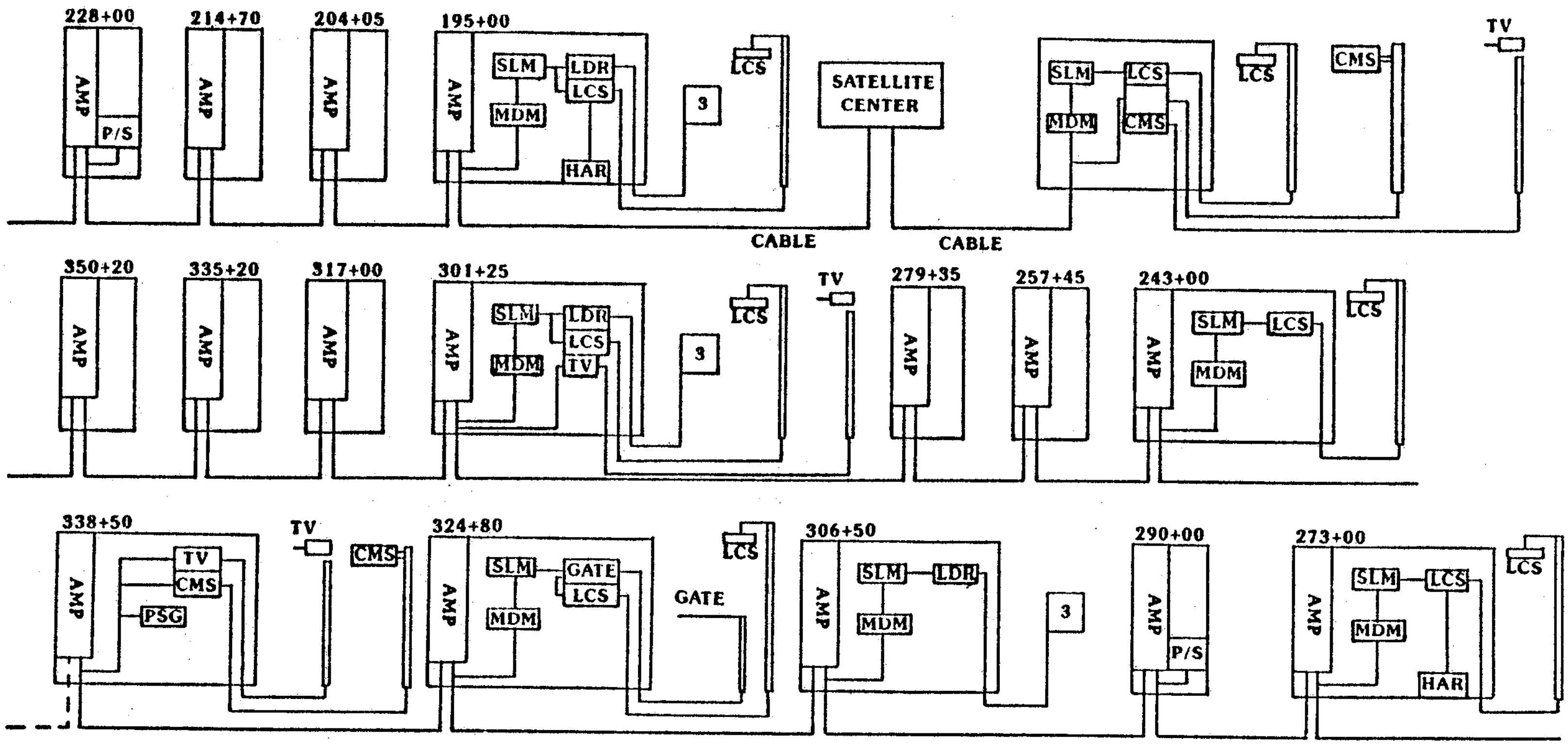
The SC&C system components presented in this manual are viewed as necessary and essential for the efficient and effective operation of a transitway. A reduction in scope of the SC&C system design requires a re-evaluation of the stated objectives of transitway operations.

Figure 2-42 illustrates an example of a field layout for an SC&C system on a transitway. Figure 2-43 illustrates a functional diagram associated with a field controller.

2.3.8 Access Authorization

2.3.8.1 General

By its very nature, a transitway is a restricted access facility. Only vehicles which qualify as high-occupancy are permitted on the transitway. These high-occupancy vehicles may range from a full-size bus to an individual car with multiple occupants. The types of vehicles which are allowed to use the transitway are controlled by the authorization process. The authorization process may be restrictive, as in one which requires attendance in a training class, fees and restrictions on vehicles. Or they may also be permissive, allowing any vehicle with a minimum number of occupants to use the transitway.



AMP - Line Amplifier
CMS - Changeable Message Sign
HAR - Highway Advisory Radio
LDR - Loop Detector
LCS - Lane Control Sign
MDM - Modem
P/S - Power Supply/Battery Backup
PSG - Pilot Signal Generator
SLM - Slave Multiplexor
TV - Television Modulator

Figure 2-42. Transitway Field Layout for a Surveillance, Communications, and Control System

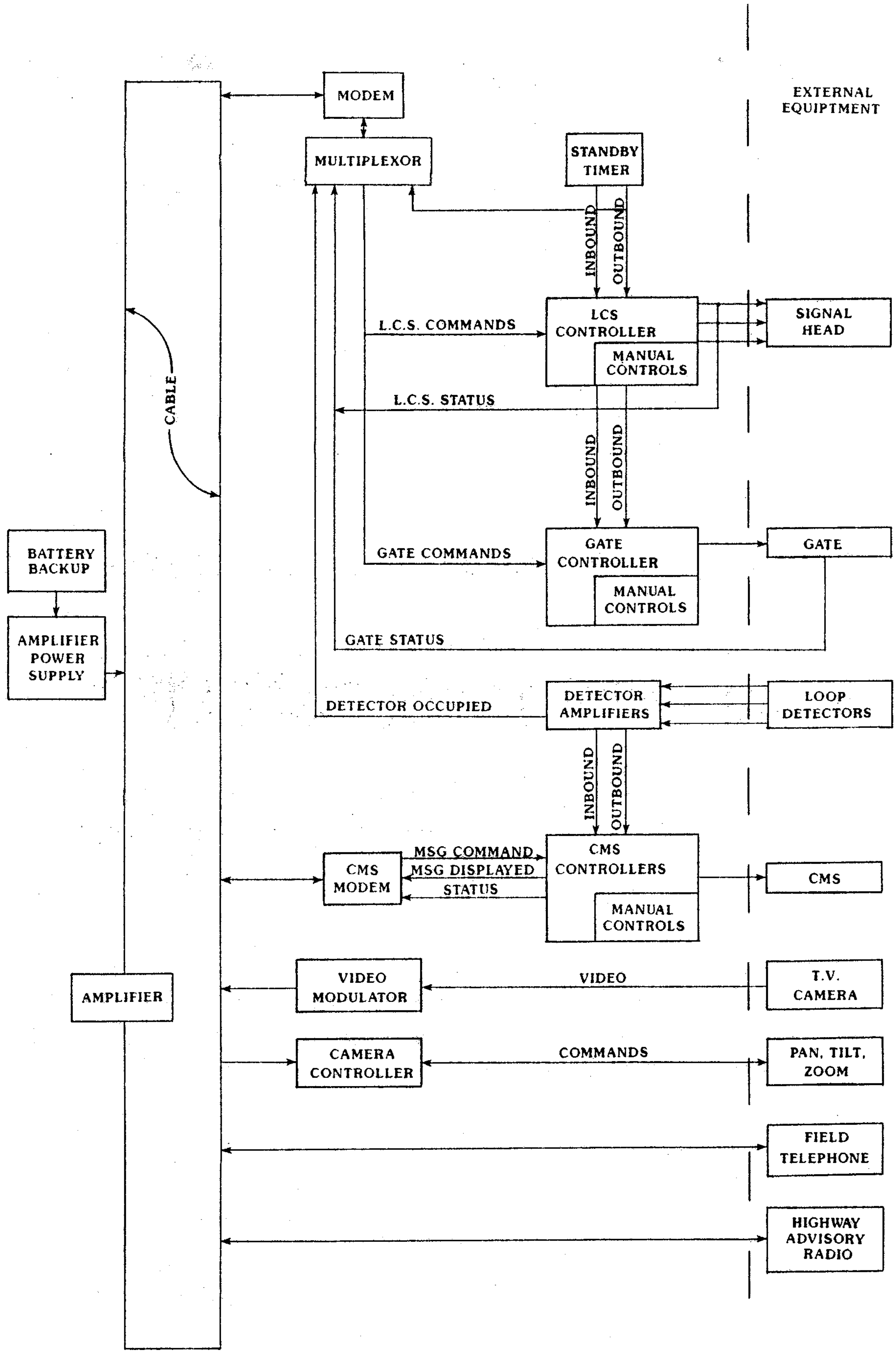


Figure 2-43. Field Controller Functional Diagram

Both types of authorization processes are used on transitways and HOV lanes in the United States today. And each has distinct advantages which suit it to particular circumstances. These circumstances can also change over time, requiring changes in authorization processes on individual facilities. For that reason, the design and operation of a transitway must remain flexible enough to adapt to changing factors which affect the authorization process to be used.

In addition to the various types of authorization procedures, access to the transitway is affected by the operational hours of the facility. If the transitway is designed as a reversible facility, then specific hours for inbound and outbound access must be specified. The responsible and/or involved public agencies should form a "Transitway Management Team" (TMT) to determine the procedures to be followed in opening and closing the lane. These procedures should also identify actions to be followed in the event of a vehicle or equipment breakdown, unusual weather, or other conditions that may require that normal operating procedures be superseded by special procedures.

2.3.8.2 Restrictive Authorization Process

The major distinction of a restrictive authorization process is that drivers must obtain permission to use the transitway from the operating authority. This permission may be granted only to certain types of vehicles which meet certain requirements, only to drivers who have completed driver training, and only when vehicles carry a minimum number of passengers. The following vehicles are frequently considered eligible for transitway use if vehicle and driver requirements are met:

1. All official public transit vehicles.
2. All official maintenance vehicles.
3. A suburban commuter bus operating under contract with the operating agency to provide transit services.
4. Other full-size transit vehicles operating regularly scheduled bus services and approved by the operating agency.

5. Other motor vehicles (vanpools and carpools) designed to carry a predetermined number of passengers, including the driver, and approved by the operating agency.
6. All official emergency vehicles.

The following requirements might be specified by the TMT before vehicles other than public buses are authorized to use the transitway (24):

1. If a group of persons desire to form a vanpool or carpool, then a minimum number of passengers, including the driver, must be registered in the vanpool or carpool at the time of authorization. In addition to the minimum registration requirement, the minimum occupancy requirement, as determined by the TMT, must also be met at all times the vehicle is using the transitway. Violation of the latter requirement is sufficient reason to revoke the vehicle's authorization permit.

2. Each vehicle owner must maintain minimum insurance requirements in some specified amounts determined by the TMT.

3. For each vehicle and driver or drivers, the operating agency must be provided with a current, valid copy of an insurance policy, or a valid certificate of insurance from the insurance company. If a company or individual is self-insured, the operating agency must be provided a self-insurance certificate from each company or independent driver and evidence of (a) cash or investment reserves and (b) the ability to pay liability claims in the amounts specified.

4. A valid State of Texas inspection sticker must be displayed according to State law.

5. Each vehicle must display a current decal issued by the operating agency in an appropriate location determined by the TMT. Vehicles without this decal shall not be permitted to use the transitway.

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6. An authorized vehicle must be driven by a certified transitway driver (see below) at all times when operating on the facility. The driver must adhere to the driving procedures developed by the TMT.

7. Although not previously used, an authorization fee, as determined by the TMT, may be assessed on each vehicle requesting authorization to use the lane.

Requirements for Driver Certification may be developed by the TMT. To be certified to drive an authorized vehicle on the transitway, every driver (including substitute drivers) might be required to (25):

1. Have a valid State of Texas drivers license.

2. Have no more than two moving violations within the prior 1-year period (moving violation records could be checked), and be in good physical condition. The operating agency may reserve the right to request a physical examination of a driver to determine fitness for driving.

3. Complete a special transitway driver training course. This course may be required to be repeated at specified intervals, in order to assure that drivers are kept up-to-date with current transitway operating policy.

4. Maintain, in the driver's possession, a transitway driver identification card.

5. Abide by the driving procedures presented in a Special Driver Training Course (these procedures should be developed by the TMT). Failure to cooperate with police or other official personnel in the use of the transitway may result in revocation of the authorization to use the facility.

6. Assume responsibility for the breakdown of the vehicle, which will include the responsibility incurred in removing the vehicle to a safe place. Procedures to follow in the event of a vehicle breakdown should be specified by the TMT. While using the lane, the driver should agree to permit the operating agency to authorize towing of the vehicle if such action is required to safely and efficiently operate the transitway.

The above vehicle and driver authorization procedures and requirements will vary from facility to facility and between different urban areas. The TMT, with representatives from all involved agencies, should determine the access authorization requirements specific to a particular transitway.

A restrictive authorization process has many advantages which may improve the efficiency of transitway operation. First and foremost is the ability to limit the number of vehicles which are eligible to operate on the transitway. Due to the many steps involved in obtaining a transitway permit, the number of vehicles which obtain the permit will be fewer than if no permit is required. This will help to keep the transitway operating at a specified level-of-service, or higher. Also, the process insures that the vehicles which do use the transitway meet minimum mechanical standards, which helps to reduce the number of breakdowns on the transitway. When breakdowns do occur, the drivers are aware of the transitway emergency procedures and can respond appropriately, reducing the delay time due to incidents. The restrictive authorization process insures that users are aware of transitway operating procedures, reducing the need for additional informational devices beyond the minimum number necessary. And, since a roster of certified transitway users is available, changes in transitway operating procedures can be disseminated quickly to the users through individual contact or in repeated training sessions. Finally, the restrictive process allows individual transitway facilities in an urban area to have differences in operating procedures, while making the users aware of these differences.

There are also disadvantages to using a restrictive authorization process. The administrative duties associated with such a procedure can

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drain needed resources from other responsibilities. In addition, the operation of a transitway may be divided between several agencies, requiring much cooperation and coordination between the groups. The restrictive procedure prevents all but the most dedicated of users from access to the transitway. The smaller number of vehicles which will use the transitway with a restrictive process may give the motoring public the impression that the transitway is under-utilized if a high level-of-service is experienced. Finally, if it becomes necessary to change from a restrictive process to a permissive process, many more modifications to the transitway are required than if a change in the reverse direction is made.

2.3.8.3 Permissive Authorization Process

The major distinction of the permissive authorization process is that almost any vehicle which meets minimum passenger occupancy requirements is permitted to use the transitway. However, certain types of vehicles, such as motorcycles, trucks, and trailers, are often prohibited from using the facility. No previous experience or training is needed to use the transitway. The only restrictions affecting the permissive process relate to the minimum number of occupants necessary to use the transitway, what types of vehicles are to be prohibited from the transitway, and when the transitway is to be in operation.

There are many advantages to a permissive authorization process. The permissive process operates in a manner most closely resembling that used on conventional roadways, resulting in fewer changes in driver behavior. All vehicles (with some exceptions noted previously) are permitted to use the transitway if they meet the occupancy requirements. Users receive all necessary information from signing and other traffic control devices. With a permissive process, many more vehicles will use the transitway, resulting in the public impression that the transitway is better utilized. If a permissive process is used, the administrative duties of the restrictive process are eliminated, and the responsibilities of the operating agencies are reduced to that of maintenance and operations.

However, there are many disadvantages to using a permissive authorization process. Most significant is the lack of control over what vehicles use the transitway. Enforcement needs are increased dramatically, due to the larger number of vehicles which are eligible for use and an increased number of "sneakers" which will try to use the transitway. Control over vehicle quality is eliminated, resulting in an increased number of breakdowns on the transitway. This, in turn, requires more efficient removal procedures. With the permissive process, transitway drivers are untrained, with increased information requirements. Therefore, a more detailed and effective information system is required on the transitway.

2.3.8.4 Minimum Occupancy Requirements

Occupancy requirements are at the heart of transitway operation. The level at which the minimum requirements are set determine how many vehicles are eligible and will use the facility. Where to set these requirements is a key decision for both the restrictive and permissive authorization processes. To insure that the facility can operate safely and effectively maintain a high level-of-service (i.e., 50 to 55 mph operation in unimpeded traffic flow), the minimum occupancy requirements should be set to limit the number of vehicles which are eligible for transitway use and still provide room for growth, so that requirements will not have to be modified at a later period of time. At the same time, the occupancy requirements should be set low enough to provide non-transitway users with the image that the transitway is well utilized.

Establishing the minimum occupancy requirement for a permissive authorization process is less complicated than for the restrictive authorization process. With a permissive process, the number that is established determines how many vehicles are eligible for transitway use. (See previous section in this Manual entitled Demand Estimation). Actual use may be very close to the number of eligible vehicles. Various transitway facilities have used two, three, and four occupants (including the driver) as the minimum requirement. Experience has shown that the lower the requirement, the higher the volume of vehicles using the transitway.

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Agencies have generally set a high requirement and then lowered it, if necessary, to increase utilization of the transitway. However, at some point in time, it may be necessary to raise the occupancy requirements to reduce the number of vehicles on the transitway and improve the level-of-service. At this time, there has been no experience with increasing the minimum requirements on permissive transitways, and the implications of such a move are uncertain at best. Therefore, minimum occupancy requirements should be set to allow for future growth in vehicular volumes while maintaining an adequate level-of-service.

Establishing minimum occupancy requirements for restricted transitways is a more complicated task. Two requirements exist with the restrictive process; the minimum occupancy to use the transitway, and the minimum number of people needed to register for the transitway. The former is often smaller than the latter in order to allow vehicles which are missing one or two of the registered people on a given day to still use the facility. The minimum occupancy may be set as low as two, three, or four people, which allows registered carpools to use the transitway. Or it may be higher to eliminate carpools, but allow vanpools and buses. The level at which the requirements should be set is dependent on the anticipated level-of-service of the transitway. The value should be set so that an acceptable level-of-service can be maintained as transitway growth occurs.

2.3.9 Incident Response

Once an incident is detected, the key to minimizing delay to transitway vehicles is the speed with which the incident is cleared. Effective incident response must include service facilities which, upon detection and location of an incident, allow for the rapid removal of that incident.

Response procedures will vary depending upon the design and operation of the transitway. The TMT should develop specific procedures and/or guidelines to be followed by authorized users of the system. Such response procedures, to be effective, must be clearly communicated to, and understood by, the drivers prior to the occurrence of the incident.

