TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA/TX-85/425-2		

4. Title and Subtitle	5. Report Date September 1985 6. Performing Organization Code
Manual for Planning, Designing, and Operating Transitway Facilities in Texas	
7. Author(s) John M. Mounce and Robert W. Stokes	8. Performing Organization Report No. Research Report 425-2
9. Performing Organization Name and Address Texas Transportation Institute The Texas A&M University System College Station, Texas 77843	10. Work Unit No. 11. Contract or Grant No. Study No. 2-8/10-84-425
12. Sponsoring Agency Name and Address Texas State Department of Highways and Public Transportation; Transportation Planning Division P. O. Box 5051 Austin, Texas 78763	13. Type of Report and Period Covered Manual Chapters 1-3 Interim - April 1984 August 1985 14. Sponsoring Agency Code

15. Supplementary Notes

Research performed in cooperation with DOT, FHWA.
Research Study Title: Preparation of Texas Manual for Planning and Design of High Occupancy Vehicle Priority Facilities - Transitways

16. Abstract

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

This report was prepared for the Texas State Department of Highways and Public Transportation (SDHPT) to provide 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 to replace existing SDHPT information on the design of high-occupancy vehicle facilities.

The Manual is divided into two primary technical divisions. These are: (1) Transitway mainlanes and connections; and (2) Transitway support facilities. Information presented within the transitway manual should promote uniformity of design and operational effeciency for transitway facilities in Texas.

17. Key Words	18. Distribution Statement
Transitways, Busways, High-Occupancy Vehicle Facilities	No restrictions. This document is available to the public through the National Technical Information Service 5285 Port Royal Road Springfield, Virginia 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	176	

Form DOT F 1700.7 (8-69)

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
in²	square inches	645.2	millimetres squared	mm²
ft²	square feet	0.0929	metres squared	m²
yd²	square yards	0.836	metres squared	m²
mi²	square miles	2.59	kilometres squared	km²
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

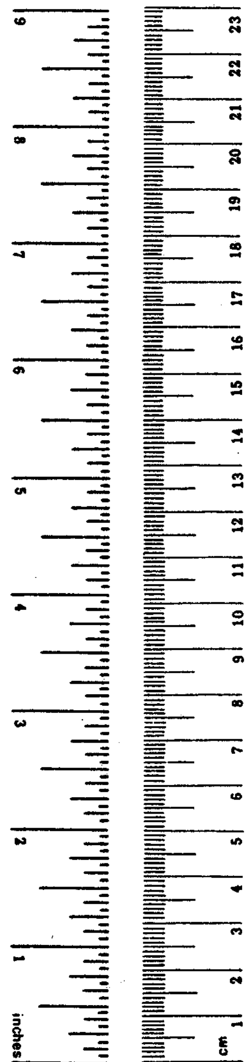
Symbol	When You Know	Multiply By	To Find	Symbol
fl oz	fluid ounces	29.57	millilitres	mL
gal	gallons	3.785	litres	L
ft³	cubic feet	0.0328	metres cubed	m³
yd³	cubic yards	0.0765	metres cubed	m³

NOTE: Volumes greater than 1000 L shall be shown in m³.

TEMPERATURE (exact)

Symbol	When You Know	Multiply By	To Find	Symbol
°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
mm²	millimetres squared	0.0016	square inches	in²
m²	metres squared	10.764	square feet	ft²
km²	kilometres squared	0.39	square miles	mi²
ha	hectores (10 000 m²)	2.53	acres	ac

MASS (weight)

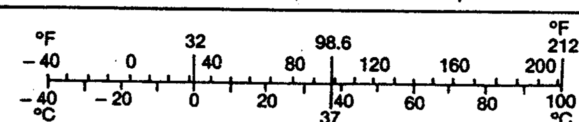
Symbol	When You Know	Multiply By	To Find	Symbol
g	grams	0.0353	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams (1 000 kg)	1.103	short tons	T

VOLUME

Symbol	When You Know	Multiply By	To Find	Symbol
mL	millilitres	0.034	fluid ounces	fl oz
L	litres	0.264	gallons	gal
m³	metres cubed	35.315	cubic feet	ft³
m³	metres cubed	1.308	cubic yards	yd³

TEMPERATURE (exact)

Symbol	When You Know	Multiply By	To Find	Symbol
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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

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

Research Study 2-8/10-84-425
Report 425-2

Prepared

by

John M. Mounce
Associate Research Engineer

Robert W. Stokes
Assistant Research Engineer

of the

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

for the

Texas State Department
of
Highways and Public Transportation

in

Cooperation with
the

Federal Highway Administration
U.S. Department of Transportation

September 1985

ACKNOWLEDGEMENTS

The development of this manual was sponsored by the Texas State Department of Highways and Public Transportation under technical advisement by the following individuals:

Mr. Tony Ball - Federal Highway Administration, Austin, Texas

Mr. Paul Bay - Metropolitan Transit Authority of Harris County, Houston, Texas

Mr. John Blain - State Department of Highways and Public Transportation, District 18, Dallas, Texas

Mr. Robert Cueller - State Department of Highways and Public Transportation, D-10 Planning, Austin, Texas

Mr. Herman Haenel - State Department of Highways and Public Transportation, D-18 Traffic, Austin, Texas

Mr. Frank Holzmann - State Department of Highways and Public Transportation, D-8 Design, Austin, Texas

Mr. John Kight - State Department of Highways and Public Transportation, District 15, San Antonio, Texas

Mr. Frank Wadlington - State Department of Highways and Public Transportation, District 12, Houston Texas

Mr. William Ward - Center for Transportation Research, Austin, Texas

Mr. Phillip Wilson - State Department of Highways and Public Transportation, D-10 Planning, Austin, Texas

Appreciation is expressed to the members of this advisory committee for their assistance and contributions. Special gratitude is also extended to Mr. Robert Cuellar for his consultation and coordination support as study monitor.

ABSTRACT

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

This manual was prepared for the Texas State Department of Highways and Public Transportation (SDHPT) to provide 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 to replace existing SDHPT information on the design of high-occupancy vehicle facilities.

The manual is divided into two primary technical divisions. These are: (1) Transitway mainlanes and connections; and (2) Transitway support facilities. Information presented within the transitway manual should promote uniformity of design and operational efficiency for transitway facilities in Texas.

IMPLEMENTATION STATEMENT

Study 2-8/10-84-425 is intended to assist the Texas State Department of Highways and Public Transportation in the planning and implementation of transitways and related support facilities in the State. The information presented in this manual should enhance the cost-effectiveness of future priority treatment projects.

TABLE OF CONTENTS

TABLE OF CONTENTS CONTINUED

TABLE OF CONTENTS CONTINUED

TABLE OF CONTENTS CONTINUED

LIST OF FIGURES

LIST OF FIGURES CONTINUED

LIST OF TABLES

LIST OF TABLES CONTINUED

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 special lanes designated for exclusive use by high-occupancy vehicles (HOV's) -- buses, vanpools, and possibly carpools. Experience has shown that these special 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 move the equivalent of at least 3 traffic lanes. Obviously, the magnitude of person movement in the HOV lanes significantly impacts freeway corridor capacity. For the facilities shown in Table 2-2, all move at least 30 percent of the total movement on the freeway (1).

It is this demonstrated ability of high-occupancy vehicle lanes to move large volumes of commuters that 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 providing for utilization of high-occupancy vehicles, can increase person movement within certain intensively traveled urban arterial corridors. Transitways may be incorporated into the existing roadway cross-sections or located in exclusive rights-of-way. Transitway facilities have been found to be technically and operationally feasible, and,

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

HOV Project	Eligible Vehicle	Peak-Hour Volume		Peak-Period Volume	
		Vehicles	Persons	Vehicles	Persons
Shirley Highway, Washington D.C., 2 lanes	Buses, 4+ Carpools	2,600	18,700	4,700	40,300[1]
I-66, Washington D.C., 2 Lanes	Buses, 3+ Carpools	2,000	8,400	3,600	14,000[2]
Lincoln Tunnel, New York City 1 lane	Buses	600	27,000	1,300	45,000[3]
El Monte Busway, Los Angeles 1 lane	Buses, 3+ Carpools	1,100	6,500	2,600	15,800[4]
I-45 N, Houston, 1 lane	Buses, Vanpools	300	5,200	400	7,600[5]

[1] 6-9:30 a.m.

[2] 4-6 p.m.

[3] 7-10 a.m.

[4] 6-10 a.m.

[5] 6-8:30 a.m.

Source: (1)

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

HOV Project	Person Volume		
	HOV	Freeway	Total
Shirley Highway, Washington, D.C.			
Peak Hour	18,700 (64%)	10,300 (36%)	29,000 (100%)
Peak Period	40,300 (57%)	30,600 (43%)	70,900 (100%)
El Monte Busway, 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 N, Houston			
Peak Period	7,600 (32%)	15,800 (68%)	23,400 (100%)

Source: (1)

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 authorized 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 (2). 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. Texas State Department of Highways and Public Transportation, Highway Design Division. Operations and Procedures Manual, 1981. Revised 1985.

2. TRANSITWAY MAINLANES

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 provide 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 Critical 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 (origin/destination) should always be performed.

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 without sacrificing any or very little 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 contiguous lengths of right-of-way can be very difficult and many times controversial. There is also an aversion to acquiring separate rights-of-way because acquiring right-of-way by eminent domain proceedings is a slow process. Transitways are most needed where congestion is worst and quick solutions are more popular than long-term ones, which suggests that locating transitways in shared rights-of-way has many practical aspects. Other places where transitways might be located could be 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, most transitways, at least in Texas, will probably be located within freeway facilities 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

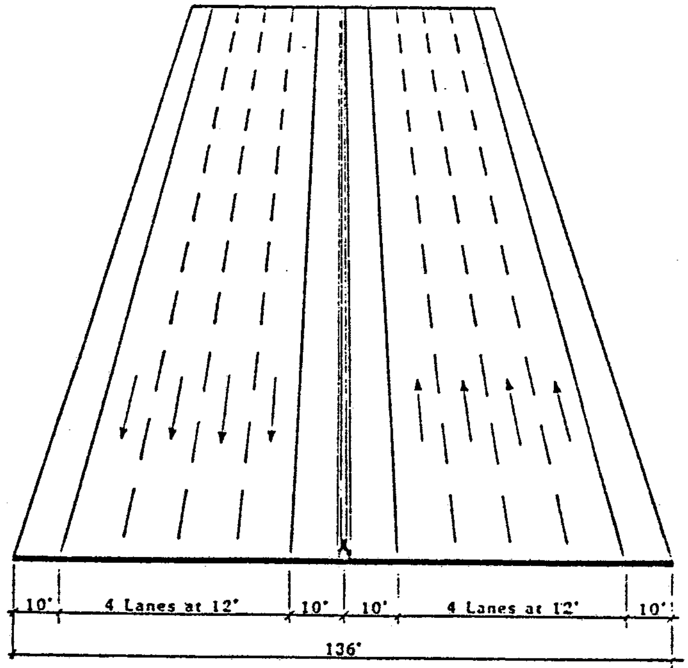
7. Cost of implementation.

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, the frequent at-grade ramps common to urban freeways in Texas limit the application of this alignment.

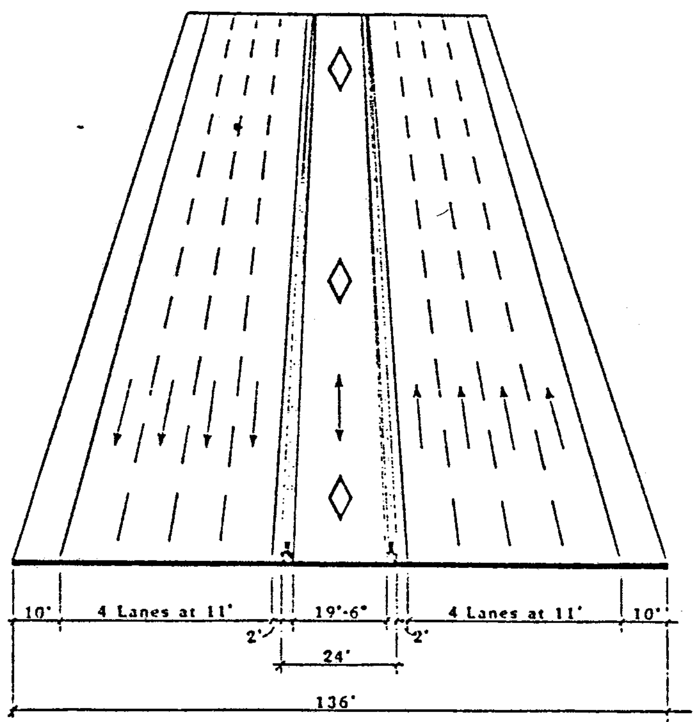
Transitways located within a freeway median are preferable where existing freeway cross-section is of sufficient width to accommodate the required transitway cross-section. These treatments are relatively simple to implement, lend themselves to staged development, and have minimal impact on ramp or interchange 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 mainlanes, or the acquisition of additional right-of-way. Typical comparative "before and after" cross-sections are shown in Figure 2-1. This modified freeway cross-section for the institution of median transitways does not 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 authorized 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.



(a) Freeway Median Without Transitway



(b) Freeway Median With Transitway

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

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 procedures for estimating transitway demand are available. Consequently, current procedures utilized by TTI for estimating the demand for transitways are based upon a synthesis of several methodologies. In recent years, the Texas Transportation Institute (TTI) has utilized the following four techniques to estimate the demands for transitway facilities in Houston: 1) The findings from a recent Federal Highway Administration (FHWA) study (2); 2) A mode-split analysis of home-based work trips in the Houston-Galveston area (3); 3) The findings from a recent TTI study that developed guidelines for sizing park-and-ride lots (4); and 4) An analogy to the contraflow lane operation on I-45N in Houston (5). A feature which all of these techniques have in common is their "quick-response" capability. Nevertheless, preliminary test applications of the quick response estimation procedures presented in this manual have, in some instances, yielded results beyond the accuracy typically associated with sketch planning techniques. Since these procedures can be implemented quickly using data which may be readily available to most planning agencies, it is suggested that the analyst apply more than one of the techniques to develop a range of estimates.

This section of the manual presents a description of each of the four estimation procedures enumerated above. The section concludes with a critique and general summary of the demand estimation procedures reviewed and presents some general guidelines concerning the application of the procedures in Texas.

2.1.4.2 FHWA Procedure

Background

A 1982 study (2) sponsored by the FHWA evaluated existing high-occupancy vehicle (HOV) lane projects in the U.S. in an effort to develop simplified techniques to predict travel volumes due to the implementation of priority treatment for HOVs on freeways. The review of current procedures revealed that no existing travel demand models have been estimated using actual before-and-after data from the broad cross-section of HOV demonstration projects sponsored by USDOT over the past 10 years. Consequently, a new model formulation was proposed and estimated using empirical before-and-after data from HOV sites across the U.S.

Applicable HOV Treatments

The existing HOV sites that were used to develop the estimation procedure shared the following basic characteristics (2):

1. The HOV lanes operate on (or adjacent to) major radial freeways serving a central city or central business district;

2. The HOV lanes ranged from 2.5 to 9 miles in length;

3. All study sites experienced force-flow or severe capacity constraint conditions on the general purpose lanes in the periods prior to implementation of the HOV lane(s); and

4. Among the HOV sites used in model estimation, many network conditions and alternative links existed, allowing different route diversion effects.

Thus, if the corridor being analyzed is atypical with respect to these basic characteristics, the models may not yield reliable results.

The FHWA procedure considers the following five travel modes (2):

1. **Nonpriority Automobiles** -- the volume of automobiles traveling in the peak hour on the general purpose lanes in either the before or after time periods;

2. **Priority Eligible Automobiles** -- the volume of automobiles traveling in the peak hour on the general purpose lanes in the before period that could be eligible to use the HOV lane(s) in the after period;

3. **Carpools on HOV Lane(s)** -- the volume of automobiles traveling in the HOV lanes in the before period that would be allowed on the HOV lanes in the after period;

4. **Priority Eligible Buses** -- the number of buses traveling in the peak hour on the general purpose lanes that would be eligible to use the HOV lane(s) in the after period; and

5. **Buses on HOV Lane(s)** -- the number of buses traveling in the peak hours on the HOV lane(s) in the before period that would use the HOV lane(s) in the after period.

The procedures can be used to forecast travel demands for the following four HOV strategies (2):

1. Dedicating a new or existing lane for bus-only HOV operations;

2. Dedicating a new or existing lane for bus and carpool operations;

3. Allowing carpools onto an existing bus-only HOV lane; and

4. Allowing carpools with lower occupancy levels onto an existing bus and carpool HOV lane.

Data Requirements

The following four types of data are needed to implement the FHWA estimation procedures (2):

1. **Peak-Hour Volumes.** In the before period, a.m. peak hour volumes are required for the following modes (see definitions above): 1) nonpriority automobiles; 2) priority eligible automobiles (note that for bus-only HOV

strategies, this volume will be zero); 3) carpools on HOV lanes (if no carpool HOV lane exists, this volume will be zero); and 4) the number of buses and passengers either eligible to move onto the HOV lane or already on the HOV lane (note that this is an either/or situation). These volumes are measured at a screen line located within the boundaries of the beginning and end point of the proposed (or existing) HOV lane(s). This screen line is also the reference point for all other measurements. Consequently, this line will indicate the location of the forecasted volumes.

Of the four peak hour volumes that may be required for a particular analysis, the one likely to be the least readily available is the volume of priority-eligible automobiles. Typically, permanent or temporary counting stations will provide good data on the total number of vehicles traveling inbound in the morning peak. However, if the proposed strategy being analyzed is to allow 3+ person carpools onto an existing or new HOV lane, the volume of 3+ person carpools is needed along with the combined volumes of two-person carpools and single occupant vehicles. If these volumes by auto occupancy are not immediately available, one could, as a first-cut approximation, use system wide auto occupancy proportions obtained from ridesharing studies (or even Census data), or more accurately conduct a special vehicle occupancy count during the morning peak commuting period.

2. Peak Hour Travel Times. For each travel mode that is pertinent to the HOV strategy being evaluated, an estimate of average door-to-door travel time is required. As indicated above, this estimate is determined for vehicles passing the screen line. Since travel times "saved" or reduced by using or not using the HOV lane are calculated as a proportion of these total door-to-door travel times, small errors in the latter will not introduce large errors in the proportions input to the model. Therefore, it is not necessary that they be determined precisely. They can be obtained from the output of existing computer models or by using information on average trip lengths and route sections having different average travel speeds.

3. Average Peak Hour Travel Speeds. Average peak hour travel speeds are required for vehicles on the general purpose lanes and, if they are present in the before period, vehicles on the HOV lane(s). The speeds are those required to travel either the length of the HOV lane(s) or the length of the general purpose lanes adjacent to the existing or proposed HOV

lane(s). These speeds should be estimated more precisely than the total travel time data since they are used to estimate travel times, and changes in travel times, over the (typically) shorter section of the freeway bounded by the HOV lane. If not already available from secondary sources, these speeds could be determined through actual measurement (e.g., by conducting a floating car travel time study).

4. Existing Freeway Supply and Capacity. The number of lanes and capacity must be specified for both the existing general purpose freeway lanes and, if they exist, for the HOV lane(s). The capacity, if not readily known, can be computed using accepted estimation procedures.

For the forecasting procedures presented here, capacity is defined as the maximum number of vehicles moving by a particular point in a given one-hour period. Thus, if empirical data should yield peak hour travel volumes that are higher than those determined through a formal application of the manual capacity calculations, the higher value should be used as the measure of capacity.

Estimation Procedure

The basic estimation procedure involves using five regression models to forecast demand volumes, and with the aid of supply relationships, obtaining equilibrium travel flows on the general purpose freeway and HOV lane(s). The procedures can be used to predict peak hour flows for: 1) Automobiles on the general purpose lanes; 2) Carpools that are already on or that will be allowed to use the HOV lane(s); and 3) Bus passengers on the HOV lane(s). Since the demand models were developed using actual before-and-after data, the models reflect the net change in volumes due to mode shifts, time-of-day changes, trip generation, and route diversion effects.

A supply model, using speed-flow relationships, is used in an iterative fashion with the predicted demand volumes to reach equilibrium travel volumes. The supply model is used to determine equilibrium speeds on the general purpose lanes (if it is possible for free-flow conditions to exist on the general purpose lanes in the after period). An examination of existing HOV facilities revealed that free-flow conditions are sometimes possible when buses and carpools are allowed to use the HOV facility and a general purpose lane is not taken away. Under all other circumstances, forced-flow conditions continued to prevail in the after period (2).

Nonpriority Auto Demand Model

$$NPA = -0.92 - 1.05\ TTNPA + 1.19\ TTPA2 + 0.12\ TTPA3/4 + 0.28\ TTBUS + 0.95\ EFCTR \qquad (2.1)$$

where

NPA = Percent change in nonpriority auto volumes (vehicles);

TTNPA = Percent change in total travel time for nonpriority autos;

TTPA2 = Percent change in total travel time for 2-person priority autos;

TTPA3/4 = Percent change in total travel time for 3 or 4+ person priority autos;

TTBUS = Percent change in total travel time for buses; and,

EFCTR = Eligibility factor.

The eligibility factor (EFCTR) in Equation (2.1) reflects the percentage change in "capacity" on the general purpose lanes made available in the after period for use by nonpriority autos (2). This variable is computed as follows:

$$EFCTR = \left[\frac{L_1^{GP}}{L_0^{GP}}\right]\left[\frac{V_0^{npa} + V_0^{Pa} + 2B_0^{Peb}}{V_0^{npa}}\right] \qquad (2.2)$$

where

L_0^{GP} = number of general purpose lanes in the before period;

L_1^{GP} = number of general purpose lanes in the after period;

V_0^{npa} = peak hour volume of nonpriority autos in the before period;

V_0^{Pa} = peak hour volume of priority-eligible autos in the before period; and

B_0^{Peb} = number of buses eligible to move to the HOV lane(s).

The eligibility factor controls for site-to-site differences in the composition of vehicles in the before period that become eligible to use an HOV facility in the after period. In addition, the factor reflects the major supply effects due to taking away a general purpose lane for use by HOV vehicles (2).

Priority Auto Demand Model

PA = - 0.2 - 6.7 TTPA2 [Q] - 7.7 TTPA3/4 [1-Q] + 4.8 TTBUS .... (2.3)

where

PA = Percent change in priority auto volumes; and,

Q = Indicator variable (1 for 2 - person priority autos, 0 for 3 or 4+ person priority autos).

Priority Bus Demand Models

B = - 1.40 TTBUS .... (2.4)

B = -0.31 TTBUS + 0.42 NOBUS .... (2.5)

B = 0.23 + 0.44 TTPA2 [Q] + 1.71 TTPA3/4 [1-Q] .... (2.6)

where

B = Percent change in peak hour bus ridership (person trips); and,

NOBUS = Percent change in the number of peak hour buses.

Equation (2.4) is applicable when only buses will use the HOV facility and bus supply is determined as a direct result of the HOV time savings. Equation (2.5) can be used when only buses will use the HOV facility and bus supply is determined apart from the ridership change expected from the HOV time savings. Equation (2.6) is used to forecast bus passenger volumes when carpools will be using the HOV lane (2).

Supply Model

A supply model was developed to estimate average running speed and thus travel time changes for different volume levels on the general purpose lanes. The relationship can be expressed in general terms as (2):

$$T_1 = T_0 \left[1 + a(V/C)^b\right] \qquad (2.7)$$

where

T_1 = travel time in time period 1;

T_0 = travel time under free-flow conditions;

V = highway traffic volume;

C = capacity of highway; and

a, b = model coefficients.

Expressed in terms of speed, S, Equation (2.7) can be written as:

$$S_1 = \frac{S_0}{1 + a(V/C)^b} \qquad (2.8)$$

where

S_1 = Speed in time period 1; and

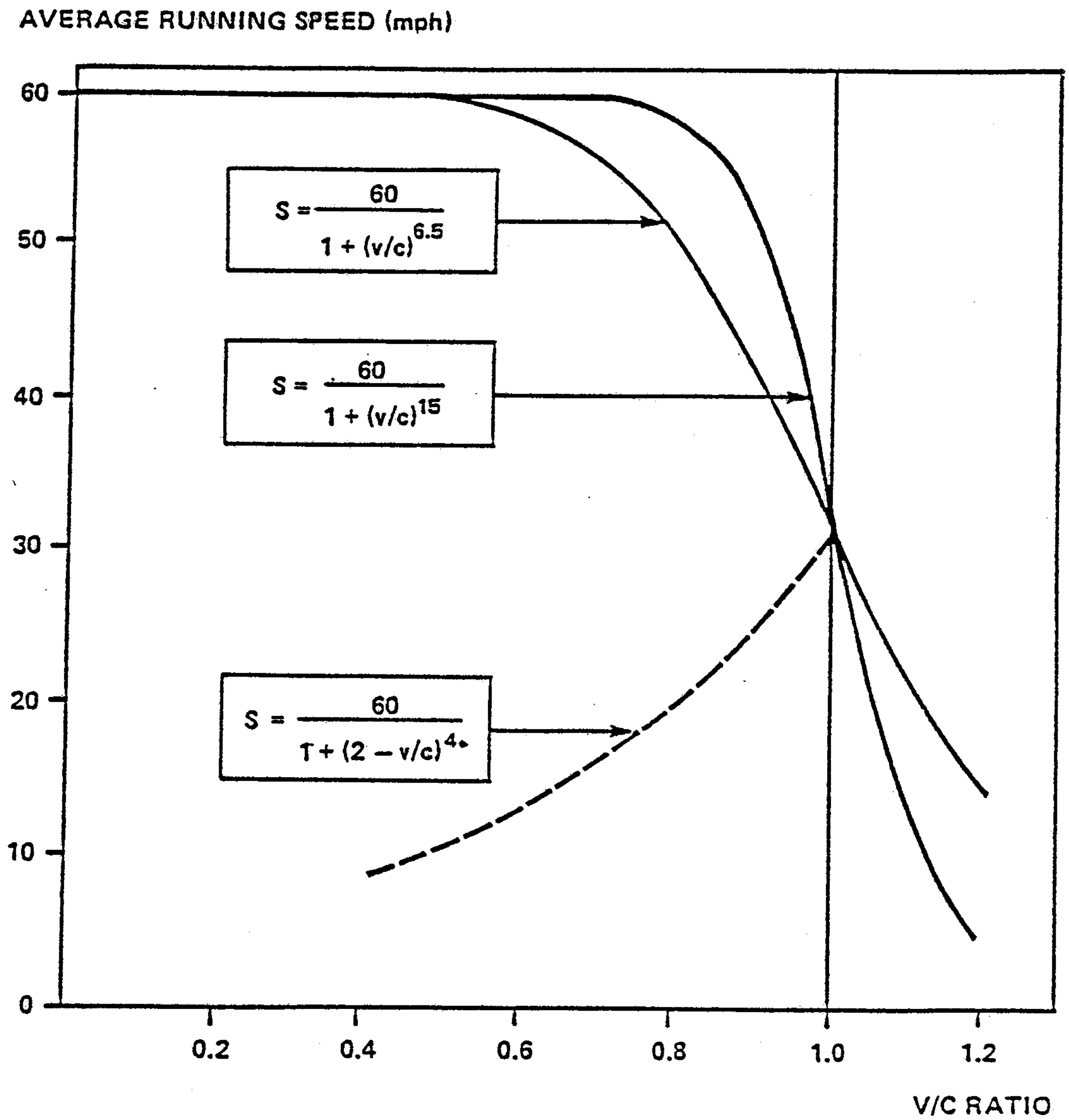
S_0 = Speed under free flow conditions

In equation (2.8), the coefficient "a" has a significant influence on the calculated travel speed when demand exactly equals capacity ($V = C$). For example, if S_0 is assumed to equal 60 mph, setting "a" equal to 1.0 will result in a S_1 speed of 30 mph when $V/C = 1$. Similarly, setting "a" equal to 1.5 will result in a S_1 speed of 40 mph. Note that the speeds at capacity are not affected by the values of the coefficient "b" (2).

The "b" coefficient on the other hand, determines the shape of the curve, or, in other words, the sensitivity of changes in speed to changes in V/C. Figure 2-2 illustrates how different values for the coefficient "b" can be used to reflect different assumptions (or differences in local characteristics) in the relationship between speed and V/C. In particular, the 1965 Highway Capacity Manual indicated that speeds decrease almost linearly as V/C (under free-flow conditions) increases from 0 to 0.9. However, more recent information presnted in Transportation Research Circular 212 (6) and observed in empirical studies (2) indicates that speeds are nearly constant on multilane freeways as V/C increases from 0 to 0.9, but decrease rapidly for values of V/C greater than 0.9. Thus, the supply relationship given in the worksheets have set "b" equal to 15.0 and "a" equal to 1.0. However, the analyst should feel free to modify these coefficient values if local conditions warrant (2).

The supply model is used by first determining whether free-flow conditions could exist on the general purpose lanes for the HOV strategy being evaluated. If the answer is no, then the existing general purpose lane speeds are used in the after period. If the answer is yes, then the before V/C ratio is used in Equation (2.8) to estimate free flow speeds and travel times. These travel times are used to forecast auto volumes on the general purpose lanes. A check is made to compare these predicted volumes to capacity. For V/C ratios greater than 1.0, it is assumed that force-flow conditions will exist. Thus, travel times are revised and new volumes computed. Alternatively, the new V/C ratio is used in Equation (2.8) to determine a revised speed and travel time and, through this iterative procedure, a new volume estimate is obtained (2).

When using the latter approach, it is possible that each subsequent iteration will lead to a better estimate of equilibrium volumes. However, it is also possible that they may not. When this happens, equilibrium travel speed (and thus volumes) can be obtained by plotting the demand curve (from two or more iterations of volumes and speeds from the demand model), and the supply curve (from two or more iterations of speeds and volumes obtained from



Source: (2)

Figure 2-2. Alternative Relationships Between V/C Ratio and Operating Speed the supply model), as well as computing the speed (and thus volume) at which the two curves intersect (2).

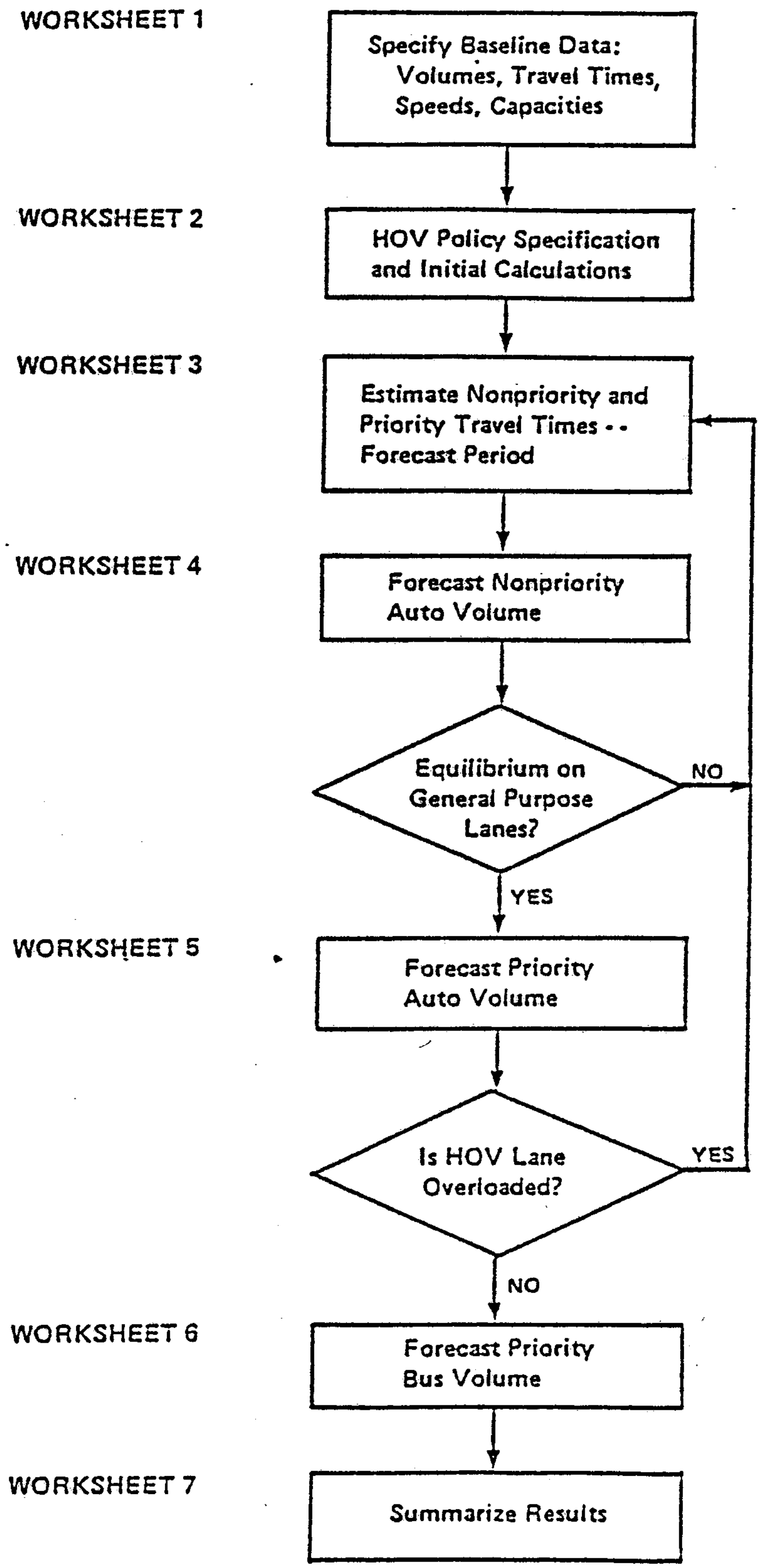
Application

The FHWA procedures have been reduced to a set of seven worksheets that are used in a sequential and, if necessary, iterative fashion to reach equilibrium. The flow chart in Figure 2-3 highlights the major activities for each worksheet. The following material summarizes the purpose of each worksheet (2).