Two types of vehicle breakdowns may occur within a transitway:

1. One not blocking the lane; or,
2. One that does block the lane.

Tests indicate that, with trained drivers using a reversible, 19.5 feet wide transitway, the vast majority of vehicle breakdowns should not block the facility (15). It should be the clear responsibility of a driver in a vehicle developing mechanical problems to make every effort to continue the journey in order to get off the transitway before stopping. Drivers experiencing vehicle breakdowns, if at all possible, should be instructed to coast as far as possible to the left side of the transitway. Desirably, both front and rear tires of the stalled vehicle will be touching the toe of the concrete median barrier, if such a barrier is used. If the driver of a vehicle approaching a disabled vehicle does not believe that sufficient space is available to pass the disabled vehicle in the transitway, the driver should be instructed not to attempt the maneuver. Under this condition, the approaching vehicle should pull as far to the left side of the transitway as possible, activate hazard lights, and wait for a bus or other vehicle to block the lane and take control of the situation. If the driver of a vehicle approaching a disabled vehicle is physically able, and is also permitted by procedures, to pass the vehicle, passing speed should be restricted to a safe maximum (25).

One important consideration in incident management on transitways is the cooperation of the agencies responsible for providing the needed response. Normally, more than one department of an agency or more than one agency is involved. Since the priorities within each agency are often different, it is sometimes difficult to achieve the full cooperation of all parties. Matters involving multiple jurisdictions can also complicate the management process. To overcome these differences, it may be necessary to create an incident management team composed of representatives of the major operating agencies and governmental entities. In the case of transitways, the TMT may serve in this capacity. At a minimum, the TMT should coordinate incident response with existing groups or freeway incident management personnel, if any.

2.3.10 Enforcement

The primary objective of enforcement by police officers on transitway facilities is to maintain the design and operational integrity of the facility for those high-occupancy vehicles designated or authorized to use it. In this regard, detection and apprehension of violators, issuance of citations to violators, and effective prosecution of violators is essential. Therefore, law enforcement personnel with full capability to issue citations must be employed on transitway facilities.

A secondary objective of enforcement by police officers on these facilities is safe and efficient operations. Depending on the type of facility and priority users, the potential hazards imposed by vehicle breakdowns, wrong way movements, and/or other vehicle encroachments into the transitway pose serious safety problems. Each of these potential hazards or conflicts will also adversely impact operations and must be a concern of the enforcement authority.

The necessary level of enforcement will vary with the design of the transitway and its operation. If a high number of access ramps are provided to a facility, a larger number of enforcement personnel will be required to insure that only authorized vehicles use the transitway. The number and design of transfer centers, park-and-ride lots, and other support facilities will also affect the level of enforcement needed. If the transitway is reversible from the morning to afternoon periods, enforcement personnel will be required during the shut-down and start-up times. Certain incident responses will require enforcement officers and/or other corrective actions.

A TTI study (26) examined the enforcement procedures of HOV lanes around the country and determined the following key concepts related to effective HOV enforcement:

- To be effective, an officer must have a safe and convenient place to issue citations or warnings. It needs to be in plain view of HOV users so that they can see when the lane restrictions are being enforced. But its use should not interfere with traffic on the HOV lane.

- To preclude high violation rates, a highly visible enforcement presence has to be maintained at a level where potential violators and legitimate users alike believe that violators have little chance to use the lane without getting caught.

- On limited access facilities, such as transitways, diversion of potential violators before they can traverse some part of an HOV lane is safer and more efficient than apprehending them after the fact. Whenever possible, enforcement areas should incorporate this concept.

Where access to the transitway facility is not controlled, tandem (two officers) enforcement at strategic points may be most applicable. This technique positions an officer at an entry area to the transitway to detect the violation. Vehicle identification is communicated to a second officer located at an exit area. The second officer is responsible for apprehension and citation of the violator. This technique may require several officers to enforce transitways with multiple entry/exit locations.

Pursuit, apprehension and citation may also be employed at selected entry locations utilizing fewer enforcement personnel. This technique involves detection and pursuit of a violator on the transitway with subsequent citation at a designated location of the facility. Application of this technique is very site specific and may only be implemented if the violator can be removed from the transitway properly. The design requirements for application of the pursuit, apprehension and citation technique are:

(1) A safe and easily accessible refuge area(s) bordering the transitway in which to cite violators; and

(2) Existence of a vantage point(s) from which enforcement personnel can observe the transitway.

As a minimum, enforcement personnel should be located at transitway terminals for identification, apprehension, and citation of violators of the transitway lane restrictions.

Enforcement areas are critical to the effective enforcement of transitway regulations. Without a place to pull over and issue citations to violators, enforcement personnel will not be able to fulfill their responsibilities. On HOV facilities which prevent police from pursuing and citing violators, violation rates may be as high as 60 to 80 percent.

The enforcement area can exist in several forms. One is a shoulder with a minimal width of at least 10 feet adjacent to the transitway lane. A citation area can also be provided adjacent to the transitway. It must be wide and long enough to provide safe refuge for the officer, violator, and their vehicles while the citation is issued. The ideal width of the citation area is 12 to 20 feet. The California Department of Transportation has adopted a standard for citation areas of 1300 feet in length, 14 feet wide, and entry and exit tapers between 50:1 and 70:1 (26). Diversion areas are another form of enforcement areas. These are located at the beginning of the facility and are used to divert ineligible vehicles from the transitway prior to entry. On reversible transitways, diversion areas can be used as citation areas at the end of the transitway.

From the standpoint of citation for noncompliance, enforcement experience on priority treatment facilities (27) indicates the need for strict enforcement at the outset of a project. To allow the public time to become accustomed to the priority treatment, violators should be issued warnings for a short period.

Strict enforcement should continue for one to two months depending upon the type of priority treatment, the number of intermediate access points, the "innovativeness" of the priority treatment, and the degree to which standardized and frequent signing and marking is utilized. Following the strict enforcement period, the enforcement effort can decrease to a more nominal level.

The effectiveness of enforcement on transitway facilities may be measured in terms of violation rates. Violation rate is defined as the percent of the total number of vehicles using the priority treatment facility which do not meet the occupancy authorization requirements. A wide range of violation rates have been observed--from 0 percent to over 90 percent. One intent of employing a certain level and type of enforcement is to achieve a violation rate that is acceptable to maintain the integrity of the transitway facility. For a limited access facility, violation rates should ideally be below 5 percent, with 10 percent considered the maximum acceptable.

Various factors will affect violation rates on a transitway facility where enforcement is applied. These factors include:

1. Transitway signing and marking;
2. Type or combination of authorized vehicles;
3. Travel time incentive;
4. Probability of apprehension;
5. Penalty for violation;
6. Accessibility to transitway facility;
7. Operating time period;
8. Level of occupancy authorization;
9. Visibility;
10. Weather conditions.
11. Availability of enforcement areas to cite violators.

Figure 2-44 highlights the need for enforcement officers on transitways with multiple entry/exit points. Violations must be controlled to maintain the priority authorization of the facility. Enforcement on transitways may come from local police agency personnel or it may be the responsibility of the operating transit authority. In this case, special transit police may enforce (detect, apprehend, cite) violations on these facilities. This

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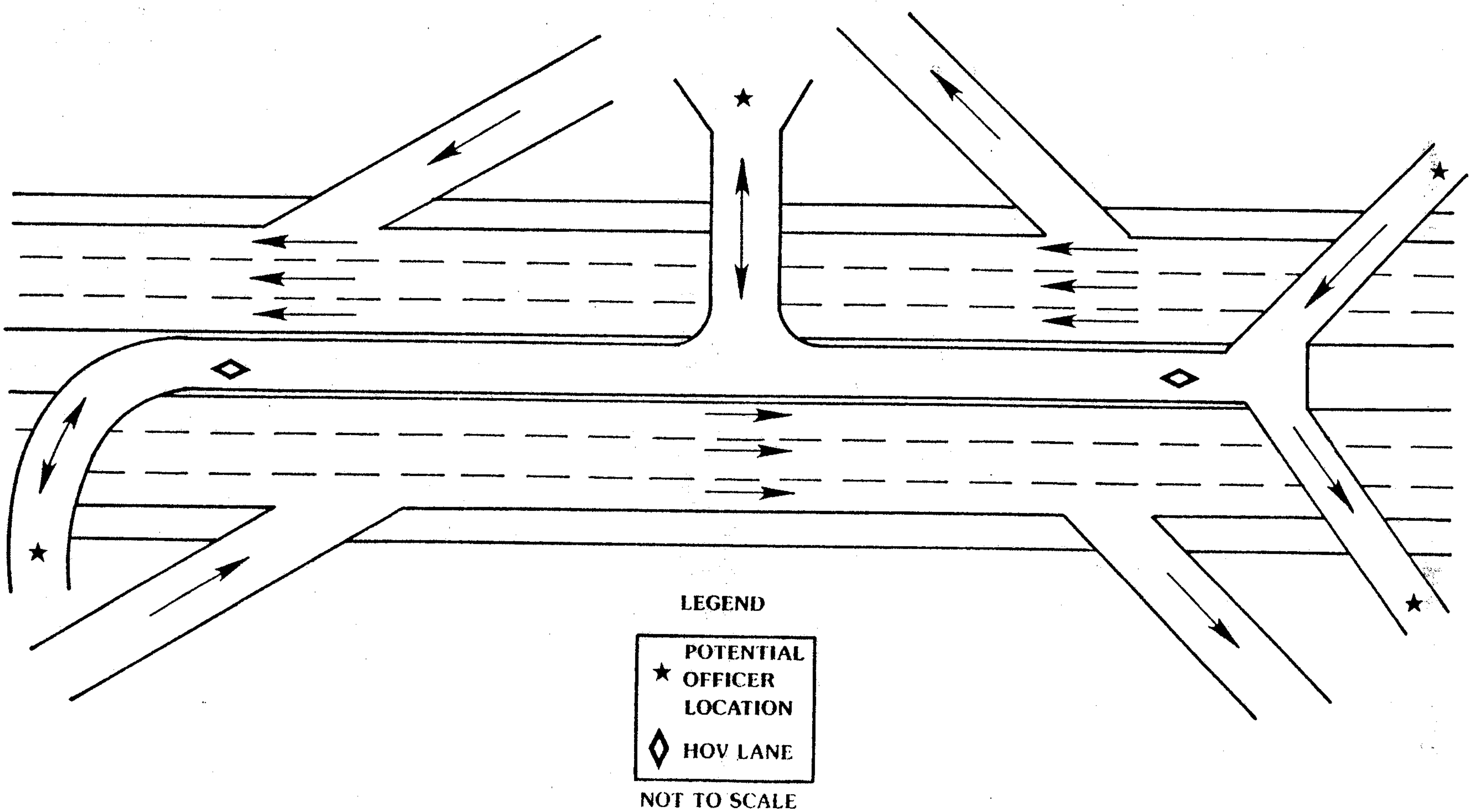


Figure 2-44. Possible Transitway Enforcement Locations

insures consistency in enforcement due to day-to-day facility operating experience by the transit police personnel.

Table 2-16 summarizes goals and objectives of enforcement personnel utilized on transitways as well as strategies for implementation and measures of effectiveness (28).

2.3.11 Transitway Information Requirements

2.3.11.1 General

Transitways have developed into a complex transportation system of which the methods used to meet motorist information requirements are a major element. Users of any given transitway have certain information requirements which need to be met for the transitway to operate in an effective manner. Additional information requirements may be imposed on the system depending on the authorization process and the types of drivers on the transitway. The proper application of traffic control devices on transitway mainlanes and connections is critical to safe and efficient transitway management and to assure operational integrity.

Traffic control devices include all traffic signs, signals, pavement markings, and other devices placed on or adjacent to the transitway by a public agency. The number and placement of signs, pavement markings, gates, signals and other traffic control devices are very site specific. Detailed consideration should be given to the design of the traffic control system as an integral part of any transitway and support facilities development. Traffic control devices cannot correct geometric design errors or inconsistencies in a transitway system; yet they can define and/or reinforce positive operations.

The amount of information provided to users is a function of the driver familiarity with the facility. Transitways which have a training requirement do not need to provide as much information to drivers as those which allow untrained or unfamiliar drivers on the facility. However, in both cases,

Table 2-16. Goals and Objectives of Transitway Enforcement Personnel

Goal	Objectives	Strategies	Measures of Effectiveness
Maintain operational integrity	• Minimize travel times • Maximize vehicle occupancy levels • Minimize violation rates	• Strict enforcement of occupancy requirements • Clear communication of nature of facility • High visibility of enforcment officers • Swift, safe removal of violators	• Violations • Violation rates • Travel times
Maintain safe operation	• Minimize accidents • Minimize incident response and clearance times	• Strict enforcement of authorization requirements • Clear communications of nature of facility • Swift, safe removal of violators	• Accidents • Accident rates • Incident response and clearance times

there is a minimal amount of information which needs to be provided to the driver. This minimal information includes notice of legal driving requirements, advance notice of access points, and warning of certain geometric elements.

Recent research (29) has evaluated the information needs of transitway motorists and has identified a number of concerns related to meeting these information requirements and how traffic control devices can be used to meet those needs. Some key concerns are identified below:

- The barrier separated transitway is similar to a freeway system with its high speeds, controlled access, and long length. Therefore, transitway signing should follow freeway signing principles as closely as possible.

- Transitway signs should use words in the legend. Research (29) indicates that symbols for the various types of vehicles are not well understood by motorists. If it is desired to use symbols in the legend, an educational plaque is recommended.

- Motorist identification of transitway information should be assisted by placing a diamond symbol on all signs which specifically apply to the transitway. In addition, transitway signs should be located directly over the lane, whenever possible.

- The use of regulatory signs on transitways should be limited to those signs which inform the driver of a law or regulation, in a manner similar to the use of regulatory signing on conventional roadways.

- Guide signs should be used on transitways to provide navigational information to motorists. These signs should be distinguishable from guide signs located on adjacent roadways. It is recommended that guide signs be located over the transitway or adjacent to the approach lane and contain a diamond symbol as part of the sign. The information contained in these transitway guide signs may include the following:

- Advance notice of transitways entrances and exits
- Distances to exits
- Guidance to entry and exit points
- Exit locations such as cross street, freeway, or park-and-rides.
- Route marker signs are recommended for each transitway. These will be used to guide motorist to the facility and once on the transitway, provide continual confirmation of the route.
- The meaning of lane-use control signal indications should correspond to similar indications used at intersections.
- Educational plaques should be erected near the entrance to HOV facilities explaining the meaning of the lane control indications.

2.3.11.2 Guidelines for the Use of Transitway Control Devices

Current research (29) has led to the development of a proposed series of guidelines for the use of traffic control devices on transitway facilities. These proposed guidelines have been developed for several new traffic control devices and also for the modified uses of existing devices.

Diamond Symbol

All transitway signs should be identified by the diamond symbol displayed as part of the sign or adjacent to it. If part of the sign legend, the diamond symbol should be located in the upper left corner of the sign. It may also be displayed by attaching an advisory plate above the sign. The diamond symbol advisory plate should prominently display the diamond symbol. "HOV" or "TRANSITWAY" may be added to the advisory plate below the diamond symbol. The color of the diamond symbol advisory plate should correspond to the color of the sign with which it is displayed.

Regulatory Signing

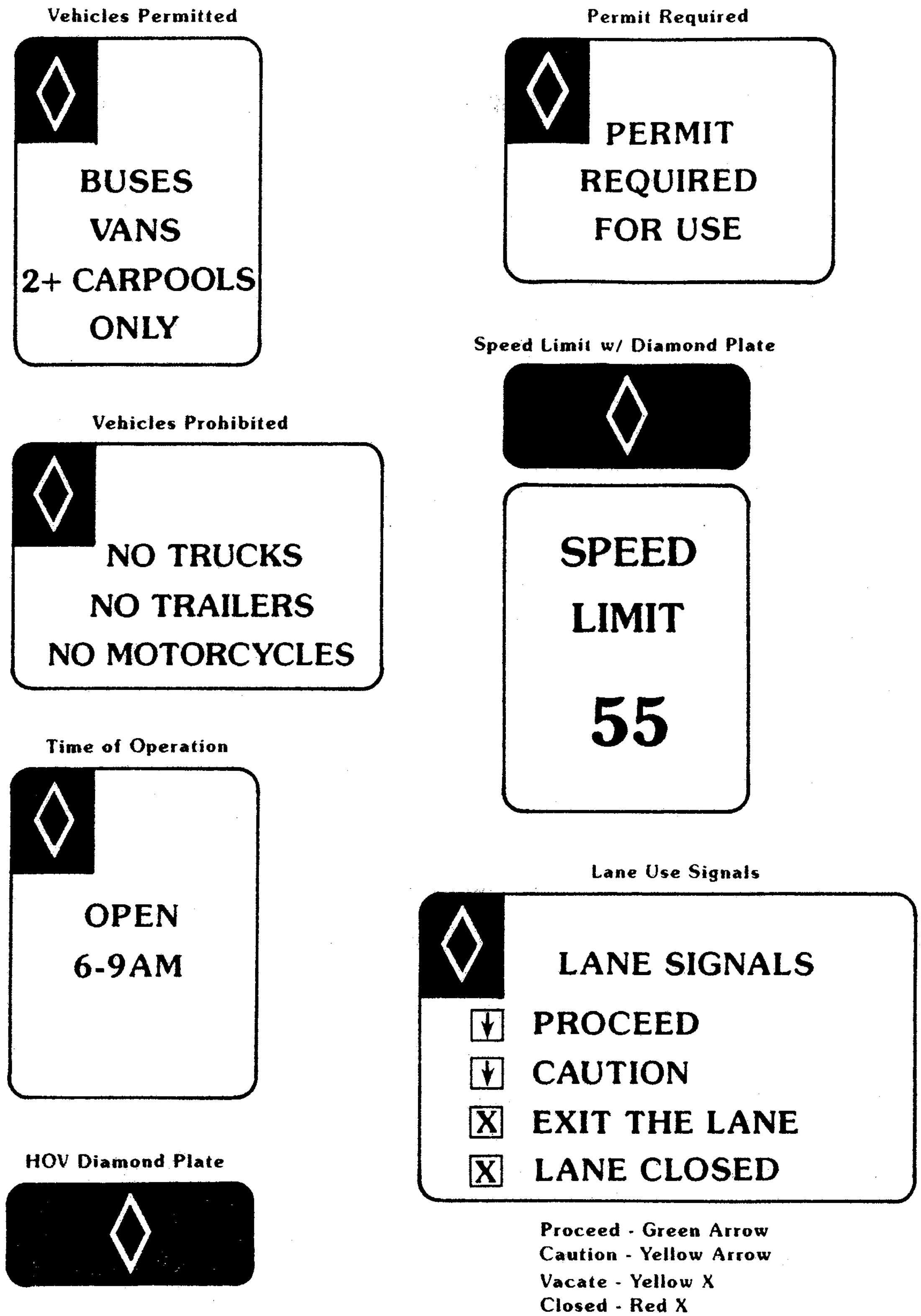
Transitway regulatory signs should be used to inform the transitway user of laws or regulations related to the use of the facility. Several new regulatory signs are proposed for use on transitways. These signs include: Vehicles Permitted, Vehicles Prohibited, Time of Operation, Permit Required for Use, Diamond Symbol Advisory Plate, and Lane-Use Control Signs. Other existing regulatory signs may be used as the need dictates. These signs should be used in the manner described in the Manual of Uniform Traffic Control Devices (MUTCD) (30). All recommended signs should follow the standard regulatory signing principles with a black legend on white background, rectangular shape, and reflectorized or illuminated if applicable during periods of reduced visibility. A white diamond symbol on a black background should be displayed with each sign, either in the upper left corner of the sign, or as a diamond symbol advisory plate above the sign. Several examples of transitway regulatory signs are shown in Figure 2-45.