First, baseline travel data consisting of before volumes, travel times, speeds, and capacity (as defined above) are assembled and listed on Worksheet #1. Next, the proposed HOV strategy to be evaluated is defined on Worksheet #2. This consists of specifying the modes that will be allowed to use the HOV lane(s), the length of the HOV lane(s), and the proposed capacity of the general purpose and HOV lanes (2).

With the information presently specified, various initial calculations are performed using Worksheet #2 to disaggregate the baseline travel time data into two components -- travel time on and off the freeway section bordered by (or adjacent to) the HOV lane(s). Worksheet #3 is used next to derive initial estimates of travel time changes, and therefore "after" travel times, that will be needed to forecast demand volumes in subsequent worksheets. The before and after travel times now known for each mode are input to a demand equation contained on Worksheet #4 to estimate the after peak hour volume of nonpriority automobiles. If it has been assumed that free-flow travel conditions are possible, a check is made to determine if the initial estimated travel times (and thus speeds) are in close agreement with the model's estimated volume (and thus travel speed and times). If these equilibrium conditions are not satisfied, revised or updated estimates of travel time are computed and the procedure is repeated (2).

When equilibrium volumes are obtained on the general purpose lanes, Worksheet #5 is used to forecast the volume of carpools (including priority eligible autos and existing HOV carpools) that will use the HOV lane(s). If carpools are not allowed on the HOV lane(s), this worksheet is not used. However, if this worksheet is used, the predicted volume of carpools on the HOV lane is compared to the capacity of the HOV lane(s) to determine whether



Source: (2)

Figure 2-3. Flow Chart of FHWA Demand Estimation Procedures the initial estimate of speed is valid. This check also determines whether the volume of carpools will exceed the HOV lane capacity, indicating that a more restrictive HOV strategy should be evaluated (2).

Worksheet #6 is used to predict the volume of priority bus users. A similar equilibration procedure is not employed, since bus volumes on the HOV lanes are not likely to exceed HOV capacity. (If necessary, however, the analyst can perform a simple test patterned after those used for nonpriority and priority eligible automobiles.) Finally, Worksheet #7 summarizes the forecasted peak hour travel volumes, speeds, and times that have been obtained from the previous worksheets (2).

Sample worksheets are shown on the following pages.

2.1.4.3 Mode Split Analysis of Home-Based Work Trips

This estimation methodology is based on a generalized mode-split analysis of home-based work (HBW) trips. Data required for implementation include the following:

1) Estimates of existing and design year HBW trip tables;

2) Estimates of existing and design year network travel times, or network traffic assignments; and

3) Estimates of mode splits (% person or vehicle trips on the transitway) for the activity centers served by the transitway.

The existing and design year trip tables provide estimates of traffic volumes (by trip purpose, mode, or other classification) between specific analysis (or traffic) zones of a metropolitan area. For the purpose of estimating transitway demands, a trip table depicting metropolitan travel patterns in terms of person-trips is preferable.

Estimates of network travel times can be used to determine the specific roadway facilities (links) which are likely to be used to complete the trip interchanges depicted in the trip table.

The key to the effectiveness of this estimation procedure is the availability of reliable estimates of transitway mode-splits. While most standard transportation planning computer program packages can estimate trip tables by

WORKSHEET 1: BASELINE DATA

Specification of Initial/Before Data

VOLUMES (PEAK-HOUR)

- Automobiles, nonpriority Vo^{npa} = ______ VPH
- Automobiles, priority eligible Vo^{pa} = ______ VPH
- Carpools on HOV lane(s) Vo^{HOV} = ______ VPH
- Buses, priority eligible Bo^{peb} = ______ BPH
- Buses on HOV lane(s) Bo^{HOV} = ______ BPH
- Bus Passengers (HOV) Vo^{b} = ______ PPH
- Bus Load Factor Lo^{b} = ______ PPB
- Trucks Vo^{T} = ______ VPH

TOTAL TRAVEL TIME (PEAK-HOUR)

- Automobiles, nonpriority To^{npa} = ______ MIN
- Automobiles, priority eligible To^{pa} = ______ MIN
- Carpools on HOV lane(s) To^{HOV} = ______ MIN
- Buses (HOV or priority eligible) To^{b} = ______ MIN

SPEEDS (AVERAGE PEAK HOUR)

- General Purpose Lane(s) So^{gp} = ______ MPH
- HOV Lane(s) - Carpools So^{c} = ______ MPH
- HOV Lane(s) - Buses So^{b} = ______ MPH

EXISTING SUPPLY/CAPACITY

- No. of General Purpose Lanes Lo^{gp} = ______
- No. of HOV Lanes Lo^{HOV} = ______
- Capacity, General Purpose Lanes Co^{gp} = ______ VHP
- Capacity, HOV Lanes Co^{HOV} = ______ VHP

WORKSHEET 2: HOV POLICY AND INITIAL CALCULATIONS

HOV Alternative: ☐ Bus Only
☐ Bus and Carpool (Carpool size:_____)

HOV Length: _____Miles

PROPOSED SUPPLY/CAPACITY

- No. of General Purpose Lanes L_1^{GP} = ______
- No. of HOV Lanes L_1^{HOV} = ______
- Capacity, general purpose lanes C_1^{GP} = ______ VPH
- Capacity, HOV Lanes C_1^{HOV} = ______ VPH
- Buses Per Hour (if exogenously determined) B_1^{HOV} = ______ BHP

EXISTING TRAVEL TIMES -- OVER HIGHWAY BOUNDED BY HOV LANES*

- Automobiles, nonpriority to^{nPa} = ______ Min.
- Automobiles, priority eligible to^{Pa} = ______ Min.
- Buses (HOV or priority elibile) to^{b} = ______ Min.

EXISTING TRAVEL TIMES -- OFF HIGHWAY BOUNDED BY HOV LANES

- Automobiles, nonpriority $To^{npa} - t_o^{npa} = t_{off}^{npa}$ = ______ Min.
- Automobiles, priority eligible $To^{Pa} - t_o^{Pa} = t_{off}^{Pa}$ = ______ Min.
- Buses (HOV or priority eligible) $To^{b} - t_o^{b} = t_{off}^{b}$ = ______ Min.

---

*Formula: Vehicles on general purpose lanes (Before Period)

$$t_o = \frac{\text{HOV Length}}{S_o^{gp}} \times 60 = \_\_\_\_\_ \text{Minutes}$$

*Formula: Vehicles on HOV lanes (Before Period)

$$t_o = \frac{\text{HOV Length}}{S_o^{B}} \times 60 = \_\_\_\_\_ \text{Minutes}$$

WORKSHEET 3: ESTIMATE TRAVEL TIMES -- FORECAST PERIOD

BUSES ON OR ELIGIBLE TO USE HOV LANES

Check one

☐ Buses already on HOV, use:

$T_1^b = T_o^b =$ _____ Minutes

☐ Buses will be eligible to use HOV, use:

$$T_1^b = \boxed{}_{\,t^b_{off}} + \frac{\boxed{}\ \text{(HOV Length)}}{\boxed{}\ \text{(Estimated Speed*)}} \times 60 = \_\_\_\_\_\ \text{Minutes}$$

AUTOS ON OR ELIGIBLE TO USE HOV LANES

Check one

☐ Autos already on HOV, use:

$T_1^{Pa} = T_o^{HOV} =$ _____ Minutes

☐ Autos will be eligible to use HOV, use:

$$T_1^{Pa} = \boxed{}_{\,t_{off}^{Pa}} + \frac{\boxed{}\ \text{(HOV Length)}}{\boxed{}\ (S_o^b \text{ or Estimated Speed*})} \times 60 = \_\_\_\_\_\ \text{Minutes}$$

---

*If estimating speed, use 50 MPH unless other data indicates otherwise

AUTOS ON GENERAL PURPOSE LANES

Check one

1. ☐ Capacity Reduction or Bus Only HOV Lane

$T_1^{npa} = T_o^{npa} =$ _____ Minutes (i.e., force-flow continues)

2. ☐ Capacity Same and Carpools Granted Priority

Assume free-flow initially unless data indicates otherwise

ESTIMATE FREE-FLOW SPEEDS AND TRAVEL TIMES

$$S_1^{GP} = \frac{60}{1.0 + \left[\dfrac{\boxed{}_{\,V_o^{npa}} + \boxed{}_{\,V_o^{P_a}}}{\boxed{}_{\,C_1^{gp}}}\right]^{15}} = \_\_\_\_\_\ \text{MPH}$$

Check: If $S_1^{GP} > S_o^{C,B}$, Set $S_1^{GP} = S_o^{C,B} =$ _____ MPH

$$T_1^{npa} = \boxed{}_{\,t^{npa}_{off}} + \left[\frac{\boxed{}\ \text{(HOV Length)}}{\boxed{}\ (S_1^{GP})} \times 60\right] = \_\_\_\_\_\ \text{Minutes}$$

COMPUTE "ELIGIBILITY FACTOR"

$$EFCTR = \frac{\boxed{}_{\,L_1^{GP}}}{\boxed{}_{\,L_o^{GP}}} \times \left[\frac{\boxed{}_{\,V_o^{nPa}} + \boxed{}_{\,V_o^{Pa}} + 2.0 \times \boxed{}_{\,B_o^{Peb}}}{\boxed{}_{\,V_o^{npa}}}\right] = \_\_\_\_\_$$

WORKSHEET 4: FORECAST NONPRIORITY AUTO VOLUME

$$\triangle_{nPa} = -0.916 - 1.053\left[\frac{\overset{T_1^{nPa}}{\square}}{\underset{T_o^{nPa}}{\square}} - 1.\right] + 1.190\left[\frac{\overset{T_1^{Pa2}}{\square}}{\underset{T_o^{Pa2}}{\square}} - 1.\right] +$$

$$+0.122\left[\frac{\overset{T_1^{Pa3/4}}{\square}}{\underset{T_o^{Pa3/4}}{\square}} - 1.\right] + 0.278\left[\frac{\overset{T_1^{b}}{\square}}{\underset{T_o^{b}}{\square}} - 1.\right] + 0.949\ \overset{EFCTR}{\square} =$$

$\triangle_{nPa}$ = ______

$$V_1^{nPa} = \left[1.0 + \overset{\triangle_{nPa}}{\square}\right] \times \overset{V_o^{nPa}}{\square} = \_\_\_\_\_\_ \text{ VPH}$$

EVALUATE RESULTS

Check one:

- $\square$ If force-flow conditions, proceed to Worksheet 5
- $\square$ If Box 2 checked, Validate Service Level Assumptions

COMPUTE VOLUME/CAPACITY RATIO -- FORECAST PERIOD

$$\frac{V_1^{nPa}}{C_1^{nPa}} = \frac{\square}{\square} = \_\_\_\_\_\_$$

DETERMINE WHICH CONDITION APPLIES

Check one:

- $\square$ If $V_1^{nPa}/C_1^{GP} < 1$; then,

  Compute $S_1^{GP'} = \dfrac{60}{1 + \left(\dfrac{\square}{V_1^{nPa}/C_1^{GP}}\right)^{15}} = \_\_\_\_\_\_$ MPH

  Check one:

  - $\square$ If $S_1^{GP'} \approx S_1^{GP}$, Equilibration achieved, Go to Worksheet 5
  - $\square$ If $S_1^{GP'} \not\approx S_1^{GP}$, Repeat with $S_1^{GP'}$, Go to Worksheet 3,

- $\square$ If $V_1^{nPa}/C_1^{GP} \geq 1$; then,

  Repeat analysis with T_1^{nPa} based on force-flow conditions. Therefore

  $T_1^{nPa} = T_o^{nPa} =$ ______ Minutes, Redo Worksheet 4

WORKSHEET 5: FORECAST PRIORITY AUTO VOLUME

Check one or Both

A. ☐ For existing carpools or priority autos with 3+ or 4+ persons:

$$\Delta_{Pa*} = -0.203 - 7.7\left[\frac{T_1^{Pa}\ \boxed{}}{T_o^{Pa*}\ \boxed{}} - 1.\right] + 4.8\left[\frac{T_1^{b}\ \boxed{}}{T_o^{b}\ \boxed{}} - 1.\right] = \_\_\_\_$$

*For existing carpools, substitute "HOV" for "Pa"

B. ☐ For prioirty autos with 2 persons allowed onto HOV lane(s):

$$\Delta_{Pa} = -0.203 - 6.7\left[\frac{T_1^{Pa}\ \boxed{}}{T_o^{Pa}\ \boxed{}} - 1.\right] + 4.8\left[\frac{T_1^{b}\ \boxed{}}{T_o^{b}\ \boxed{}} - 1.\right] = \_\_\_\_$$

COMPUTE PRIORITY AUTO VOLUME

$$V_1^{Pa} = \left[1.0 + \underset{\Delta Pa}{\boxed{}}\right] \times \underset{V_o^{Pa}}{\boxed{}} = \_\_\_\_ \text{ VPH}$$

COMPUTE TOTAL CARPOOLS ON HOV LANE

$$V_1^{HOV} = \underset{V_1^{Pa}}{\boxed{}} + \left[\left(1.0 + \underset{\Delta HOV}{\boxed{}}\right) \times \underset{V_o^{HOV}}{\boxed{}}\right] = \_\_\_\_ \text{ VPH}$$

CHECK SERVICE LEVEL ASSUMPTIONS

$$V/C_{HOV} = \frac{\underset{V_1^{HOV}}{\boxed{}} + \underset{B_{o,1}^{HOV}}{\boxed{}}}{\underset{C_1^{HOV}}{\boxed{}}} = \_\_\_\_$$

Check one

☐ If $V/C_{HOV} \gtrsim 0.80$, then initial speed assumptions (S_1^{HOV}) are valid.

☐ If $V/C_{HOV} > 0.80$, repeat analysis with $S_1^{HOV'} = \dfrac{60}{1 + [V/C_{HOV}]^{15}}$

Check: If $S_1^{HOV'} < S_1^{GP}$, set $S_1^{HOV'} = S_1^{GP} =$ ____ MPH

NOTE: If V/C_{HOV} remains > 0.95, HOV strategy may not be appropriate.

WORKSHEET 6: FORECAST PRIORITY BUS VOLUME

A. Bus Only on HOV Lane (bus supply determined endogenously)

$$b = -1.404 \left[\frac{T_1^b \ \boxed{}}{T_{ob} \ \boxed{}} - 1. \right] = \_\_\_\_\_$$

B. Bus Only on HOV Lane (bus supply determined exogenously)

$$b = -0.308 \left[\frac{T_1^b \ \boxed{}}{T_o^b \ \boxed{}} - 1. \right] + 0.422 \left[\frac{B_1^{HOV} \ \boxed{}}{B_o^{Peb} \ \boxed{}} - 1. \right] = \_\_\_\_\_$$

C. Buses and 3+ or 4+ Person Carpools on HOV Lane

$$b = +0.227 + 0.435 \left[\frac{T_1^{Pa} \ \boxed{}}{T_o^{Pa} \ \boxed{}} - 1. \right] = \_\_\_\_\_$$

D. Buses and 2+ Person Carpools on HOV Lane

$$b = +0.227 + 1.710 \left[\frac{T_1^{Pa} \ \boxed{}}{T_o^{Pa} \ \boxed{}} - 1. \right] = \_\_\_\_\_$$

COMPUTE PRIORITY BUS VOLUME

$$V_1^b = \left[1.0 + \underset{b}{\boxed{}} \right] \times \underset{V_o^b}{\boxed{}} = \_\_\_\_\_ \text{PPH}$$

$$B_1^{HOV} = \frac{V_1^b \ \boxed{}}{L_o^b \ \boxed{}} = \_\_\_\_\_ \text{BPH (Unless Exogenously Determined)}$$

WORKSHEET 7: SUMMARY RESULTS

VOLUMES (PEAK-HOUR)

- Automobiles, nonpriority V_1^{nPa} = _____ VPH
- Carpools on HOV Lane(s) V_1^{HOV} = _____ VPH
- Buses on HOV Lane(s) B_1^{HOV} = _____ BPH
- Bus Passengers on HOV Lane(s) V_1^b = _____ PPH

TOTAL TRAVEL TIME (PEAK-HOUR)

- Automobiles, nonpriority T_1^{nPa} = _____ Min.
- Carpools on HOV Lane(s) T_1^{Pa} = _____ Min.
- Buses on HOV Lane(s) T_1^b = _____ Min.

SPEEDS (AVERAGE PEAK-HOUR)

- General Purpose Lane(s) S_1^{GP} = _____ MPH
- HOV Lane(s) S_1^{HOV} = _____ MPH

travel mode, the resulting trip tables do not explicitly account for the modal shifts which can result from the implementation of an HOV priority treatment strategy. Consequently, the primary disadvantage of this methodology is the lack of data on transitway mode-splits.

With the exception of data on transitway mode-splits, the data needed to implement this estimation procedure should be available from local transportation planning agencies. Most metropolitan areas in Texas have calibrated and implemented transportation planning computer program packages and can provide detailed information on existing and forecasted traffic volumes by origin and destination for the major highway facilities in a particular urban area. By applying estimates of transitway mode-splits, the analyst can then estimate potential transitway demands.

The basic estimation procedure can be summarized as follows:

1) Define the freeway corridor to be analyzed;

2) Tabulate peak period HBW trips between those traffic zones in the freeway corridor and the major activity centers which will be served by the transitway;

3) Assign the major activity center trip demands to the freeway and arterial networks on the basis of peak period travel times (If available, network assignments performed using standard computer assignment algorithms may also be used); and

4) Apply mode-split distributions to the HBW trips to estimate potential transitway demands. In the absence of local data, the mode-split distributions shown in Tables 2-1 and 2-2 may be used as general guides.

2.1.4.4 Park-and-Ride Demand Estimation

The third technique for estimating transitway demand is based on procedures developed by TTI for estimating park-and-ride lot patronage (4). These techniques include a market area population technique, a modal split technique, and two regression procedures. Each procedure is outlined below.

Table 2-1. Bus Mode Split at Park-and-Ride Lots With and Without Transitways, Houston

Park-and-Ride Lot/Priority Treatment	Percent of Travel by Bus
North Shepherd (with priority treatment)	33%
Addicks (without priority treatment)	15%

Note: Mode split is defined as the percent of park-and-ride lot market area population working in downtown that uses the park-and-ride service.

Source: (5)

Table 2-2. Mode Splits Associated With Selected Transitway Projects

Project	Mode Split
I-45 Contraflow, Houston	
Bus	33%
Vanpool	19
TOTAL	52%
El Monte Busway, Los Angeles	
Bus	25%
Carpool	20
TOTAL	45%

Note: Mode split as defined in Table 2-1. For I-45N, these are trips from the park-and-ride market areas to downtown. For El Monte, these are trips from the east end of the busway to downtown.

Source: (5)

Market Area Population Technique

Analysis of survey data from park-and-ride lots in Texas indicates that the population of the park-and-ride lot market area can be used to estimate the number of park-and-ride patrons destined for the CBD. The percentage of the market area population that is represented by ridership varies between Texas cities. However, within Texas cities, a general range appears to exist. Table 2-3 summarizes these data.

From the data shown in Table 2-3, it is not possible to identify what the "ultimate" demand for park-and-ride might be (i.e., ridership that might be generated from a highly congested corridor with priority treatment). The Houston lots on I-45N are filled to capacity, and that restricts additional lot usage. As such, the value for Kuykendahl may represent a minimum value for that type of service. It is known that this minimum value holds for at least one park-and-ride space per 0.028 market area population. Careful definition of the actual market area, taking into account overlapping market areas in the I-45N corridor, suggests that Kuykendahl, at present, may be serving as much as 2.4% of the market area population. If more parking spaces and buses were provided, it is not unreasonable to assume this percentage would be greater. Indeed, based on today's demand and not accounting for future growth, Kuykendahl may easily be able to serve demand representing 2.5% to 3.0% of the market area population. As a general guide, it is suggested that a market share of 2.5 - 3.0% be used to estimate park-and-ride lot patronage in heavily traveled corridors which have a high attraction to the CBD.

The basic steps in applying the market area population technique to estimate transitway demands are outlined below:

1) **Define Market Area.** It is suggested that the transitway market area be estimated by assuming that park-and-ride facilities will be located at the upstream and downstream ends of the transitway. Any intermediate gaps in the market area can then be filled by drawing lines tangent to the upstream and downstream market areas. Typical market area shapes are shown in Figure 2-4.

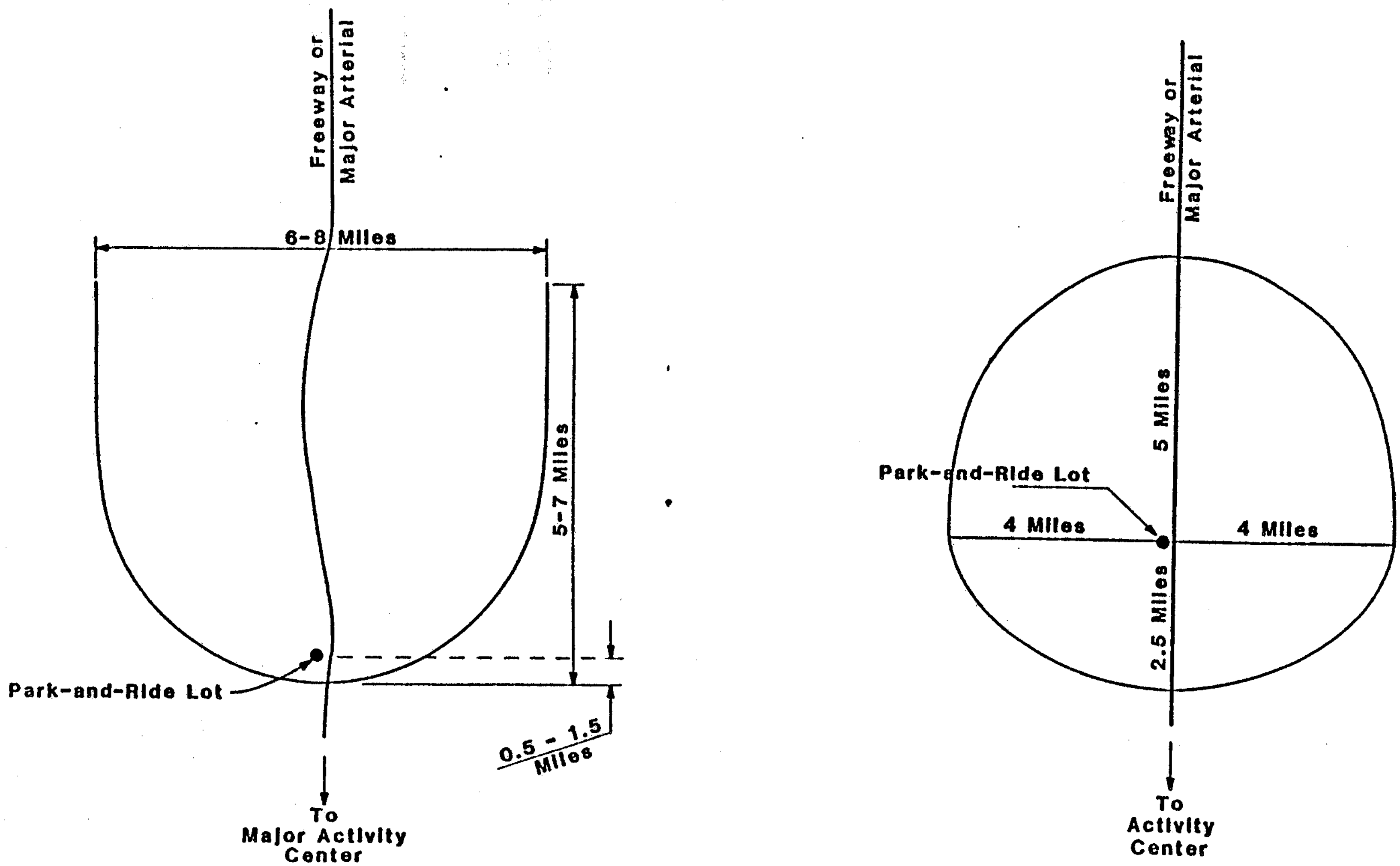
2) **Estimate Market Area Population.** Census data and/or population projections prepared by local planning agencies can be used.

Table 2-3. Ridership as a Percentage of Population in the Park-and-Ride Market Area

City and Park-and-Ride Lot	Ridership as a % of Market Area Population	"Guideline" for City
Austin		
North Park-and-Ride	0.6	
US 183 North[1]	0.3	0.3 to 0.6
Dallas Area		
Garland South	0.8	
Garland North	1.3	
North Central	0.4[2]	0.4 to 1.3
Las Colinas	0.8	
Redbird	0.7	
Pleasant Grove	0.4	
El Paso		
Montwood[3]	0.4	
Northgate[4]	0.07	0.07 to 0.4
Fort Worth		
Meadowbrook	0.05	
College Avenue	0.3	0.05 to 0.3
Houston[5]		
Champions	0.9	
Kuykendahl	2.1	
N. Shepherd	1.0	
Edgebrook	0.8	0.7 to 2.0
Clear Lake	0.8	(constrained due
Beechnut (both lots)[6]	0.9	to size of lots
Sharpstown	0.3[7]	currently available)
Alief	0.9	
Westwood	1.1	
Katy/Mason	0.7	
Kingwood	1.4	
Lots serving contraflow lane		2.5 to 3.0
San Antonio		
Windsor Park	0.5	
McCreless	0.2[8]	varies up to 1.2
South Park	0.1	
Lackland	1.1	
Wonderland	1.2	
Nacogdoches[9]	0.2	

[1]Includes 3 lots served by the same bus—US 183 North #1, #2 and #3.
[2]Ridership is lower than would be expected due to paid parking, competing local bus service, poor lot access/accessibility and lot not located upstream of congestion.
[3]Includes 2 lots served by the same bus—Montwood and Vista Hills.
[4]Includes 2 lots served by the same bus—Northgate and Rushfair.
[5]Ridership at most of the Houston lots is constrained by parking spaces available.
[6]Includes 2 lots served by the same bus—Meyerland and Sage.
[7]Low percentage due to small lot size.
[8]Lot located in an uncongested corridor and relatively close to activity center.
[9]Includes 2 lots served by the same bus-Broadway and Bitters.

Source: (4)



Source: (4)

(a) Dallas, Garland and Houston, Texas

(b) San Antonio, Texas

Figure 2-4. General Shapes of "Typical" Park-and-Ride Lot Market Areas

3) **Estimate CBD Patrons.** Estimates of CBD patrons are obtained by multiplying market area population by ridership as percent of market area population (values in range of 2.5 - 3.0% appear reasonable for heavily traveled corridors in major urban areas of Texas).

4) **Account for Non-CBD Patrons.** In the absence of local data it may be assumed that CBD patrons account for roughly 85% of total patronage with the balance (15%) destined to non-CBD locations.

5) **Estimate Transitway Vehicle Demands.** The ridership (persons) estimates derived from Step 4, can be converted to peak period vehicle demands by applying vehicle occupancy and authorized vehicle distribution factors. Based on experience from the I-45N contraflow lane in Houston, the following factors would appear to be reasonable for most planning applications:

a) 65% of total ridership can be assumed to be on buses;

b) Bus occupancy = 50 persons/bus; and

c) Vanpool occupancy = 9 persons/vanpool.

Mode-Split Technique

The market area analysis previously described assumes that all market areas have an equal affinity to the activity centers being served by park-and-ride. While that approach is simple to apply and uses the most readily available data, it does not account for the fact that different parts of a corridor or urban area can have different attraction rates to the activity centers being served.

To use the modal-split procedure it is necessary to identify that component of the market area population that works in the activity center served by park-and-ride. This information is not always readily available and, as a result, the attractiveness of this approach is diminished due to data availability concerns. Table 2-4 summarizes the available modal split data for Texas park-and-ride lots.

The following guidelines--recognizing constraints imposed by lot sizes or lots not located in accordance with the lot location guidelines--might be used for park-and-ride analysis.

- **Dallas area lots.** 10% to 20% modal split
- **Houston area lots.** 15% to 30% modal split, with some modal-splits in the range of 50%.

Perhaps Table 2-4 is most helpful in estimating potential modal-split. Data shown in Table 2-4 suggest that, if a lot is located properly and a sufficient number of parking spaces is provided, modal-splits in the range of 50% could be attained. That value might be useful in identifying the "upper end" of potential lot size (and demand).

Application of the mode-split technique consists of the following steps:

1) **Define Market Area.** Same as for Market Area Population Technique previously presented.

2) **Estimate Market Area Population Working in Activity Centers.** Census data and/or local survey data may be used.

3) **Estimate Park-and-Ride Patrons.** Estimates of patrons are obtained by multiplying the estimates of market area population working in the activity centers by the activity center mode splits. CBD mode splits on the order of 25%, and non-CBD mode splits on the order of 10% would appear to be reasonable for most planning applications.

4) **Estimate Transitway Vehicle Demands.** Same as for Market Area Population Technique.

Regression Analysis

The data for 35 park-and-ride lots in Texas were analyzed to develop equations that can be used to predict park-and-ride patronage. The following represent some of the more applicable equations.

RIDERS = -160 + 204CI + 0.0034MAPOP .... (2.9)

RIDERS = -86 + 0.8MIN + 0.002MAPOP .... (2.10)
(for CI 1.3)

RIDERS = 61 + 0.1MIN + 0.001MAPOP .... (2.11)
(for 0.9 CI 1.2)

Table 2-4. Estimated Modal-Split for Texas Park-and-Ride Lots

City and Lot	Modal Split[1]	Procedure to Estimate Modal Split[2]
Dallas/Garland Area		
Dallas North Central	7% to 8%	TTI Surveys and Census Analysis
Pleasant Grove	8%	Census Analysis
Oak Cliff	4%	Census Analysis
Garland, North & South	21%	TTI Surveys
Houston		
Clear Lake City	52%	Census Analysis
Gulf Edgebrook	24%	Census Analysis
Westwood	10%	TTI Surveys
Champions	23%	TTI Surveys
N. Shepherd	27%	TTI Surveys
Kuykendahl	22%	TTI Surveys
Kingwood	29%	Census Analysis
Beechnut (2 lots)	13%	Census Analysis
Alief	28%	Census Analysis
Sharpstown	4%	Census Analysis
Katy/Mason	50%	Census Analysis

[1]Modal split is defined as the percent of the market area population working in the activity center served by the park-and-ride service.

[2]In using census data, the percent of the population working in the CBD was obtained from 1970. Due to the massive growth in many of the areas being considered, applying the 1970 percentage to the 1980 market area results in potential error.

Source: (4)

RIDERS = 7 + .43MIN .... (2.12)
(for CI 0.9)

where

RIDERS = Average daily ridership (round trip);

CI = Freeway congestion index (defined as Delay (min)/10 min + (AADT/Lane)/20,000);

MAPOP = Park-and-ride lot market area population; and

MIN = A control based on service provided (i.e. the minimum of the following 2 variables: 1) auto parking spaces x 1.5 persons/auto; or 2) peak-period bus seats). The variable adjusts for the fact that at many existing lots, demand is controlled by facilities or services provided.

While the equations using the variable MIN do a good job of "predicting" ridership at existing lots, their use in estimating demand at new lots requires estimating the value of MIN. Since MIN can vary considerably between lots in a given urban area, the best approach might be to locate an existing lot that is similar to the proposed lot in terms of congestion index, distance to the activity center, and market area population. Using this approach, the value of MIN for an existing lot can be used in the appropriate regression equation to estimate ridership at the new lot. Table 2-5 presents values of MIN at a number of park-and-ride lots in Texas.

In the absence of a comparable existing lot that can be used to determine the MIN value, one of two approaches might be used. First, the typical values in Table 2-6 can be applied. These values were obtained for each urban area by averaging the numbers shown in Table 2-5. It should be noted that, due to the large variation in MIN values for a given urban area, use of the "typical" value may affect the accuracy of the estimate.

Alternatively, since MIN is somewhat related to variables such as market area population, distance to activity center, and congestion index, those values for the proposed new lot can be used to estimate a value of MIN (Figure 2-5).

Table 2-5. Estimated Values of the Variable MIN at Selected Texas Park-and-Ride Lots

Lot	# of Peak Buses X Seats =	Parking Spaces X 1.5*	MIN
Austin			
North Park and Ride	3 X 45 = 135	260 X 1.5 = 390	135
US 183 North[1]	2 X 43 = 86	239 X 1.5 = 359	86
US 183 Express	1 X 43 = 43	146 X 1.5 = 219	43
Dallas Area			
Garland South[2]	20 X 50 = 1000	440 X 1.5 = 660	660
Garland North[2]	13 X 50 = 650	320 X 1.5 = 480	480
North Central	11 X 50 = 550	1300 X 1.5 = 1950	550
Las Colinas	3 X 50 = 150	150 X 1.5 = 225	150
Red Bird	7 X 50 = 350	315 X 1.5 = 473	350
Pleasant Grove	7 X 50 = 350	624 X 1.5 = 936	350
El Paso			
Montwood[3]	4 X 47 = 188	75 X 1.5 = 113	113
Northgate Express[4]	4 X 47 = 188	209 X 1.5 = 314	188
Fort Worth			
Meadowbrook	2 X 48 = 96	25 X 1.5 = 38	38
College Avenue	6 X 48 = 288	185 X 1.5 = 278	278
Houston			
Kingwood	12 X 47 = 564	950 X 1.5 = 1425	564
Champions	10 X 47 = 470	349 X 1.5 = 524	470
Kuykendahl	29 X 47 = 1363	1300 X 1.5 = 1950	1363
North Shepherd	21 X 47 = 987	750 X 1.5 = 1125	987
Gulf Sage	10 X 47 = 470	230 X 1.5 = 345	345
Clear Lake	10 X 47 = 470	325 X 1.5 = 488	470
Beechnut Express[5]	12 X 52 = 624	487 X 1.5 = 731	624
Sharpstown	7 X 47 = 329	200 X 1.5 = 300	300
Alief	12 X 47 = 564	300 X 1.5 = 450	450
Westwood	16 X 47 = 752	600 X 1.5 = 900	752
Katy	5 X 47 = 235	170 X 1.5 = 255	235
San Antonio			
Windsor	6 X 47 = 282	167 X 1.5 = 251	251
McCreless	5 X 47 = 235	117 X 1.2 = 140	140
South Park	3 X 47 = 141	64 X 1.2 = 77	77
Lackland	5 X 47 = 235	136 X 1.5 = 204	204
Wonderland	13 X 52[7] = 676	474 X 1.5 = 711	676
Nacogdoches[6]	5 X 47 = 235	123 X 1.2[8] = 148	148

*1.5 - assumed maximum average auto occupancy.
[1]Includes 3 lots served by the same bus- US 183 North, Covenant and NW Hill.
[2]Since the buses from Garland North also stop at Garland South, parking spaces are used to establish the MIN values for Garland.
[3]Includes 2 lots served by the same bus - Montwood and Vista Hills.
[4]Includes 2 lots served by the same bus - Northgate and Rushfair.
[5]Includes 2 lots served by the same bus - Meyerland and Sage.
[6]Includes 2 lots served by the same bus - Bitters and Broadway.
[7]Bus capacity was inflated to account for numerous standees.
[8]Auto occupancy lower than state average.

Source: (4)

Table 2-6. "Typical" MIN Values for Urban Areas in Texas.

Urban Area	"Typical" MIN Value[1]
Houston	600
Dallas	425
San Antonio	250
Austin, El Paso, and Fort Worth	125 to 175

[1] Obtained by averaging the values in Table 2-5.

Source: (4)

The equations using the MIN variable accept the fact that current park-and-ride patronage is often controlled by either facilities (i.e., parking spaces available) or service (i.e., number of buses provided to the lot). These equations, in most instances, predict ridership at existing lots within 25% of actual ridership.

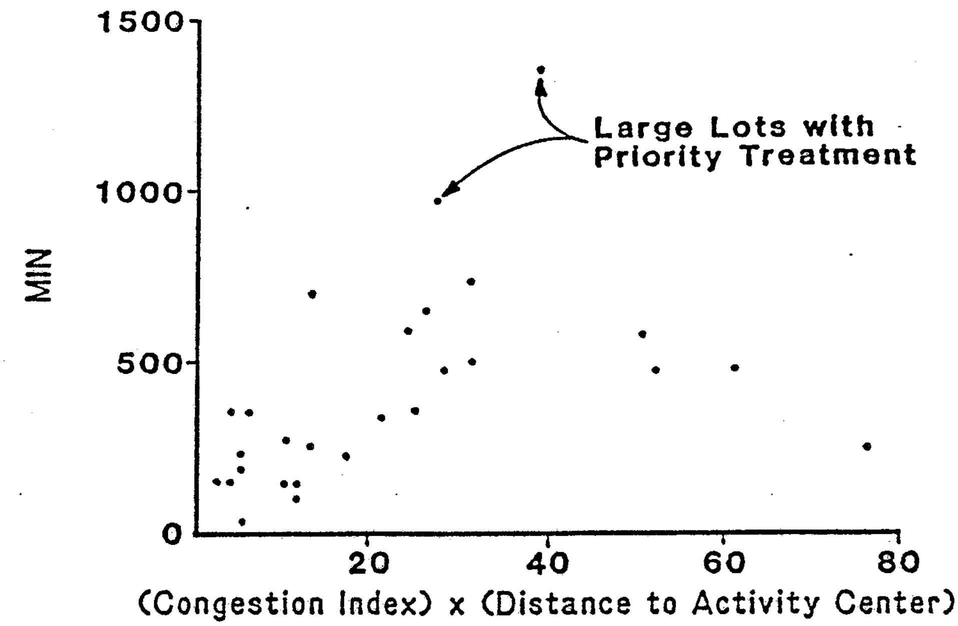
The regression equation using the CI variable (Eq. 2.9), while somewhat easier to apply, is generally less accurate in predicting ridership than the equations using the MIN variable. In most instances, the CI equation has been found to predict ridership at existing lots within about 50% of observed ridership. In using Eq. (2.9), or in selecting the appropriate MIN equation, the analyst may find the CI values given in Table 2-7 useful.

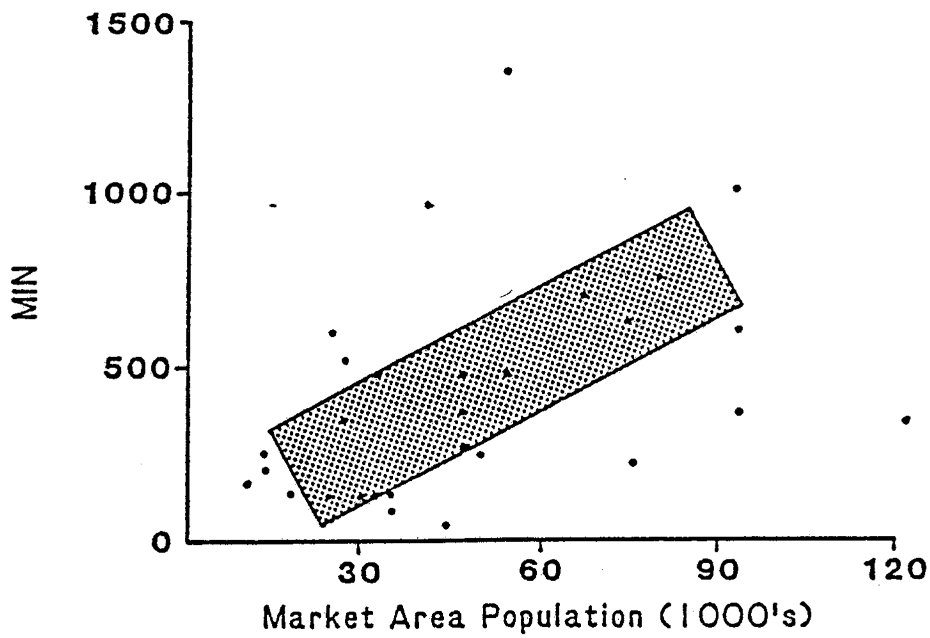
Having developed ridership estimates from the appropriate regression equation(s), the analyst can convert the ridership estimates to peak period transitway vehicle demands on the basis of the following general planning factors:

a) 65% of total ridership can be assumed to be on buses;

b) Bus occupancy = 50 persons/bus; and

c) Vanpool occupancy = 9 persons/vanpool.





Source: (4)

Figure 2-5. Relationship Between the Variable MIN and Selected Descriptors of Park-and-Ride Lots

Table 2-7. Congestion Indices (CI)

City and Facility	AADT/Lane	# of Lanes	Delay in Minutes	CI
Austin				
US 183 N	7,925	6	1.5	0.5
Mo Pac	6,466	6	1.0	0.4
I-35 N	7,188	8	1.5	0.5
I-35 S	18,367	6	2.0	1.1
Dallas				
Stemmons (I-35 E North)	13,210	10	5.0	1.2
N. Central (US 75 N)	20,517	6	18.0	2.8
Thornton East (I-30 E)	13,400	8	15.0	2.2
Thornton South (I-35 E South)	12,800	8	1.0	0.7
LBJ or North Side (I-635)	20,363	8	2.0	1.2
US 175	6,550	6	2.0	0.5
US 67	7,500	6	2.0	0.6
El Paso				
I-10 E	11,780	10	3.0	0.9
US 54	8,817	6	1.0	0.5
I-10 W	12,775	4	1.0	0.7
Fort Worth				
West (I-30 W)	22,675	4	8.0	1.9
South (I-35 W South)	13,900	6	3.0	1.0
East (I-30 E)	8,888	8	2.0	0.6
Houston				
Southwest (US 59 S)	21,633	9	11.0	2.2
Katy (I-10 W)	24,457	7	15.0	2.7
North (I-45 N)	19,000	8	15.0	2.5
Eastex (US 59 N)	15,225	8	11.0	1.9
East (I-10 E)	14,863	8	5.0	1.2
Gulf (I-45 S)	24,443	7	15.0	2.7
West Loop (I-610)	25,363	8	8.0	2.1
San Antonio				
S. Pan Am (I-35 S)	20,425	4	4.0	1.4
I-10 W	21,450	4	9.0	2.0
N. Pan Am (I-35 N)	20,110	4	3.0	1.3
US 281 N	10,062	8	2.0	0.7
I-37 S	8,725	8	0.0	0.4
US 90 W	8,775	8	0.0	0.4

Source: (4)

2.1.4.5 Contraflow Lane Analogy

The fourth technique which has been used by TTI to estimate transitway demands is based on an analysis of travel data for the existing I-45N contraflow lane (CFL) in Houston (Figure 2-6).

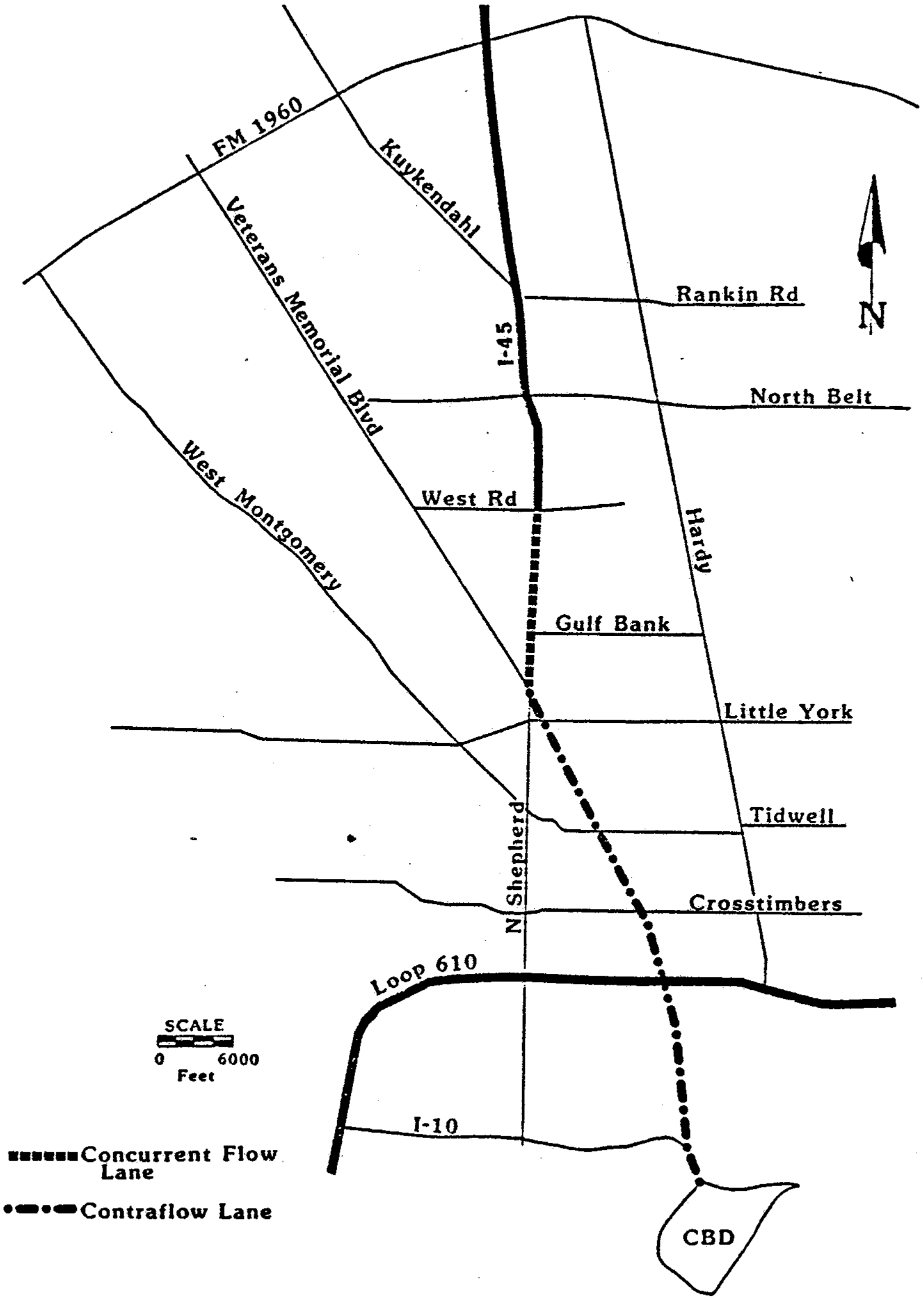
I-45 North Freeway is a standard 6- and 8-lane Interstate Highway that serves one of the fastest growing corridors of the Houston metropolitan area. The population of the North Freeway corridor is estimated to have increased 58% between the years of 1970 and 1979 to a population of over 500,000 persons. Average weekday traffic on the North Freeway increased from 96,000 vehicles in 1970 to 135,000 vehicles in 1979 (Figure 2-7). Parallel arterial streets have experienced similar growth rates (5).

During this same time period, the increased demand for peak period trips resulted in severe traffic congestion along I-45 North. Travel time surveys originating in the Houston central business district (CBD) revealed that a distance of 18 miles could be traveled in 30 minutes during the afternoon peak period in 1969. By 1976, however, only 11 miles could be traveled in the same amount of time, a reduction of 40%. The length of the peak periods also increased. In 1978, both morning and afternoon peak hour travel speeds averaged about 20 mph for 10 miles with hourly volumes ranging from 1,800 to 1,900 vehicles per lane. In addition, certain freeway segments typically experienced congestion for more than 2 hours during each peak period (5).

The contraflow lane was officially opened on August 28, 1979. Figure 2-8 summarizes observed bus and vanpool ridership on the CFL.

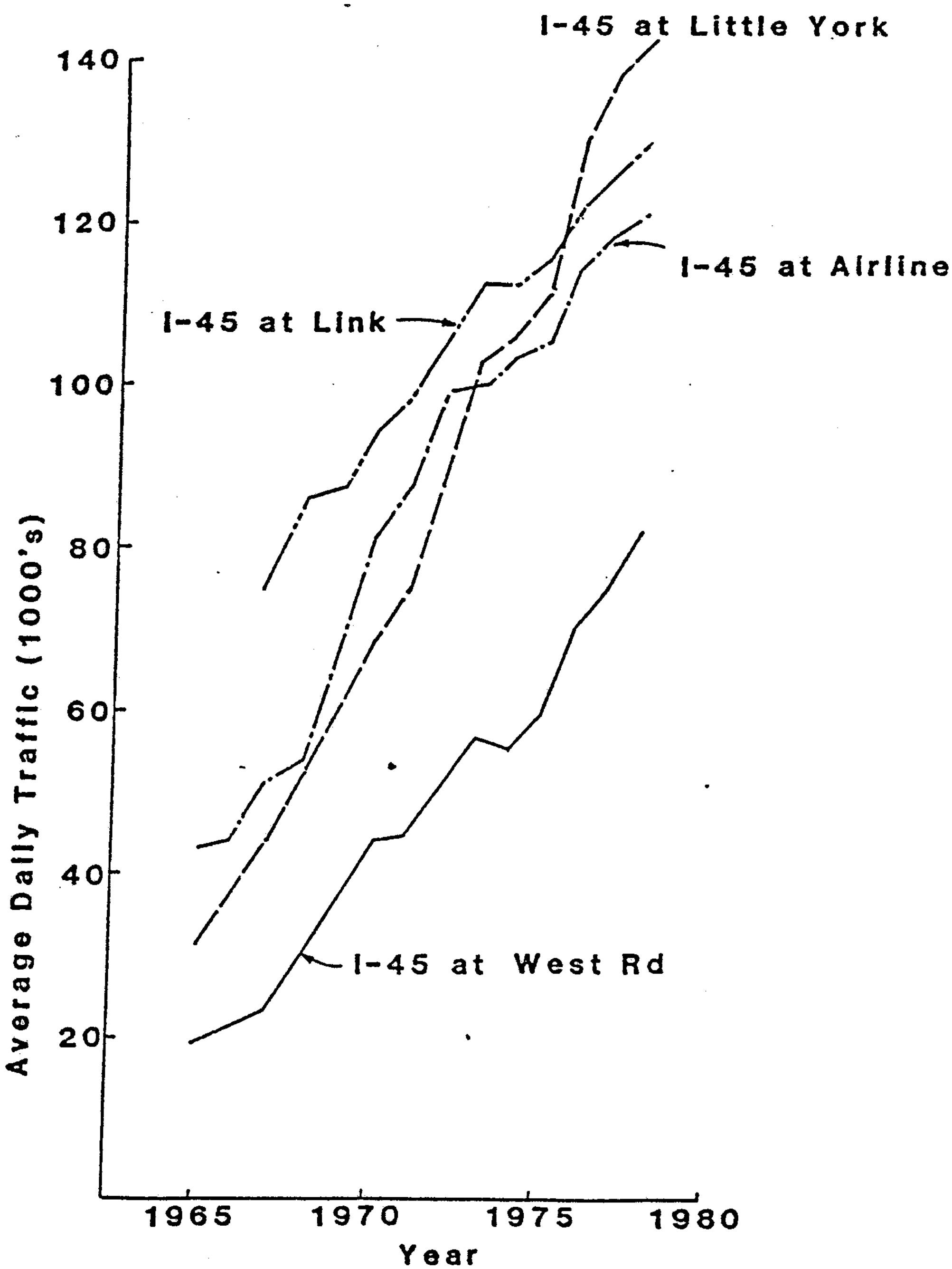
In using the observed usage of the I-45N CFL to estimate potential demands for comparable facilities on other radial freeways, the procedure used by TTI has been to simply factor the CFL volumes by the ratio of CBD work trips served on the freeways being considered for transitway treatment relative to those served on I-45N. Implementation of this procedure requires information on the number of CBD work trips on the freeways being analyzed. Table 2-8, which shows estimates of CBD work trip usage for selected radial freeways in Houston, illustrates the type of data required.

Analogies based on operating statistics from other transitways (e.g., Katy Transitway) could also be used to estimate the demand for facilities being considered in similar corridors.



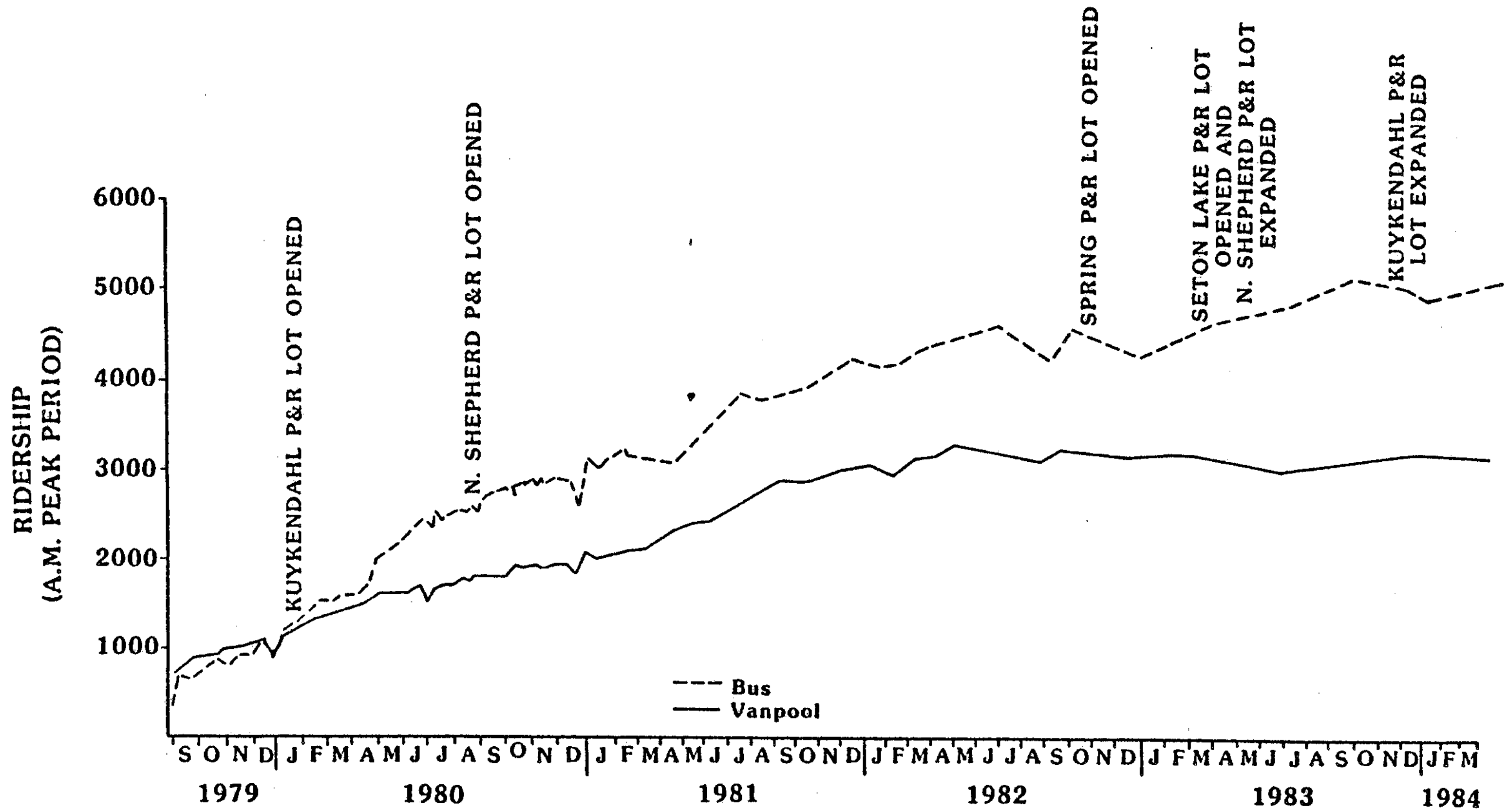
Source: (5)

Figure 2-6. North Freeway Contraflow Lane, Houston



Source: (5)

Figure 2-7. Historical Trends in Average Daily Traffic at Selected Count Locations in the I-45 Corridor



Source: (5)

Figure 2-8. Growth in North Freeway Contraflow Lane Bus and Vanpool Ridership

TABLE 2-8. Estimated Percentage of Total 1985 CBD Work Trips Using Selected Radial Freeways in Houston.

Freeway	No. of CBD Work Trips Assigned to Each Freeway	Percent of Total CBD Work Trips Assigned to Each Freeway	No. CBD Work Trips Served Relative to North Freeway
Eastex	13,500	9	0.6
Gulf	21,500	15	1.0
Southwest	23,000	16	1.1
Katy	23,500	17	1.1
North	22,000	15	1.0
Total 5 Freeways	103,500	72	

Source: (7)

2.1.4.6 Validation of Estimation Procedures

In order to provide an indication of the relative accuracy of the estimation procedures presented in the previous sections, the procedures were used to estimate potential demands for the I-10W (Katy Freeway) transitway in Houston. The estimates were compared with observed usage and relative estimation errors were calculated. Table 2-9 summarizes the results of the validation tests.

As shown in Table 2-9, the bus demand estimates developed from the FHWA and park-and-ride procedures are in fairly close agreement with the observed values. Likewise, the vanpool demand estimates developed using the park-and-ride procedures do not differ substantially from the observed demand. Finally, simply averaging the demand estimates developed from the four procedures appears to produce results that may be adequate for most planning applications.

2.1.4.7 Summary and Suggested Guidelines

Very few transitways are currently in operation in the United States. As a result, no generally accepted procedures for estimating transitway demand are available.

The Texas Transportation Institute has used several relatively independent procedures for estimating demands for transitway facilities in Houston. These procedures differ in the amount of data and manpower required for implementation and each technique has certain advantages and disadvantages. Consequently, no single procedure is clearly superior to the others.

While the FHWA estimation procedures appear to provide reasonably accurate estimates of bus demands, the procedures have two significant shortcomings. First, the procedure tells how much existing transit and carpool utilization will increase due to provision of an HOV lane. This causes problems in corridors where little to no transit service exists prior to implementation of the priority lane.

The second major drawback of the FHWA procedures is that they estimate bus and carpool utilization. Vanpooling, which is extremely popular in Texas, is not considered.

Table 2-9. **Observed and Estimated 1985 Peak-Hour Vehicle Demands, Katy Transitway Houston.**

Estimation Method[a]	Peak Hour Vehicles			Percent Error (Relative to observed)		
	Bus	Vanpool	Total	Bus	Vanpool	Total
FHWA Procedure	45	30[b]	75	13%	-77%	-56%
HBW Trip Mode-Split	72	247	319	80	90	88
Park-and-Ride Estimation[c]	33	123	156	-18	-5	-8
Contraflow Analogy	60	240	300	50	85	76
Average	52	160	212	30	23	25
Observed[d]	40	130	170	-	-	-

[a] Assumptions are: (1) Buses account for 65% of total person movement; (2) 50 persons/bus, 9 persons/vanpool; (3) Existence of three park-and-ride lots; and (4) Mode-splits of 25% bus and 15% vanpool for CBD, and 10% bus and 7.5% vanpool for non-CBD activity centers.

[b] These are actually 4+ person carpools.

[c] Demands are average values developed from the market area population, mode-split, and regression techniques (equations 2.9 and 2.10).

[d] Observed volumes are from only six months of operation. Due to the short utilization period, the observed volumes are probably a conservative measure of potential utilization.

Several of the estimation procedures discussed require information concerning transitway mode-splits; information which is not typically readily available. However, "default" mode-split values based on a rather limited amount of data from Houston are presented and may be factored for use in other areas in Texas. Additionally, the estimation procedures based on TTI research do not explicitly address carpool demand estimation.

In short, procedures for estimating transitway demands are still fairly crude. Nevertheless the procedures discussed in this section can be used to develop a range of demand estimates which should be reasonable for most planning applications.

In estimating the potential demand for a transitway facility, the following general guidelines are suggested.

1) It is suggested that the analyst develop a range of estimates using several of the estimation procedures presented in this manual. The analyst should use his knowledge of the local area to select a best estimate of potential demand. Alternatively, if there are no obvious "outliers" in the range of estimates, the average of the estimates developed from the various procedures could be used as a best estimate. In short, it is suggested that the analyst take the time to experiment with estimate procedures. Users of these procedures are encouraged to test the sensitivity of each method by varying the input assumptions and analyzing the results to see which procedure seems most reasonable in a given situation.

2) In the absence of local data, the following mode-splits (% person trips) for major activity centers in Houston may be adjusted to reflect local employment and used as default values in the demand estimation procedures.

CBD (employment = 170,000) 25-35% (Bus), 20% (Vanpool)

Non-CBD (employment = 32-70,000) 10% (Bus), 7.5% (Vanpool)

Users of the procedures are encouraged to use local data in place of the default values wherever possible.

3) While the estimation procedures presented in this manual do not explicitly address carpool demand estimation, the following guidelines provide an indication of the potential magnitude and impact of carpools on transitways. (Auto occupancy is a critical variable in all of the

methodologies presented in this section. Though some historical, system-wide data are available for major urban freeways, little is available on a corridor basis and little is known about projecting these data. Consequently, the following guideline should be viewed as only general value).

a) Data from major freeways in Houston and Dallas suggest that 3+ person carpools typically account for 2-3% of peak period freeway volumes. Carpools with 4 or more occupants typically account for roughly 1% of peak period freeway traffic. However, experience has shown that priority treatment for HOVs can encourage a substantial increase in carpools. Consequently, decisions concerning carpool authorization criteria can significantly effect transitway level-of-service.

b) Based on planning estimates developed for four transitways in Houston, facilities with one lane in the peak direction should be sufficient to accommodate the demand which could be generated from most urban freeways when buses, vanpools, and carpools of 4+ occupancy are authorized to utilize the transitway. Based on preliminary analyses in Houston, reducing carpool occupancy requirements from 4+ to 3+ occupants could necessitate increasing the transitway cross-section from 1-lane to 2-lanes in some heavily traveled corridors. Setting the authorization criterion at 4+ occupants may insure a high level-of-service on the transitway. Additionally, as utilization of the facility stabilizes, the 4+ criterion could be re-evaluated and reduced to 3+ occupants if necessary. If, on the other hand, the initial authorization criterion is set at 3+ occupants, attempts to raise the minimum occupancy requirements are likely to be unpopular.

2.1.5 <u>Design Concepts</u>

Once the decision to authorize specific high occupancy vehicles to utilize the transitway has been made and 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 2-9 illustrates the single lane transitway mainlane configuration.

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, required width 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 separated (off-freeway) implementation. Figure 2-10 depicts the multiple lane transitway configuration.

2.1.5.2 Terminal Connections

The design of terminal connections to a transitway depends upon the decision to directly interface transitway authorized vehicles with freeway non-HOV traffic or to provide indirect interface into frontage roads or adjacent surface streets. Direct connection is accommodated by at-grade slip ramps; while indirect connection is accomplished utilizing elevated flyover ramps.

Figure 2-11 illustrates the merge/diverge of transitway vehicles with the freeway mainlanes by means of a median slip ramp. The facility shown is a single lane, reversible transitway; however, obvious modification of this design concept would accommodate two lane, two way operation. This type of slip ramp terminal is particularly applicable to temporary or phased transitway implementation.

Elevated flyover ramps allow terminal connections on either end of the transitway. From outer areas, one way or two way connection may be provided into freeway frontage roads for either collection or distribution of authorized high occupancy vehicles. At inner city terminal areas, flyover ramps