Warning Signing

When used on transitways, warning signs are necessary to inform the user of geometric changes and converging lanes. Standard warning signs currently found in the MUTCD are sufficient for use on transitways, if identified as a transitway sign by a diamond symbol in the upper left corner of the sign or by a diamond symbol advisory plate. Warning signs may be mounted above or to the side of the lane to which they apply. Examples of transitway warning signs are shown in Figure 2-46.

Guide Signing

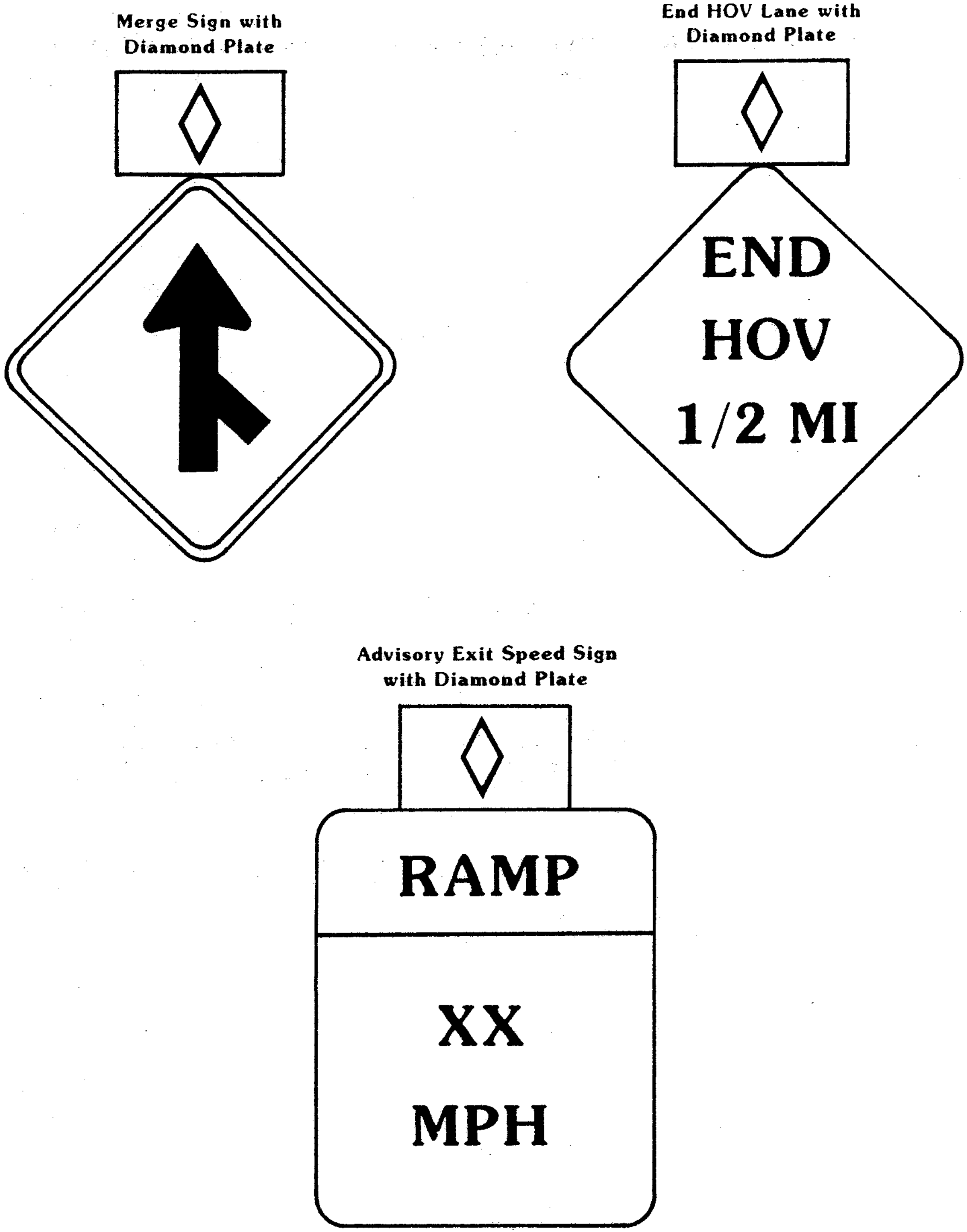
Guide signs provide navigational and guidance assistance to motorists. Functions of these guide signs include: giving directions to destinations, furnishing advance notice of the approach to entrances and exits, directing drivers into appropriate lanes, identifying routes and directions on routes, and showing distances to destination. The transitway guide signs should be identified by a diamond symbol in the upper left corner. The diamond symbol



All signs are black on white background

Source: Ref. (27)

Figure 2-45. Transitway Regulatory Signs



All signs are black on yellow background

Source: Ref. (27)

Figure 2-46. Transitway Warning Signs

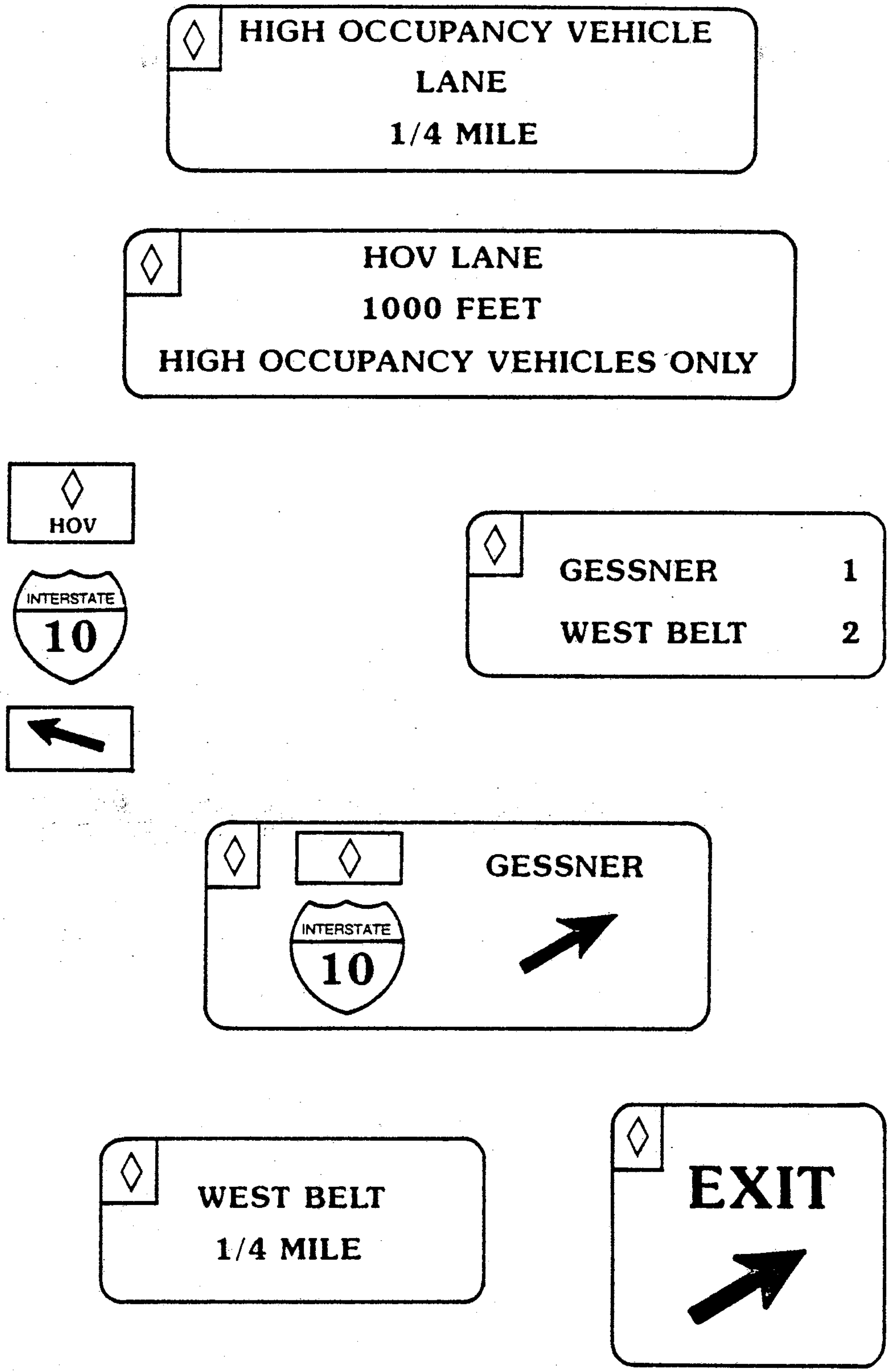
should match the sign color and be displayed on a white background. Transitway guide signs should otherwise follow the MUTCD guidelines for freeway guide signs.

A diamond symbol advisory plate should be combined with the standard route marker to indicate directions to the transitway. The route markers should be used in the manner described in the MUTCD to indicate the proper direction to gain access to the transitway. Several examples of proposed guide signing for transitways are shown in Figure 2-47.

Lane-Use Control Signals

The use of lane-use control signals is critical in providing real-time information to transitway users. Research (29) has indicated that drivers associate the meaning of the lane-use control signals with similar indications found on intersection signals. Transitway operation can be enhanced with the use of four lane-use control signals; steady green arrow, flashing yellow arrow, steady yellow "X", and steady red "X". The meanings proposed for each of these indications are described below:

- STEADY DOWNWARD GREEN ARROW - vehicle is traveling in the correct direction.
- STEADY RED X - transitway lane is closed to traffic.
- FLASHING RED X - vehicle is traveling in the wrong direction.
- FLASHING DOWNWARD YELLOW ARROW - an accident, incident, or wrong way movement is located ahead.



Source: Ref. (27)

Figure 2-47. Transitway Guide Signs

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3. TRANSITWAY SUPPORT FACILITIES

3.1 GENERAL

The transitway can be viewed as an authorized HOV express "conduit" along a freeway corridor to the CBD or other major attraction areas. However, a transitway is only viable and successful if adequate "portals" or support facilities are provided. Three distinctive types of transitway support facilities should be considered. These are:

1. Transit Transfer Centers;
2. Park-and-Ride Lots; and
3. Park-and-Pool Areas.

Transit transfer centers are major interchange facilities directly connected to the transitway. They are located closer to the CBD than other types of transitway support facilities and allow a transfer of transit users from CBD HOV vehicles to HOV vehicles destined to other major activity centers not on the transitway route. These types of facilities may also serve as transit terminals whereby passengers transfer from transitway authorized vehicles to other major transit modes (light/heavy rail) which serve specific destinations.

Park-and-ride lots are located farther out in a corridor and may or may not have direct access to a transitway. These facilities provide auto parking for bus passengers. This concept expands the area of viable express bus service and generates demand for transitway utilization. Collection and distribution of patrons is simplified and minimal.

Park-and-pool areas are often located even farther (20-25 miles) out in a corridor from the CBD. These areas are similar to park-and-ride lots as parking is provided as an incentive for HOV staging. In this case, the travel mode is in vans or cars. Again, these facilities may or may not have direct access to a transitway.

Each type of transitway support facility serves a separate authorized HOV. Planning and design considerations are different for each. Variances in demand, physical constraints, and operational requirements dictate that each type of HOV be separated as much as possible from the other. This is accommodated by each type of facility. However, any particular support facility may provide a multiplicity of HOV services.

This chapter of the manual addresses the planning, design, and operations associated with the specified transitway support facilities. Much of this information was assimilated from previous studies sponsored by the SDHPT under Project 205 entitled "Priority Use of Freeway Facilities" (1-8).

3.2 TRANSIT TRANSFER CENTERS

3.2.1 General

Transitways are intended to provide express service from outlying collection points to major urban activity centers. However, it is not possible in most cases for a single transitway to serve all the major activity centers of an urban area. Consequently, interchange facilities should be provided to connect the transitway with supplemental services and/or other transitway facilities.

Transit transfer center planning and design embodies basic traffic engineering, transit operations, and site planning principles. Planning guidelines for transit centers should consider (1) transit route structures; (2) passenger interchange needs; (3) passenger arrival and departure patterns; and (4) land requirements, availability, impacts, and costs (9). These factors, coupled with obvious economic and environmental considerations, can be used to determine when transit centers should be developed, where they should be located, and how they should be designed and related to urban land-use and development patterns (9). The design and operations of transfer centers should (1) provide priority access to transitway vehicles by grade-separated approaches; (2) maximize bus berth capacity by keeping bus layover times to a minimum; (3) minimize the number

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of different bus routes using each berth; and (4) minimize walking distances for transferring passengers.

This section of the manual contains planning and design guidelines for transit transfer centers. General planning considerations are discussed first, followed by design and operating guidelines. The guidelines presented pertain to the functional considerations of transfer center design.

3.2.2 Planning Guidelines

3.2.2.1 Location

Evaluation of potential sites for transfer centers should consider the following criteria (10):

1. Land Availability and Costs. Transfer centers should be located on land that is vacant or easily acquired. Land acquisition costs should be reasonable relative to the total number of passengers served and the site's proximity to major interchange points. The site should be large enough to accommodate expansions for possible future growth.

2. Land Use Compatibility. The transfer center should be located where it can complement nearby land uses, such as retail stores and residences. Land in or adjacent to industrial uses should be avoided, or if economically feasible, conflicting industrial uses should be acquired. The location should result in minimal adverse operational effects on adjacent areas in the immediate vicinity of the site. Careful study of present/future traffic projections, circulation patterns, future construction projects, and the projected impact of the facility are therefore very essential.

3. Passenger Attraction. The transfer center should be located to make transit service as effective as possible. An analysis should be made of existing transit schedules to determine the number of trips and usage, and the flexibility to adjust schedules to use the facility. The center and its relation to nearby areas should maximize passenger attraction. This implies

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an attractive design, clear signing and amenities, and no incompatible activities in surrounding areas that would discourage people from changing buses. As a minimum, space should be available for seating.

4. Passenger Interchange. The location of the center should encourage direct and convenient transfer from one bus to another. Across-the-platform transfer should be provided, and passengers should not be required to cross roadways in changing buses. Walking distances between buses should be kept to a minimum, preferably less than a few hundred feet. Separate berthing areas should be provided by major "geographic" destination, or route groupings (transit riders which are dropped off and picked up by another person). Transfer centers should have the ability to serve kiss-and-ride patrons. Interface with other transportation modes (such as local buses, taxis) is an essential feature of successful transfer facilities.

5. Accessibility and Circulation. Transfer centers should be located to minimize travel times to and from free-flowing approach roads and transitways. Buses should be able to enter and leave the center with a minimum number of turns and conflicts. Ideally, buses from any direction should be able to enter or leave any berth.

3.2.2.2 Berth Requirements

The size of a transfer center will depend on several things, including the financial resources that are available. Given a set of financial constraints, the size of the transit center will be influenced by the following (11):

1. Number of passengers forecast to pass through the facility daily;
2. Number of buses anticipated to use the facility daily;
3. Number of riders forecast to be awaiting a transit vehicle at the site during its busiest hour;
4. Number of buses requiring berths at the facility during its peak use period; and
5. Number of buses requiring layover space during the peak hour.

The number of bus berths required varies directly with the maximum number of passengers to be served, the loading and unloading times required per passenger, and the clearance times between buses per boarding or alighting passenger (9). The relationships between these variables can be expressed in analytical terms as shown in Table 3-1. The relationships shown in Table 3-1 imply that loading requirements can be reduced by (1) increasing the number of centers, thereby reducing the boarding and alighting passengers at the maximum load point; (2) reducing the loading and unloading times per passenger through multiple doors on buses, prepayment, and/or separation of loading-unloading; and (3) using larger buses to reduce the clearance interval time losses between successive vehicles. Thus, the person-capacity of berthing areas appears to be largely dependent on the number of doors per bus and the method of fare collection.

3.2.3 Design Guidelines

3.2.3.1 General

The following dimensions should guide transfer center development (10):

a) Minimum Inside Turning Radius - 30 feet
(rear inside wheel) - (35 feet preferable)
b) Minimum Outside Turning Radius - 50 feet
Front Overhang - (55 feet preferable)
c) Minimum Clear Road Width - 24 feet
d) Additional Recessed Area for Shallow
Saw Tooth Loading (40 foot bus) - 8 feet
e) Maximum Passenger Island Width
(loading both sides) - 25 feet
f) Unit Width for Sketch Planning
(2c + 2d + e) - 90 feet
g) Minimum length of Bus Berth
(40 foot bus) - 65 feet

Table 3-1. Capacity Equations Relating Maximum Load Point Conditions to Berth Capacity

VARIABLE	EQUATION [b]
Minimum headway at stop	$h' = B\,b + C$
Maximum buses per berth per hour	$f' = \frac{3{,}600}{h'} = \frac{3{,}600}{B\,b + C}$
Max. passengers per berth per hour	$G = f'\,B = \frac{3{,}600\,B}{B\,b + C}$
Effective berths required to serve J passengers	$N = \frac{J}{G} = \frac{J\,(B\,b + C)}{3{,}600\,B}$
Bus frequency required to serve J passengers per hour	$f = f'\,N = \frac{J}{B}$
Bus frequency at maximum load point	$f = \frac{P}{S}$
Passengers per bus at heaviest station	$B = X\,S$
Minimum headway at heaviest stop	$h' = B\,b + C = bXS + C$
Buses per hour at heaviest stop	$f' = \frac{3{,}600}{h'}\ \frac{3{,}600}{bXS + C}$
Number of effective berths at heaviest stop [c]	$N = \frac{f}{f'} = \frac{P(bXS + C)}{3{,}600\,S}$

[a] Boarding conditions govern.