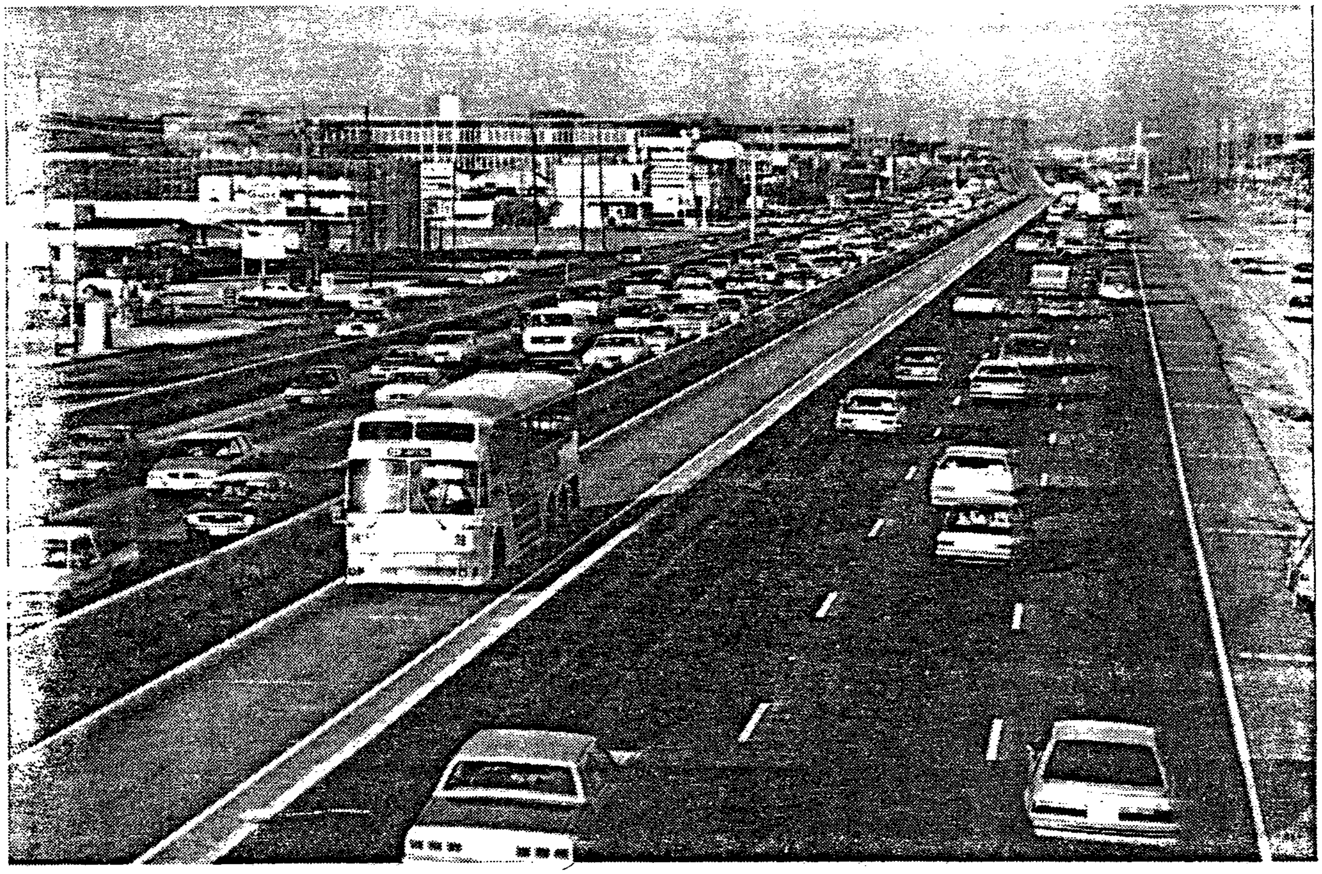


Figure 2-9. Single Lane Transitway Configuration

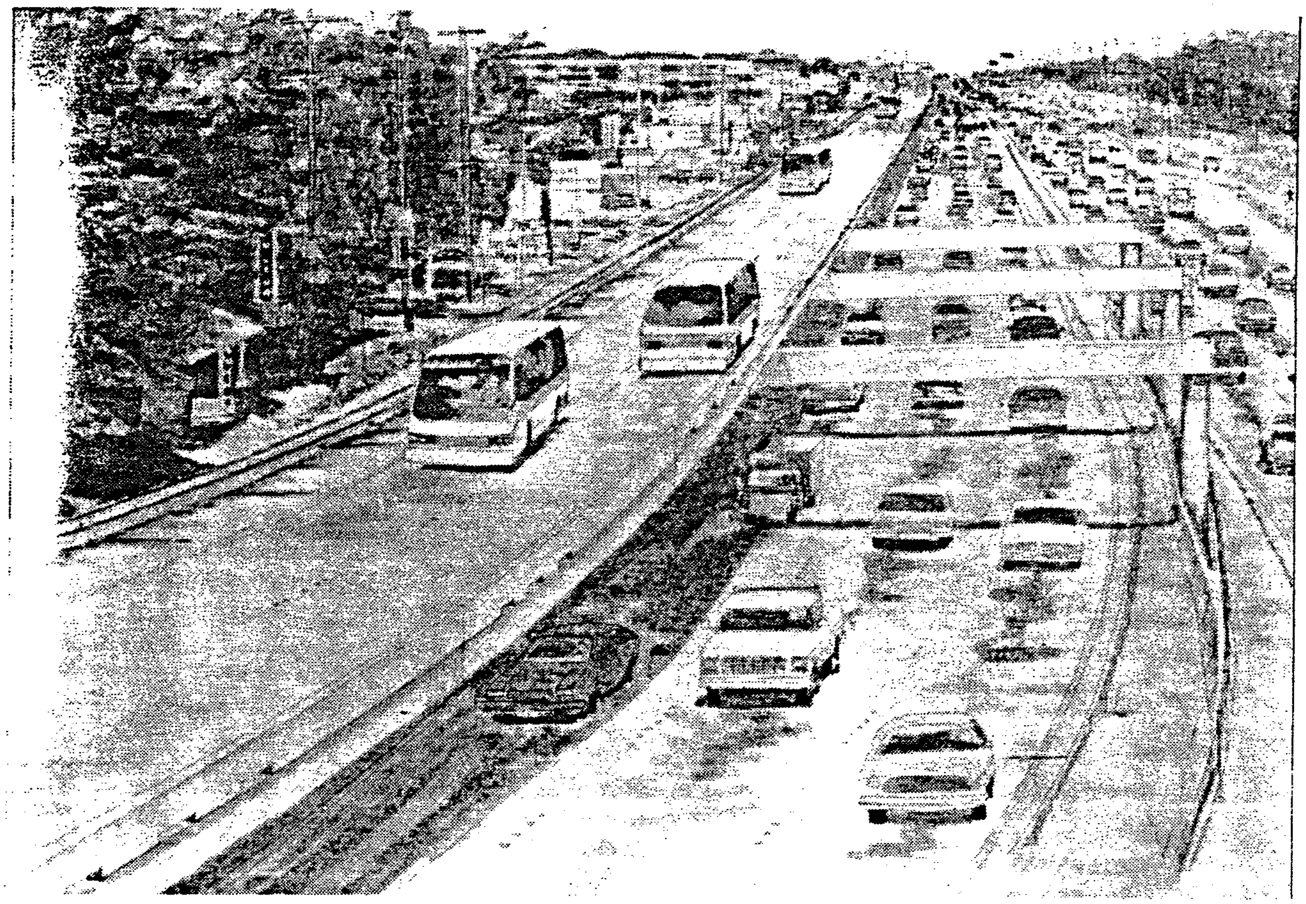


Figure 2-10. Multiple Lane Transitway Configuration

Figure 2-11. Median Slip Ramp Terminal

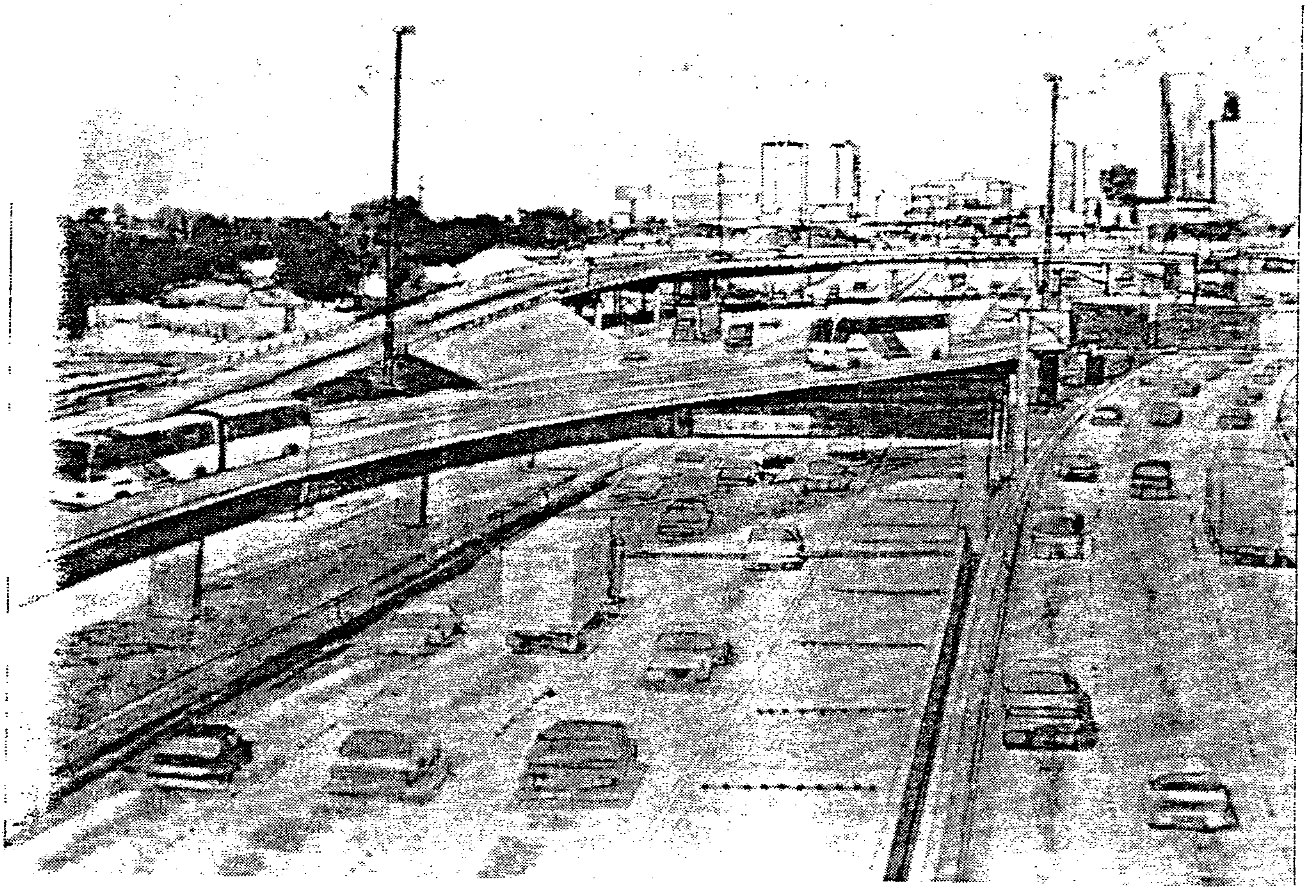


Figure 2-12. Flyover Ramp Terminal

may be connected to frontage road pairs or into existing two way or one way street pairs with available capacity. This concept is shown in Figure 2-12.

2.1.5.3 Intermediate Access

Intermediate connections to the transitway allow access on and off the facility to freeway mainlanes at critical locations, transit transfer centers, park-and-ride lots, and park-and-pool areas. These connections may be made at-grade with intermediate slip ramp openings (temporary) or by grade separated interchanges.

Intermediate access to at-grade median transitways may be provided by openings in the separation barrier. Sufficient open width must be allowed for merge/diverge maneuvers at normal operating speeds. Figure 2-13 illustrates this concept. Care should be taken in locating intermediate, at grade median access points because of potential recurring problems that may result if vehicles entering or leaving the median 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 "Tee" or from both sides of the freeway "Cruciform". Sufffficient width and length of structure must be provided for acceleration and deceleration transitional HOV movements on the transitway mainlanes. Examples of design are shown in Figure 2-14.

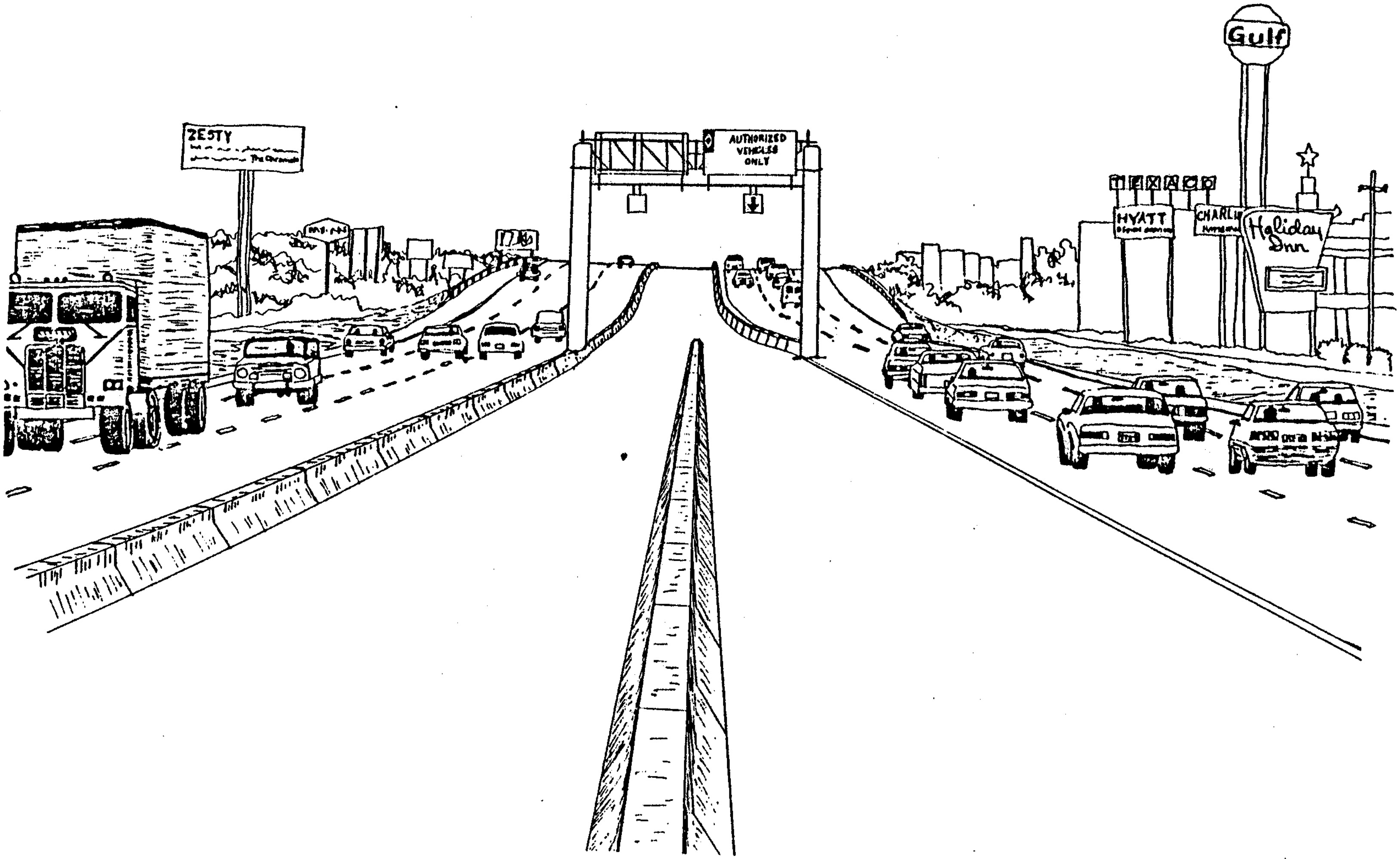


Figure 2-13. Intermediate Slip Ramp At Grade

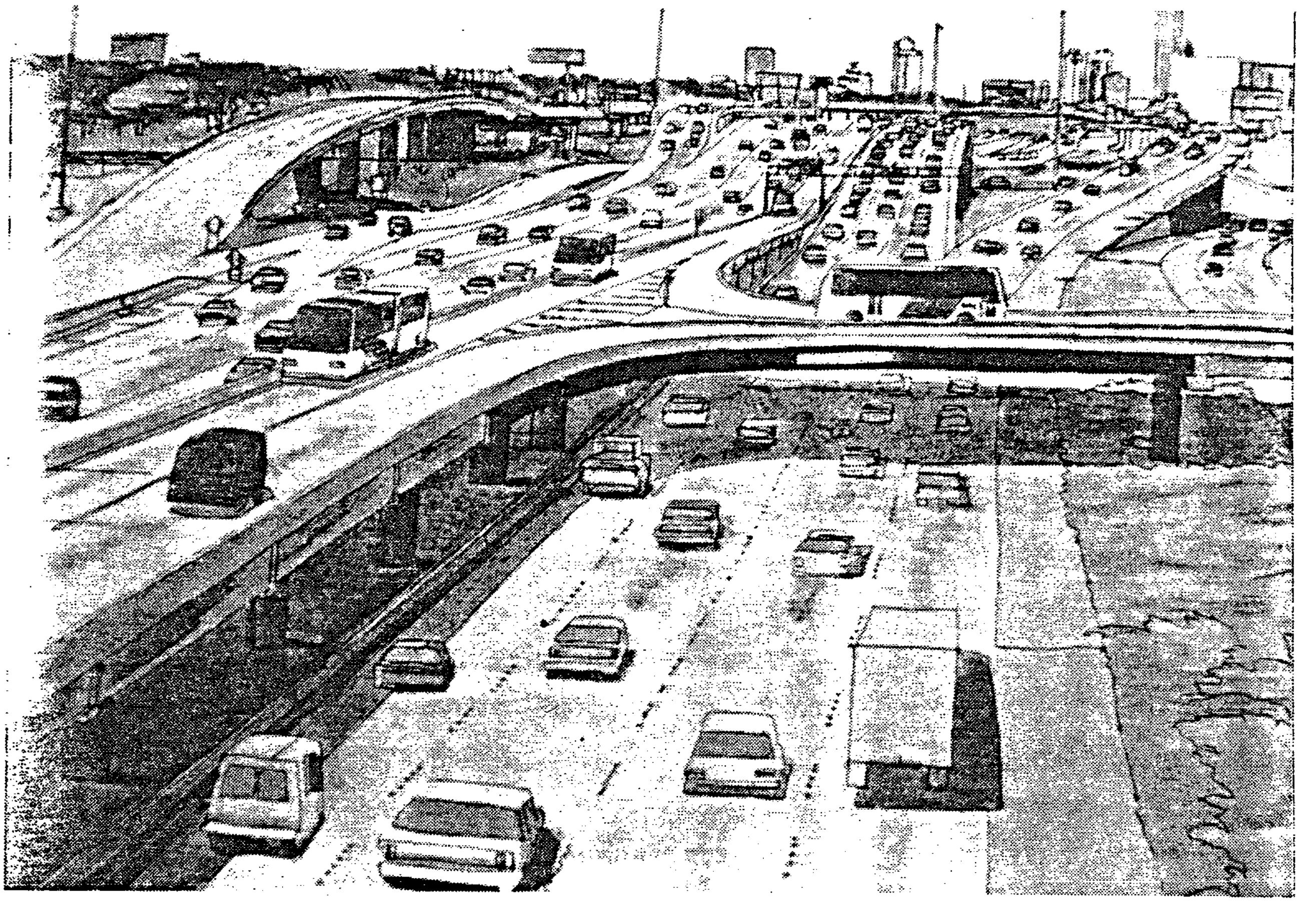


Figure 2-14. Grade Separated Interchange

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. 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 of these factors.

Design criteria for transitways are presented at two levels: (1) desirable; and (2) usual minimum. Values indicated as desirable are recommended for design to insure acceptable operations. Values shown as usual minimum, while safe, are to be used only 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 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) as 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 (8) indicates a LOS "A" capacity of 1200 passenger car equivalents per lane per hour (pce/lane/hr) (with buses equal to 2.0 vanpools/carpools) as desirable. A LOS "C" capacity (1500 pce/lane/hr) may be accepted as usual minimum for transitways with bus, vanpool, and carpool as authorized vehicles.

2.2.3 Design Speed

Design of transitway facilities should maximize travel time savings as an incentive for motorists to utilize high-occupancy vehicle modes of travel. Operating speed for express through movements should be no less than 50 mph and optimal for all interchanging or transitional movements. Corresponding design speeds 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 elevated "flyover" type ramps, whether an intermediate or terminal connection, and at-grade "slip" ramps for median ingress/egress.

Other types of transitway ramp connections associated with grade separated intersections with transitway mainlanes will require lower design speeds for turn maneuvers. Adequate acceleration and deceleration lane lengths should be incorporated at these intersections for speed transition.

Lower ramp design speeds may also be appropriate where conditions of restrictive geometry or right-of-way exists 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". Passenger cars serve carpools while vans serve vanpools.

Dimensions representing vehicles within the general classes applicable to transitway design are shown in Table 2-10 (9). 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 2-10. Design Vehicle Dimensions

Design Vehicle Type	Symbol " "	Height (ft)	Width (ft)	Length (ft)	Overhang Front (ft)	Overhang Rear (ft)	Wheel Base (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	"B"	13.5	8.5	40	7	8	25
Articulated Bus*	"A-B"	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: (9)

The single unit bus, either intercity or transit, is the largest vehicle 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.

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 rate for acceleration is

2.0 mph/second and for deceleration is 2.5 mph/second, which assumes standing bus passengers. Figure 2-15 illustrates bus acceleration characteristics measured during a recent series of demonstration tests (10).

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 2-11 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 2-11. Transitway Stopping Sight Distance Values

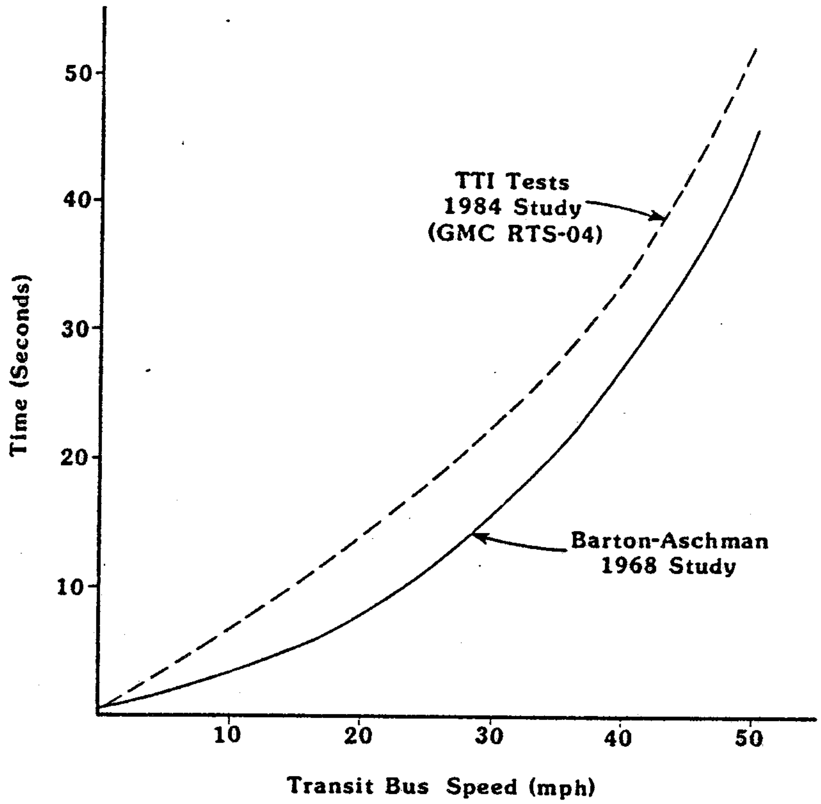
Transitway Design Speed (mph)	Minimum Stopping Sight Distance (Ft.)
30	200
40	275
50	400
60	525

Source: (9).

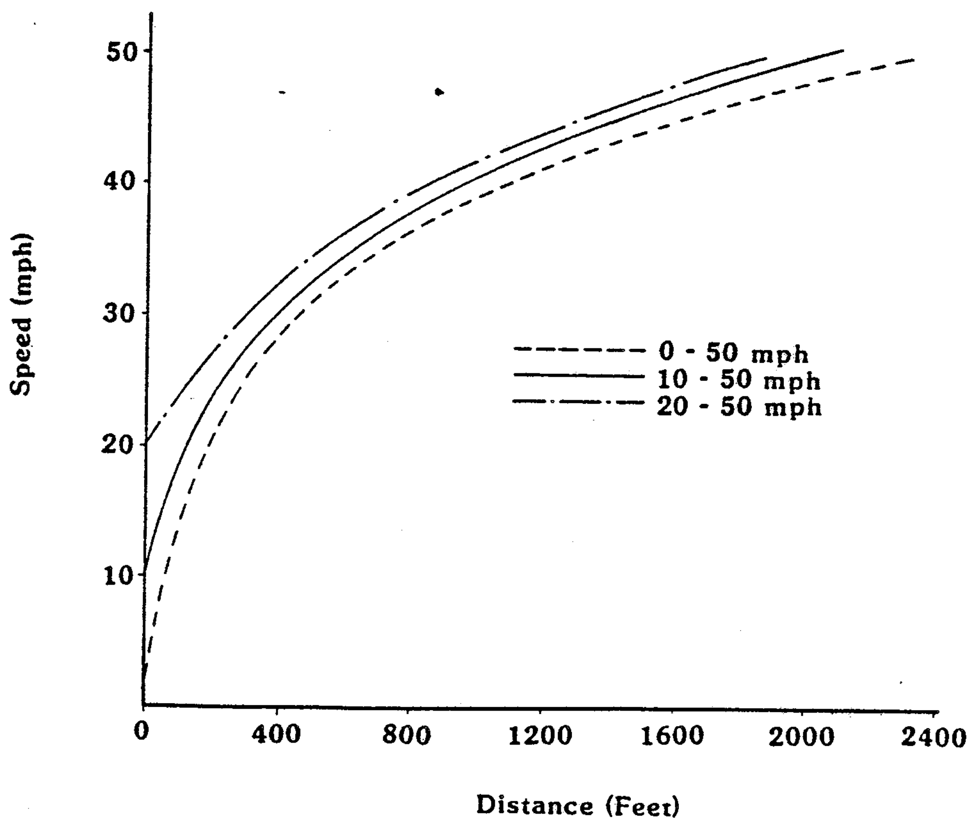
2.2.5 Alignment

2.2.5.1 General

Transitway alignment should conform to AASHTO (9) 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 2-11. Only under special



Source: (10)



Source: (2)

Figure 2-15. Bus Acceleration Characteristics 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 superelevations slightly higher than otherwise justified. Table 2-12 presents recommended values for superelevation rates on transitways.

Table 2-12. 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

2.2.5.3 Horizontal Curvature

Horizontal curvature on transitways is dependent upon the joint relationship between design speed, pavement side friction, and superelevation to effect safe, smooth, and comfortable travel. Table 2-13 presents recommended

Table 2-13. Recommended Maximum Degree of Curvature (Minimum Radius) for Horizontal Curvature on Transitways

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

Source: (9)

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.

2.2.5.4 Vertical Curvature

Length of vertical curvature on transitways is dependent on the requirements for stopping sight distance as previously discussed and determined by algebraic sum of gradients (crest or sag) on the facility. Transitways introduced into the median of freeways will typically adhere to the existing vertical curvature. For design on independent transitways, K-values should be utilized to calculate the recommended minimum length of vertical curvature. These calculations assume a driver eye height of 3.5 feet (passenger car being most critical), an object height of 0.5 feet, parabolic curvature, and the presence of fixed source lighting for an urban environment. Table 2-14 indicates recommended K-values for length of transitway vertical curves over a range of design speeds and both crest and sag conditions.

Table 2-14. Transitway Vertical Curve Criteria (K-Factors)

Design Speed	Minimum K Factors*	
(mph)	Crest (stopping)	Sag (comfort)
60	190	80
50	110	55
40	60	35
30	30	15

*Ft/% change in algebraic difference in gradients

Source: (9)

2.2.6 Gradients

2.2.6.1 General

Recommended gradients should reflect current AASHTO (9) practice to insure both safety and uniformity of operation in concert with the capabilities of the vehicles authorized on the transitway. Consideration must be given to both maximum and minimum grades.

2.2.6.2 Maximum Grades

Table 2-15 shows recommended maximum grades for transitway mainlanes and ramps. On existing freeways with transitway retrofit, existing grades should be utilized. Values exceeding 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.

Table 2-15. Recommended Grades on Transitways

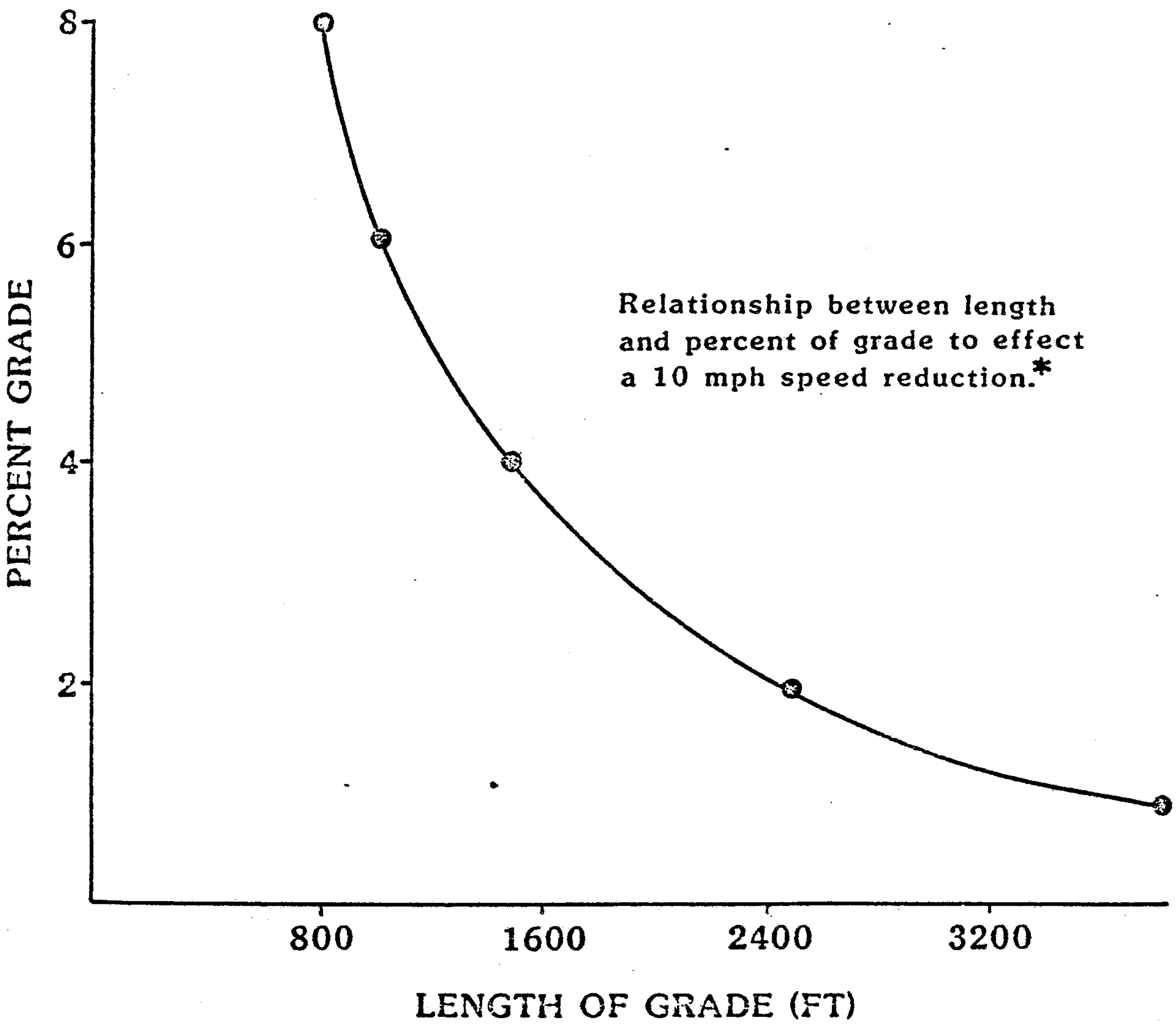
Transitway Segment	Maximum Grade (%)
Mainlane (50-60 mph)	6
Ramp (30-40 mph)	8

Source: (12).

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 2-16 illustrates speed degradation for a standard transit single unit bus "B" with an average weight to horsepower ratio of approximately 175 (13). As can be seen, long grades at or near the maximum should be avoided wherever possible, due to effect on operations.

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.



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

Figure 2-16. Speed Reduction of Typical Transit Vehicle Due to Length and Percent of Grade

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 (9). 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., the concrete barrier physically separating the transitway). Figure 2-17 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 Cross-Section

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). In addition, consideration relative to available space for location and cost effectiveness

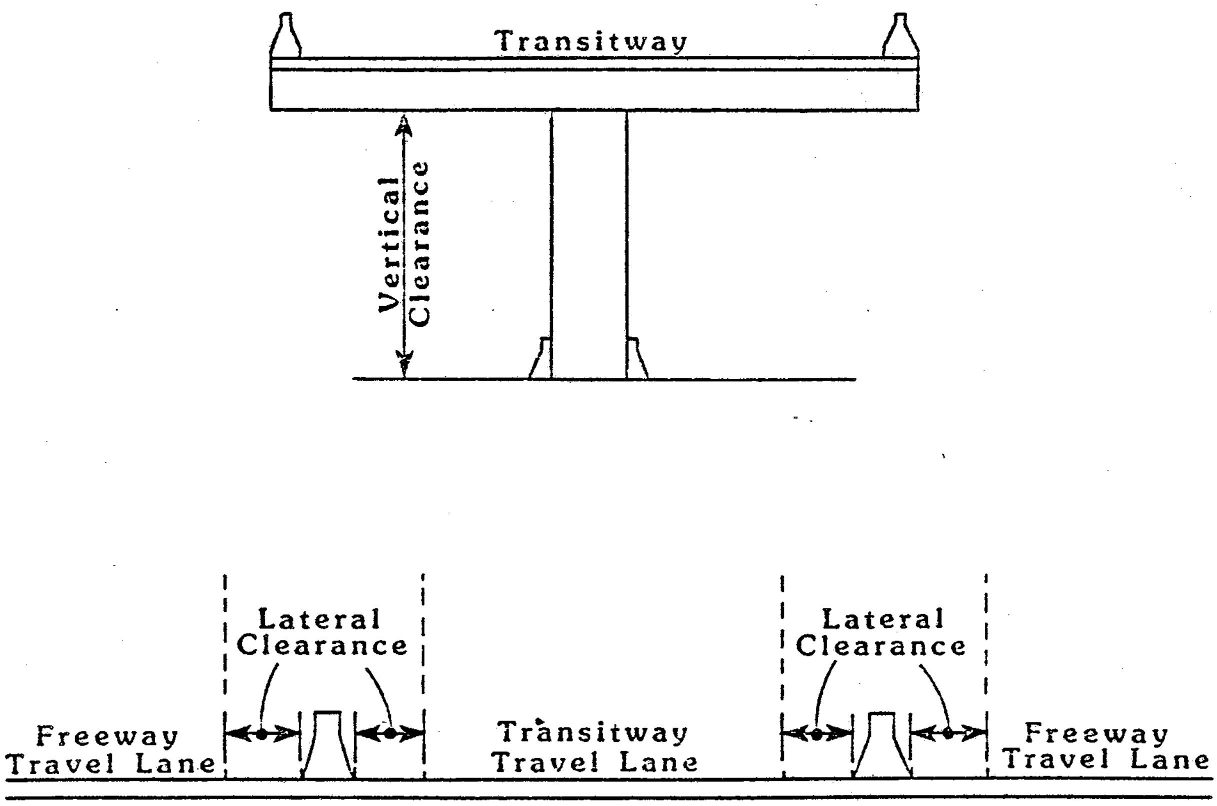


Figure 2-17. Vertical and Lateral Clearance Envelopes

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.

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 recent study (10), conducted to establish minimum total pavement widths for transitways which maintain acceptable operations under conditions of passing stalled vehicles, have been incorporated into the following recommendations for transitway cross-section.

2.2.8.2 Pavement Width

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 (14). 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 approximately 25 feet and an outer front wheel radius of 42 feet. This path reduces in width 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 2-16 shows recommended pavement widening for transitway mainlanes for various horizontal curve radii and design speeds.

Table 2-16. 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

*Two-lane, two-way operation only.

Source: (14)

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 2-17.

Table 2-17. 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: (14).

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 center mainlane to the barrier should be 8.0 feet, to allow for possible future expansion to two 12-foot mainlanes with 2-foot minimum clearance offsets to barrier each side.

On multiple lane transitways, the breakdown shoulder may be located in the center to separate each lane with two-way operation. This shoulder should desirably 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 2-18 to 2-20. Both desirable and usual minimum dimensions are shown for single lane versus multiple lane and at-grade versus elevated transitway facilities. Figures 2-21 and 2-22 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 pceph), two-way operation.

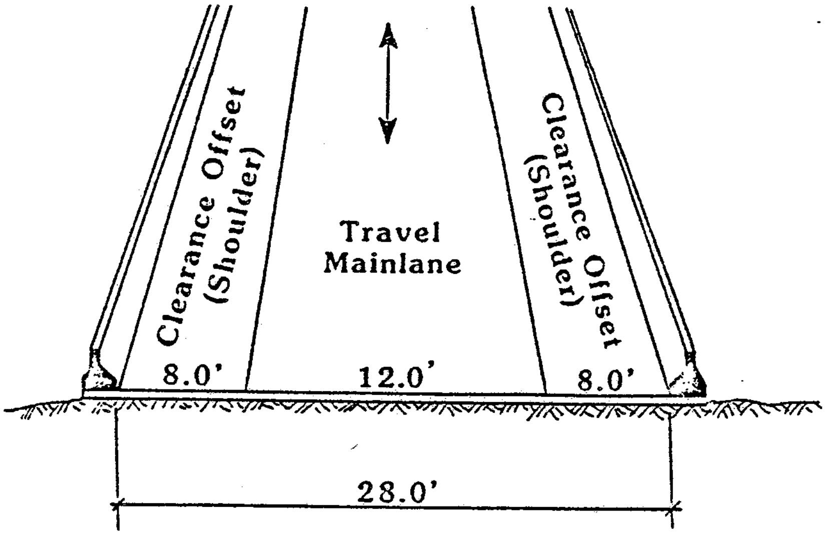
2.2.8.3 Acceleration/Deceleration Lanes

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.

Tables 2-18 and 2-19 summarize recommended deceleration and acceleration lane lengths for various combinations of transitway mainlane design speed and ramp exit/entrance design speeds. Desirable and usual minimum taper lengths to allow lane transition are included in the total recommended speed change distances (L_d, L_a).

The recommended length of these acceleration or deceleration lanes is based upon the previously specified nominal rates for single unit buses (acceleration = 2.0 mph/second, deceleration = 2.5 mph/second) and the performance curves given in Figure 2-15. Limits of the lane length and taper length are illustrated in Figure 2-23.

DESIRABLE TRANSITWAY CROSS SECTION
SINGLE LANE AT GRADE
ONE-WAY



USUAL MINIMUM TRANSITWAY CROSS SECTION
SINGLE LANE AT GRADE
ONE-WAY

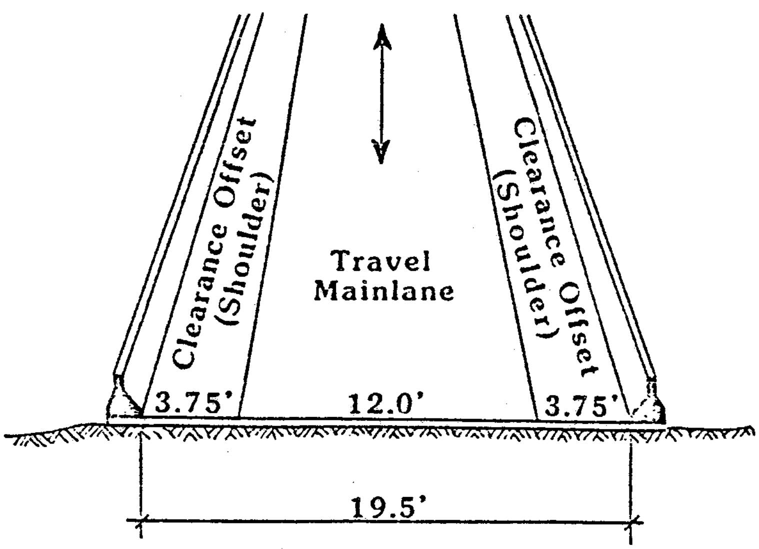
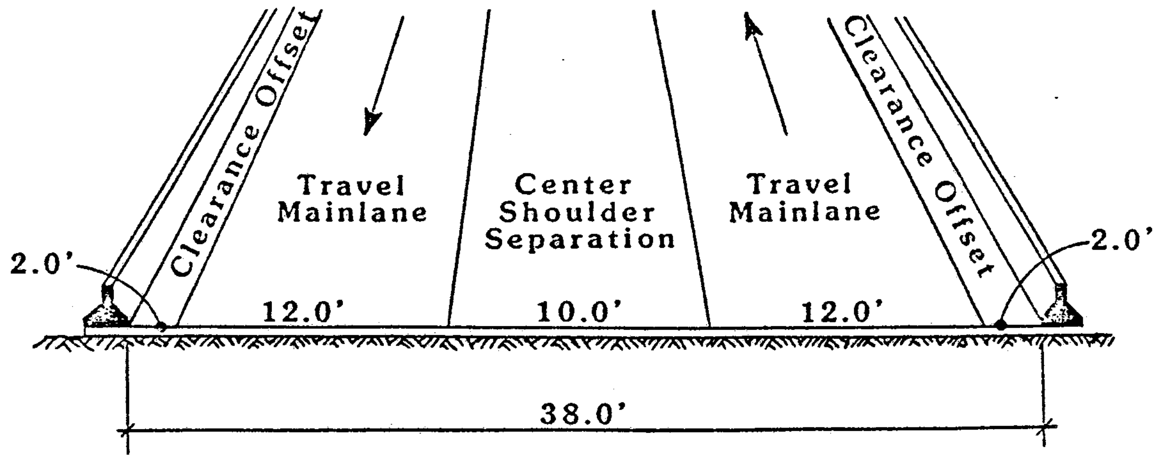


Figure 2-18. Total Mainlane Cross Sections For Single Lane, At Grade Transitway

DESIRABLE TRANSITWAY CROSS SECTION
MULTIPLE LANE AT GRADE
TWO-WAY



USUAL MINIMUM TRANSITWAY CROSS SECTION
MULTIPLE LANE AT GRADE
TWO-WAY

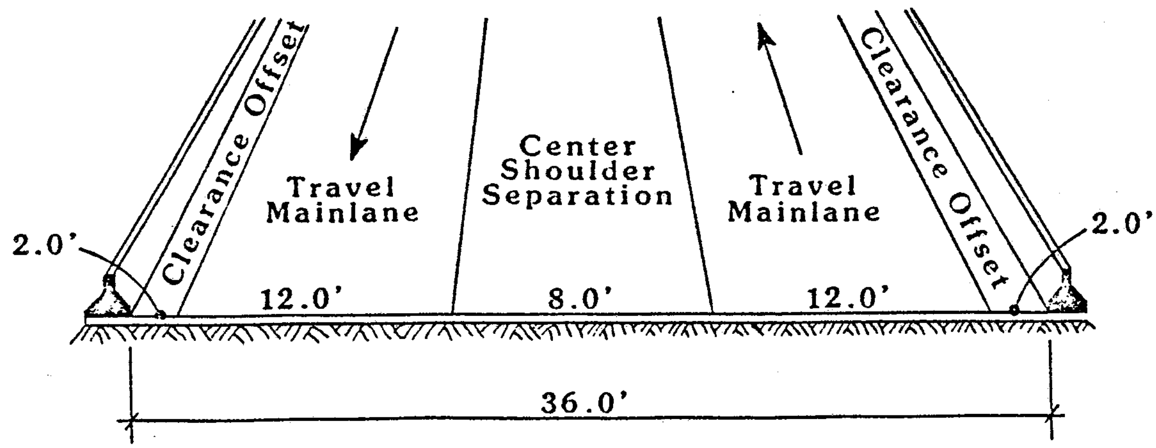
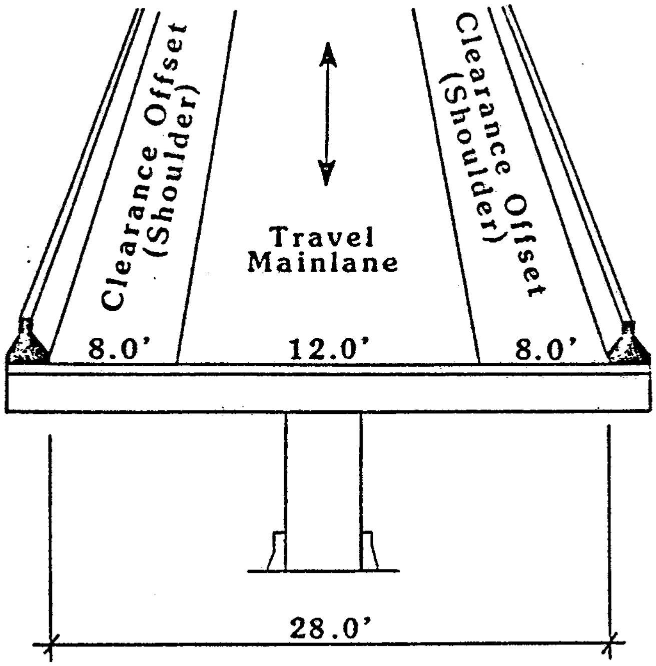


Figure 2-19. Total Mainlane Cross Sections For Multiple Lane, At Grade Transitways

RECOMMENDED TRANSITWAY CROSS SECTION
SINGLE LANE ELEVATED
ONE-WAY



RECOMMENDED TRANSITWAY CROSS SECTION
MULTIPLE LANE ELEVATED
ONE-WAY OR TWO-WAY

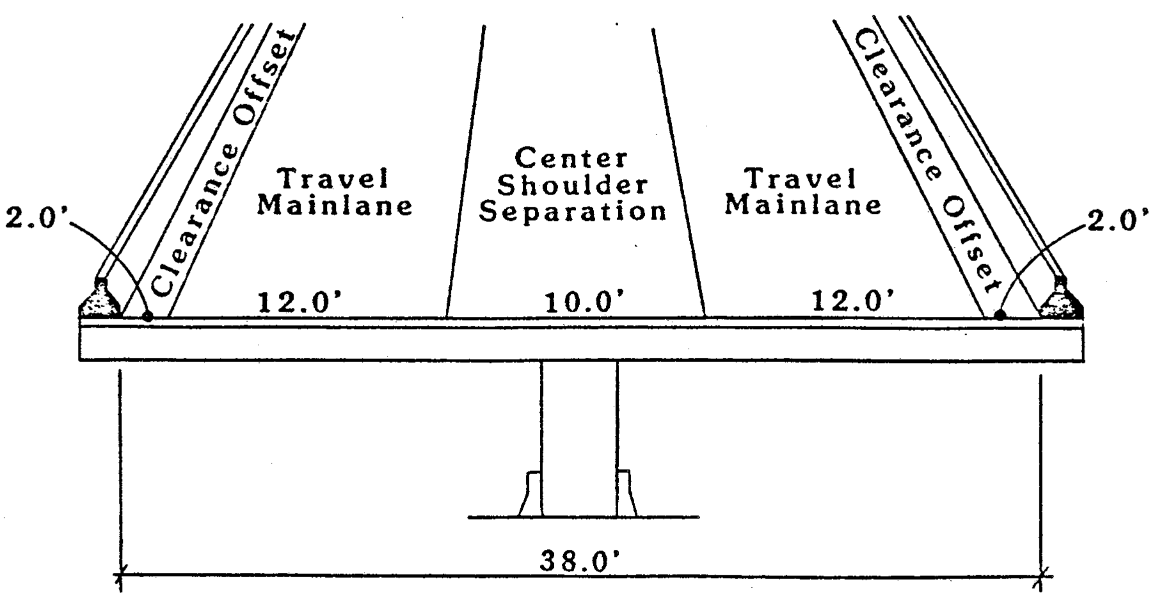


Figure 2-20. Total Mainlane Cross-Section For Single and Multiple Lane, Elevated Transitways

RECOMMENDED TRANSITWAY CROSS SECTION
MULTIPLE LANE AT GRADE
TWO WAY OR ONE-WAY REVERSIBLE

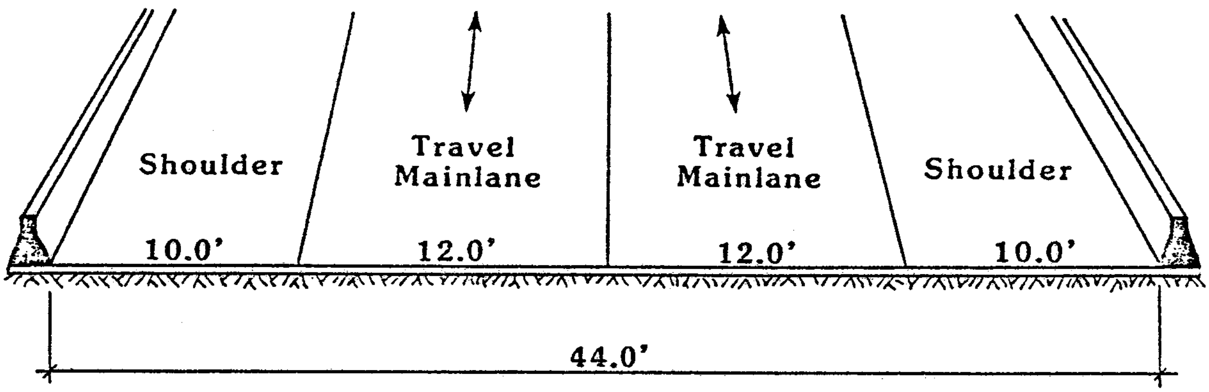


Figure 2-21: Total Mainlane Cross-Section for Multiple Lane, Unrestricted ROW With Two-Way Operation

MINIMUM TRANSITWAY CROSS SECTION
MULTIPLE LANE AT GRADE
ONE-WAY, RESTRICTED ROW
TWO-WAY, LOW VOLUME OPERATION

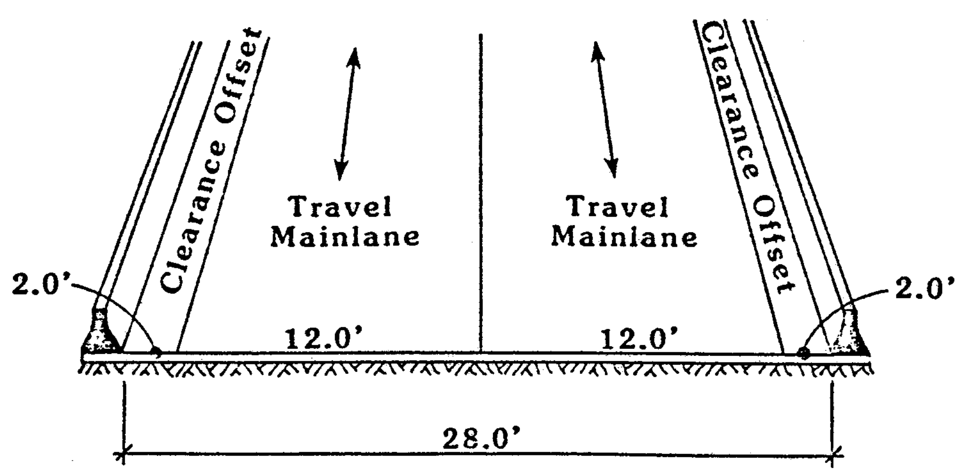


Figure 2-22: Total Mainlane Cross-Section for Multiple Lane, Restricted ROW With One-Way Operational or Low Volume, Two-Way Operation

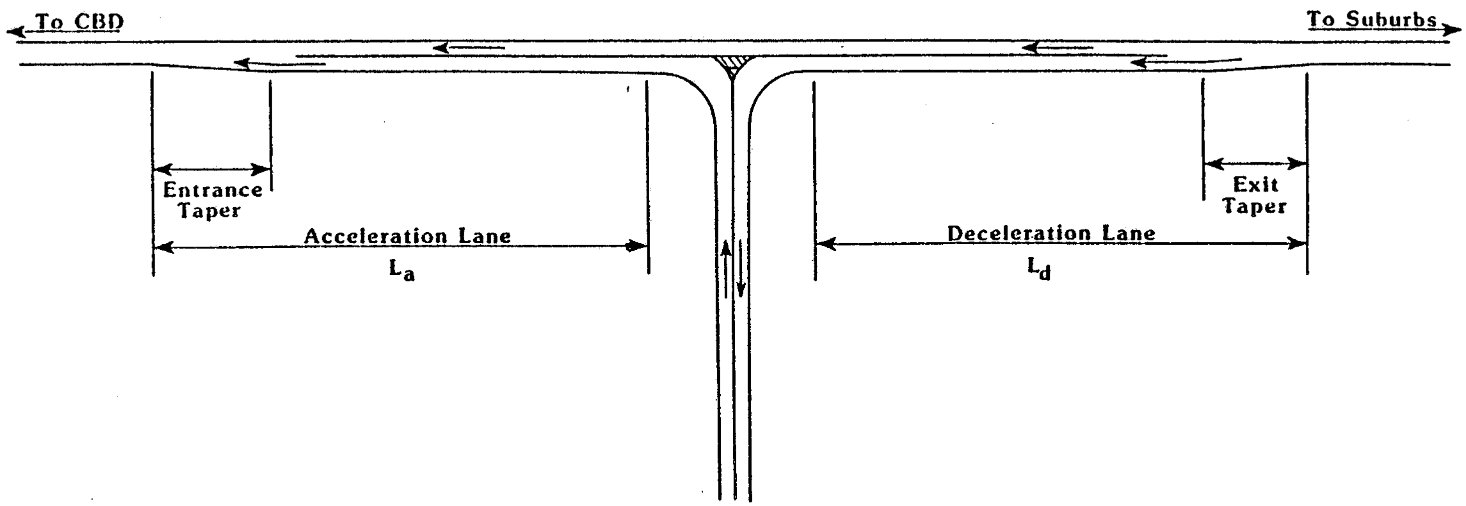


Figure 2-23. Acceleration and Deceleration Lane Length With Taper Limits

Table 2-18. Recommended Lengths (L_d) for Deceleration Lanes

Transitway Mainlane Design Speed (mph)	Length of Deceleration Lane (ft) for Ramp Exit Design Speed (mph)				
	0	10	20	30	40
40	320	300	240	140	--
50	500	480	420	320	180
60	720	700	620	520	400

*Desirable taper - 30:1; usual minimum taper - 20:1

Table 2-19: Recommended Lengths (L_a) for Acceleration Lanes

Transitway Mainlane Design Speed (mph)	Length of Acceleration Lane (ft) for Ramp Entrance Design Speed (mph)				
	0	10	20	30	40
40	400	380	300	---	---
50	900	870	800	500	---
60	1600	1550	1500	1200	700

Desirable taper - 50:1; usual minimum taper - 20:1

The values shown represent acceleration and deceleration at 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.

2.2.9 Special Features

2.2.9.1 Median Slip Ramps

Where temporary 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 distance. Figure 2-24 illustrates a typical design layout.

2.2.9.2 Intermediate Elevated Intersections (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 "T" or "cruciform" configuration with an approximate 90° angle between transitway mainlanes and ramps. A plan and profile design is shown in Figure 2-25. 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 and appropriate lengths of speed change lanes as previously discussed applied 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 2-26 presents an example of this concept. As can be seen, the terminal openings are flared and widened for 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.

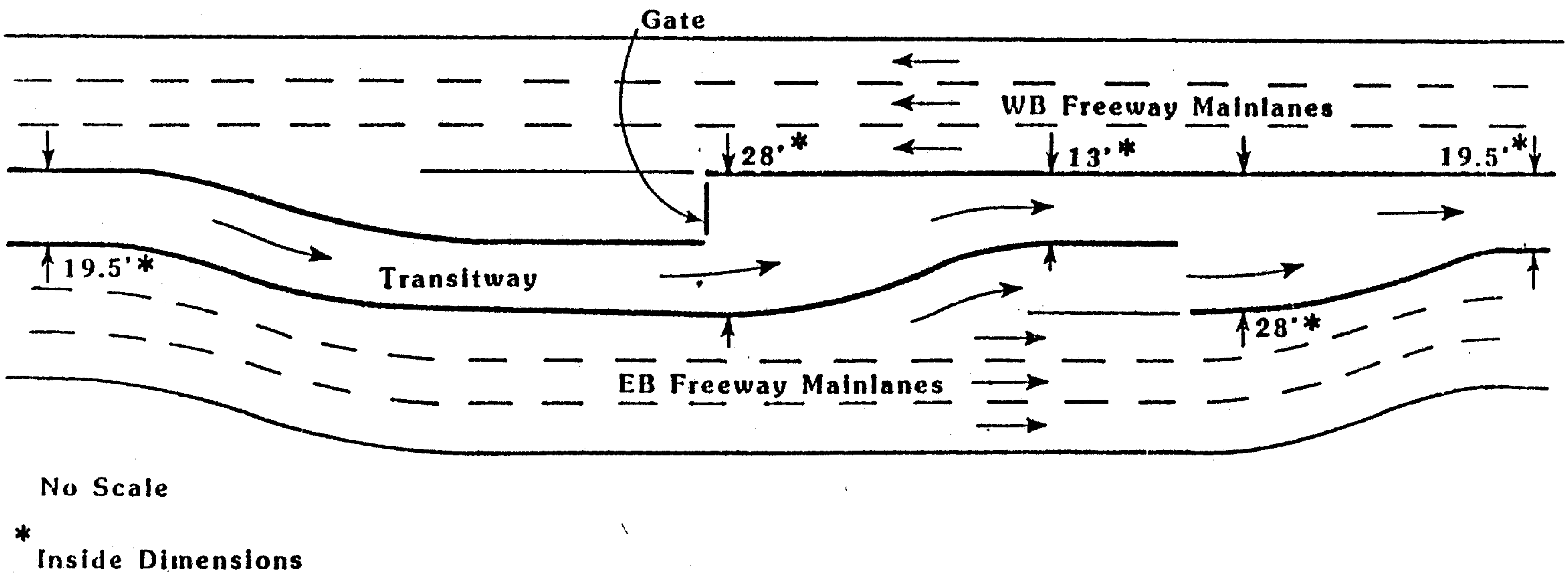


Figure 2-24. Schematic Layout of Median Slip Ramp Intermediate Access

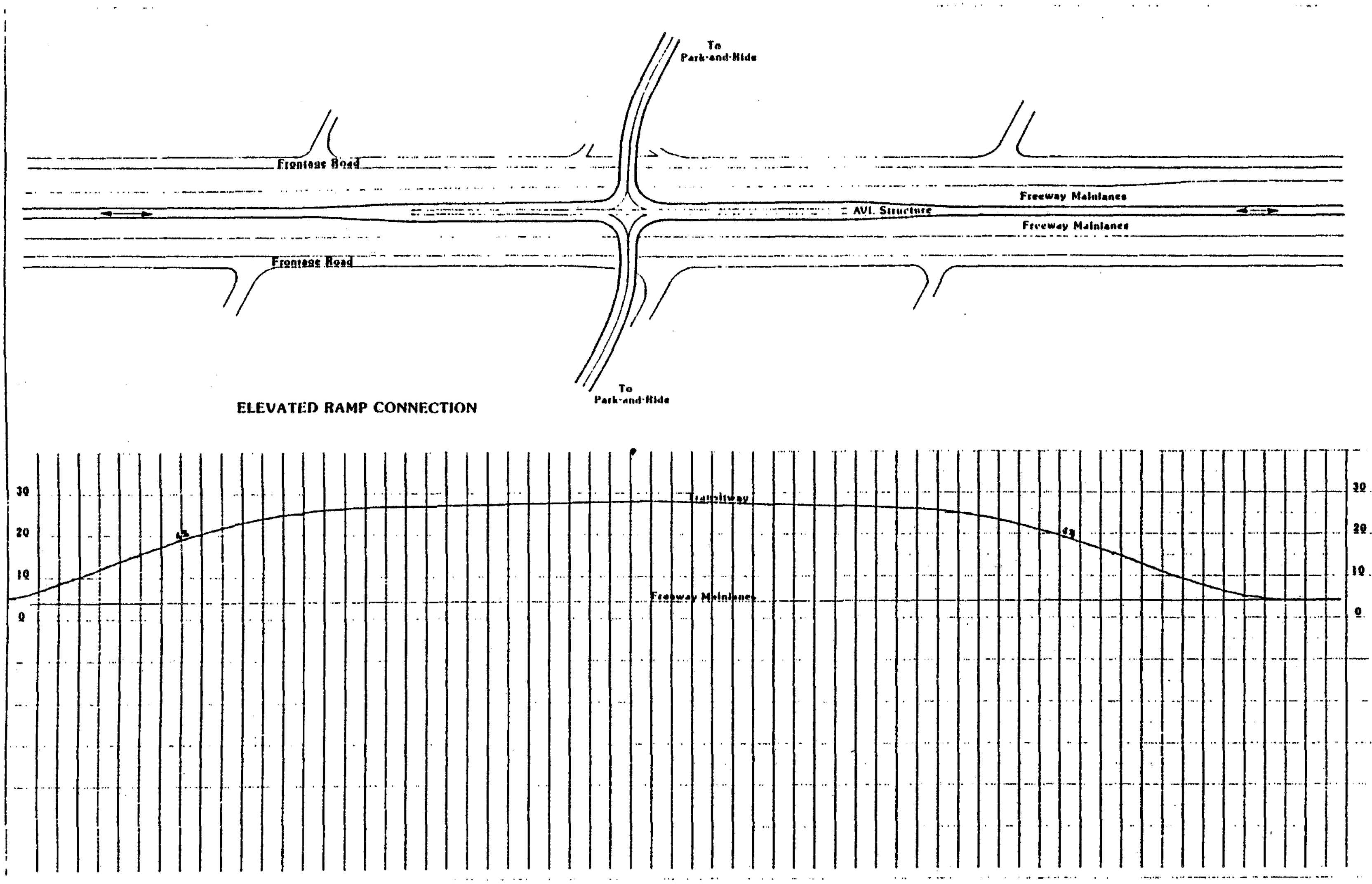


Figure 2-25. Example Design of Elevated Intermediate Access Interchange

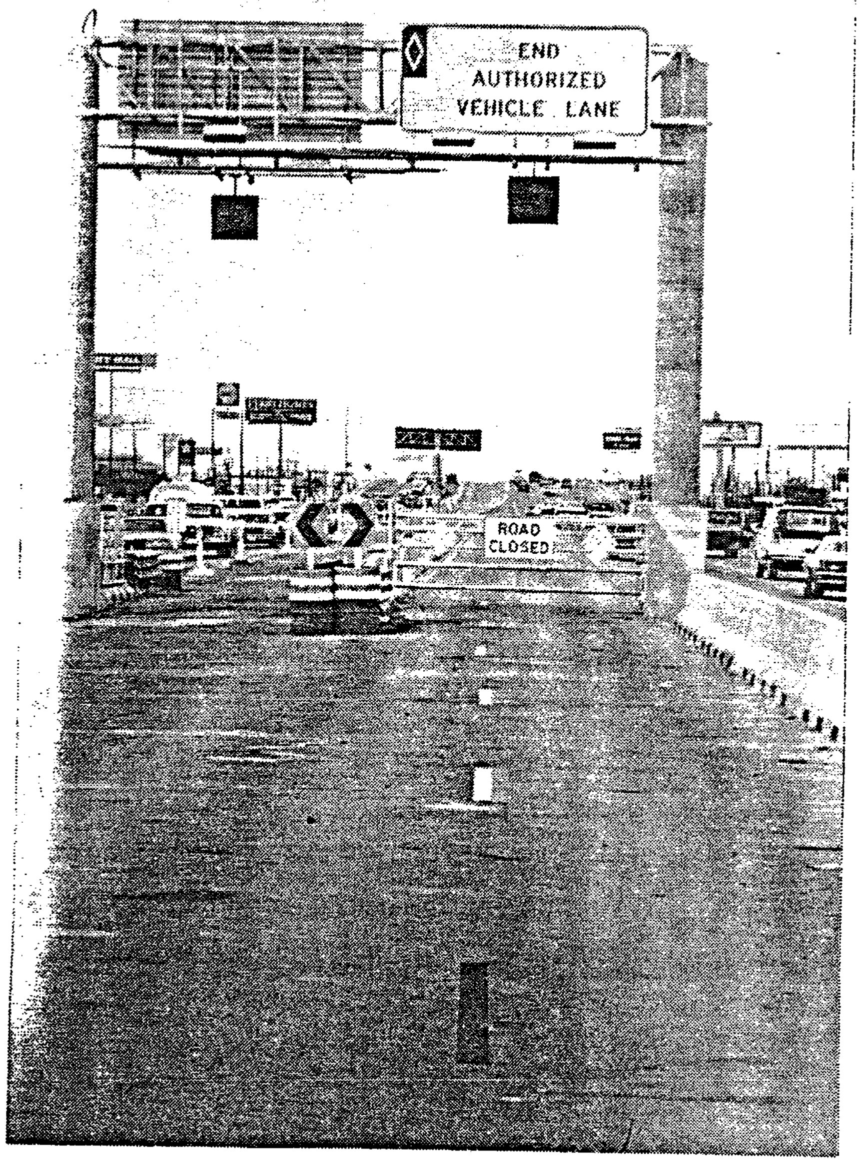


Figure 2-26. At Grade, Median Terminal Connection

Transitway terminal connections may also be accomplished with elevated ramp structures which "flyover" the at-grade freeway from median transitway mainlanes. Authorized vehicles enter and exit the transitway directionally from freeway mainlanes, 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. Figure 2-27 illustrates one design for an elevated ramp terminal connection.

2.2.10 Summary

Table 2-20 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 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.

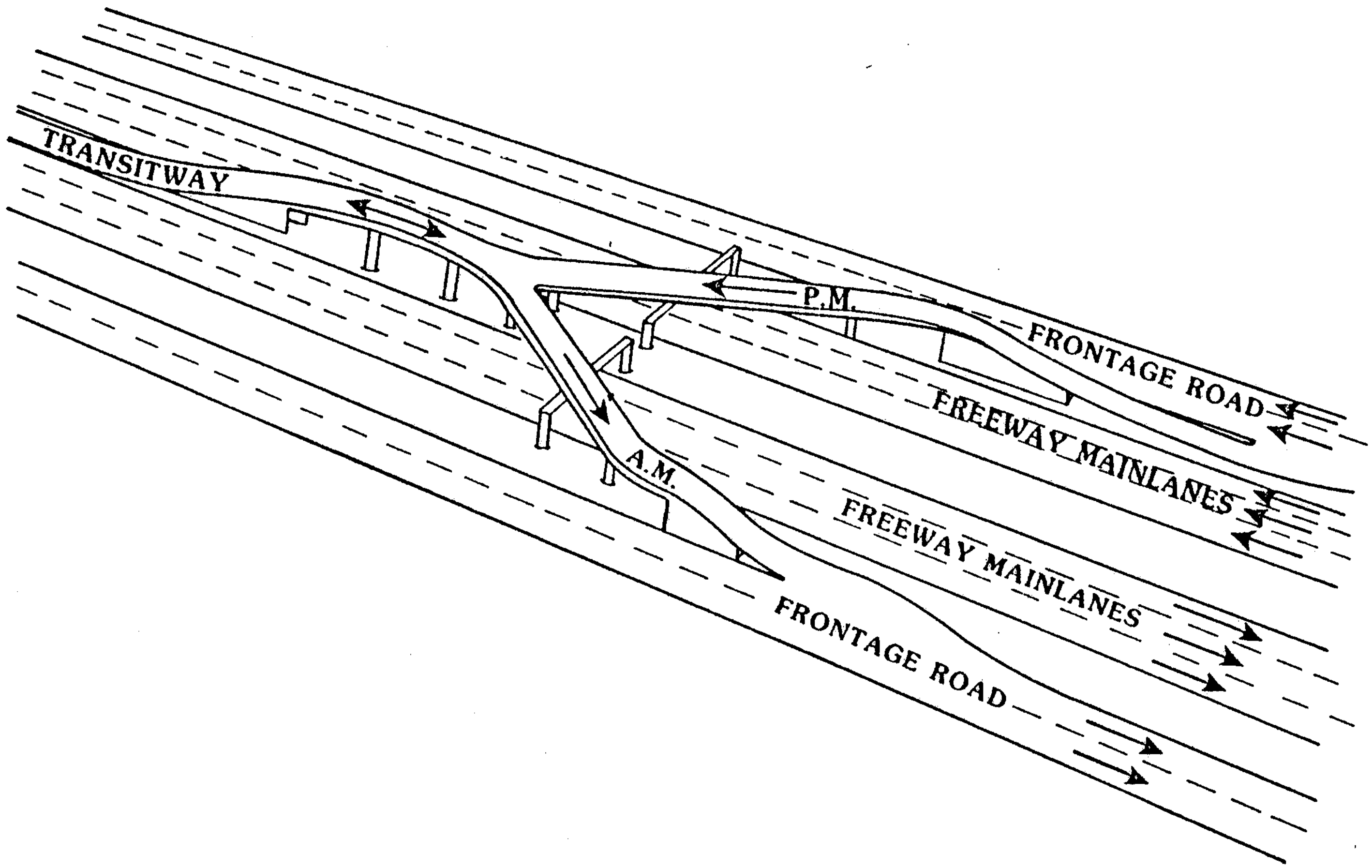


Figure 2-27. Elevated Flyover Terminal Connection

Table 2-20. Summary of Design Criteria

Criteria (Minimum or Maximum)	Mainlane		Ramp	
	Usual	Desirable	Usual	Desirable
Design Speed (mph)	40	60	30	40
Alignment				
Stopping 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=35 sag	k=190 crest k= 80 sag	k=30 crest k=15 sag	k=60 crest k=35 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	2.0	8.0
Multiple	8.00	10.00	8.0	10.0
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

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 might be exercised at a low level with on-site personnel and passive signing/delineation. Maximum control might involve sophisticated surveillance and detection with complete computer integration and dynamic, real-time signing/delineation. The level of control would depend upon the demand and extent of any particular transitway system. Operational control might even evolve from low to high level as the final transitway design is implemented in stages.

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 along with policy and procedures for access authorization. Enforcement and incident response will also be addressed and examples of typical transitway signing presented.

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 in implementation decisions.

2.3.2 Surveillance, Communication, and Control

2.3.2.1 General

Surveillance, Communications, and Control (SC&C) refers to automated 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 is traffic surveillance. The provision of information to the motorists through signs, delineation, signals and/or auditory means is communications. The application of traffic restraints on direction of flow by signs and signals is traffic control.

A typical SC&C system provided on a transitway consists of on-site personnel with radio communication, or electronic sensors in the pavement connected by cable to a central computer to measure traffic conditions. The computer will communicate with and control users of the transitway by devices placed over the transitway and access ramps. These devices include programmable message signs, lane control signals, ramp metering signals, vehicle authorization gates, traffic signals and dynamic signs. Verification of system operations and assistance with other functions such as enforcement and maintenance may be accomplished manually with on-site personnel or by Closed Circuit Television Systems (CCTV).

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. Perhaps more importantly, SC&C systems are designed to detect and respond to disabled vehicles, wrong-way operations and unauthorized vehicles (15).

A partial or full blockage of a transitway in a narrow cross section can occur as a result of mechanical failures or driver error that results in 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 AVL is blocked, the delay cost per minute increases. As shown in Figure 2-28, a lane carrying 6000 persons per hour will be delayed 100 person minutes for the first minute the lane is blocked. The second minute of delay will add an additional 300 person minutes and for the fifth minute of the delay, 900 person minutes.