[b] Nomenclature:

- A = Alighting passengers per bus in peak 10 to 15 min;
- a = Alighting service time, in sec per passenger;
- B = Boarding passengers per bus in peak 10 to 15 min;
- b = Boarding service time, in sec per passenger;
- C = Clearance time between successive buses (time between closing of doors on first bus and opening of doors on second bus), in sec;
- D = Bus dwell time at a stop (time when doors are open and bus is stopped), in sec per bus;
- f = Bus frequency, in buses per hour (all routes using a facility) at maximum load point. (If all buses stop at all stations, $= N\,f'$);
- h = Bus headway on facility at maximum load point, in sec ($= 3{,}600/f$);
- f' = Maximum peak bus-frequency at a berth, in buses per hour;
- h' = Minimum bus headway at a berth, in sec ($= 3{,}600/f'$);
- G = Boarding passenger capacity per berth per hour;
- H = Alighting passenger capacity per berth per hour;
- J = Passengers boarding at heaviest stop (hourly rate);
- K = Passengers alighting at heaviest stop (hourly rate);
- L = Peak-hour load factor at the maximum load point, in passengers per bus seat per hour;
- N = Number of effective berths at a station or bus stop ($= N'u$);
- N' = Number of berth spaces provided in a multi-berth station;
- P = Line-haul capacity of bus facility past the maximum load point, in persons per hour (hourly flow rate based on maximum 10 to 15 min);
- S = Seating capacity of bus (varies with design);
- u = Berth utilization factor; an efficiency factor applied to total number of berths to estimate realistic capacity of a multi-berth station ($= N/N'$);
- X = Percentage of maximum load point passengers boarding at heaviest stop ($= J/P$);
- Y = Percentage of maximum load point passengers alighting at heaviest stop ($= K/P$).

[c] Can be solved for P where N is given.

Source: Ref. (9)

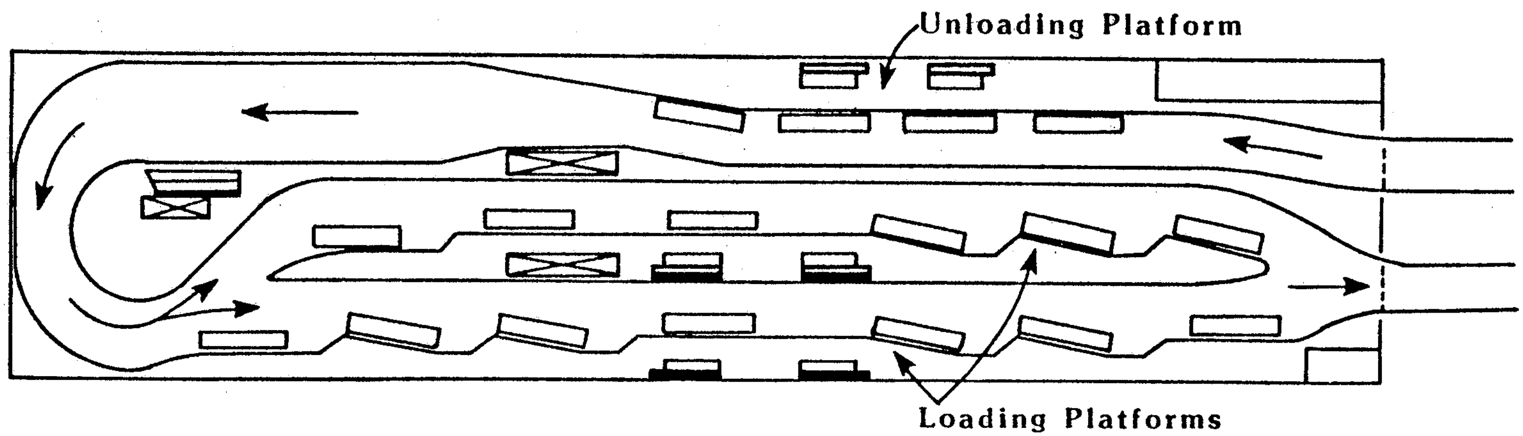
Figure 3-1 illustrates a linear (sawtooth) configuration for a transitway transfer center. Figure 3-2 shows an example layout for a transfer center located on a larger, more symmetrical site. Specific criteria for designing berth and platform areas are presented in the following subsection.

3.2.3.2 Bus Berth and Platform Criteria

Illustrative "parallel" and "shallow-sawtooth" berth criteria are shown in Figure 3-3 for both single-unit and articulated buses. These criteria reflect bus dimension and maneuvering requirements. The in-line (parallel) normal berth and shallow-sawtooth platform arrangements allow for passing of stalled buses. The minimum berth requirements of in-line platform would be used where physical, cost, or other conditions limit right-of-way (9).

The roadway width and the amount of lineal space at a bus loading platform are directly related where designs allow departing buses to pull out from the platform around a standing bus. Figure 3-4 shows how a 40-ft bus, having a 16-ft clearance ahead, actually uses 22 feet of roadway width for its pull-out maneuver. This condition requires a roadway width of at least 24 feet, and a total minimum berth length of 56 feet for each bus. Thus, five buses would require 264 feet of lineal distance. The shorter the berth length allowed, the wider the roadway must be, and conversely (9).

Considerable linear space is necessary to permit a bus to overtake and pull into a platform ahead of a standing bus. Illustrative platform requirements for 28 and 40 foot buses are shown in Figure 3-5. A 40-foot bus requires 92 feet to pull in, assuming the rear end of the bus is 1 foot out from the platform curb, 80 feet when the rear end of the bus is 2 feet from the outside of the curb, and 56 feet when a 5 foot "tail out" is permitted. Thus, for any runway where such maneuvers are permitted, the road width should assure adequate safe clearance for vehicles in the outside or overtaking lane (9). Illustrative station platform design criteria are shown in Figure 3-6. The use of parallel versus shallow pull-through sawtooth loading will depend on site characteristics and space availability (9).



SAWTOOTH TRANSIT CENTER CONFIGURATION

Figure 3-1. Linear (Sawtooth) Configuration for a Transitway Transfer Center

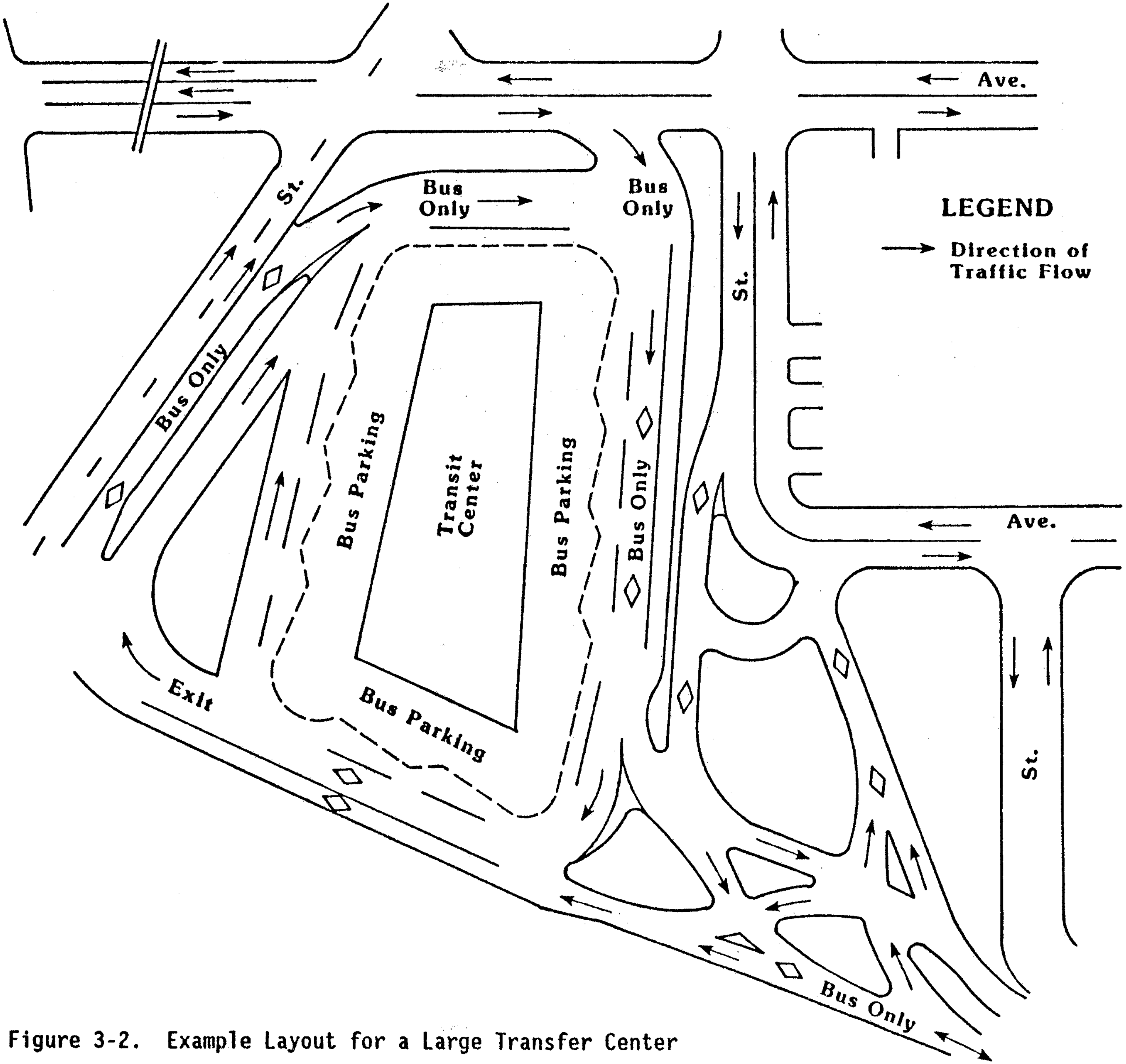
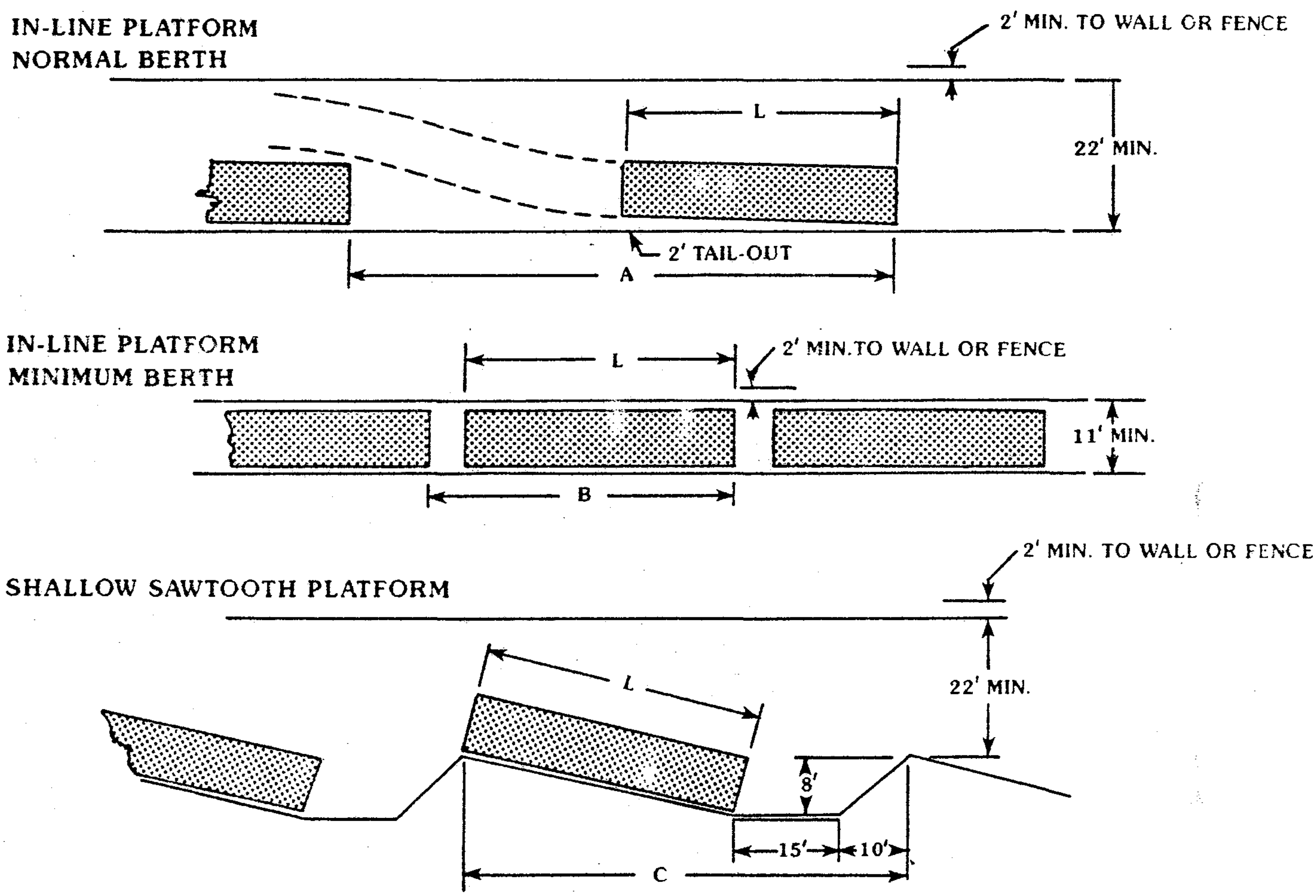


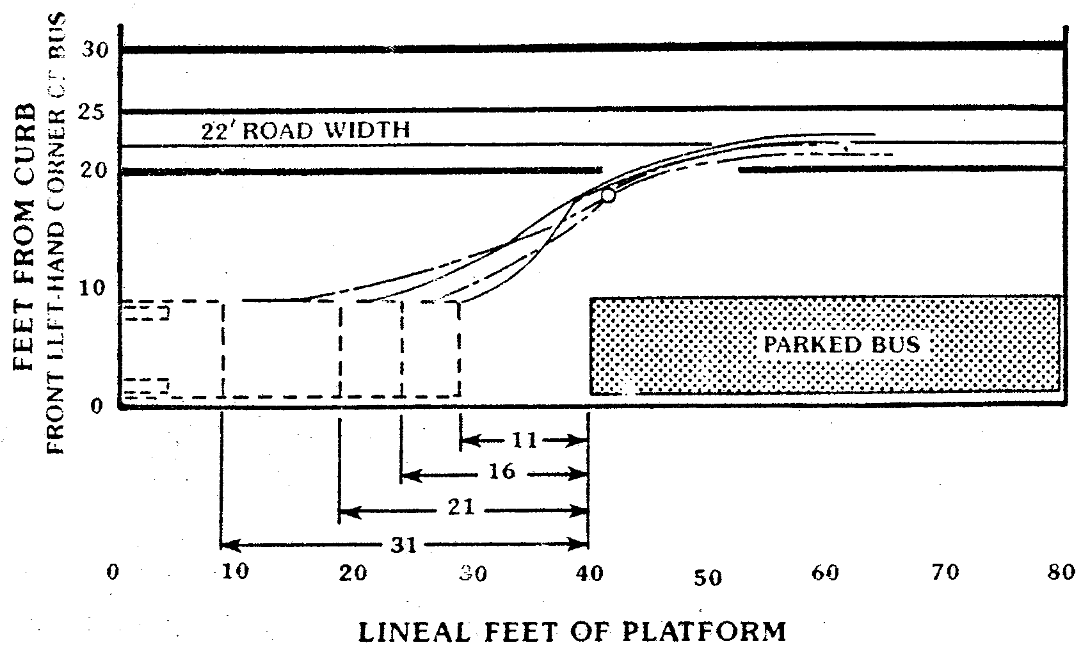
Figure 3-2. Example Layout for a Large Transfer Center



BUS POSITIONS DEPENDENT ON ARRIVAL SEQUENCE. IF INDEPENDENT PULLOUTS DESIRED, INCREASE ROADWAY WIDTH TO 22 FT. MIN. AND ADD 11 FT. TO BERTH LENGTH.

	SINGLE UNIT BUS	ARTICULATED BUS
L	40'	60'
A	80'	100'
B	45'	65'
C	65'	85'

Figure 3-3. Bus Berth Criteria



PULL-OUT DISTANCE	ROAD WIDTH	BERTH LENGTH
11'	23'	51'
16'	22'	56'
21'	21'-8"	61'
31'	21'	71'

Figure 3-4. Roadway Clearance and Bus Berth Clearance Requirements

	BERTH LENGTH REQUIRED FEET	
BUS LENGTH	28'	40'
TAIL-OUT FEET		
1	68'	92'
2	54'	80'
3	50'	66'
4	46'	60'
5	43'-6"	56'