2.3.2.3 Types of Systems

Two types of SC&C systems have possible application: (1) a system with Satellite Control Centers operating independently; and (2) a system with a Central Control Center. Both designs can be implemented in phases and provide backup capability in case of equipment outage. This distributed logic design allows data processing and control decisions at several levels

Length of time lane blocked in minutes	Additional delay for each time interval in person-minutes	Cumulative delay for total time blocked in person-minutes
0	0	0
1	100	100
2	300	400
5	900	2500
15	2900	25000

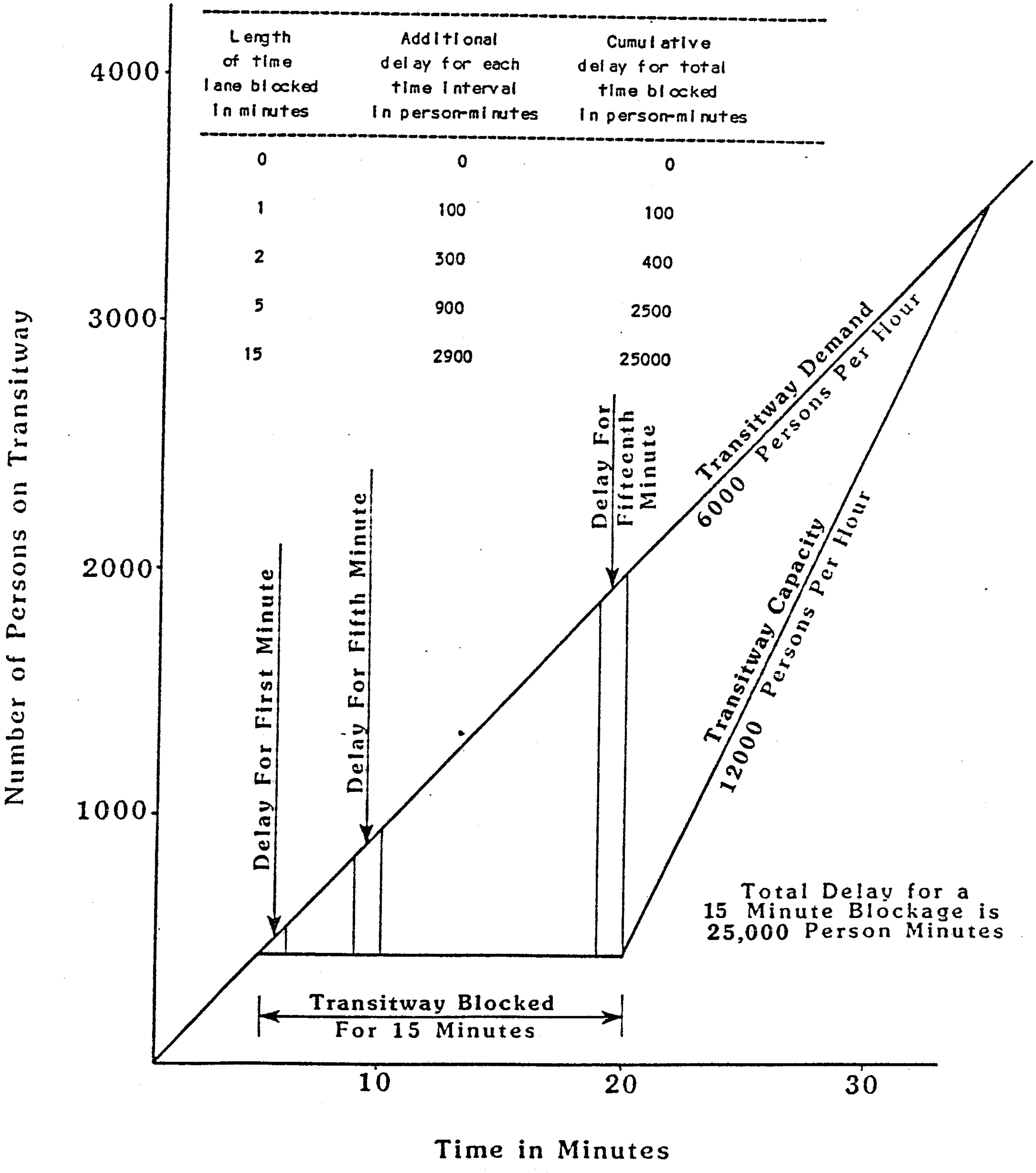


Figure 2-28: Effect of Lane Blockage

which reduces cost and extends system reliability. A typical hierarchy is as follows:

1. The communications and control devices can be operated manually in the field from a controller installed near the device. This level of control could be stage one of an operations plan and used for back-up in the event of malfunctions in the computer or data transmission equipment to the Satellite Control Center (SCC). The design is limited with regard to effective incident and other traffic management and requires a considerable number of personnel. This design should be applied only as an interim measure while stages 2 and/or 3 discussed below are implemented.

2. The SC&C system can be operated manually or automatically by controllers located in a Satellite Control Center adjacent to a transitway. The data from the surveillance systems (closed circuit television and electronic detection) are processed at the Satellite Control Center. This could be the second stage of an operations plan, or back-up to the Central Control Center.

3. The SC&C system can be operated manually or automatically by the central controller at the Central Control Center by communicating with the Satellite Controllers. The processed data from the Satellite Control Center are transmitted to the Central Control Center for display and monitoring functions.

The Central Control Center (CCC) is a combination of automatic data processing, display and control, and of manual surveillance and control. The operators can monitor the data systems and traffic operations by the computer system printouts, dynamic display maps, and video displays.

The CCC may monitor the operations and controls on several transitways. The CCC can display traffic operations in real time on closed circuit television, and operations status information on maps with dynamic displays, interactive graphics and computer cathode ray tube (CRT) monitors. The CCC can monitor actions taken by the computer system in response to traffic conditions sensed by the electronic surveillance devices.

The operators of the CCC can use the visual and electronic surveillance systems to determine if appropriate action is being taken by the computer programs. The operators can supplement, replace, or override the control decisions taken by the computer programs. The operators can also dispatch appropriate response services to any transitway.

The SC&C System can record the actions that are being taken by the computer system, the CCC operators, and the deployment/operations work force. The CCC operations can record traffic conditions, and prepare reports and summaries of daily travel characteristics.

The CCC computer can monitor and note the condition of all electronic equipment in the field, Satellite Center and Central Control Center. The operators can note the equipment failures and prepare work orders for the repairs. The operators can develop priorities for the maintenance activities and prepare schedules for the repairs.

The CCC can also assume responsibility for the security of the transitway system. The CCC can have radio communication with a central enforcement dispatcher and on-site patrol vehicles assigned to each transitway, as well as the operations crew and maintenance crews.

The Central Control Center-Satellite Control concept is recommended and where applicable provides several advantages to operations management of a transitway.

Advantages of central control include:

- It can be readily determined if equipment and personnel from other transitways should be deployed.
- Response to incidents will be more systematic and consistent throughout the transitway system.
- Expertise of central control supervisors will be enhanced by the opportunity to observe and direct the clearance of a larger number and variety of incidents.

The costs of a small transitway system would favor the Satellite Control Center concept. For one transitway, the Central Control Center could be completely eliminated without effecting operations.

2.3.2.4. Control Center Equipment

The equipment normally found in control centers consists of the computer and its related peripheral equipment, communication consoles, display components, and equipment for dispatching emergency and maintenance vehicles to the problem locations. Figure 2-29 illustrates an example of a control center layout. Table 2-21 lists the required equipment discussed in the following text.

Computer

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

1) Monitors Status of Traffic Operations. The center's computer will have the current status on the traffic volumes and speeds by type of vehicle using the transitway.

2) Activates Incident Alarm System. A satellite computer monitors the detection system for probable incidents that affect operations and/or safety. If an incident is detected, the satellite computer activates controls to display warnings to the transitway users, and notifies the central control computer of the situation.

The central control computer activates the alarm system to alert the operator and provides traffic operations status reports. The operator can use the CCTV Systems, the radio communications system or other surveillance capabilities to verify the incident, and to determine the course of action to return the transitway to normal operations.

3) Activates Wrong Way Movement Alarm. The procedure for detecting and responding to a probable wrong way operation is the same as that for detecting incidents in the same direction of flow. A different computer program is used to monitor the detection system for this function, and a different set of controls and warnings are displayed.

The central control computer activates the wrong way movement alarm and the operator takes appropriate action to verify the operation and to respond to the situation.

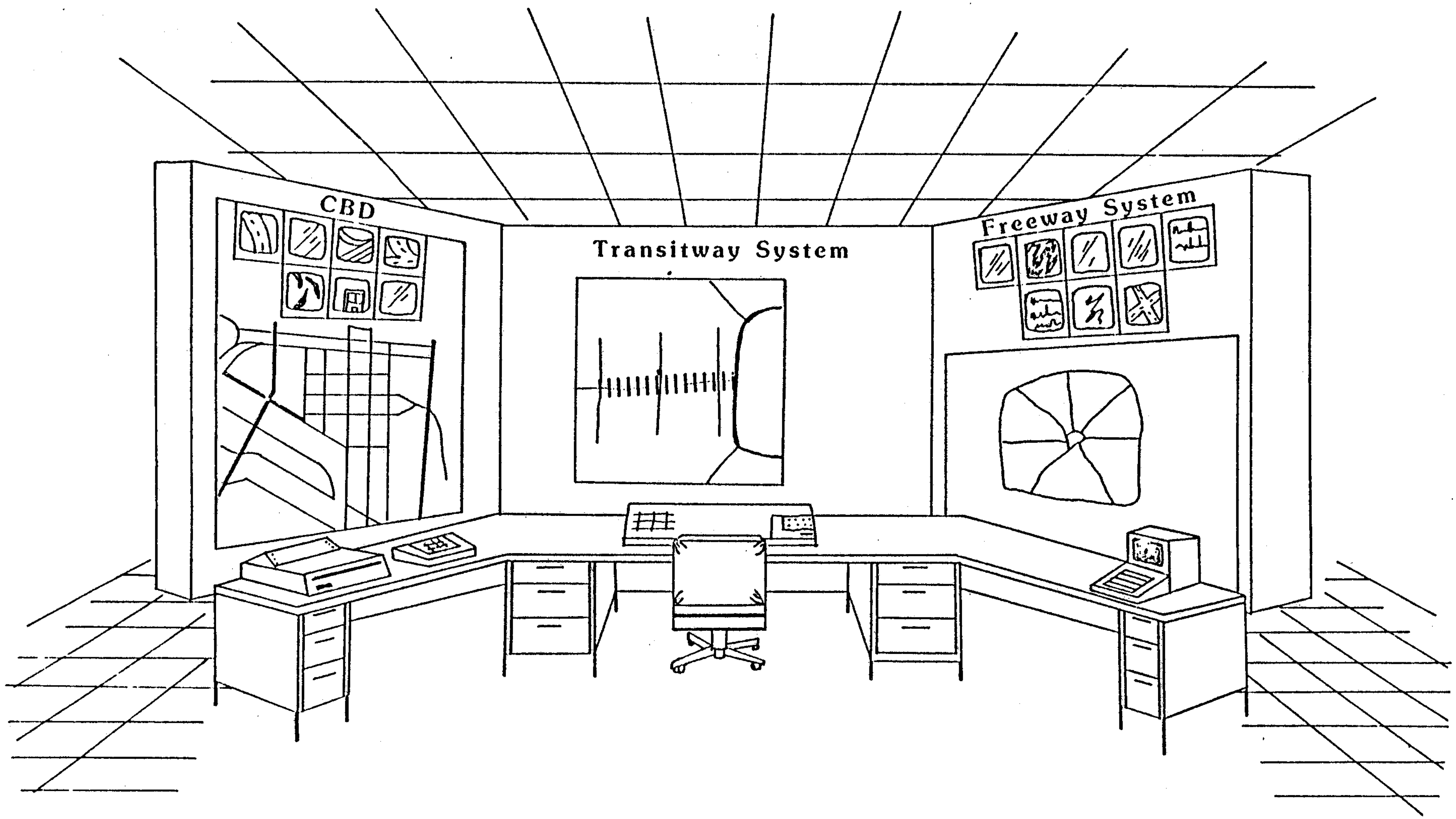


Figure 2-29. Example of a Control Center Layout

Table 2-21. Surveillance, Communications and Control System Equipment For A Typical Central Control Center

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 switches 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 switches for display map	Computer Interface equipment	Radio systems
Disc Drive	Camera control systems with AVL		Control switches for computer reports		
Tape Drive	Switching system				
Line Printers	Video cassette recorders		Alarm for monitoring traffic conditions		
Character Printers					

4) Monitors Status of Signs and Signals. All of the electronic equipment in the field will be monitored for proper operation. If a probable malfunction is detected, the central control computer will record the information on hard copy on one of the printers and update a report that is available to the operator on the CRT.

5) Commands Sign Messages. The central control computer can command the changeable message signs by addressing the predesignated codes or by formatting a unique message.

6) Commands Lane Control Signal and Dynamic Signs. The central control computer can change the status of the lane control signals used to convey messages to the transitway users.

7) Controls Access to Transitway. If access facilities are provided with electronic authorization systems that use automatic gates or ramp metering signals that control demand, the central computer can override local controllers to allow or deny entry to the transitway.

Closed Circuit Television (CCTV)

The closed circuit television system receives video signals from cameras placed on 40 foot minimum height poles adjacent to the transitway at approximately 1 mile intervals. The CCC can access any camera through a switching system operated by the personnel in the control room. Camera locations can be displayed simultaneously from the transitway on monitors installed in the wall. The position of the cameras and the functions of the telephoto lens can be adjusted with a camera control system on the console. Video cassette recorders can be used to record the signals from any camera.

The CCTV is an important element of the surveillance system. Its primary function is verification of the electronic surveillance system. It also serves other important functions which are listed below:

1) Verification of Electronic Detection. Incident detection algorithms used to detect the full or partial blockage of the transitway is subject to error because of the spacing of detectors, the malfunctions of detectors, and the variations of traffic conditions. The CCTV enables the algorithm to be biased in the direction of early detection with a higher error of false calls

instead of a late detection with a lower error of incidents not detected. False calls can easily be confirmed by the visual surveillance.

2) Confirmation of Equipment Operation. The SC&C System should have the capability to confirm the sending and receiving of commands to signs and signals. The CCTV provides an additional check on the proper operation of the device. Also, the operation of automatic gates, the position of manually operated gates and the operation of vehicle sensors can be monitored quickly by one 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 that is useful in 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 or environmental conditions undetected by electronic surveillance may dictate the opening or closing of a transitway. The operator with visual surveillance of a transitway may be able to make these decisions directly or assist the field crews in assessing the conditions.

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

6) Training Transitway Users and Operators. Video tapes of signs and signals, proper and improper vehicle operations, and emergency procedures can be used to instruct persons that are authorized to use a transitway and the agency personnel that are charged to operate, enforce and maintain a transitway.

Dynamic Display Map

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

The map can provide the operator with real time information in an easily recognizable format for an entire transitway network. Problem areas can be quickly identified, equipment failures displayed, and the general situation can be continuously monitored, while the operator uses the CCTV and computer systems to examine specific locations for more detailed data.

Control Panel

The control panel provides the operator with direct input to the computer, instead of the standard keyboard with coded inputs. This approach simplifies the actions of the operator, and reduces the time required to make control commands.

The control panel will perform four basic functions:

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

2) Activate the display map for its various functions;

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

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

Communication System

Data can be received from the Satellite Control Centers by one or more communications systems. Four communications systems have been considered: (1) microwave; (2) coaxial cable; (3) fiber optic cable; and (4) leased telephone lines. Regardless of the system selected, 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 room with environmental controls to prevent overheating and to reduce noise.

2.3.2.5 Field Equipment

Various types of equipment may be installed in the field to expedite transitway operations. The following equipment systems should be considered in the planning and design of transitways.

Field Communications Subsystems

Field equipment, which is to be interconnected with the control center equipment with communications cable, should have line amplifiers placed at a spacing of approximately 2000 feet or less. Power supplies with battery backup capability may be installed as required to power the line amplifiers. The power from the power supplies would be distributed to the other amplifiers via communications cable.

At field cabinets where detectors or lane control signals are located, the communications cable can be connected to a modem which demodulates the signals for input into a multiplexor (serial to parallel converter). The multiplexor is then connected to the detectors and lane control signals.

Changeable Message Sign Subsystem

Changeable message signs (CMS) may be employed at the terminals of a transitway and possibly at specified intermediate locations to convey to the transitway users the status of the transitway (i.e. open, closed, congested, accident, etc.). The CMS typically displays a message of three lines with twenty characters per line in 12 inch or 18 inch high letters. The CMSs are generally driven by a CMS microprocessor controller in a field cabinet. Most CMS controllers have their own modem and connect directly to the coaxial cable. Manual control of a specific set of messages is also possible at the CMS controller.

Lane Control Signal Subsystem

Lane control signals (LCS) may be utilized along a transitway. These should be located at terminals and at approximate 6000 feet 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 (green downward 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 yellow downward arrow).

The lane control signals are driven by a controller in a field cabinet. The controller is commanded by a multiplexor (MUX) which is connected to the communications cable via a modem. Manual control of the LCS will be provided by switches.

TV Surveillance Subsystems

TV cameras may be utilized on a transitway. These should normally be located at each terminal and at intervals of approximately 1.0 mile. The TV cameras should furnish visual surveillance to verify that the CMS, LCS and gates at each terminus are in their correct mode. They also can provide visual confirmation of free-flow conditions, incidents, or congestion along a transitway as well as the freeway.

The cameras should be mounted at a minimum height of 40 feet. The following remote control features should be provided for each camera: pan, tilt, zoom, focus, iris control, and windshield wiper. The TV cameras should be connected to a video modulator and then connected to the communications cable. The camera controls are connected to the communications cable through a receiver and a camera controller.

Loop Detector Subsystem

Loop detector stations should be installed on the transitway at terminals and approximately every 1.0 mile. Each station should consist of 3 loops, each 6 feet by 6 feet at approximately 30 foot spacings. The time-on time-off data from these detectors can be used to determine volume, speed, direction of flow, and vehicle classification. The loop detectors are wired to detector amplifiers in the field cabinets. These amplifiers are then connected to the slave multiplexor and to the communications cable through the modem.

Barrier Gate Subsystem

Under initial, temporary, or phased transitway operation, manually operated gates may be used to control entry into the transitway. More sophisticated, remote controlled barrier gates may be added to the system at a future date as operation is extended.

Backup Timer Subsystem

Precision standby timers (SBT) may be provided to control the lane control signals and changeable message signs in the event communications is lost with central control or satellite control. These timers can operate on a time-of-the-day, day-of-the-week basis.

Equipment Failure Redundancy

During normal operation of the system, a minicomputer should directly control the lane control signals and should process the detector data. The changeable message signs should be supervised by the minicomputer during normal operations. The minicomputers will usually be located at the SCC. There are several steps of system failure and thus different levels of redundancy backup. The normal and backup levels of operation are summarized in Table 2-22.

Table 2-22. Summary of Levels of System Operation

Component	Controlling Device at Different Levels of Operation			
	Normal	Level 1 Backup*	Level 2 Backup**	Level 3 Backup***
LCS	Minicomputer	SBT	SBT	Manual Switch
CMS	Mini/CMS Controller	CMS Controller	SBT	Manual Switch
Detectors	Minicomputer	None	None	None
TV	TV controls	TV controls	None	None

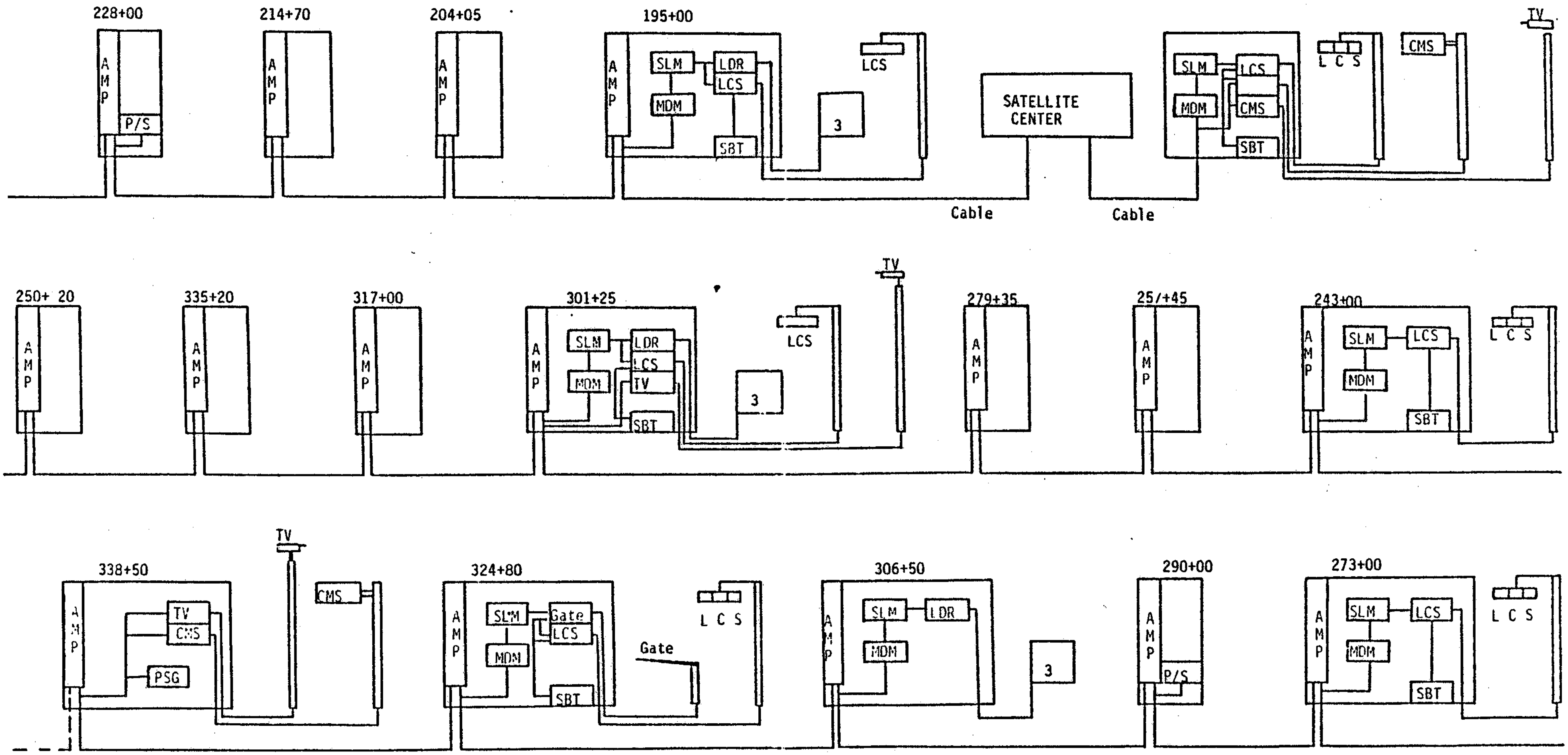
*Level 1 backup in effect if minicomputer and/or master multiplexor fail.

**Level 2 backup in effect if communication cable fails.

***Level 3 backup in effect on demand or if standby timers fail.

2.3.2.6 Summary

Figure 2-30 presents an example of a field layout for a surveillance, communication and control system on a transitway. Figure 2-31 illustrates the functional diagram associated with a field controller.



AMP - Line Amplifier
CMS - Changeable Message Sign
LDR - Loop Detector
LCS - Lane Control Signal

MDM - Modem
P/S - Power Supply/Battery Backup
PSG - Pilot Signal Generator

SBT - Standby Timer
SLM - Slave Multiplexor
TV - Television Modulator

Figure 2-30. Example of Transitway SC&C System Design

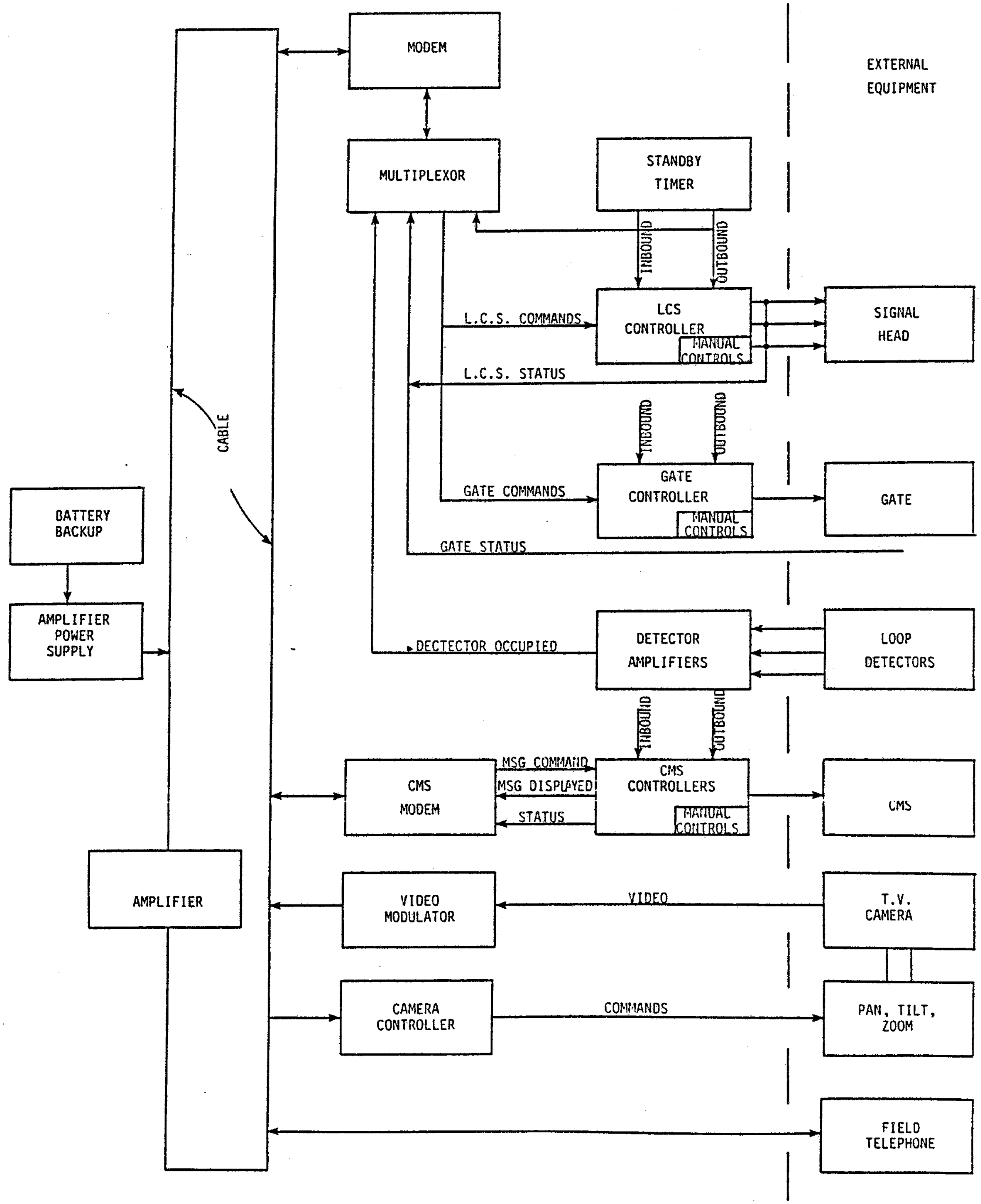


Figure 2-31. Field Controller Equipment

2.3.3 Access Authorization

Because of the special purpose of a transitway, only authorized vehicles whose drivers have participated in a special driver training program should be allowed on the facility. To ensure 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 operating agency should only authorize certain high occupancy vehicles to use the transitway. The following vehicles are frequently considered eligible for transitway use if vehicle and driver requirement 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) designed to carry a predetermined number of passengers, including the driver, and approved by the operating agency.

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" 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. The following requirements might be specified by the Management Team before vehicles other than public buses are authorized to use the transitway (16):

1. If a group of persons with a van designed to carry 8 or more passengers desires to operate on the transitway, a minimum of 8 passengers, including the driver, must be registered in the vanpool at the time of authorization. A minimum number of passengers, as determined by the Management Team, must ride in the vanpool while it

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 such as, vehicle liability insurance with not less than $250,000 coverage per person for bodily injury, not less than $500,000 coverage per occurrence, not less than $100,000 coverage for property damage.

3. For each vehicle and driver, 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 on (a) the lower left corner of the front windshield just above the State inspection sticker, and (b) the lower right corner of the back window.

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 Transitway Management Team.

7. An authorization fee, as determined by the Management Team, may be assessed on each vehicle requesting authorization to use the lane.

Requirements for Driver Certification may be developed by the Management Team. To be certified to drive an authorized vehicle on the transitway, every driver (including substitute drivers) might be required to (16).

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.

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 Management Team). 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 responsbility incurred in removing the vehicle to a safe place. Procedures to follow in the event of a vehicle breakdown should be specified by the Mangement Team. 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 Management Team, with representatives from all involved agencies, should determine the access authorization requirements specific to a particular transitway.

2.3.4 Incident Response and Enforcement

Once an incident is detected, the key to minimizing delay to transitway vehicles is the speed with which the incident is cleared. Effective incident reponse 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 Transitway Management Team 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 (10). 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 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 (17).

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 jurisdicitons 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 Transitway Management Team may serve in this capacity. At a minimum, the Transitway Team should coordinate incident response with existing groups or freeway incident management personnel, if any.

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 facilites 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.

As a minimum, enforcement personnel should be located at transitway terminals for identification, apprehension, and citation of violators of the transitway lane restrictions. These individuals would also be strategically located for incident response.

2.3.5 Signing and Delineation

Critical to safe and efficient transitway management is the proper application of traffic control devices on transitway mainlanes and connections 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.

Regardless of the type of traffic devices needed to supplement the basic design features and to insure intended operation on the transitway facility, the signs will need to be in accordance with the MUTCD and full and complete attention should be given to the following five basic considerations (18).

1. Design of the device should assure that such features as size, contrast, colors, shape, composition, and lighting or reflectorization are combined to draw attention to the device; that shape, size, colors, and simplicity of message combine to produce a

clear meaning; that legibility and size combine with placement to permit adequate time for response; and that uniformity, size, legibility and reasonableness of the regulation combine to command respect.

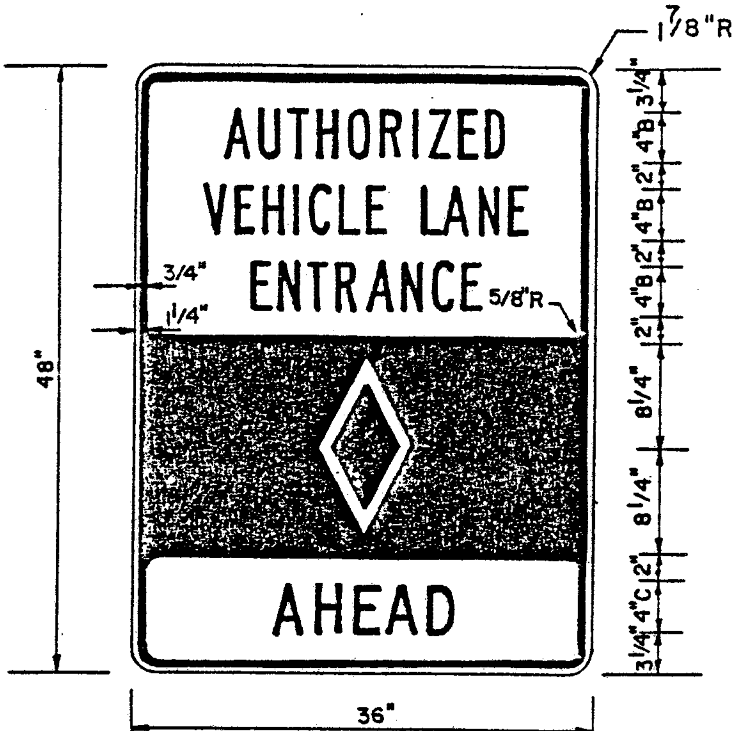
2. Placement of the device should assure that it is within the cone of vision of the viewer so that it will command attention; that it is positioned with respect to the point, object, or situation to which it applies to aid in conveying the proper meaning; and that its location, combined with suitable legibility, is such that an authorized vehicle driver traveling at normal speed has adequate time to make the proper response.

3. Operation or application should assure that appropriate devices and related equipment are installed to meet the traffic requirements at a given location. Furthermore, the device must be placed and operated in a uniform and consistent manner to assure, to the extent possible, that HOV operators can be expected to properly respond to the device, based on their previous exposure to similar traffic control situations.

4. Maintenance of devices should be to high standards to assure that legibility is retained, that the device is visible, and that it is removed if no longer needed. Clean, legible, properly mounted devices in good working condition command the respect of transitway users.

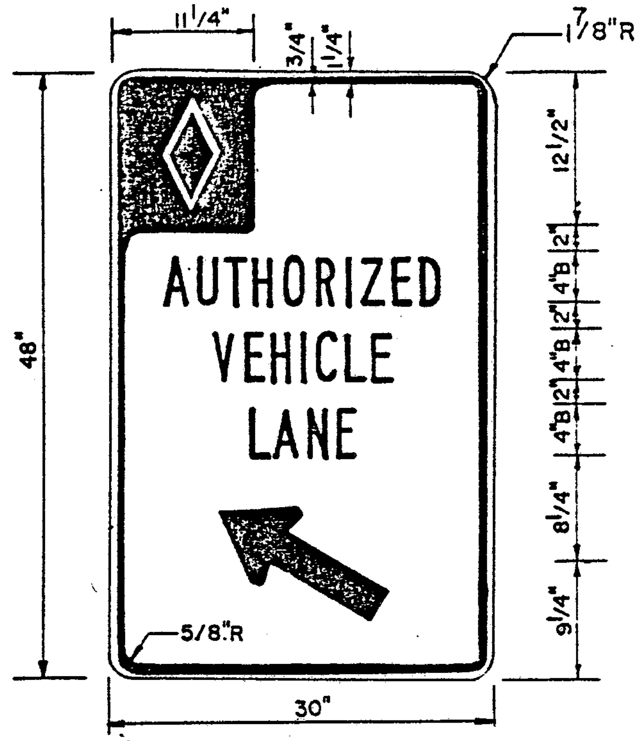
5. Uniformity of traffic control devices simplifies the task of the road user because it aids in recognition and understanding. It aids public highway and transit officials through economy in manufacture, installation, maintenance and administration.

Figure 2-32 presents several typical transitway signs.