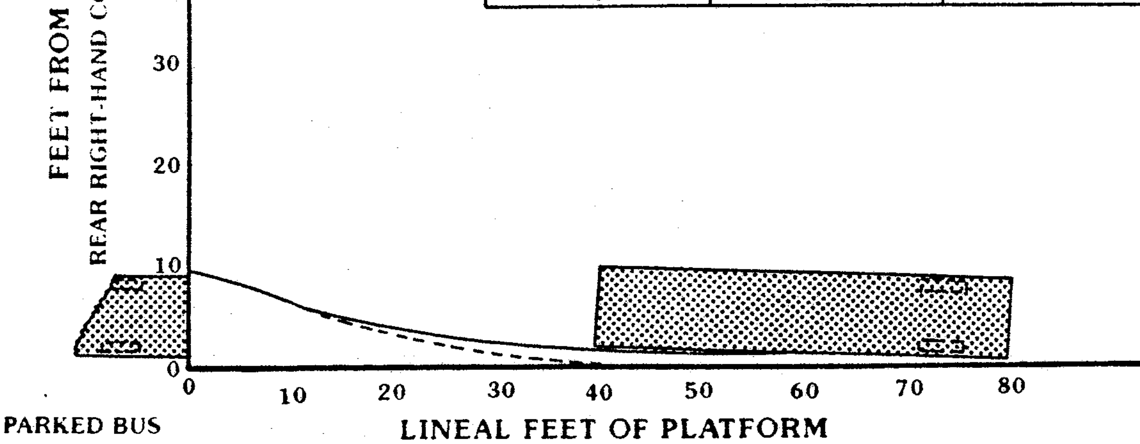
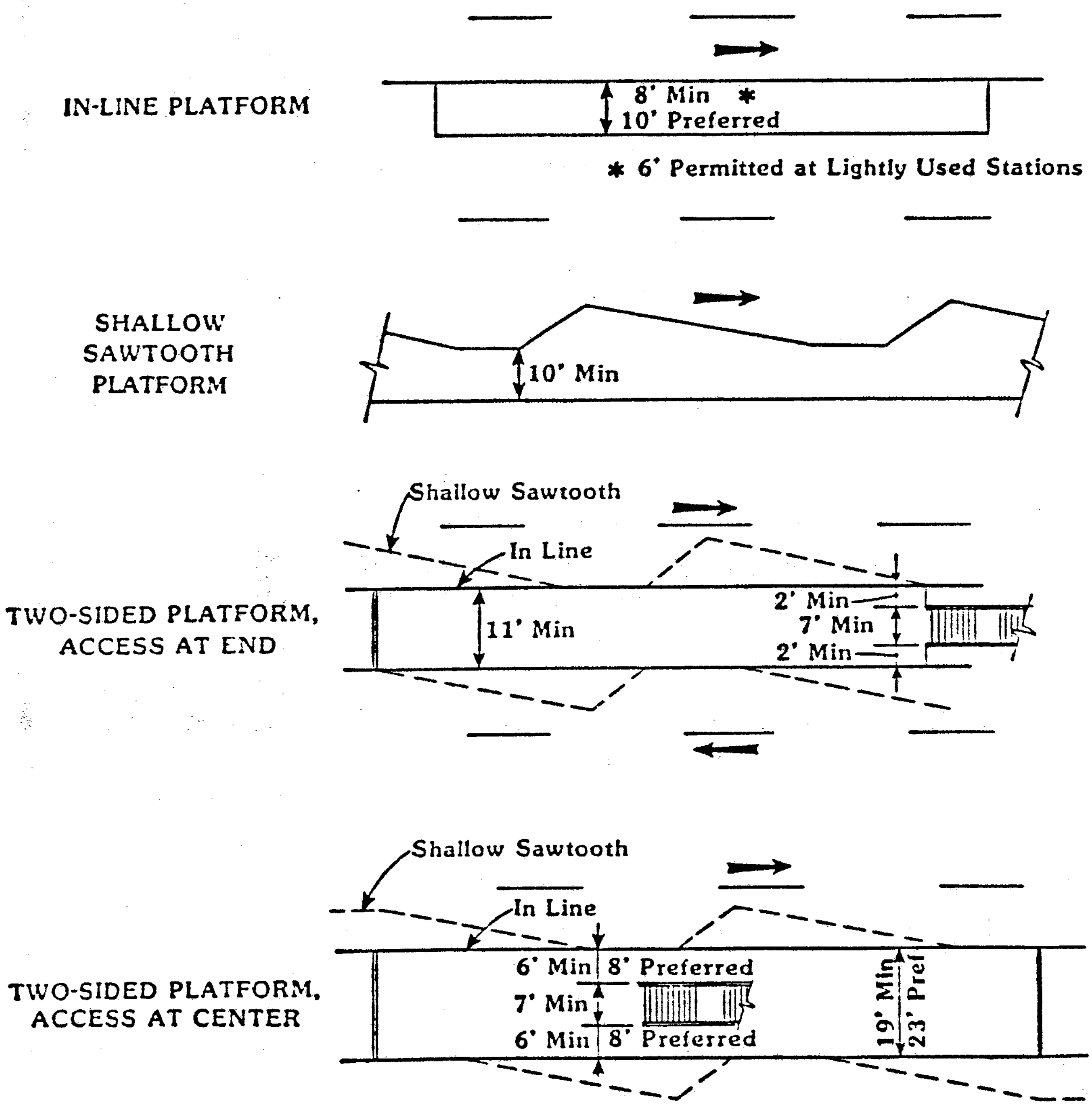


Figure 3-5. Transfer Center Platform Requirements



Source: (9)

Figure 3-6. Illustrative Platform Design Criteria

Single parallel platforms should be at least 6 feet and preferably 10 feet wide. Shallow (single) sawtooth platforms should be at least 10 feet wide at the point of minimum width (9).

Two-sided island platforms should be at least 11 feet wide (9). A minimum station length of 80 to 100 feet allows for two bus berths (9). Pedestrian walkways should be at least 5 feet wide and stairways at least 6 feet, bridges at least 8 feet, and tunnels at least 10 feet (9).

3.2.4 Operating Considerations

3.2.4.1 Traffic Control

Traffic signals may be required at the access points of large transfer facilities located on major streets to provide safe and efficient use of the facilities. Signalization should be considered only after a thorough study of traffic in the area and should be warranted or justified in the manner prescribed in the MUTCD. Existing traffic signals may require adjustments of timing or phasing to accommodate transfer facility traffic (12).

Signing used in conjunction with the transfer center must be designed in accordance with the MUTCD as well as state and local criteria and policies for informational signs. The messages should be brief yet concise, with an indication of the service provided as shown in Figure 3-7. Signs should utilize standard guidance methods to direct traffic to the facility. Where traffic must be directed to a facility not visible from the transitway, use should be made of trailblazer assemblies and directional arrows.

Signs pertaining to moving traffic should be reflectorized, and some signs such as the entrance identification sign, may be lighted. Information signs should be placed in well-lighted areas. Signing in joint use transfer areas, such as shopping centers, should not interfere with the owner's uses (12).

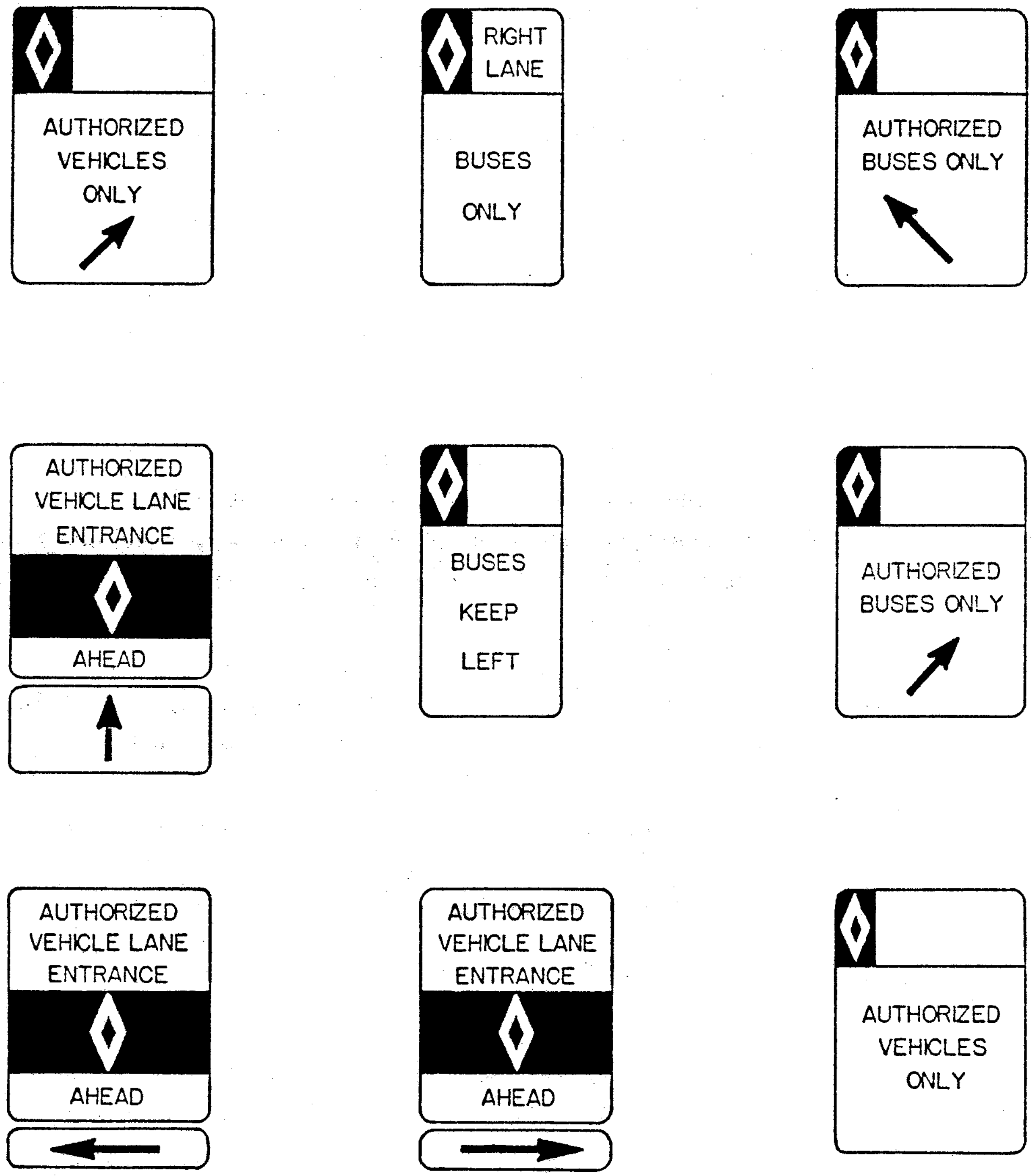


Figure 3-7. Example Transfer Center Lead-in Signing

3.2.4.2 Security

Passenger security has become a major issue for urban mass transportation systems. Perceived security is a primary determinant of transit mode choice and use patterns. Fear of crime and harassment is the most significant factor preventing transit use in some of our large cities, especially those with older transit systems. Even frequent users of transit often schedule their trips to avoid travel during certain times of day (13).

Attempts to control transit crime may involve manpower (police), technology (crime countermeasures), or design. Various police deployment strategies can have marked effects on criminal activity. Similarly, closed circuit television (CCTV), a technological solution, has proven to be very effective for reducing certain types of transit crime (13).

Many transit security problems are designed-oriented or architecturally based. Stations are often designed so that unused spaces become problem areas. Extensive open areas, which were planned for peak period overflow areas, are likely to become areas for loitering, drug dealing, illicit sexual activity, or other undesirable activities (13).

Unused areas of stations may be closed off, and perhaps used for office, storage, machinery, or training areas. New stations may be planned without such areas. Flexible barriers may be used to regulate the amount of station area available, which may expand or contract for peak and off-peak periods.

3.3 PARK-AND-RIDE LOTS

3.3.1 General

This section presents an overview of the important features needed to plan, design and operate a transitway support facility known as a park-and-ride lot. Park-and-ride lots are part of a strategy designed to intercept automobiles at outlying locations along transitway corridors. They can substantially expand the catchment areas of the express bus service and the

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utilization of transitways. They can also simplify bus routing patterns, reduce bus mileage in low-density areas, and improve express service reliability by enabling the automobile to provide neighborhood collection and distribution. Express buses can operate predominantly in line-haul services with increased trunk-line frequency, and simplified collection/distribution.

Consideration in park-and-ride lot planning and design must be given to a number of features including access points and internal circulation, parking space layout, pavements, shelters, bicycle facilities, traffic control devices, lighting, and landscaping. When dealing with a specific site, it will not always be possible to optimize each feature, and compromises will be required. The degree to which the desirable attributes of any component is sacrificed to obtain the benefits of a competing component can only be dealt with on a site specific basis. Primary concerns during the planning and design stages should include: safe and efficient traffic flow for all modes of travel, both on and adjacent to the site; an adequate number of usable parking spaces; facilities for the user which are comfortable and attractive; and facilities that accommodate elderly and handicapped patrons. Some vanpool or carpool activity may occur at park-and-ride lots and should be considered, as it presents the possibility that internal circulation may be somewhat more complicated. Another activity to be considered is kiss-and-ride provision. This may also add to the internal circulation problem if not properly incorporated into the facility layout and design (8).

3.3.2 Planning Guidelines

3.3.2.1 Lot Location

In some highly developed urban areas, little choice may be available concerning the selection of potential parking lot locations. In effect, land availability and/or cost may greatly restrict alternative lot locations. Nevertheless, the following guidelines should be considered in locating potential park-and-ride facilities (8). If several of these guidelines are not adhered to, utilization of the lot may be less than expected.

- Park-and-Ride service will generate the greatest ridership in travel corridors that experience intense levels of traffic congestion. As a general guide, this level of congestion expressed as average daily traffic per lane approaches about 20,000.

- The park-and-ride lot should be located in advance of the more intense traffic congestion. Potential park-and-ride patrons should have the opportunity to select the park-and-ride alternative prior to encountering the more heavily congested peak-period traffic.

- Lots should be located at least 4 to 5 miles from the activity center served. In major urban areas it appears that park-and-ride lots should not be located much closer to downtown than the freeway loop (generally 4 to 7 miles).

- Given appropriate development patterns, there appears to be no outer limit concerning how far a lot can be located from the activity center. Successful lots in Texas are located as far as 30 miles from the destination.

- The lot should be located in a geographic area having a high affinity to the activity center being served by the park-and-ride operation. Since relatively few patrons backtrack to use a park-and-ride lot, the lot should be located so that the area immediately upstream of the park-and-ride facility generates sufficient travel demand to the activity center being served.

- As the total population in the park-and-ride market area or watershed increases and as the percentage of that population working in the activity center served by the park-and-ride operation increases, so will park-and-ride utilization. As a result, the magnitude of development at the activity center will be an important determinant of potential park-and-ride utilization.

- Lots should be developed with both good access and good accessibility. Both accessibility (a measure of the ease with which potential users can get to the general area of the park-and-ride lot) and the access (a measure of how easily users can get into and out of the specific lot site) associated with a park-and-ride facility can influence utilization.

- Generally speaking, there should be no charge for parking at the park-and-ride facility.

- If the current number of park-and-ride spaces available are sufficient to handle "all" the demand from a given watershed, other lots in that same travel corridor should be located no closer together than 4 to 5 miles.

- Park-and-ride service should not be expected to compete with local bus routes.

If flexibility exits in the selection of a specific lot site, the following factors should also be considered in determining the preferred lot location (8):

- To minimize development costs, the site should be flat and well drained. compatibility with adjacent land uses also needs to be considered.

- Space should be available for expansion of the lot. Initial demand may be underestimated, and demand should increase over time.

- Preferably, a park-and-ride lot will be located on the right side of the roadway to conveniently intercept inbound traffic. However, numerous successful lots have been developed that were not located in this manner.

3.3.2.2 Shared Versus New Facilities

Two general approaches can be used in implementing park-and-ride service. One alternative is to construct new facilities specifically designed to serve as exclusive park-and-ride terminals. The second alternative is to utilize the unused portion of an existing parking lot to serve as the parking area for the park-and-ride service. As listed below, both of these alternative approaches have certain advantages and disadvantages (8).

Shared Lots, Advantages

- The parking facility is already available and, therefore, the lead time to implementation of park-and-ride service is reduced.
- The parking area and access roadways already exist.
- Due to the lower capital requirements, shared lots can be used as a means of testing demand.
- The shopping opportunities available at some shared-lot locations may encourage ridership.

Shared Lots, Disadvantages

- The park-and-ride operation must be worked into the existing lot layout.
- Space may not be available for expansion.
- It may be difficult to obtain assurance that a certain number of parking spaces will be available on a daily basis.
- Many of the amenities provided will be temporary in nature.

- During peak periods, especially the evening peak, congestion within the lot and at the access points may be intensified due to traffic generated by the shared use.

3.3.2.3 Single Versus Multiple Lots

Given an estimated demand for park-and-ride service, a question arises as to whether that demand can better be served by providing one large lot or two or more smaller lots. Some of the advantages and disadvantages of these approaches are listed below (8). It appears that, as long as maximum lot size constraints are not exceeded, the advantages of providing one large facility generally exceed the disadvantages of the large lot.

Multiple Lots, Advantages

- Provision of multiple lots results in a larger geographical area being included in the total park-and-ride market area.

- If the maximum parking lot size constraints (1,800-1,900 parking spaces/bus loading area) are exceeded, multiple lots may provide a means of accommodating the demand.

- If either land availability and cost or available surface capacity pose problems in providing one large lot, it may be more economical to provide multiple smaller lots rather than incur massive land and/or street improvement costs to build a single large facility.

- Smaller lots will reduce both congestion and walking distances within the lot.

- A smaller percentage of the total trip distance will be made by auto.

Multiple Lots, Disadvantages

- The construction, maintenance, and operation costs of one large facility will be less (assuming similar land costs and facilities) than those of multiple smaller lots.

- If express bus service is provided, longer headways will exist in the multiple-lot situation (assuming comparable bus load factors).

- Bus breakdowns may pose a greater problem in the multiple lot situation, where the breakdown might cause headways to increase from the scheduled 15 or 20 minutes to 30 or 40 minutes.

- Provision of certain amenities (security, information, shelters, vending machines, etc.) may be more easily justified at one large facility than at several smaller facilities.

3.3.2.4 Demand Estimation

A recent TTI study (14) has identified several techniques to estimate park-and-ride demand. Utilization of these techniques provides a range of estimates; the analyst will need to apply judgement in developing a specific estimate for a specific site. The analysis focuses on park-and-ride operations in Houston, Texas. As such, the procedures documented apply to extremely large urban areas with intense area-wide congestion. Also, since all the data are from Houston, some potentially significant predictive variables such as downtown parking cost and bus headways (which are frequent at all Houston lots) are essentially the same for all lots and, thus, do not appear in equations developed in this report to predict park-and-ride utilization. In transferring the findings to other cities, this limitation should be realized.

Park-and-ride lots draw their demand from a watershed or market area. In Houston, Dallas, and Garland, this market area is generally parabolic in shape, with a vertex 0.5 to 1.0 mile downstream of the lot, an axis of 7 miles in length following the major artery upstream of the lot, and with a chord of 8 miles in length. In San Antonio, the market area has been found to be nearly circular in shape, with a diameter of 7.5 to 8.0 miles. The center of the circle is located about 1.25 miles upstream of the lot. The shapes of both of these market areas are shown in Figure 3-8.

An overview of selected demand estimation techniques used for park-and-ride facilities shows the variety of approaches currently used in practice. In recognition of the uncertainty surrounding park-and-ride project planning, demand estimates desirably should be expressed as ranges rather than point estimates or values. For this reason, transportation planners should employ several (three or more) of the outlined procedures in investigating any particular site for potential park-and-ride development. Table 3-2 summarizes the estimating techniques and their data requirements.