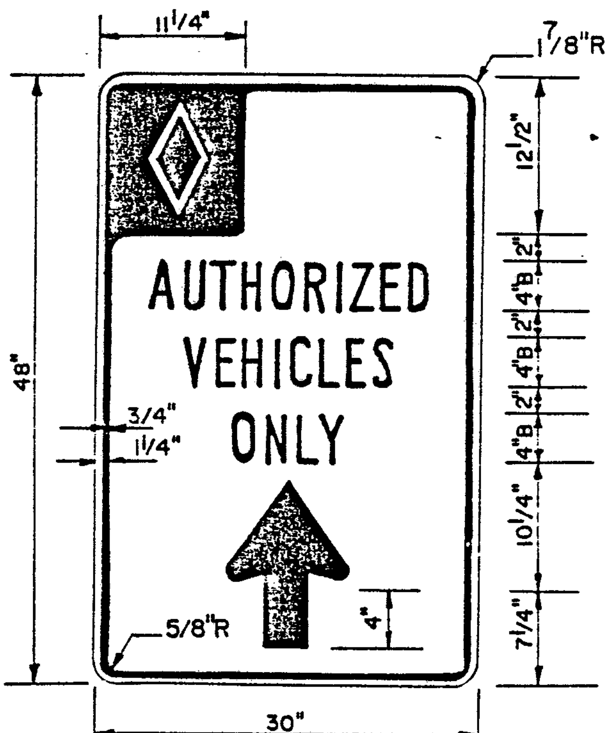
S1
36"x 48"

LETTERS: BLACK
BORDER.: BLACK
BACKGROUND: WHITE REFLECTIVE
SYMBOL : REFL WHITE ON BLACK



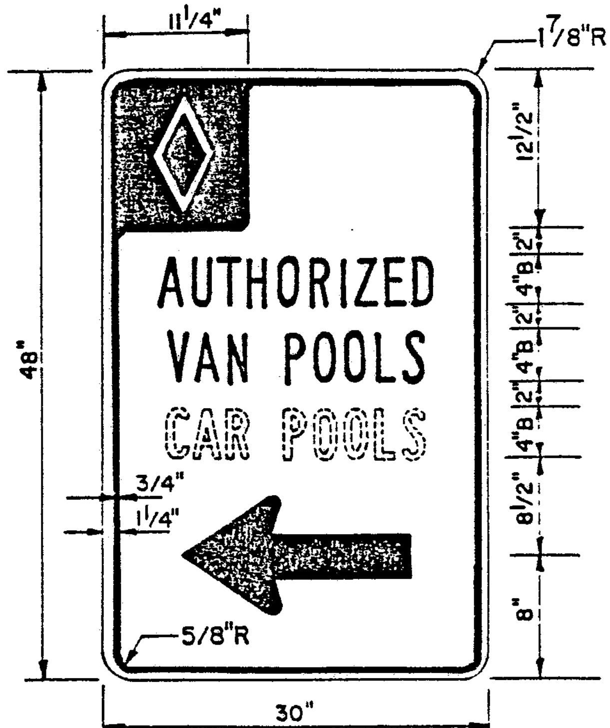
S3NL
30"x 48"

LETTERS : BLACK
ARROW : BLACK
BORDER : BLACK
BACKGROUND: WHITE REFLECTIVE
SYMBOL : REFL WHITE ON BLACK



S4S
30"x 48"

LETTERS : BLACK
ARROW : BLACK
BORDER : BLACK
BACKGROUND : WHITE REFLECTIVE
SYMBOL : REFL WHITE ON BLACK



S6L
30"x 48"

LETTERS: BLACK
ARROW : BLACK
BORDER : BLACK
BACKGROUND: WHITE REFLECTIVE
SYMBOL : REFL WHITE ON BLACK

Figure 2-32. Transitway Signing

2.4 REFERENCES

1. Spielberg, F., et al. Evaluation of Freeway High Occupancy Vehicle Lanes and Ramp Metering, Rept. No. DOT-P-30-80-28. D. Baugh and Associates, August 1980.

2. Parody, T.E. Predicting Travel Volumes for HOV Priority Techniques, Rept. Nos. FHWA/RD-82/042(043). Charles Rivers Associates Inc., April 1982.

3. Benson, J.D., et al. Development and Calibration of Travel Demand Models for the Houston-Galveston Area. Texas Transportation Institute and Barton Aschman Associates, 1979.

4. Bullard, D.L., and D.L. Christiansen. Guidelines for Planning, Designing, and Operating Park-and-Ride Lots in Texas, Res. Rept. 205-22F. Texas Transportation Institute, October 1983.

5. Bullard, D.L. and D.L. Christiansen. Effectiveness of Transit Operations in Texas Cities, Tech. Rept. 1077-1F. Texas Transportation Institute, August 1984.

6. Transportation Research Board. Circular 212: Interim Materials on Highway Capacity, January, 1980.

7. Texas Transportation Institute. Houston Corridor Study, Final Rept. July 1979.

8. Urban Mass Transportation Administration. The Operation and Management of the Shirley Highway Bus-on-Freeway Demonstration Project, Final Rept. Smith and Locke Associates, Inc., September 1980.

9. American Association of State Highway and Transportation Officials. A Policy on Geometric Design of Highways and Streets, 1984.

10. Texas Transportation Institute. Transitway Width Assessment, November, 1984 (Draft).

11. California Dept. of Transportation, Report on Design Criteria for Busways, Orange County Transit District Concept Design, CALTRANS Cooperative Agreement No. 3607. April, 1982.

12. Metropolitan Transit Authority of Harris County Texas. Uniform Design Standards Manual. Bovay Engineers Inc./Parsons Brinkerhoff, July 1981.

13. Phone Conversation with R. Mahaffey, Metropolitan Transit Authority, March 20, 1985.

14. Levinson, H.S., C.L. Adams, and W.F. Hoey. Bus Use of Highways: Planning and Design Guidelines, NCHRP Rept. 155. 1975.

15. Sperry Corporation. Conceptual Design for AVL Surveillance, Communication and Control System, Houston, Texas. March, 1983.

16. Texas Transportation Institute. Phase I Operating Plan Katy Freeway Transitway. August 1984.

17. Texas Transportation Institute. Procedures for Managing Vehicle Breakdowns Phase I Katy Freeway Transitway. August 1984.

18. U.S. Department of Transportation. Manual on Uniform Traffic Control Devices for Streets and Highways. Federal Highway Administration, 1978.

3. TRANSITWAY SUPPORT FACILITIES

3.1 GENERAL

The transitway mainlane 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. These facilities are located closer to the CBD than other types of transitway support facilities and allow a transfer of transit users from HOV vehicles destined to the CBD to other HOV vehicles destined to other major activity centers not along the transitway route. These type of facilities may also serve as a transit terminal 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 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 incentive for HOV staging. However, the express transit mode becomes either authorized vanpools and/or carpools. 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 titled "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 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 necessary, 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 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. Transfer centers should have the ability to serve kiss-and-ride

patrons. Interface with other transportation modes (such as local buses, taxis, etc.) 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.

Table 3-1. Capacity Equations Relating Maximum Load Point Conditions To Berth Capacity[a]

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: (9)

3.2.3 Design Guidelines

3.2.3.1 General

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

a)	Minimum Inside Turning Radius (rear right wheel)	30 feet (35 feet preferable)
b)	Minimum Outside Turning Radius Front Overhang	50 feet (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

Figure 3-1 illustrates a linear (sawtooth) configuration for a transitway transfer center. Figure 3-2 show 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 for 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

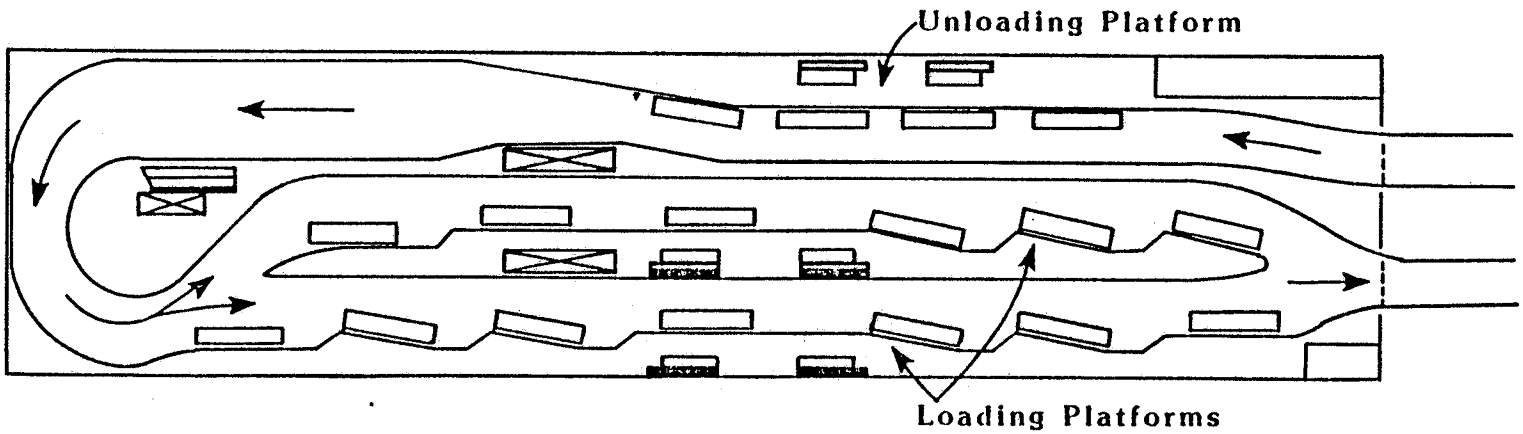


Figure 3-1. Linear "Sawtooth" Configuration for Transit Transfer Center

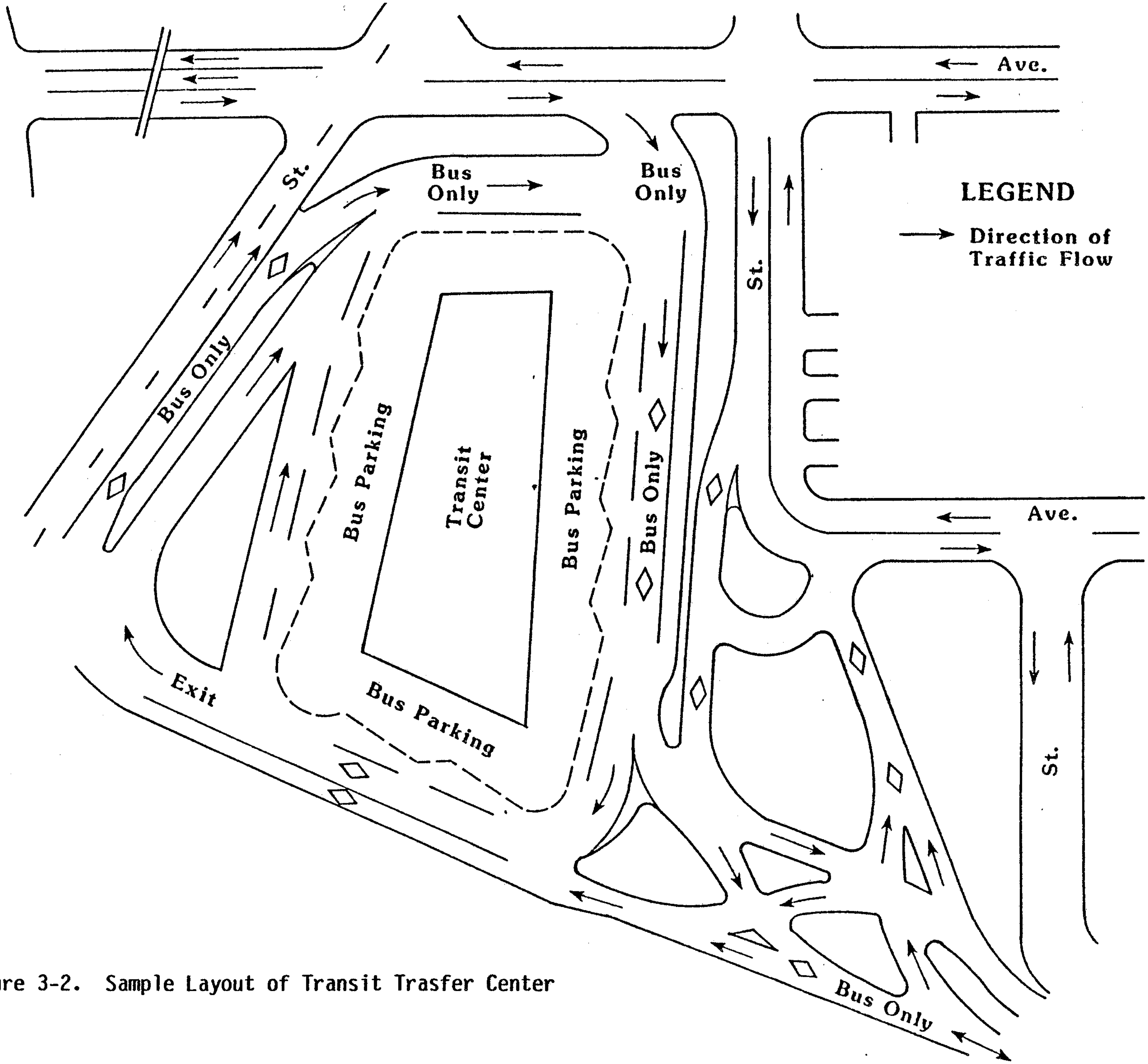
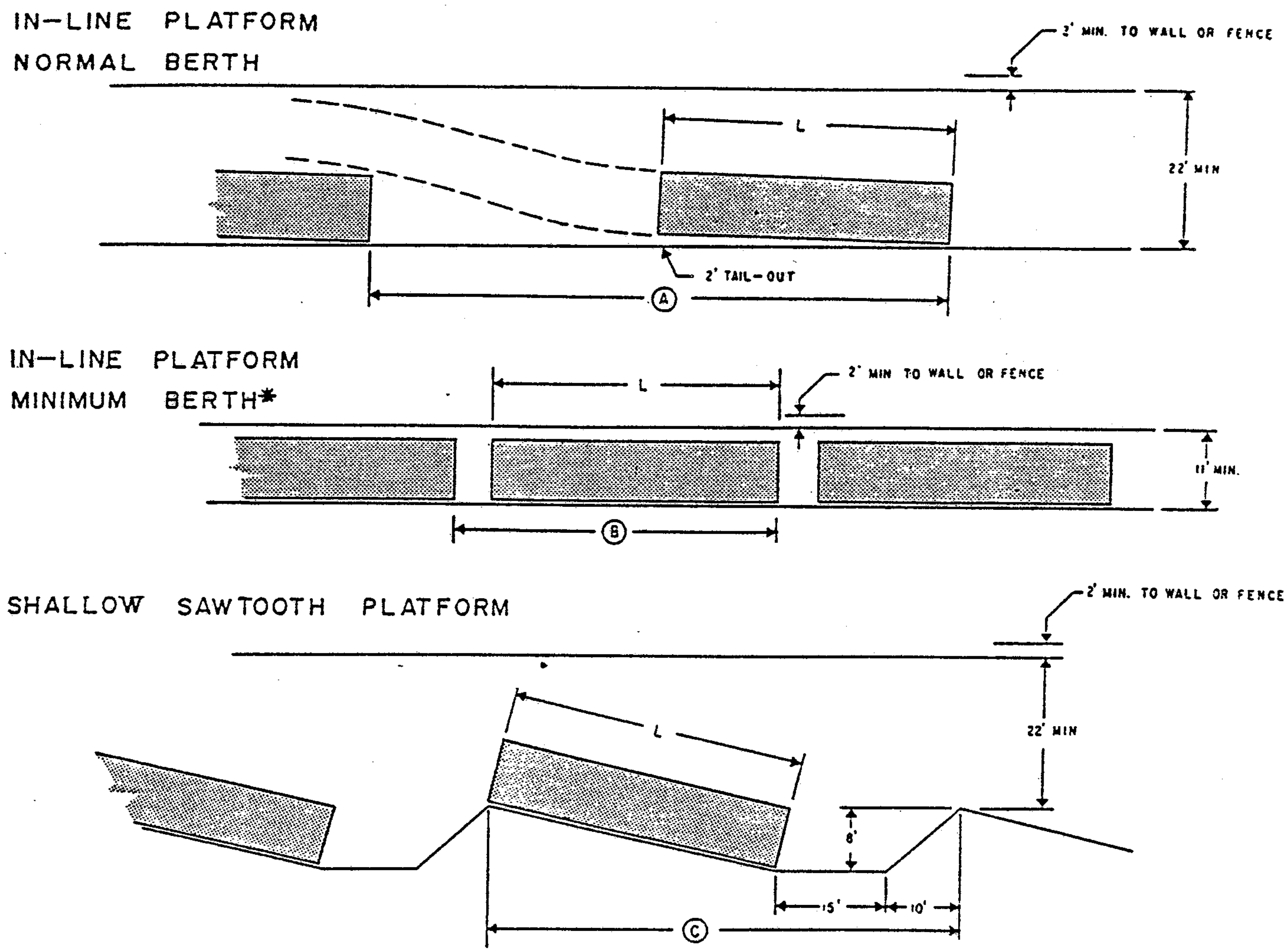


Figure 3-2. Sample Layout of Transit Trasfer Center



* 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'
Ⓐ	80'	100'
Ⓑ	45'	65'
Ⓒ	65'	85'

Source: (9)

3-3. Illustrative Bus Berth Criteria.

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 ft of roadway width for its pull-out maneuver. This condition requires a roadway width of at least 24 ft, and a total minimum berth length of 56 ft for each bus. Thus, five buses would require 264 ft of lineal distance. The shorter the berth length allowed, the wider the roadway must be, and conversely (9).

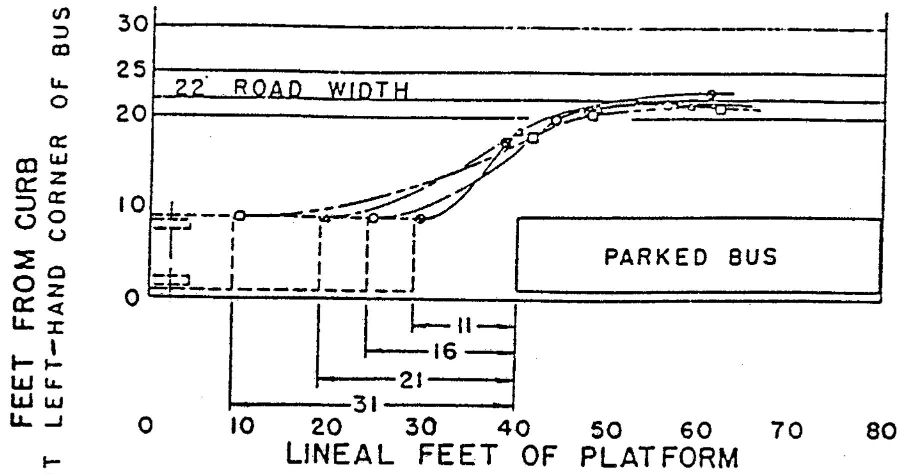
Considerable linear space is necessary to permit a bus to overtake and pull into a platform ahead of a standing bus. Illustrative platform requirements for 28- and 40- ft buses are shown in Figure 3-5. A 40-ft bus requires 92 ft to pull in, assuming the rear end of the bus is 1 ft out from the platform curb, 80 ft when the rear end of the bus is 2 ft from the outside of the curb, and 56 ft when a 5-ft "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). Single parallel platforms should be at least 6 ft and preferably 10 ft wide. Shallow (single) sawtooth platforms should be at least 10 ft wide at the point of minimum width (9).

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

3.2.4 Operating Considerations

3.2.4.1 Traffic Control

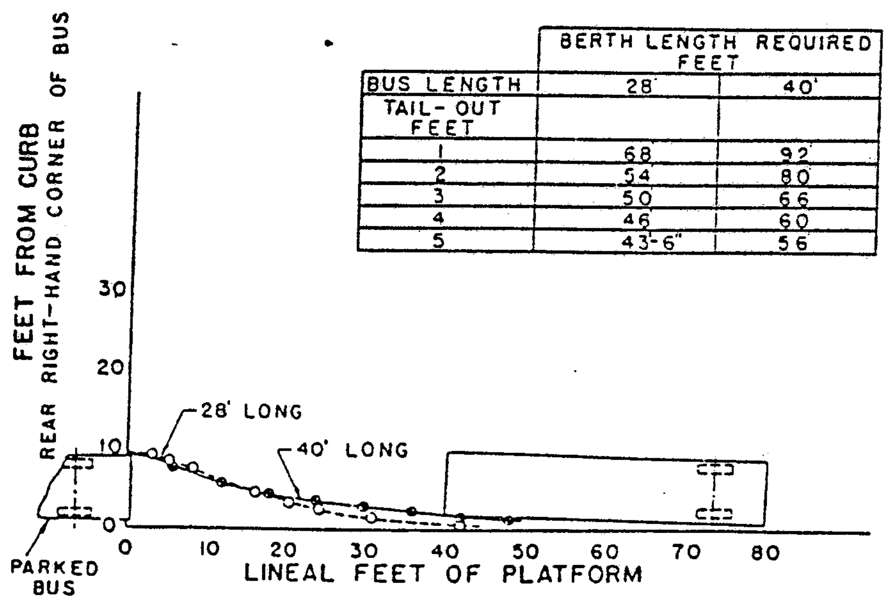
Traffic signals may be required at the access points of large transfer facilities located on major streets to provide safe and efficient use of the facilities. Signalization should be considered only after a thorough study of traffic in the area and should be warranted or justified in the manner prescribed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



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

Source: (9)

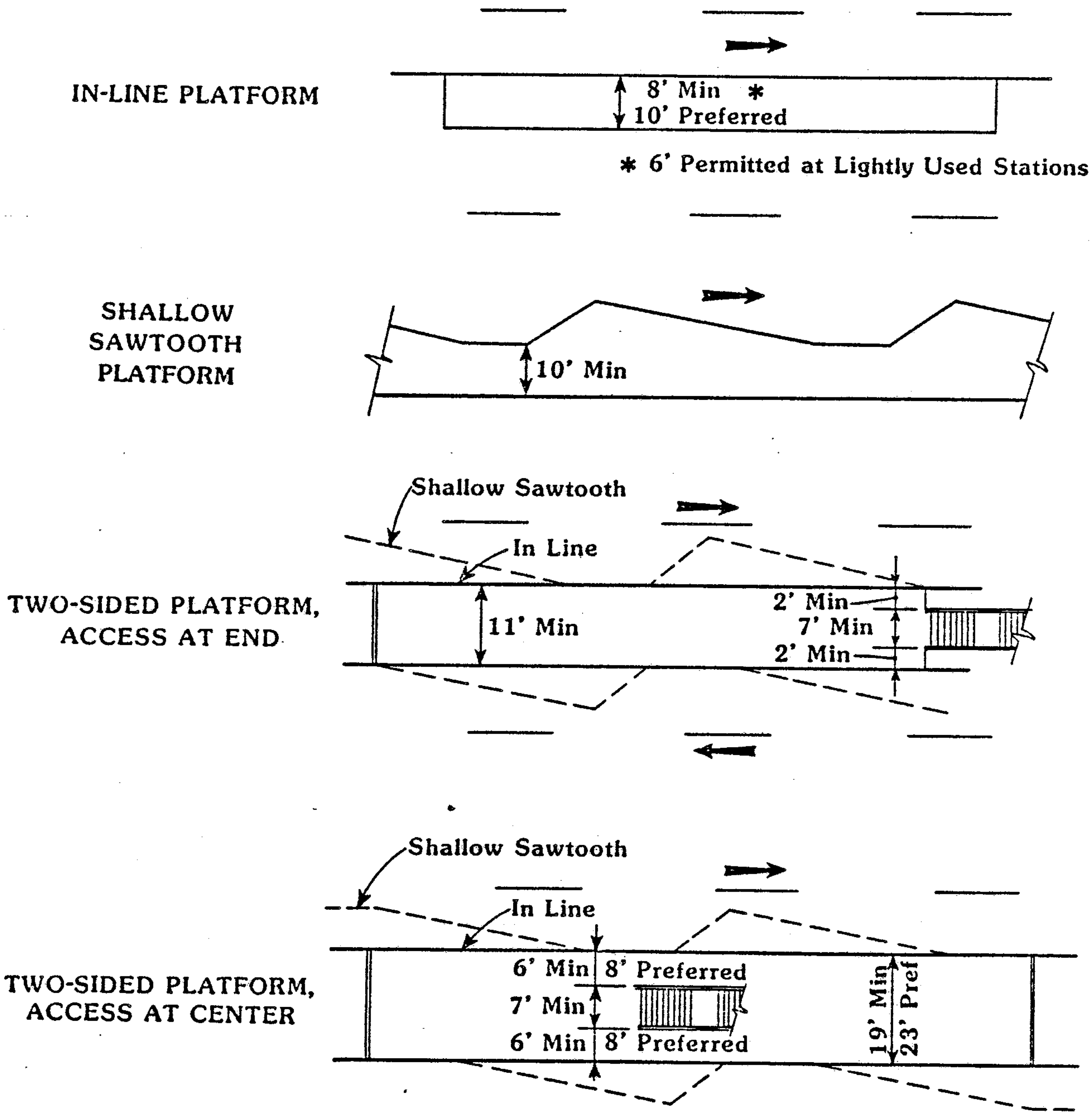
3-4. Required Clearances and Berth Lengths at Selected Pullout Distances for 40-ft GMC Buses.



	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

Source: (9)

3-5. Required Berth Lengths as Compared to Bus Tail-out for 28-ft and 40-ft GMC Buses.



Source: (9)

Figure 3-6. Illustrative Platform Design Criteria

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).

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 design-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 offices, 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 or off-peak

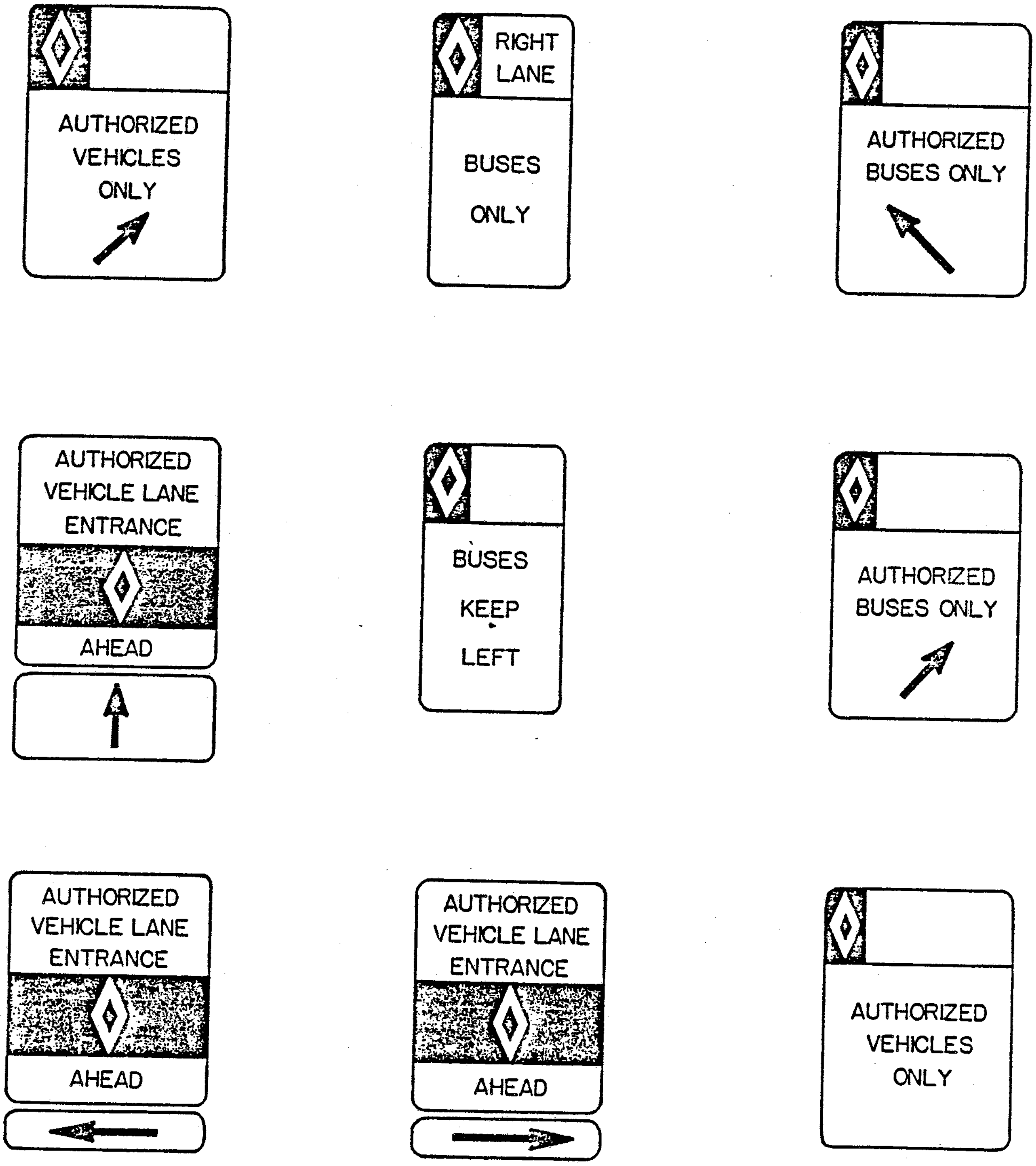


Figure 3-7. Example Transfer Center Lead-in Signing

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 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 predominately 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 exists 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,

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 street 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.

- Although multiple lots may provide an adequate number of total spaces, a probability exists that one of the smaller lots may become filled while others have substantial unused capacity.

3.3.2.4 Demand Estimation

Park-and-ride lots draw their demand from a rather well-defined watershed or market area. This watershed is generally parabolic in shape with a vertex 0.5 to 1.0 mile downstream of the lot, an axis of 5 to 7 miles following the major artery upstream of the lot, and with a chord of 6 to 8 miles (Figure 3-8). When market areas of multiple lots overlap, this geographic area must be adjusted accordingly. Experience has also shown that the number of park-and-ride patrons per parked auto in the lot varies from 0.0 to 6.3 (Table 3-2). For planning purposes, however, 1.5 persons per parked vehicle is generally used.

In Texas, in many instances, facilities and services are constraining the demand; if more parking spaces and more buses were available, a greater park-and-ride ridership might be served. Many lots have demonstrated that a substantial demand exists for high-level transit service in those cities which experience heavy traffic congestion. The actual magnitude of that demand remains unquantified in many corridors, because sufficient services have not been provided to serve that demand. The estimation guidelines presented are based on existing experiences at park-and-ride lots in Texas (8). These guidelines may provide conservative estimates of actual demand in heavily congested corridors.

Using information that is generally available for urban areas in Texas, three different procedures can be used to estimate potential park-and-ride utilization. In evaluating a potential lot site, it is suggested that all three procedures be used to provide a range of estimates. That range can then be used as a basis for further planning and decision-making. The alternative approaches, as defined below, assume that the park-and-ride facility has been located according to the guidelines previously discussed.

- Market Area Population - The percentage of the total population living in the park-and-ride watershed that is represented by ridership at the park-and-ride lot, i.e., (ridership ÷ market area population) X 100.

Table 3-2. Park-and-Ride Patrons Per Parked Vehicle

Location	Patrons Per Parked Vehicle
Houston, TX	
Sage	1.7
Bellaire	1.4
W. Loop Sage/Meyerland	1.4
Westwood	1.5
Clear Lake	1.5
Alief	1.5
North Shepherd	1.4
Kuykendahl	1.3
Champions	1.3
Kingwood	1.5
Katy/Mason	1.4
Average	1.4
Dallas, TX	
Garland North	1.7
Garland South	1.2
Dallas N. Central	1.5
Pleasant Grove	1.5
Oak Cliff	1.4
Average	1.5
San Antonio, TX	
University	1.7
Wonderland	1.4
McCreless	2.9
Windsor Park Mall	1.4
Bitters	1.6
Broadway	3.0
Average	2.0
Fort Worth, TX	
Jefferson Unitarian Church	1.5
Herman E. Clark Stadium	2.0
K-Mart	3.0
Edgepark Meth. Church	1.7
Alta Mesa Church of Christ	0.0
Montgomery Ward	1.3
Ridglea Baptist Church	1.7
Arlington Hts. Christ. Church	2.0
Average	1.6
El Paso, TX	
Vista Hills	6.3
Montwood	2.3
Rushfair	3.0
Northgate	1.5
Pecan Grove	0.0
Average	2.6
Seattle, WA	1.5
Hartford, CT	1.7
Richmond, VA	1.6
Average, All Cities	1.7
Average, Texas Cities	1.8

Source: (8)

- Modal Split - The percentage of the person-trips that originate in the park-and-ride watershed, terminate in the activity center served by park-and-ride, and actually use the park-and-ride service.
- Regression Equations - The data base is evaluated in all possible manners to develop equations that can be used to estimate park-and-ride patronage.

Market Area Population

Analysis of data indicates that the population in the park-and-ride lot watershed or market area can be used to obtain a "ballpark" estimate of potential park-and-ride lot utilization (8). The percentage of market area population that is represented by ridership varies between Texas cities and between corridors within cities. In general, however, the guidelines suggested in Table 3-3 appear to be applicable. Variation between cities and between corridors within cities can be at least partially explained by certain characteristics of the urban area that would be expected to influence park-and-ride utilization. Some of these data are shown in Table 3-4.

Using only market area population as a variable assumes that all market areas have a similar affinity for the activity centers being served. Total market area population is a more readily available variable than is the percentage of that market area population that works in the activity center. If there is reason to suspect that different corridors have significantly different affinities to the activity center, census or travel data can be used to make adjustments to the market area population.

Table 3-3. Ridership as a Percentage of Population in the Park-and-Ride Market Area

City and Park-and-Ride Lot	Ridership as a % of Market Area Population	"Guideline" for City
Austin		
North Park-and-Ride	0.6	
US 183 North[1]	0.3	0.3 to 0.6
Dallas Area		
Garland South	0.8	
Garland North	1.3	
North Central	0.4[2]	0.4 to 1.3
Las Colinas	0.8	
Redbird	0.7	
Pleasant Grove	0.4	
El Paso		
Montwood[3]	0.4	
Northgate[4]	0.07	0.07 to 0.4
Fort Worth		
Meadowbrook	0.05	
College Avenue	0.3	0.05 to 0.3
Houston[5]		
Champions	0.9	
Kuykendahl	2.1	
N. Shepherd	1.0	
Edgebrook	0.8	0.7 to 2.0
Clear Lake	0.8	(constrained due
Beechnut (both lots)[6]	0.9	to size of lots
Sharpstown	0.3[7]	currently available)
Alief	0.9	
Westwood	1.1	
Katy/Mason	0.7	
Kingwood	1.4	
Lots serving contraflow lane		2.5 to 3.0
San Antonio		
Windsor Park	0.5	
McCreless	0.2[8]	varies up to 1.2
South Park	0.1	
Lackland	1.1	
Wonderland	1.2	
Nacogdoches[9]	0.2	

[1]Includes 3 lots served by the same bus—US 183 North #1, #2 and #3.
[2]Ridership is lower than would be expected due to paid parking, competing local bus service, poor lot access/accessibility and lot not located upstream of congestion.
[3]Includes 2 lots served by the same bus—Montwood and Vista Hills.
[4]Includes 2 lots served by the same bus—Northgate and Rushfair.
[5]Ridership at most of the Houston lots is constrained by parking spaces available.
[6]Includes 2 lots served by the same bus—Meyerland and Sage.
[7]Low percentage due to small lot size.
[8]Lot located in an uncongested corridor and relatively close to activity center.
[9]Includes 2 lots served by the same bus-Broadway and Bitters.