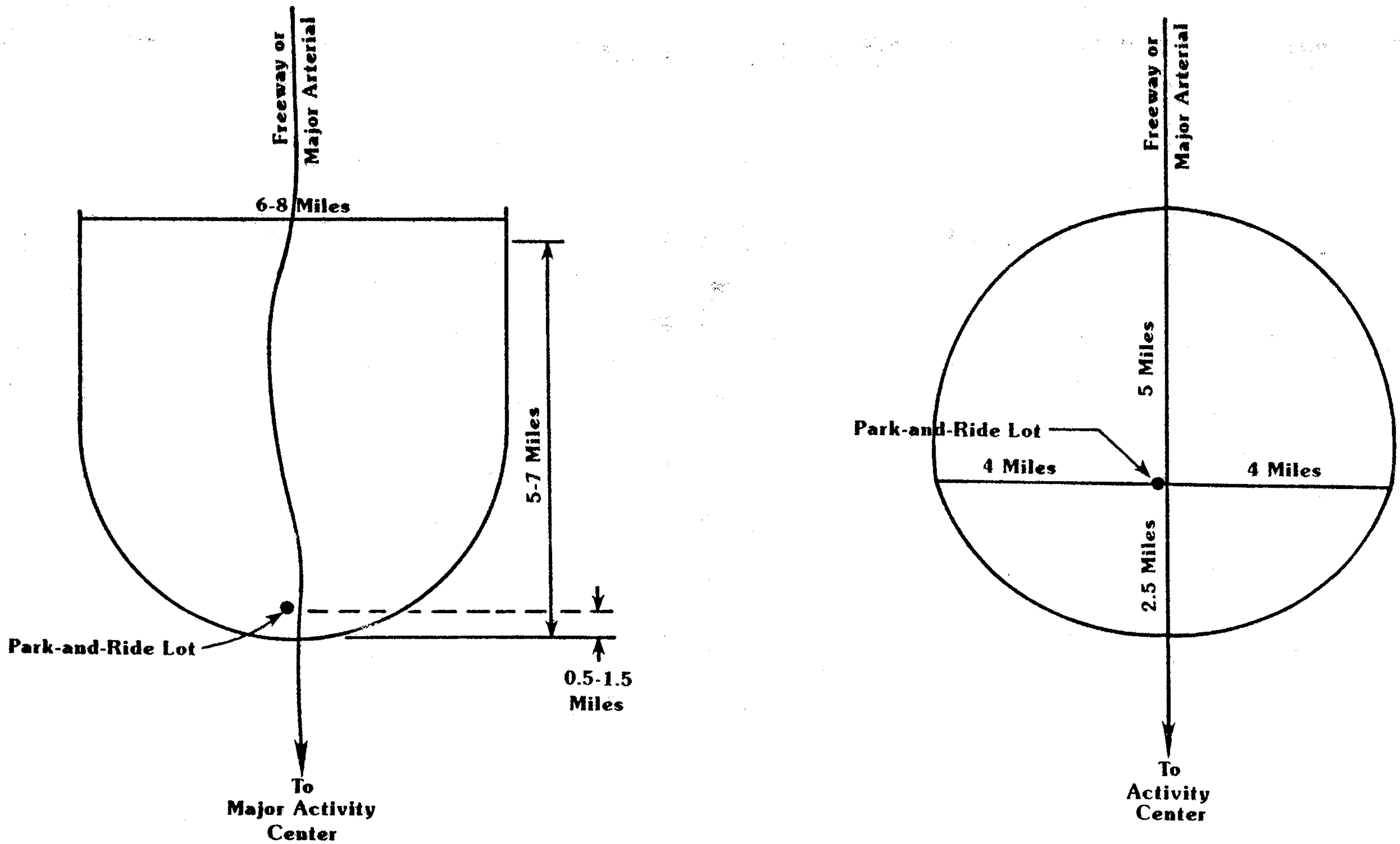
Distinctive differences in ridership exist for those park-and-ride lots served by transitways and those without transitway service. Ridership growth at lots with transitways appears to be affected most by congestion on the freeway and employees in the park-and-ride market area destined to the CBD. Specifically, the average of congestion indices encountered along the freeway portion of the trip and CBD-destined employees in the market area emerged as good ridership predictor variables.

For lots without transitway service, growth in ridership is more dependent upon the months the lots have been operating and on the distance of the lot from the activity center. Those with the greatest ridership increases were located at least 11 miles from the activity center, with the mean distance beginning at 20 miles.

3.3.3 Design Criteria

3.3.3.1 Access/Egress Points

A major consideration in the location of a park-and-ride facility is the access to, and egress from, the lot. Peaking data for two park-and-ride lots



(a) Dallas, Garland and Houston, Texas

(b) San Antonio, Texas

Figure 3-8. Park-and-Ride Lots Market Area Shapes

Table 3-2. Summary Overview of Park-and-Ride Demand Estimation Techniques

Estimation	Primary Data Requirements	Relative Complexity
Georgia Demand Model GOPARK II	a. Market area definition or boundaries b. Subdivision of the Market areas by three travel time categories c. Number of home-based work trips originating from each of the three subdivision of the market area to a specified destination(s). d. Number of peak-period (i.e, am peak) trips on adjacent primary facility (i.e, freeway) destined to specified destination(s). e. Attraction percentages for candidate work trips from each market area subdivision and for the primary facility.	High
Georgia Demand Model GOPARK	a. Market are definition or boundaries. b. Number of home-based work trips from the market area to specified destinations(s). c. Number of peak-period (i.e., a.m. peak) trips on adjacent primary facility (i.e, freeway) destined to specified destination(s). d. Attraction percentages for trips from the market area and the prime facility.	↑
Modal Split	a. Market area definition or boundaries. b. Population residing within the market area. c. Identification of the population component that works in the activity center or centers served by the park-and-ride facility. d. Percent of the eligible population component likely to use the service. e. Possible adjustments because of priority treatment, roadway congestion, etc. (optional).	
Regression Analysis	a. Market area definition or boundaries. b. Population residing within the market area. c. Relative measure (i.e, congestion index) of roadway congestion from lot to destination. d. Employment or other surrogate for demand to the activity center. e. Measure of service relating to age of service and distance from the activity center. f. Possible adjustments unique (i.e., priority treatments) to a particular site (optional).	
Market Area Population	a. Market area definition or boundaries. b. Population residing within the market area. c. Percentage of market area population determined to be potential users. d. Possible adjustments for particular site because of roadway congestion, priority treatments, surrounding density, travel affinities, etc. (optional).	
The ITE	a. Location or site identification b. Peak period traffic volume (i.e., a.m. peak) on adjacent freeway(s) and arterial(s). c. Diversion percentage for the primary facility and for the secondary facilities.	↓ Low

in Houston are summarized in Table 3-3. As a general guideline, it appears that 40% of daily directional traffic occurs in the peak hour, and that 30% of peak hour traffic occurs in the peak 15 minutes.

Table 3-3. Peaking Characteristics at Two Houston Park-and-Ride Lots

Traffic Data	Park-and-Ride Lot	
	North Shepherd	Kuykendahl
Arriving Traffic (vehicles)		
Daily Volume	1,296	1,577
Peak Hour Volume	502 (7:15-8:15)	677 (6:45-7:45)
Peak 15 Minutes	140 (8:00-8:15)	201 (7:15-7:30)
Peak Hour/Daily	40%	43%
Peak 15 Minutes/Peak Hour	29%	30%
Exiting Traffic (vehicles)		
Daily Volume	1,284	1,563
Peak Hour Volume	577 (4:45-5:45)	643 (5:00-6:00)
Peak 15 Minutes	194 (5:15-5:30)	186 (5:45-6:00)
Peak Hour/Daily	45%	41%
Peak 15 Minutes/Peak Hour	34%	29%

Source: Ref. (8).

To minimize possible adverse effects on the surrounding traffic flow patterns, the following guidelines are suggested (8):

- The most efficient access point to a park-and-ride lot will usually be from a collector or local street rather than from a major arterial or freeway ramp.

- Should it be necessary to provide access on an arterial route, entrances should be located so as to avoid queues from nearby intersections or freeway interchanges.

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- If a choice readily exists, it may be desirable for the park-and-ride lot to be located on the right side for inbound traffic.

- Entrances and exits should be located as far from intersections as possible and preferably at midblock. This reduces the conflicts between the major flow of traffic and the park-and-ride users.

- When a park-and-ride lot is located on the left side of a two-way arterial for inbound traffic, left turn storage will be desirable to accommodate inbound automobiles in the morning.

- Park-and-ride lots located along one-way arterials require special consideration; it is recommended that they be located between the two streets comprising a one-way pair, providing access from both streets.

- Planning, design and development criteria for park-and-ride access by feeder systems such as local transit, paratransit, kiss-and-ride, bikeways and pedestrian ways, should be determined and provided when the need is apparent.

- In planning the access points for a park-and-ride lot, separate entrance/exit roads for transit vehicles are desirable.

Ideally, a park-and-ride lot should have at least two access/egress points (8). In terms of theoretical capacity, a single access/egress point (one lane in each direction) may be sufficient, although possible vehicular queueing both inside and on the periphery of the lot makes two access/egress points preferable.

To estimate access/egress design capacity, a value of approximately 300 vehicles per hour per lane is suggested. Using this figure, which assumes that parking fees are not being collected at the entrance to the lot, Table 3-4 provides a summary of automobile access/egress requirements at park-and-ride lots.

Table 3-4 Auto Access/Egress Requirements for Varying Park-and-Ride Demands

Design Demand* (vehicles/day)	Minimum Number of Directional Lanes
Less than 750	1 in each direction
750 to 1,500	2 in each direction
1,500 to 2,250	3 in each direction

*Based on 40% of the total demand arriving during the peak hour and a capacity of 300 vehicles per hour per lane.

Source: Ref. (8).

Lot size constraints suggest that park-and-ride daily demand should not exceed approximately 1,800-1,900 vehicles per bus loading area. Such lots can be adequately served by 3 lanes for ingress and 3 for egress. The actual number of entrance/exit locations required at the lot to accommodate this number of lanes (6 total) will depend on whether the access points are designed as one-way entrance and exit drives or as common (2-directional) entrance and exit drives. If possible, entrances should be designed such that a vehicle approaching the site from any direction could miss one entrance and find a second one available without circuitous routing. The number of vehicular entrances along any one street should be spaced at least 350 feet apart. Access to the lot from two different roadways is desirable. Finally, the capacity of the intersections in the vicinity of the lot must also be evaluated to determine the types of improvements, if any, that may be required as a result of the park-and-ride lot.

3.3.3.2 Internal Lot Design

In many respects, the layout of a park-and-ride lot is similar to the layout of a regular parking lot. Guidelines concerning regular parking lot design are readily available (12). Park-and-ride lots are different, however, in that they must accommodate transfers between automobiles and buses, they must provide some short-term parking for kiss-and-ride patrons as well as long-term parking; and they must be designed to handle most of their traffic in two short peak periods daily. In addition, certain amenities are often provided at park-and-ride lots which are not usually found at regular parking lots. A discussion of those features which are unique to the design of a park-and-ride facility is presented in this section. In providing these park-and-ride components, the need to develop safe, convenient circulation patterns for all modes should be recognized as being of primary importance.

Bus Loading Area

Location. The bus loading/unloading area represents the focal point of the park-and-ride facility. All parking areas are oriented toward this location and, as a consequence, an initial step in the design process involves establishing the location of the loading area. Two general alternatives exist; the loading area can be located on the periphery of the lot, or within the lot.

For the reasons listed below, the loading location adjacent to the parking area may be preferred. However, well designed park-and-ride lots can also function satisfactorily with the bus-loading area located within the lot.

- The land requirements for the loading/unloading area are minimized.
- The conflict between autos and buses exiting and entering the lot may be eliminated.
- The time required for a loaded bus to enter the line-haul thoroughfare is generally reduced.

Locating the loading area adjacent to the lot does pose certain problems. The average walking distance from the parking spaces to the loading area is increased. Pedestrian flows along the sidewalk adjacent to the lot may be interrupted. Also, sufficient curb length must be available; nearly 550 feet of curb space is needed to provide a bus-loading area with space for two parked buses (8).

If the bus loading area is located within the lot, several factors should be recognized. The closer the loading area is located to the center of the lot, the shorter the average walking distance will become. Observations at Houston lots suggest that 650 feet should be the maximum walking distance patrons must walk to reach the bus loading area. Bus circulation within the lot should be minimized both to conserve space and to reduce bus travel time to the line-haul facility. At least one source (8) suggests that, after park-and-ride demand exceeds 500 all-day spaces, it is desirable to provide separate bus access roads to the loading/unloading area; that conclusion is supported by observations at lots in Houston where this is a common practice.

Bus Loading Space Capacity. Space needs to be provided within or adjacent to the park-and-ride lot for buses to park while loading and unloading passengers. If both the loading and unloading of passengers occur at the same location, the morning peak will determine capacity requirements, since the loading of passengers generally requires more time than the unloading of passengers (8). This will be true unless the loading passengers have already paid their fare, in which case the loading and unloading of passengers require similar periods of time.

In order to assure that streets and circulation roadways are not blocked, it is suggested that a sufficient number of loading spaces be provided so that a 90 percent certainty exists that demand will not exceed space supply during the peak hour. It is further suggested that one additional loading space be provided for possible use by broken-down buses, service, or emergency vehicles. The resulting design guidelines are summarized in Table 3-5.

In general, for the types of park-and-ride operations that will exist in Texas, two to three bus loading spaces will be needed at each bus loading area. It is particularly critical that sufficient bus loading space be provided at those locations where buses load at turnouts located adjacent to streets; inadequate space at those locations will cause the waiting bus to block a moving traffic lane.

Table 3-5. Number of Bus Loading Spaces Required[1] to Accommodate Varying Levels of Transit Service

Average Headway During Peak 15 minutes	Service Time[2]			
	60 seconds	120 Seconds[3]	180 Seconds	300 Seconds
5 minutes	2	3	3	4
10 minutes	2	2	3	3
20 minutes	2	2	2	2

[1]Sufficient loading space is provided so that one space is available for use by a broken-down vehicle, and there is 90 percent certainty that the demand will not exceed the remaining capacity.
[2]The bus loading time or the required bus waiting time, whichever is longer.
[3]In the absence of other data, 120 seconds represents a reasonable time to load a 50-passenger bus.

Source: Ref. (8).

Functional Considerations

Several different types of parking (handicapped, kiss-and-ride and park-and-ride) will typically be included in the parking area. In addition, special parking for bicycles and motorcycles may also be provided. Desirably, the design should minimize the transfer time from these parking areas to the bus loading area. In terms of proximity to the bus shelter, handicapped, bicycle, and motorcycle parking should be immediately adjacent to the loading area; kiss-and-ride parking should be given the next priority in terms of proximity; the park-and-ride all-day parking area will generally be the farthest removed from the bus loading area.

Handicapped Parking Preferably, it should not be necessary for handicapped patrons to cross any internal-circulation roadways in traveling from their parking location to the bus loading area. In addition, handicapped patrons should never be forced to travel behind parked cars (8).

In determining the number of handicapped spaces to be provided a park-and-ride lot, the guidelines in Table 3-6 have been suggested (8).

Table 3-6. Guidelines for Determining Parking Space Requirements

Total Parking Spaces	Minimum Number of Handicapped Spaces
1 to 25	1
26 to 50	2
51 to 75	3
76 to 100	4
101 to 150	5
151 to 200	6
201 to 300	7
301 to 400	8
401 to 500	9
501 to 1000	2%
over 1000	20 plus 1 for each 100 over 1000

Source: Ref. (8).

Recent studies at two park-and-ride lots in Houston, however, indicate that while handicapped spaces are being utilized, they generally are not utilized by handicapped persons.

In the design of handicapped spaces, individual stalls should be 17 feet long by 8 feet wide, with an additional 5 feet between stalls for access. Appropriate signing or pavement markings should indicate the restricted use of these spaces for handicapped persons. Curbs to and from the bus loading area should be depressed for wheelchairs (as dictated by local standards) and wheelchair ramps should be provided where necessary to facilitate the movement of handicapped patrons (8).

Bicycles and Motorcycles. An area for bicycles with racks or lockers should be designated near the bus loading area but not so close as to create hazards or inconveniences for pedestrians. At the present time, a negligible percentage of patrons in Texas ride bicycles to park-and-ride sites. However, if the specific site appears to have the potential for many bicyclists (adjacent residential areas or connecting bikeways), space could be provided. Motorcycles may also be given space near the bus loading area in which to park.

In designing bicycle storage facilities, the lot layout normally consists of stalls 2 feet by 6 feet at 90 degrees to aisles of a minimum width of 5 feet. For motorcycles, the stall should be increased to 3 feet by 6 feet (8).

Kiss-and-Ride Parking. An area that allows kiss-and-ride, taxi, paratransit, or other short-term parking only should be set aside and clearly marked. This area should be near the bus loading area and convenient to use so that kiss-and-ride parking will take place in the designated spaces rather than creating conflicts with the other access modes. The kiss-and-ride parking process requires only curb space in the morning to drop off passengers. In the afternoon, however, the auto driver usually arrives before the bus passenger and must wait. This creates the need for a kiss-and-ride parking area that is easy to drive into and out of. Kiss-and-ride parking areas need to be signed (preferably as 20-minute parking), marked, and enforced to assure their use as short-duration parking areas only.

Initially, it is necessary to estimate the percentage of total park-and-ride patronage that will take advantage of the kiss-and-ride mode. In Texas it appears that approximately 22% of the total patronage will use the kiss-and-ride arrival mode (Table 3-7).

Table 3-7. Kiss-and-Ride Patrons as a Percent of Total Park-and-Ride Patronage

City	Kiss-and-Ride Patrons as a % of Total Park-and-Ride Patronage
Houston	15
Dallas/Garland	20
Fort Worth	26
El Paso	31
San Antonio	19
Non-Weighted Average	22

Source: Ref. (8).

Estimates of total daily park-and-ride vehicular demand will have been developed during the initial stages of the park-and-ride planning process.

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Multiplying that value by an average vehicular occupancy of 1.5 yields daily patronage. Approximately 40% of that demand can be expected to occur during the peak hour (8). Thus, of the total daily patronage, approximately 9% (22% of daily patronage x 40% of daily patronage arriving during the peak hour) is represented by peak-hour, kiss-and-ride patrons. Typical kiss-and-ride occupancy is approximately 1.1 patrons per vehicle (Table 3-8); peak-hour kiss-and-ride patrons divided by 1.1 yields peak-hour kiss-and-ride vehicles. Thus, the following equation can be used to estimate peak-hour kiss-and-ride vehicular demand (8).

$$q = 0.11\ k$$

where: q = peak-hour kiss-and-ride vehicular demand

k = total daily park-and-ride vehicular demand

Table 3-8. Park-and-Ride Patrons Per Arriving Kiss-and-Ride Vehicle, Houston

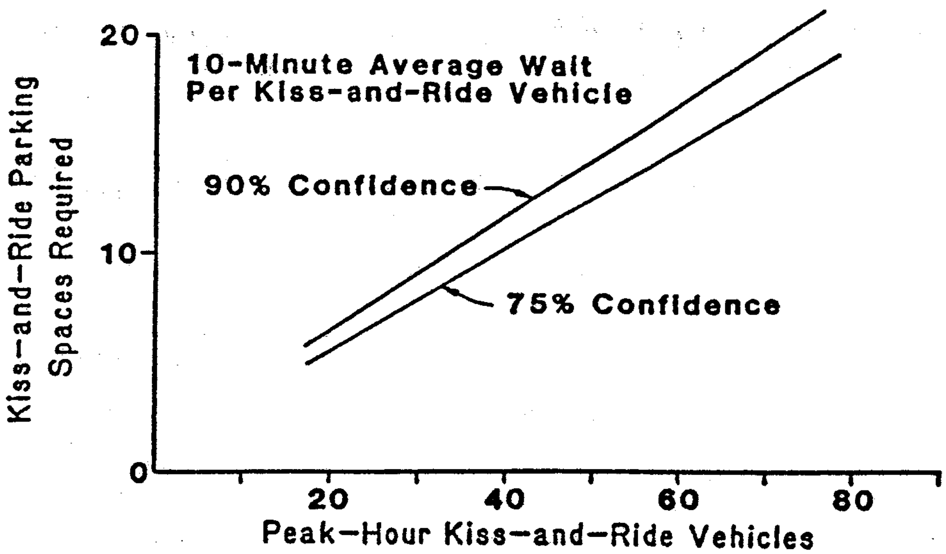
Occupancy Data*	Park-and-Ride Lot	
	North Shepherd	Kuykendahl
One Patron	87%	92%
Two Patrons	12%	7%
Three or More Patrons	1%	1%
Average Patrons/Kiss-and-Ride Vehicle	1.15	1.10

*Data shown represent a two-day average value.

Source: Ref. (8).

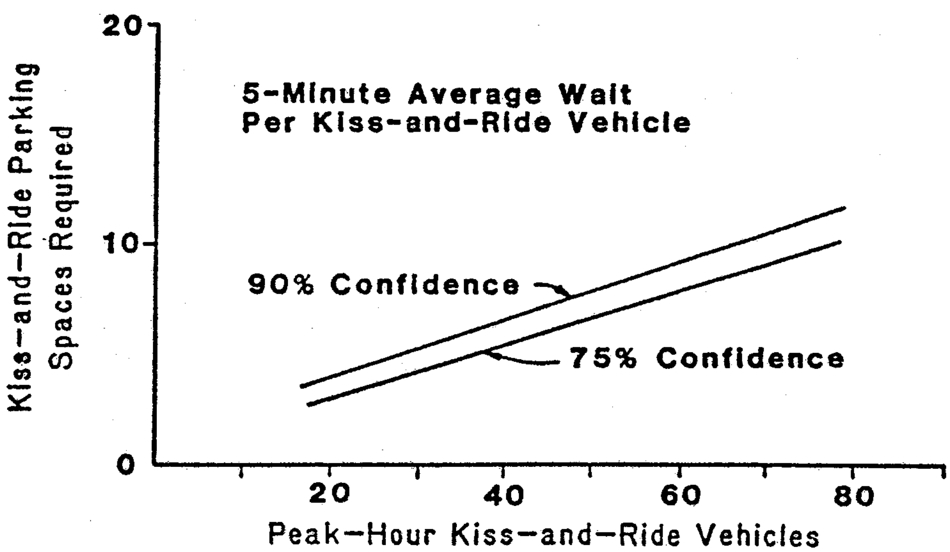
Of the two kiss-and-ride operations--dropping passengers off in the morning and picking passengers up in the evening--the evening operation determines capacity requirements since it consumes more time than the morning drop-off operation. The expected afternoon waiting time is a function of bus headways.

Given the peak-hour demand and an estimate of average waiting time, multiple channel queueing theory can be used to determine the number of parking spaces that need to be reserved for use by kiss-and-ride vehicles. Figures 3-9 and 3-10 summarize the results of this type of analysis using



Source: Ref. (8)

Figure 3-9. Peak 15-Minute Kiss-and-Ride Parking Space Requirements, 10-Minute Wait



Source: Ref. (8)

Figure 3-10. Peak 15-Minute Kiss-and-Ride Parking Space Requirements, 5-Minute Wait data from lots in Texas, assuming average waiting periods per kiss-and-ride vehicle of 5 minutes and 10 minutes. These design values are based on the peak 15 minutes within the peak hour; it is assumed that 30% of the peak hour traffic occurs during the peak 15 minutes. These relationships depict the number of kiss-and-ride spaces that need to be provided to assure that, with varying levels of confidence, demand will not exceed capacity during the peak 15 minutes of the peak hour. Figure 3-9 (which assumes a 10-minute kiss-and-ride vehicle dwell time) might be viewed as representing a desirable design level; Figure 3-10 represents a minimum design level. Data in Houston suggest that a design dwell time in the range of 7.5 minutes seems appropriate. As a general guideline, it appears that 1% to 3% of the total parking spaces in a park-and-ride lot should be devoted to the kiss-and-ride operation.

Long-Term Parking. By far, the most used access mode is the automobile that is driven to the park-and-ride lot and left all day. The parking for these long-term users should be close to the bus loading area, yet should not interfere with higher priority access modes.

Park-and-ride all-day parking is generally designed to be right-angle parking; this provides a simple, orderly configuration and also requires less land area per space. The parking aisles are typically alighted at right angle to the bus loading area to facilitate convenient pedestrian movement. Standard dimensions for parking stalls are recommended in Table 3-9.

Table 3-9. Typical Parking Dimensions

Type of Auto	Stall Width	Stall Length	Aisle Width
Standard	8.5' - 9.5'	18' - 20'	24' - 26'
Compact	7.5' - 8.5'	15' - 17'	20' - 22'

Source: Ref. (8).

In recent years, due to energy conservation and cost considerations, the trend in automobile designs has been toward shorter, narrower, lighter weight and more economical vehicles. In fact, observations at two Houston lots

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revealed that between 23% and 37% of the total vehicles in the park-and-ride lots were compacts and sub-compacts (Table 3-10).

Table 3-10. Parking Space Utilization and Vehicle Type

Parking Data*	Park-and-Ride Lot	
	North Shepherd	Kuykendahl
Number of Spaces	765	1,296
Parked Vehicles	786	1,176
% of Spaces Used	103%	91%
Compacts and Subcompacts as a % of Total Vehicles	23%	37%

*Data shown represent a two-day average value.

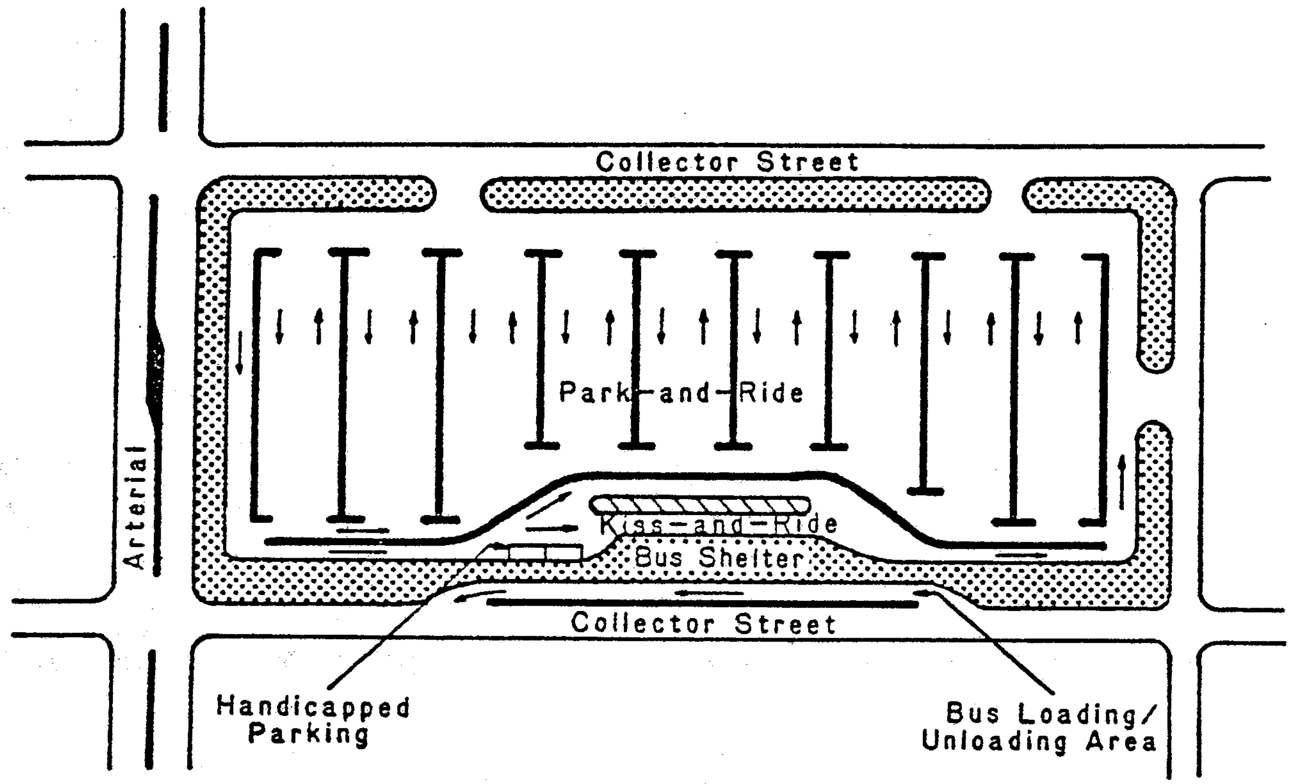
Source: Ref. (8).

While it is necessary for the greatest portion of the park-and-ride lot aisles and stalls to be dimensioned and marked to accommodate standard sized automobiles, specific areas within the lot designated for "small cars only" and laid out at a smaller scale might be considered, recognizing that operational and enforcement problems may result. It is further suggested that these spaces be placed in a prime location to encourage their use, because if they are not convenient, small car drivers will park in the more convenient, standard sized car spaces. Finally, because the vast number of larger cars now in use will gradually decrease, the parking lot layout should allow for future revisions to stall sizes, aisle widths, and module dimensions.

A representative layout of a park-and-ride facility is illustrated in Figure 3-11. Other examples of park-and-ride lot layouts may be found in the AASHTO Guide for the Design of High-Occupancy Vehicle and Public Transfer Facilities (12).

Pedestrian Flow Considerations

As noted previously, the distance a patron has to walk from his/her car to the bus loading area should, desirably, not exceed 400 feet. A distance



Source: Ref. (8)

Figure 3-11. Representative Layout for a Park-and-Ride Facility of 650 feet was the observed maximum in Houston. A walking distance of 1,000 feet should be viewed as an absolute maximum.

The parking area should be laid out to facilitate safe and convenient pedestrian movement to and from the bus loading area. Pedestrians will tend to follow the most direct route from the vehicle to the loading area.

To assist in laying out a park-and-ride lot, the "coefficient of directness" may be utilized. This coefficient is determined from the following formula.

$$C = \text{coefficient of directiveness} = \frac{\text{designated walking path distance}}{\text{straight-line distance}}$$

It is suggested that pedestrian flow patterns be designed so that this coefficient of directness does not exceed a value of 1.2; 1.4 should be considered an absolute maximum value.

3.3.3.3 Amenities

Various amenities for the patrons can be included in the park-and-ride site design to make the service more desirable and promote its general acceptance. These amenities might include lighting, bus shelters, public telephones, landscaping, security personnel, trash receptacles, newspaper stands, vending machines, information displays, and public restrooms. Whether some or all of these amenities should be provided at a park-and-ride facility will depend on local conditions and the capital and operating cost constraints.

<u>Bus Shelters</u>

Bus shelters placed adjacent to the bus loading areas are an amenity commonly provided at new park-and-ride lots to offer users protection from adverse weather conditions. The types of shelters provided can vary from small, semienclosed shelters with benches, to large fully enclosed air-conditioned buildings with public restrooms, vending machines, etc. The type of shelter that should be provided will depend on the local climate, the number of park-and-riders to be served, the average wait time and financial constraints. Surveys in three Texas cities revealed that shelters were not perceived as being important.

In those instances where the provision of shelters is desirable, at least 4 square feet of shelter area should be provided per person (8). This should be viewed as a minimum value in that other sources suggest that as much as 8 to 13 square feet should be provided per person (8). These space guidelines are for the waiting area only. Space devoted to vending machines, fare collection, restrooms, etc., must be in addition to the required waiting area.

Assuming that the shelter area will provide 8 square feet of covered structure per estimated occupant, the recommended occupant load determination is as follows (8):

Number of Auto Drivers = 1.00 X
Number of Auto Passengers = 0.35 X
Number of People Who Walk to Facility = 0.15 X
Number of Kiss-and-Ride Patrons = 0.20 X
Number of Bicycle and Motorbike Patrons = 0.30 X
Total Number of Patrons = 2.00 X
X = Number of Parking Spaces

This is only a guideline, and individual sites will need community input and research to determine their actual occupant load distribution.

Lighting

Adequate lighting at park-and-ride facility is important from a safety standpoint and serves as a deterrent to vandalism in both the parking areas and bus shelters during months when the days are shorter and commuters may have to use the facility in the dark. The full lighting system should provide the proper illumination levels to all areas of the park-and-ride lot,

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yet not infringe upon the adjacent community. As a minimum, light levels should be maintained at 1.0 foot-candles.

Public Telephones

Public telephones located at the park-and-ride site enable commuters to arrange for private auto, taxi or paratransit pick-up service. Public telephones also enable a commuter with automobile trouble to phone for help. This is an important consideration.

Trash Receptacles, Newsstands, Vending Machines

The provision of trash receptacles at a park-and-ride site is a rather inexpensive measure which can reduce the amount of maintenance required (provided the receptacles are located at convenient locations and are used).

Newsstands and vending machines are additional features sometimes provided to park-and-ride patrons. While these may be desirable from a passenger comfort standpoint, the provision of these particular amenities may also contribute to the litter problem both at the lot and on-board the transit vehicles.

Landscaping

Landscaping of park-and-ride facilities improves aesthetics. It should consist of plantings that will be compatible with the operation of the facility. In general, the types of plantings and their placement should not interfere with:

- Adequate lighting for the area, thus resulting in a potential safety hazard to the patrons;
- The proper placement of traffic control devices; or
- The ability of pedestrians, including the handicapped, to use the facility.

In addition, care should be taken to select plants compatible with local climatic conditions along with the ability to withstand extreme sun (or shade), wind, pollution, poor water condition, and marginal soils. Also, they should be decorative, long-lasting, susceptible to few diseases, require little maintenance, and be readily available at a reasonable cost. Trees provide shade and visual interest, reduce glare, and are less costly to maintain than shrubs and ground cover. Landscaping should be designed in such a manner that hiding places for vandals will be minimized.

While landscaping is desirable from an aesthetic point of view, in extremely hot areas such as Houston and El Paso, maintenance can be extensive. Furthermore, survey findings show that this feature is not an important factor in generating ridership.

3.3.3.4 Joint-Use Facilities

An exiting parking lot at a shopping center, drive-in theater, sports stadium or other large activity center that is also used for park-and-ride patron parking is a joint-use facility. Although many joint-use facilities are temporary or interim lots in nature, the following factors must be considered before such lots are used by a park-and-ride operation (8).

Size

A parking lot must be selected that is large enough for the usage it is expected to receive and for its possible expansion. The size of lot that is required will depend on the type of bus service to be provided at the lot. For example, an express bus from a remote lot (10-20 miles from the destination) would attract more riders and would, therefore, need to use a large shopping center or sports arena, while lots that are served by a local route and are nearer the destination (4-10 miles) usually generate fewer patrons and can utilize churches or neighborhood shopping centers.

Delineation

The part of the lot designated for park-and-ride use should be well marked to prevent interference with other traffic in the lot and make it easier for the commuter to use. There should be bus logo, directional and informational signs as well as painted parking stalls and crosswalks. The bus loading area should also be clearly designated for improved safety for pedestrians and mobility for buses.

Design

Another problem with joint-use parking lots is that they are not designed for transit vehicles. Alterations may be required at the entrances and exits of the lot to accommodate the wider turning radii, greater axle loads and allowable grades for these vehicles. As with the exclusive park-and-ride lot, the loading area and roadways that will be used by the buses should be constructed with heavy load carrying pavement. A way to avoid alternating the lot might be to provide a loading zone for buses directly off the street. This would allow the lot to be used by park-and-ride automobiles without requiring buses to enter the lot.

Amenities

The need for amenities at a joint-use lot is not as great as for the more permanent facilities. The additional expenditures are usually not warranted, as the facility is either an interim lot or serves too few people. Generally, the amenities for the joint-use lot should include a bus shelter with benches, an information board that indicates the schedules, trash receptacles and newspaper vending machines. There is less need for additional security measures since the park-and-ride operation would most likely share a lot that is lighted and has some form of security already available.

3.3.4 Operational Considerations

3.3.4.1 Directional Signing

Directional signing is needed in the vicinity of park-and-ride lots to guide commuters to the facility. These signs are especially important in areas where the commuter must go through the park-and-ride facility to enter the transitway from the street system. Guide signing should assist in directing unfamiliar transitway users to access location and aid enforcement by routing non-transitway traffic away from the restricted lane.

Driver information needs fall into a hierarchy with control needs at the top, followed by situational needs, and with navigational needs at the lower end. The directional signing used to guide motorists to a park-and-ride facility meet the navigational needs of the driver and are classified as guide signs. Therefore, they should follow the guidelines established in the MUTCD for guide signs and should be located away from areas with high control and situational information needs.

Park-and-ride directional signs should be designed in accordance with current MUTCD as well as state and local criteria and policies. The MUTCD provides guidelines for the design of park-and-ride signs (Section 2D-41). Recommended standards for park-and-ride signs are (15) (16):

- Rectangular in shape;
- Reflectorized with white legend and border on green background;
- Contain the word message park-and-ride and directional information;
- (Optional) contain local transit logo (standard color and shape, vertical dimension 18 inches or less) and/or the carpool symbol;
- 20/40 visual acuity in daylight condition;
- Letter series "D";
- Design legibility distance of 23 feet/inch of height;
- 40 mph roadway design speed;
- 3 to 20 degree cone of vision;

- 600 to 825 feet decision sight distance;
- Mounted according to general specification for erection of signs.

Messages should be brief and should utilize standard guidance methods to direct traffic to the facility, as illustrated in Figure 3-12. In those instances where commuters must be directed from a major highway to a lot not visible from the highway, trailblazer assemblies incorporating the park-and-ride legend or logo along with directional arrows should be employed.

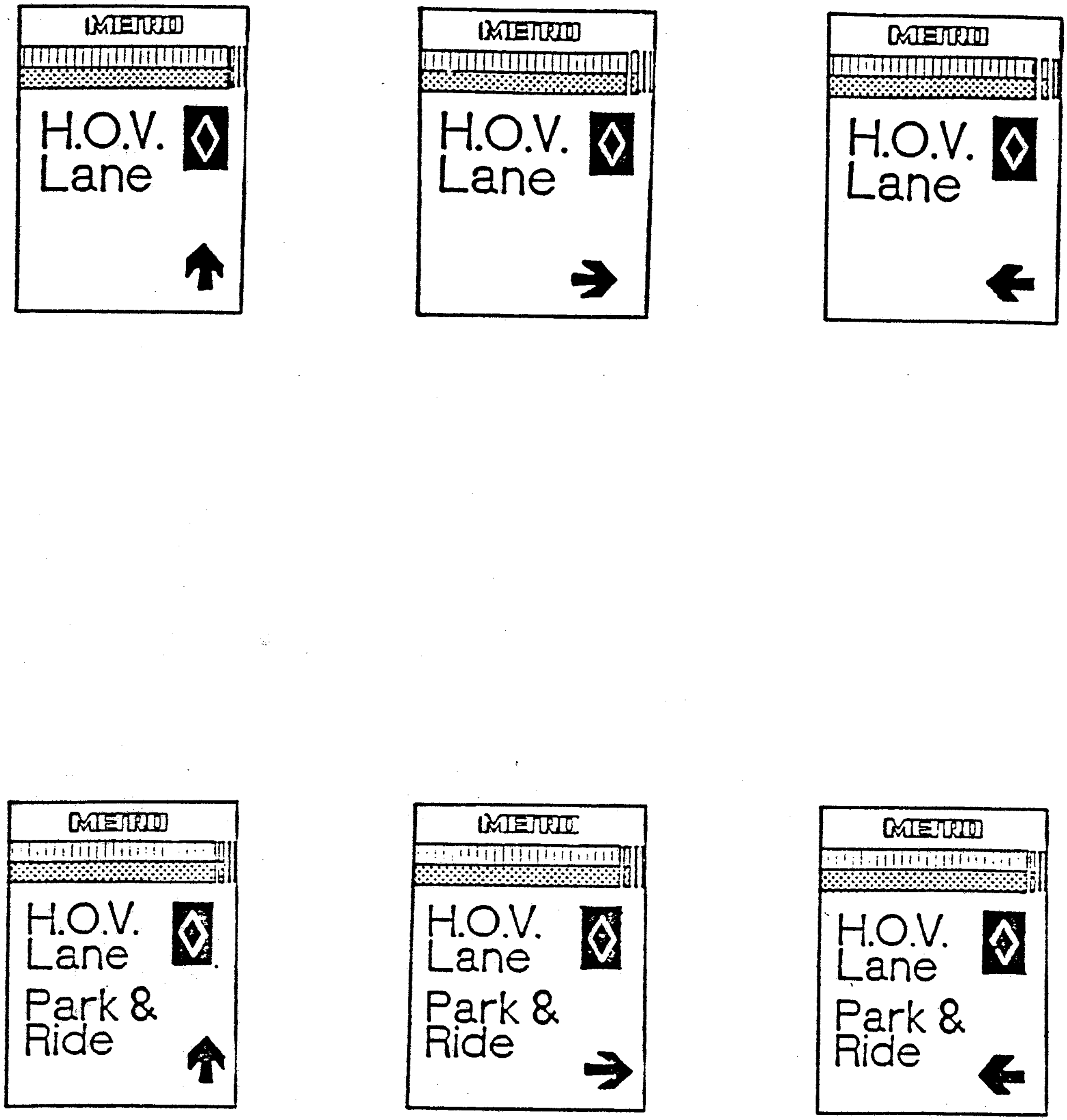
Directional signs may also be needed within the park-and-ride facility to indicate lot entrances and exits, transitway entrances and exits, and the desired traffic flow patterns. These signs should also be designed according to the previously mentioned principles for guide signs.

If a park-and-ride facility is designed and located for commuters destined from a residential area to a major activity center, the primary directional signing should be placed on major arterials between the residential area and the park-and-ride facility.

3.3.4.2 Informational Signing

Directional and informational signs along the major routes and on the streets leading to the park-and-ride facility should be provided to introduce the park-and-ride service to commuters.

Informational signing may be provided in the vicinity of park-and-ride facilities to introduce the park-and-ride service to commuters and give potential users a source to obtain information about park-and-ride and transitway use. In general, the sign will give a phone number along with the type of service offered by the facility. This type of sign should be located near the park-and-ride facility, in an area with high visibility to non-transitway users. As this type of sign is not related to the task of driving, the location should be in an area which places little or no demands on the driver and will allow them to observe the sign. The sign should



Source: Ref. (16)

Figure 3-12. Examples of Park-and-Ride Lot Signing comply with MUTCD standards for informational signing and consist of white letters on a blue background (Section 2F-57).

3.3.4.3 Traffic Signals

The nature of the traffic generated by a park-and-ride lot (i.e., relatively low traffic volumes with definite peaking characteristics) is usually not sufficient to warrant a separate traffic signal for the lot. However, traffic signals may, on occasion, be justified at the exit of a park-and-ride lot onto a major arterial to provide safe and efficient use of the facility.

3.3.4.4 Security

Security personnel, either stationed at the lot on a full-time basis or assigned to patrol the park-and-ride facility on a random basis, is another important feature to insure passenger safety and guard against vandalism. Experience in Texas has shown that lots with no security may be susceptible to vandalism and that provision of random security checks can greatly reduce acts of vandalism.

3.3.4.5 Information Systems

Systems which display information (transit schedules, route maps, etc.) pertaining to the park-and-ride services as well as other services provided by the local transit operation can be helpful to commuters.

3.4 PARK-AND-POOL AREAS

3.4.1 General

Park-and-pool is a term used to describe a parking area or facility where commuters can rendezvous, park one or more of their vehicles, and share a ride by vanpool or carpool to a common destination. The parking areas may be designated lots with sign delineation or informal rendezvous, staging

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areas on public right-of-way, or private property. Park-and-pool lots can vary considerably in size, design and support services. Generally speaking, a park-and-pool area is essentially a scaled-down park-and-ride lot. Consequently, the general planning, design and operating guidelines presented for park-and-ride lots are applicable to park-and-pool areas, particularly if it is anticipated that the park-and-pool lot may be up-graded to park-and-ride status in the future.

3.4.2 Planning Guidelines

3.4.2.1 Location

Park-and-pool survey data from the Dallas, Houston, and San Antonio areas suggest that park-and-pool areas located 20 to 25 miles from the activity centers they are intended to serve can attract a significant proportion of the potential park-and-pool market (4). Thus, preliminary identification of potential park-and-pool areas can be accomplished by identifying areas along major freeway corridors which are 20 to 25 miles from major urban activity centers. Existing parking lots at a shopping center, drive-in theater, sports stadium, or other large activity center should also be identified as potential park-and-pool sites.

The definition of park-and-pool market areas is highly contingent upon the local roadway or access system and the topography surrounding any particular site. Knowledge of the urban area is essential in defining a representative catchment zone or market area for a particular location. As a general guide, based upon Dallas study findings (7), the initial area to be defined for investigation should be approximately 50 to 100 square miles in size. The configuration most easily applied is a circle with its center located at the proposed site.

Park-and-pool survey data provide considerable information on personal characteristics (Table 3-11) and travel patterns (Table 3-12) of park-and-pool users in Texas. These data should prove useful in evaluating potential park-and-pool sites.

Table 3-11. Summary of Personal Characteristics of Park-and-Pool Participants

Characteristic	Dallas Area Poolers	Houston/ San Antonio Poolers	West Houston Poolers
Age (years)			
50th Percentile	34.5	35.7	38.0
85th Percentile	51.5	49.8	44.0
Sex			
Male	52%	61%	50%
Female	48%	39%	50%
Years of Education			
50th Percentile	14.8	13.5	16.0
85th Percentile	16.9	15.8	16.0
Occupation			
Professional	36%	39%	51%
Clerical	22%	21%	18%
Managerial	21%	8%	21%
Reason for Pooling			
Cost of Driving	76%	———	———
Cost of Parking	11%	———	———

Table 3-12. Summary of Travel Patterns of Park-and-Pool Participants

Travel Pattern	Dallas Area Poolers	Houston/ San Antonio Poolers	West Houston Poolers
Prior Mode of Travel			
Drove Alone	55%	67%	56%
Carpooled/Vanpooled	27%	30%	29%
Number of Persons in Pool			
50th Percentile	3.4	3.4	3.0
85th Percentile	10.2	11.0	12.0
Average (Mean)	5.2	———	5.3
Distance Traveled: Home to Lot (Mile)			
50th Percentile	3.5	3.7	4.0
85th Percentile	9.8	9.8	8.0
Average (Mean)	5.9	———	6.4
Distance Traveled: Lot To Destination (Miles)			
50th Percentile	21.5	28.0	24.5
85th Percentile	31.2	44.7	30.0
Average (Mean)	23.2	———	23.8

3.4.2.2 Size

Estimating demand for park-and-pool facilities depends, to a large extent, upon catchment or market area definition. A Dallas study (7) examined the applicability of parabolic and hyperbolic shapes to describe the areas of pooler origins. Data analysis seems to indicate that the market zone for park-and-pool in the Dallas urbanized area can best be described with a circle or an ellipse (Figure 3-13).

The size, configuration and orientation of the market area varies widely and appears to be related to the roadway or access system, physical or geographic constraints, and urban development surrounding the park-and-pool site. Professional judgement and knowledge of the local area must be applied in the definition of market area for any given site. Park-and-pool lots in the Dallas area with the highest patronage were represented by market areas ranging from 56 to 78 square miles in size and having a radius (r) of between 4.2 and 5.0 miles (7).

Analysis of survey data from Dallas park-and-pool users indicates that market area population density (persons/sq. mile) can be used to estimate potential park-and-pool demand (7). In the Dallas study (7), the overall average of poolers to population was about .07% when the market area falls in the 50 to 100 square mile range. However, the more successful park-and-pool facilities, or those with over 100 commuters, were found to have pooler to population ratios in the range of .15% to .24% (7). It should be noted that the computed pooling demand represents individuals or commuters and not the number of vehicles. Average or observed vehicle occupancy rates must be applied to the demand estimate for conversion to the number of vehicles or parking spaces required.

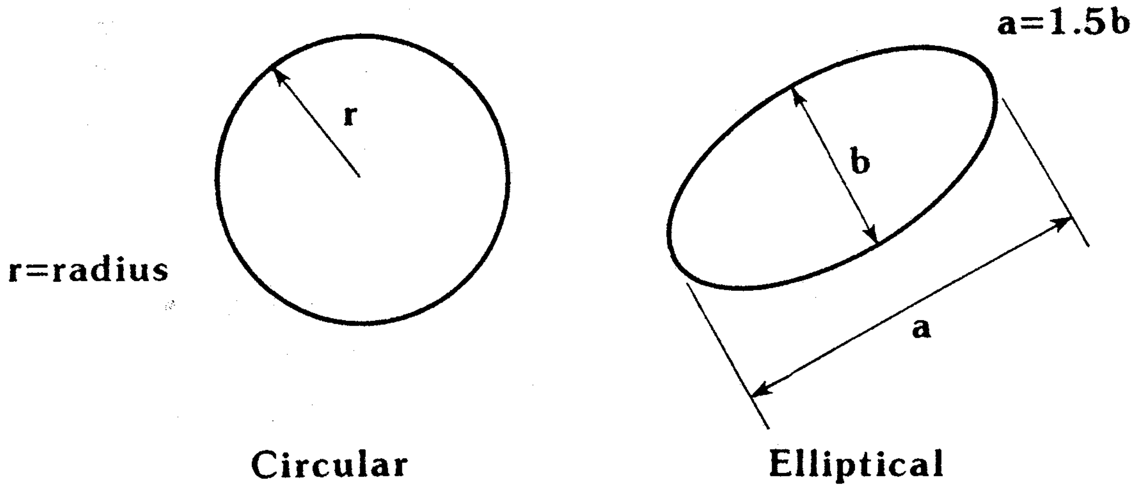

Figure 3-13. Suggested Market Area Configurations for Park-and-Pool in Dallas Urbanized Area

3.4.3 Design Guidelines

3.4.3.1 Parking Area

The layout of a park-and-pool lot is similar to the layout of a regular parking lot. Park-and-pool parking is generally designed to be right-angle parking; this provides a simple, orderly configuration and also requires less land area per space. Standard dimensions for parking stalls are recommended in Table 3-9.

In recent years, due to energy conservation and cost considerations, the trend in automobile designs has been toward shorter, narrower, lighter weight and more economical vehicles. In fact, observations at 2 Houston park-and-ride lots revealed that between 23% and 37% of the total vehicles in the lots were compacts and subcompacts (Table 3-10).

While the greatest portion of the park-and-pool lot aisles and stalls should be dimensioned and marked to accommodate standard sized automobiles, specific areas within the lot designated for "small cars only" and laid out at a smaller scale might be considered, recognizing that operational and enforcement problems may result. It is further suggested that these spaces be placed in a prime location to encourage their use, because if they are not convenient, small car drivers will park in the more convenient, standard car spaces. Finally because the vast number of larger cars now in use will gradually decrease, the parking lot layout should allow for future revisions to stall sizes, aisle widths, and module dimensions.

A representative layout of a park-and-pool facility is illustrated in Figure 3-14.

3.4.3.2 Signing

Directional and informational signs along the major routes and on the streets leading to the park-and-pool facility should be provided to introduce commuters to the service. Proper "lead-in" trailblazer sign placement on

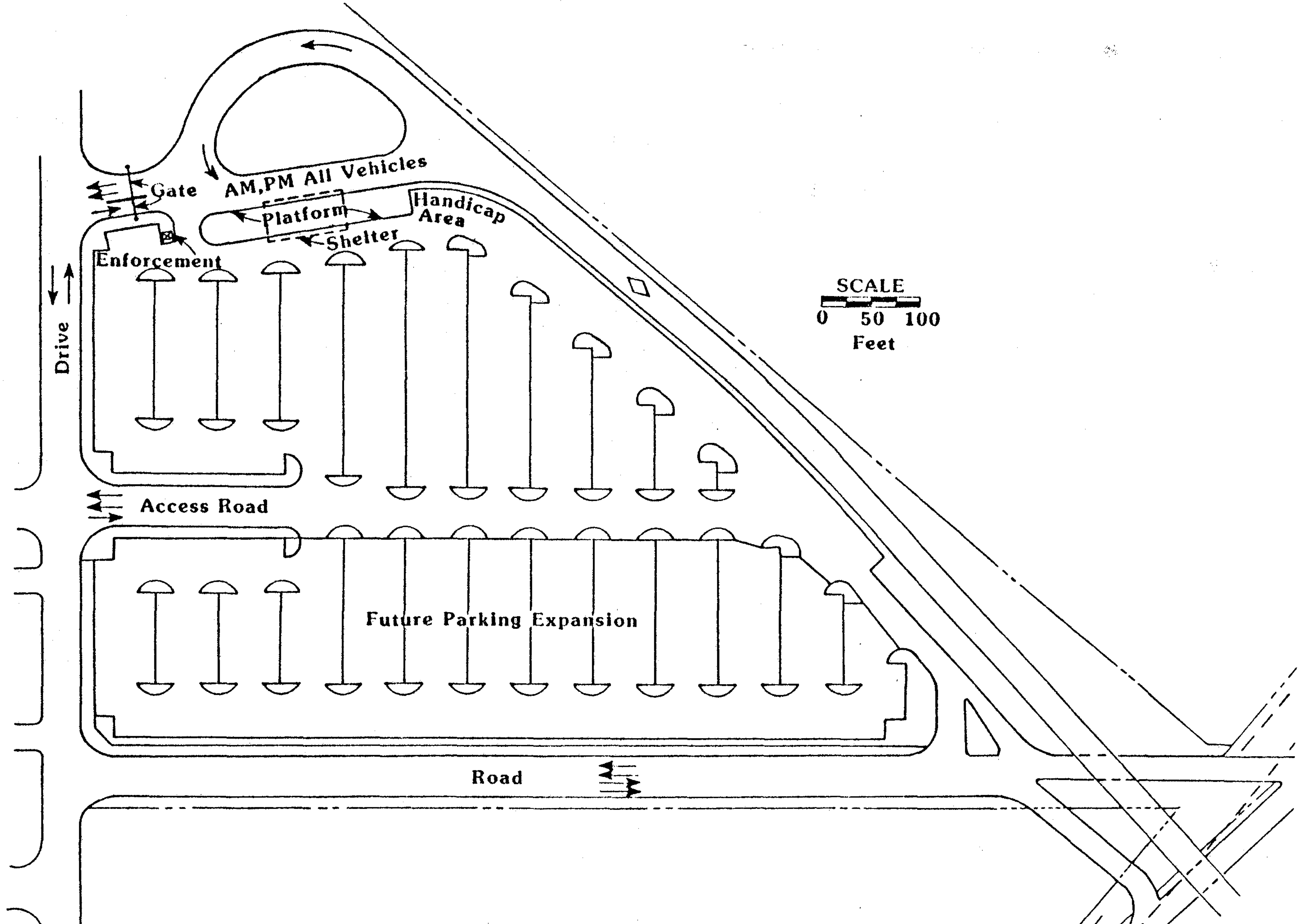

Figure 3-14. Example Layout of Park-and-Pool Area

high volume roads should intercept potential users on their normal paths and guide them to the park-and-pool facility.

If a park-and-pool facility is designed and located to attract commuters destined from a residential area to a major activity center, the primary "lead-in" signing should be placed on major arterials between the residential area and the facility. In addition, other informational signs should be placed at the site to indicate lot entrances and exits and the desired traffic flow patterns.

Park-and-pool signs should be designed in accordance with current MUTCD as well as state and local criteria and policies. Messages should be brief and should utilize standard guidance methods to direct traffic to the facility, as illustrated in Figure 3-15. In those instances where commuters must be directed from a major highway to a lot not visible from the highway, trailblazer assemblies incorporating the park-and-pool legend or logo along with directional arrows should be employed.

Figure 3-15. Park-and-Pool Signing

3.5 REFERENCES

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ABBREVIATIONS USED IN MANUAL

AASHTO	American Association of State Highway and Transportation Officials
AMV model	Alan M. Voorhees and Associates, Inc. Binary Mode Choice Model
AVL	Authorized Vehicle Lane
BAA model	Barton-Aschman Associates Mode Choice Model
CBDEMP	Employees residing in the market area destined for the central business district
CCC	Central Control Center
CCTV	Closed Circuit Television System
CMS	Changeable Message Sign
CSI model	Cambridge Systematics, Inc. Disaggregate Modal Choice Model
FHWA	Federal Highway Administration
HAR	Highway Advisory Radio
HOV	High-Occupancy Vehicle
HBW	Home-based work
ICI	Average freeway congestion index
JTW	Journey-to-Work
LARTS	Los Angeles Regional Transportation Study
LCS	Lane Control Signal
LOS	Level-of-Service
MAPOP	Park-and-ride lot market area population
MO	Number of months lot has been in operation
MUTCD	Manual of Uniform Traffic Control Devices
O-D	Origin-Destination
pce	passenger car equivalents
pcephpl	passenger car equivalents per hour per lane
SC&C	Surveillance, Communications, and Control
SDHPT	State Department of Highways and Public Transportation
TMT	Transit Management Team
TTI	Texas Transportation Institute
UTPS	Urban Transportation Planning System

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