Source: (8)

Table 3-4. Ridership as Related to Market Area Compared to Other Indicators of Park-and-Ride Potential, by City

City	Ridership as a % of Market Area Population	"Representative" Congestion Index	Average Monthly Pkg. Cost	Activity Center Employment
Houston	0.7 to 2.0*	2.0 to 3.0	$85	158,000
Dallas Area	0.4 to 1.3	1.0 to 2.0	75	126,000
San Antonio	varies up to 1.2	0.5 to 1.5	35	38,000
Austin	0.3 to 0.6	0.5 to 1.0	55	17,000
Fort Worth	0.05 to 0.3	0.5 to 1.5	57	45,000
El Paso	0.07 to 0.4	0.5 to 1.0	40	19,000

*In general, the Houston percentages are constrained by parking spaces available.

Source: (8).

The effect of priority treatment on park-and-ride lot utilization is somewhat difficult to accurately assess due to the limited amount of data available. However, data for Houston (the only city in Texas with priority treatment currently available) suggests that, at properly located lots in congested corridors with priority bus service, perhaps as much as 2.5% to 3% of the total market area population could be served by park-and-ride. That percentage has continued to increase over the past several years since the I-45 Contraflow Lane in Houston opened.

Modal Split

The market area analysis described above assumes that all market areas have an equal affinity to the activity centers being served by park-and-ride. While that approach is simple to apply and uses the most readily available data, it does not account for the fact that different parts of a corridor or an urban area can have different attraction rates to the activity centers being served.

Using the modal split procedure, however, requires the identification of that component of the market area population that works in the activity centers served by park-and-ride. Since this information is not always readily available, the attractiveness of this approach is somewhat diminished. Table 3-5 summarizes the available modal split data for Texas park-and-ride lots.

The modal split data show a wide spread. Some agreement with the congestion correlation appears to exist; modal splits tend to be relatively high in the more congested corridors.

The following guidelines--recognizing constraints imposed by lot sizes or lots not located in accordance with the lot location guidelines--might be used for park-and-ride analysis.

- Dallas area lots - 10% to 20% modal split
- Houston area lots - 15% to 30% modal split, with some modal splits in the range of 50%.

Those modal splits in the range of 50% suggest that if a lot is properly located and if a sufficient number of parking spaces is available, the result could be a significantly higher than "normal" modal split. That value might then be useful in identifying the "upper end" of potential lot size. Since surveys indicate that about half the persons perceive the need to have an auto available during the day, the 50% modal split value may mean that, in effect, all the eligible demand is being served.

As was the case with the market area analysis, data are not sufficient to determine the effect of priority treatment on park-and-ride utilization. While the Houston data do suggest that the priority treatment lots are serving a greater modal share than the non-priority lots (Table 3-6), this could be true because relatively more parking spaces are presently provided at the priority-treatment lot locations. It appears that bus modal splits at least in the range of 25% are associated with priority treatment lots (Table 3-7). While it cannot conclusively be demonstrated, it appears that the provision of priority treatment increases modal split by at least 50%.

Regression Analysis

Multiple regression is a common approach to demand estimation. The results of these analyses can be relatively easy to utilize, and available statistical analysis computer programs simplify the use of this analytical tool.

Table 3-5. Estimated Modal Split For Selected Texas Park-and-Ride Lots

City and Lot	Modal Split[1]	Procedure to Estimate Modal Split[2]
Dallas/Garland Area		
Dallas North Central	7% to 8%	TTI Surveys and Census Analysis
Pleasant Grove	8	Census Analysis
Oak Cliff	4	Census Analysis
Garland North & South	21	TTI Surveys
Houston		
Clear Lake City	52	Census Analysis
Gulf Edgebrook	24	Census Analysis
Westwood	10	TTI Surveys
Champions	23	TTI Surveys
N. Shepherd	27	TTI Surveys
Kuykendahl	22	TTI Surveys
Kingwood	29	Census Analysis
Beechnut (2 lots)	13	Census Analysis
Alief	28	Census Analysis
Sharpstown	4	Census Analysis
Katy/Mason	50	Census Analysis

[1]Modal split is defined as the percent of the market area population working in the activity center served by park-and-ride that uses the park-and-ride service.

[2]In using census data, the percent of the population working in the CBD was obtained from 1970. Due to the massive growth in many of the areas being considered, applying the 1970 percentage to the 1980 market area results in potential error.

Source: (8)

Table 3-6. Possible Impacts of Priority Treatment on Park-and-Ride Utilization Based on Market Area Analysis, Houston Lots

Houston Park-and-Ride Lots	% of Market Area Population Using Park-and-Ride	Available Parking Spaces per Market Area Population	Park-and-Ride Patrons Per Available Parking Space
3 lots with Priority Treatment	1.17%	0.012	0.97
8 lots without Priority Treatment	0.75%	0.007	1.02

Source: Ref. (8)

Table 3-7. Possible Impacts of Priority Treatment on Park-and-Ride Utilization Based on Modal Split Analysis, Houston Lots

Houston Park-and-Ride Lots	Modal Split*	Available Parking Spaces per Market Area Population	Park-and-Ride Patrons Per Available Parking Space
3 lots with Priority Treatment	24%	0.012	0.97
8 lots without Priority Treatment	15%	0.007	1.02

*Modal split values shown are weighted averages for the lots shown in Table 3-6.

Source: Ref. (8)

The data for 35 park-and-ride lots in Texas (all that were in service at the time of the study) were combined and analyzed to develop equations that can be used to predict park-and-ride patronage. Since data are included from several lots in smaller urban areas with limited utilization, the equations tend to underestimate utilization at the larger lots in congested urban areas. The following represent some of the more applicable equations.

1. ridership = -160 + 204 (CI) + 0.0034 (MAPOP)

where:

CI = congestion index for line-haul roadway (refer to Table 3-8)

MAPOP = total population in the park-and-ride lot market area

In most instances this equation predicts ridership at existing lots within 50% of actual ridership.

2. A. Ridership = -86 + 0.8 (MIN) + 0.002 (MAPOP)

Note: Applies to lots with CI $\geq$ 1.3

B. Ridership = 61 + 0.1 (MIN) + 0.001 (MAPOP)

Note: Applies to lots with CI between 0.9 and 1.2

C. Ridership = 7 + 0.43 (MIN)

Note: Applies to lots with CI $\leq$ 0.9

where:

MIN = a control based on service provided. It equals the minimum of the following 2 variables: 1) auto parking spaces x 1.5 persons/auto; or 2) peak-period bus seats. The equation thus reccognizes that at many existing lots demand is controlled by facilities provided.

Guidelines for The Selection of MIN. While the equations using the variable MIN do a good job of "predicting" ridership at existing lots, their use in estimating demand at new lots requires estimating the value of MIN. Since MIN can vary considerably between lots in a given urban area, the best approach might be to locate an existing lot that is similar to the proposed lot in terms of congestion index, distance to the activity center, and market area population. Using this approach, the value of MIN for an existing lot (Table 3-9) can be used in the appropriate regression equation to estimate ridership at the new lot.

Table 3-8. Congestion Indices (CI)

City and Facility	AADT/Lane	# of Lanes	Delay in Minutes	ICI
Austin				
US 183 N	7,925	6	1.5	0.5
Mo Pac	6,466	6	1.0	0.4
I-35 N	7,188	8	1.5	0.5
I-35 S	18,367	6	2.0	1.1
Dallas				
Stemmons (I-35 E North)	13,210	10	5.0	1.2
N. Central (US 75 N)	20,517	6	18.0	2.8
Thornton East (I-30 E)	13,400	8	15.0	2.2
Thornton South (I-35 E South)	12,800	8	1.0	0.7
LBJ or North Side (I-635)	20,363	8	2.0	1.2
US 175	6,550	6	2.0	0.5
US 67	7,500	6	2.0	0.6
El Paso				
I-10 E	11,780	10	3.0	0.9
US 54	8,817	6	1.0	0.5
I-10 W	12,775	4	1.0	0.7
Fort Worth				
West (I-30 W)	22,675	4	8.0	1.9
South (I-35 W South)	13,900	6	3.0	1.0
East (I-30 E)	8,888	8	2.0	0.6
Houston				
Southwest (US 59 S)	21,633	9	11.0	2.2
Katy (I-10 W)	24,457	7	15.0	2.7
North (I-45 N)	19,000	8	15.0	2.5
Eastex (US 59 N)	15,225	8	11.0	1.9
East (I-10 E)	14,863	8	5.0	1.2
Gulf (I-45 S)	24,443	7	15.0	2.7
West Loop (I-610)	25,363	8	8.0	2.1
San Antonio				
S. Pan Am (I-35 S)	20,425	4	4.0	1.4
I-10 W	21,450	4	9.0	2.0
N. Pan Am (I-35 N)	20,110	4	3.0	1.3
US 281 N	10,062	8	2.0	0.7
I-37 S	8,725	8	0.0	0.4
US 90 W	8,775	8	0.0	0.4

Source: (8)

Table 3-9. Estimated Values of the Variable MIN at Selected Texas Park-and-Ride Lots

Lot	# of Peak Buses X Seats =	Parking Spaces X 1.5*	MIN
Austin			
North Park and Ride	3 x 45 = 135	260 X 1.5 = 390	135
US 183 North[1]	2 X 43 = 86	239 X 1.5 = 359	86
US 183 Express	1 X 43 = 43	146 X 1.5 = 219	43
Dallas Area			
Garland South[2]	20 X 50 = 1000	440 X 1.5 = 660	660
Garland North[2]	13 X 50 = 650	320 X 1.5 = 480	480
North Central	11 X 50 = 550	1300 X 1.5 = 1950	550
Las Colinas	3 X 50 = 150	150 X 1.5 = 225	150
Red Bird	7 X 50 = 350	315 X 1.5 = 473	350
Pleasant Grove	7 X 50 = 350	624 X 1.5 = 936	350
El Paso			
Montwood[3]	4 X 47 = 188	75 X 1.5 = 113	113
Northgate Express[4]	4 X 47 = 188	209 X 1.5 = 314	188
Fort Worth			
Meadowbrook	2 X 48 = 96	25 X 1.5 = 38	38
College Avenue	6 X 48 = 288	185 X 1.5 = 278	278
Houston			
Kingwood	12 X 47 = 564	950 X 1.5 = 1425	564
Champions	10 X 47 = 470	349 X 1.5 = 524	470
Kuykendahl	29 X 47 = 1363	1300 X 1.5 = 1950	1363
North Shepherd	21 X 47 = 987	750 X 1.5 = 1125	987
Gulf Sage	10 X 47 = 470	230 X 1.5 = 345	345
Clear Lake	10 X 47 = 470	325 X 1.5 = 488	470
Beechnut Express[5]	12 X 52 = 624	487 X 1.5 = 731	624
Sharpstown	7 X 47 = 329	200 X 1.5 = 300	300
Alief	12 X 47 = 564	300 X 1.5 = 450	450
Westwood	16 X 47 = 752	600 X 1.5 = 900	752
Katy	5 X 47 = 235	170 X 1.5 = 255	235
San Antonio			
Windsor	6 X 47 = 282	167 X 1.5 = 251	251
McCreless	5 X 47 = 235	117 X 1.2 = 140	140
South Park	3 X 47 = 141	64 X 1.2 = 77	77
Lackland	5 X 47 = 235	136 X 1.5 = 204	204
Wonderland	13 X 52[7] = 676	474 X 1.5 = 711	676
Nacgdoches[6]	5 X 47 = 235	123 X 1.2[8] = 148	148

*1.5 - assumed maximum average auto occupancy.
[1]Includes 3 lots served by the same bus- US 183 North, Covenant and NW Hill.
[2]Since the buses from Garland North also stop at Garland South, parking spaces are used to establish the MIN values for Garland.
[3]Includes 2 lots served by the same bus - Montwood and Vista Hills.
[4]Includes 2 lots served by the same bus - Northgate and Rushfair.
[5]Includes 2 lots served by the same bus - Meyerland and Sage.
[6]Includes 2 lots served by the same bus - Bitters and Broadway.
[7]Bus capacity was inflated to account for numerous standees.
[8]Auto occupancy lower than state average.

Source: (8)

In the absence of a comparable existing lot that can be used to determine the MIN value, one of two approaches might be used. One approach is to use the values in Table 3-10. The values were obtained for each urban area by averaging the numbers shown in Table 3-9. Again, it should be noted that, due to the large variation in MIN values for a given urban area, use of the "typical" value increases the error of the estimate.

Alternatively, since MIN is somewhat related to variables such as market area population, distance to activity center, and congestion index, those values for the proposed new lot can be used to estimate a value of MIN (Figure 3-9).

Table 3-10. "Typical" MIN Values For Urban Areas in Texas

Urban Area	"Typical" MIN Value*
Houston	600
Dallas	425
San Antonio	250
Austin, El Paso, and Fort Worth	125 to 175

*Obtained by averaging the values in Table 3-9.

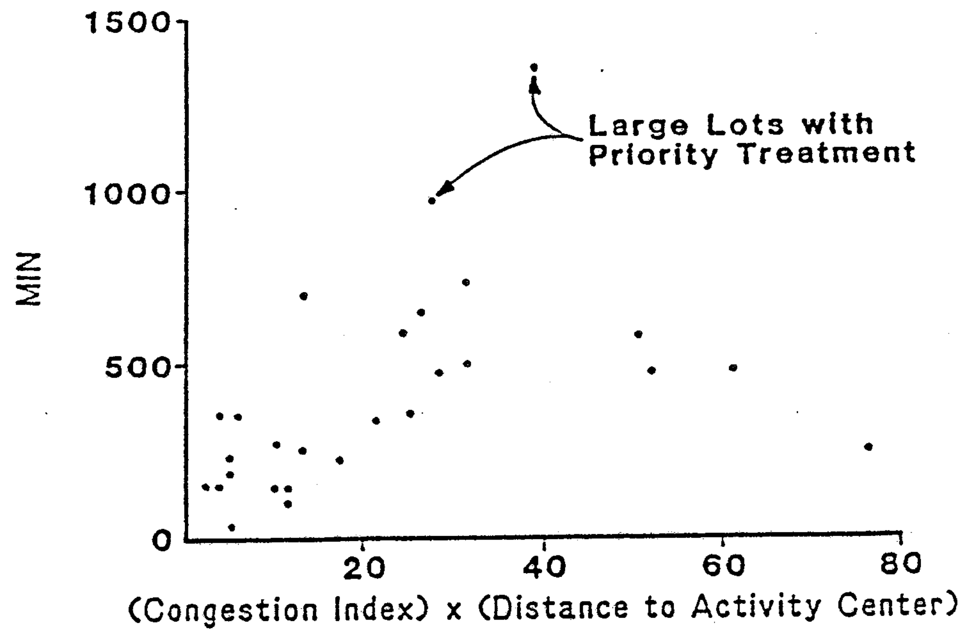
Source: (8).

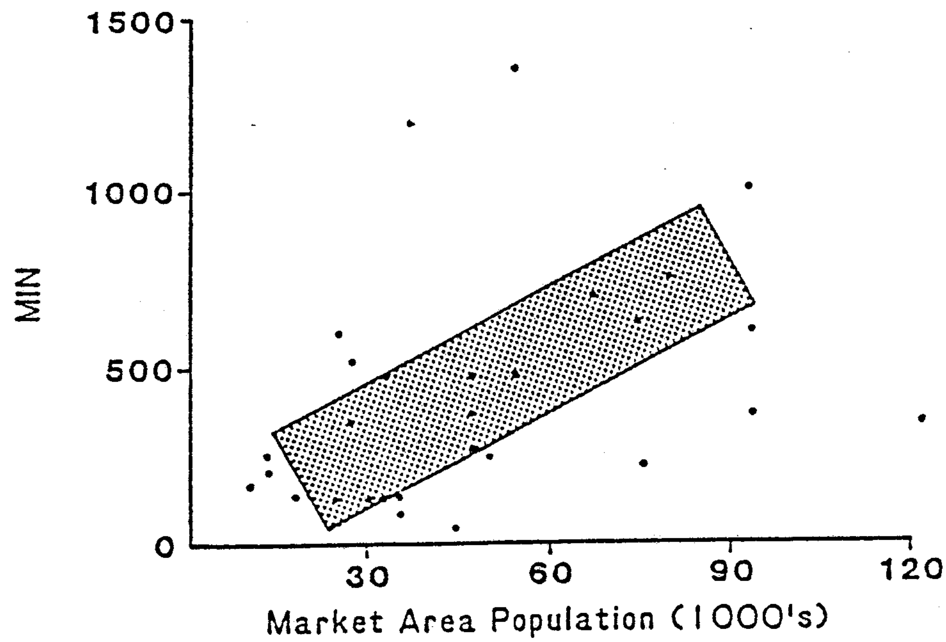
The equations using the MIN variable account for the fact that current park-and-ride patronage is often controlled by either facilities (i.e., parking spaces available) or service (i.e., number of buses serving the lot). These equations, in most instances, predict ridership at existing lots within 25% of actual ridership.

3.3.2.5 Lot Size

The maximum desired lot size of a park-and-ride facility can be constrained by walking distance, bus headways and other factors.

Walking Distance Constraint. Ideally, the maximum walking distance from the location in which the car is parked to the bus loading area should not exceed 400 feet (8). This maximum may not always be practical, however. More realistic maximum walking distances fall into the range of 600 to 1,000 feet (8). Experience at Texas lots has shown that, when patrons must walk





Source: (8)

Figure 3-9. Relationship Between the Variable MIN and Selected Descriptors of Park-and-Ride Lots distances greater than 650 feet, many will park in restricted areas of the lot or on adjacent roadways in order to shorten the distance they must walk to board the bus. Therefore, excessively long walking distances may require moving the bus loading area to a more centralized location. Thus, for each bus loading area provided at a park-and-ride facility, walking distance will place a constraint on lot size. Table 3-11 lists two examples of how walking distance can affect the total lot size, assuming that the walking distance will not exceed 650 feet (an observed distance that functions satisfactorily at several Houston lots).

Table 3-11. Constraint of Walking Distance on Maximum Park-and-Ride Lot Size Per Bus Loading Area

Type of Lot Layout	Maximum Number of Auto Parking Spaces*
Loading area in the center of a square lot	1,900
Loading area on the periphery of a square lot	1,000

*Based on all parking spaces within 650 feet of the bus loading area and 450 sq. ft. per parking space.

Source: (8).

__Bus Headway or Service Constraint__. The frequency of service, or bus headways, provided at each loading location places a constraint on the amount of demand that can be accommodated at the park-and-ride facility. Although bus headways in the range of 5 to 10 minutes are most desirable from an operational point of view, headways as little as 3 minutes have been successfully attained at certain lots in Texas. These headways are maintained during peak hours at several Houston lots.

Based on this constraint, parking lot size per bus loading area should not exceed about 1,800 parking spaces. However, it is feasible to provide more than one bus loading area, possibly with the different loading areas serving different destination points, in order to increase the parking demand that can be accommodated at a specific lot.

loading area or designing the lot layout such that bus loading area conflicts, excessively long walking distances and access problems are minimized.

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 in Houston are summarized in Table 3-13. 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.

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.
- 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 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 2 streets comprising a one-way pair, providing access from both streets.

Table 3-12. Summary of Constraints on Park-and-Ride Lot Size Per Bus Loading Area

Constraint	Suggested Guideline
Constraints on maximum size	
Number of All-Day Parking Spaces	1800-1900
Walking distance	650 feet
Bus headways (service)	10-15 minutes
Constraints on minimum size	
Number of All-Day Parking Spaces	250
Bus headways (service)	20 minutes

Source: (8)

Table 3-13. 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: (8)

- 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). Although in terms of theoretical capacity, a single access/egress point (one lane in each direction) may be sufficient. 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 entry to the lot, Table 3-14 provides a summary of automobile access/egress requirements at park-and-ride lots.

Table 3-14 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: (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 ft 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 3-15.

In general, for the types of park-and-ride operations that will exist in Texas, 2 to 3 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 3-15. Number of Bus Loading Spaces Required[1] to Accommodate Varying Levels of Transit Service

Average Headway During Peak	Service Time[2]			
15 minutes	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: (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 parking, bicycles and motorcyles 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 at a park-and-ride lot, the guidelines in Table 3-16 have been suggested (8).

Table 3-16. Guidelines for Determining Handicapped 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: (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 3-17).

Table 3-17. 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: (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. 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 3-18); peak-hour kiss-and-ride patrons divided by 1.1 yields peak-hour kiss-and-ride vehicles.

Table 3-18. 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: (8).

Thus, the following equation can be used to estimate peak-hour kiss-and-ride vehicular demand (8).

$$q = 0.11\ k$$

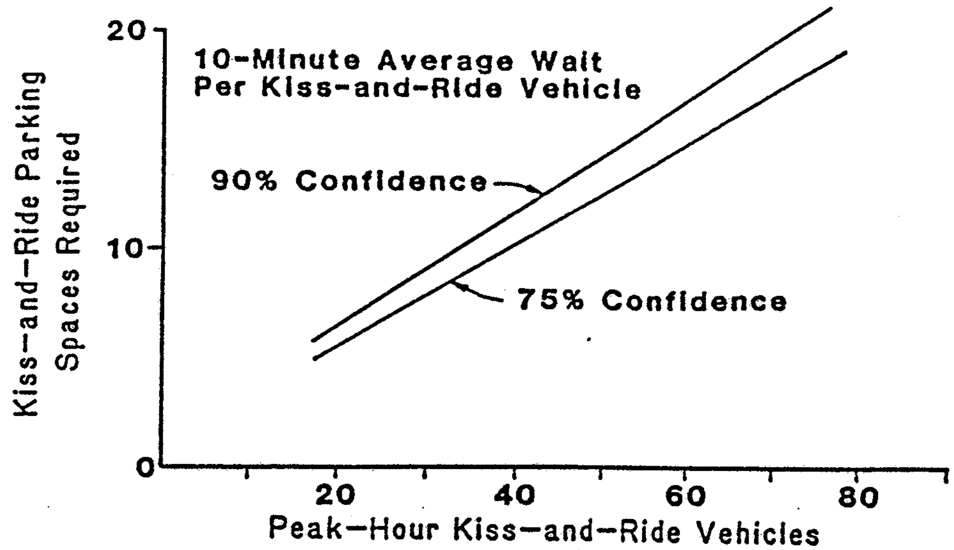
where: q = peak-hour kiss-and-ride vehicular demand
k = total daily park-and-ride vehicular demand

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 3-10 and 3-11 summarize the results of this type of analysis using 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 3-10 (which assumes a 10-minute kiss-and-ride vehicle dwell time) might be viewed as representing a desirable design level; Figure 3-11 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.

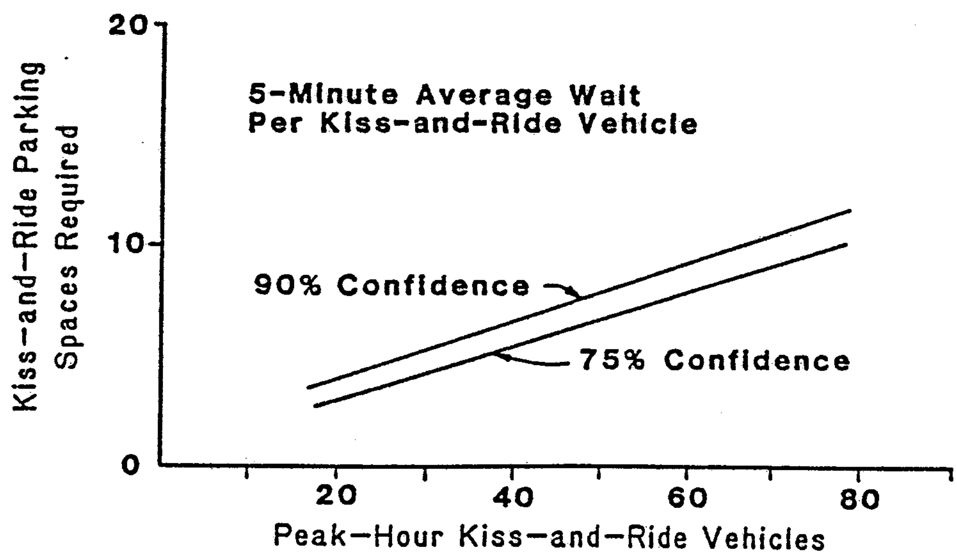
Long-Term Parking. By far, the most used access mode is the automobile that is driven to the park-and-ride lot and left all day. The parking for these long-term users should be close to the bus loading area, yet should not interfere with higher priority access modes.

Park-and-ride all-day parking is generally designed to be right-angle parking; this provides a simple, orderly configuration and also requires less



Source: (8)

Figure 3-10. Peak 15-Minute Kiss-and-Ride Parking Space Requirements Assuming an Average 10-Minute Wait Per Vehicle



Source: (8)

Figure 3-11. Peak 15-Minute Kiss-and-Ride Parking Space Requirements Assuming an Average 5-Minute Wait Per Vehicle land area per space. The parking aisles are typically aligned at right angle to the bus loading area to facilitate convenient pedestrian movement. Standard dimensions for parking stalls are recommended in Table 3-19.

Table 3-19. 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'	10' - 22'

Source: (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 revealed that between 23% and 37% of the total vehicles in the park-and-ride lots were compacts and sub-compacts (Table 3-20).

Table 3-20. 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: (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 3-12. 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 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.

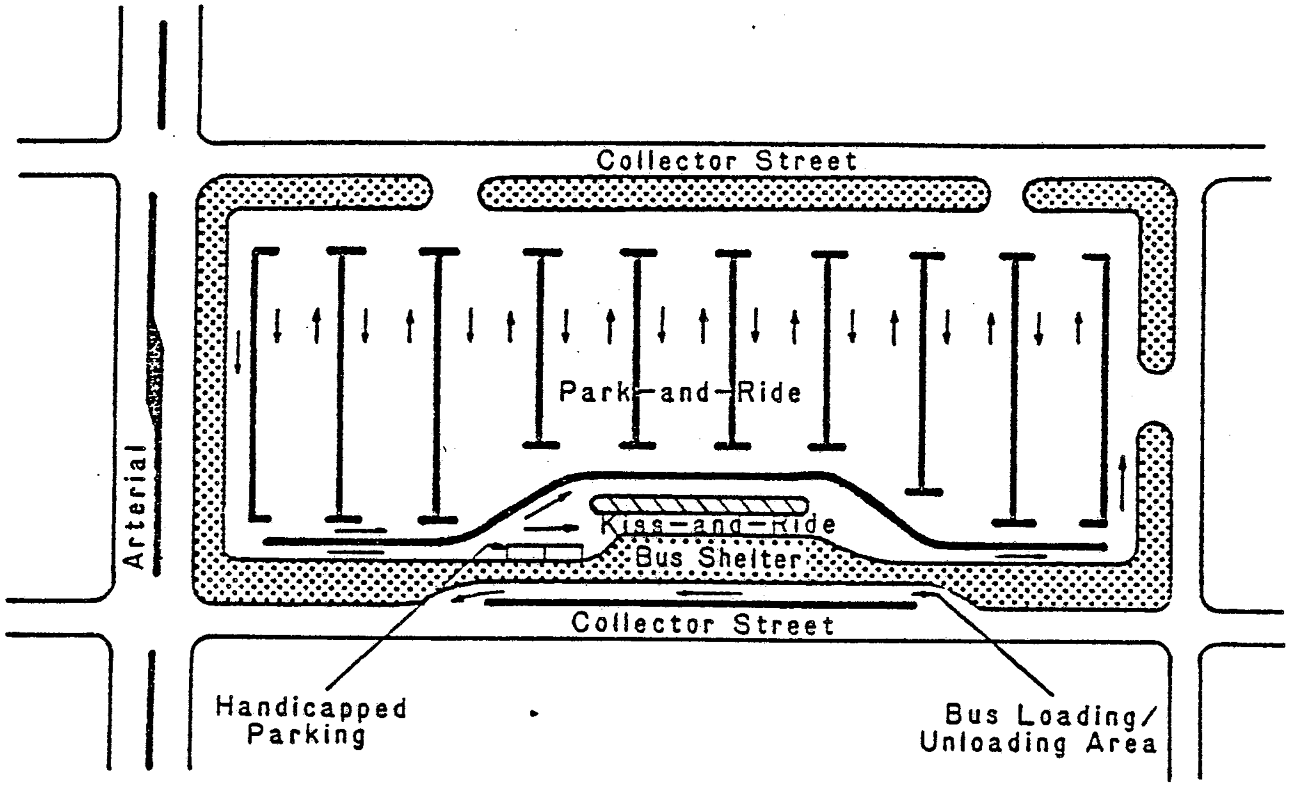
To assist in laying out a park-and-ride lot, the "coefficient of directness" may be utilized. This coefficient is determined from the following formula.

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

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.



Source: (8)

Figure 3-12. Representative Layout for a Park-and-Ride Facility

Bus Shelters

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, semi-enclosed 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 3 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 a park-and-ride facility is important from a safety standpoint and serves as a deterrent to vandalism in both the parking areas 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, 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 use 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 existing 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 altering 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 it 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 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. Proper "lead-in" trailblazer sign placement on high volume roads should intercept potential users on their normal paths and guide them to the park-and-ride facility.

If a park-and-ride 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 park-and-ride facility. In addition, other informational signs should be placed at the park-and-ride site to indicate lot entrances and

Park-and-ride "lead-in" 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 3-13. 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.

Recommended standards for park-and-ride signs are (8):

- Rectangular in shape,
- Reflectorized with white legend and border on green background;
- Mounted according to general specification for erection of signs;
- Contain the word message, Park-and-Ride;
- (Optional) contain local transit logo (standard color and shape; vertical dimension 18 inches or less).

3.3.4.2 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.

3.3.4.3 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 ensure 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.

3.3.4.4 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.

Figure 3-13. Examples of Park-and-Ride Lot Signing

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 areas on public right-of-way or private property. Park-and-pool areas are typically located beyond transit service limits. 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 3-21) and travel patterns (Table 3-22) of park-and-pool users in Texas. These data should prove useful in evaluating potential park-and-pool sites.

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 3-14).

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 to 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.

Table 3-21. Summary of Personal Characteristics of Park-and-Pool Participants

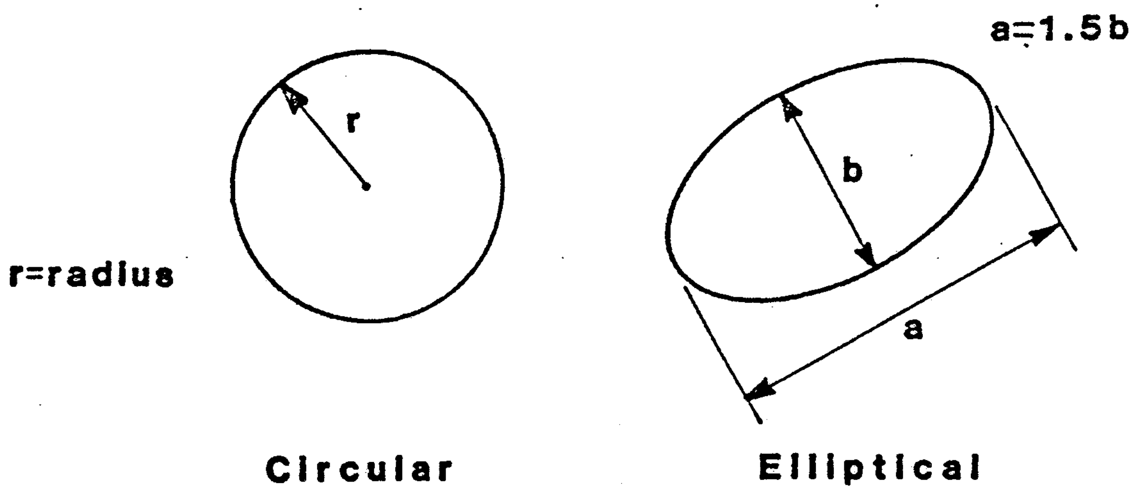
Characteristic	Houston/ San Antonio Poolers	Dallas Area Poolers
Age (years)		
50th Percentile	35.7	34.5
85th Percentile	49.8	51.5
Sex		
Male	61%	52%
Female	39%	48%
Years of Education		
50th Percentile	13.5	14.8
85th Percentile	15.8	16.9
Occupation		
Professional	39%	36%
Clerical	21%	22%
Managerial	8%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

Source: (7)

Table 3-22. Summary of Travel Patterns of Park-and-Pool Participants

Travel Pattern	Houston/ San Antonio Poolers	Dallas Area Poolers
Prior Mode of Travel		
Drove Alone	67%	55%
Carpooled/Vanpooled	30%	27%
Number of Persons in Pool		
50th Percentile	3.4	3.4
85th Percentile	11.0	10.2
Average (Mean)	----	5.2
Distance Traveled: Home To Lot (Miles)		
50th Percentile	3.7	3.5
85th Percentile	9.8	9.8
Average (Mean)	----	5.9
Distance Traveled: Lot To Destination (Miles)		
50th Percentile	28.0	21.5
85th Percentile	44.7	31.2
Average (Mean)	----	23.2

Source: (7)



Source: (7)

Figure 3-14. Suggested Market Area Configurations for Park-and-Pool in Dallas Urbanized Area

3.4.3 Design Guidelines

3.4.3.1 Parking Area

The lay-out 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 3-23.

Table 3-23. 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'	10' - 22'

Source: (12).

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 sub-compacts (Table 3-24).

Table 3-24 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: (8).

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 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-pool facility is illustrated in Figure 3-15.

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 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 3-16. 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.

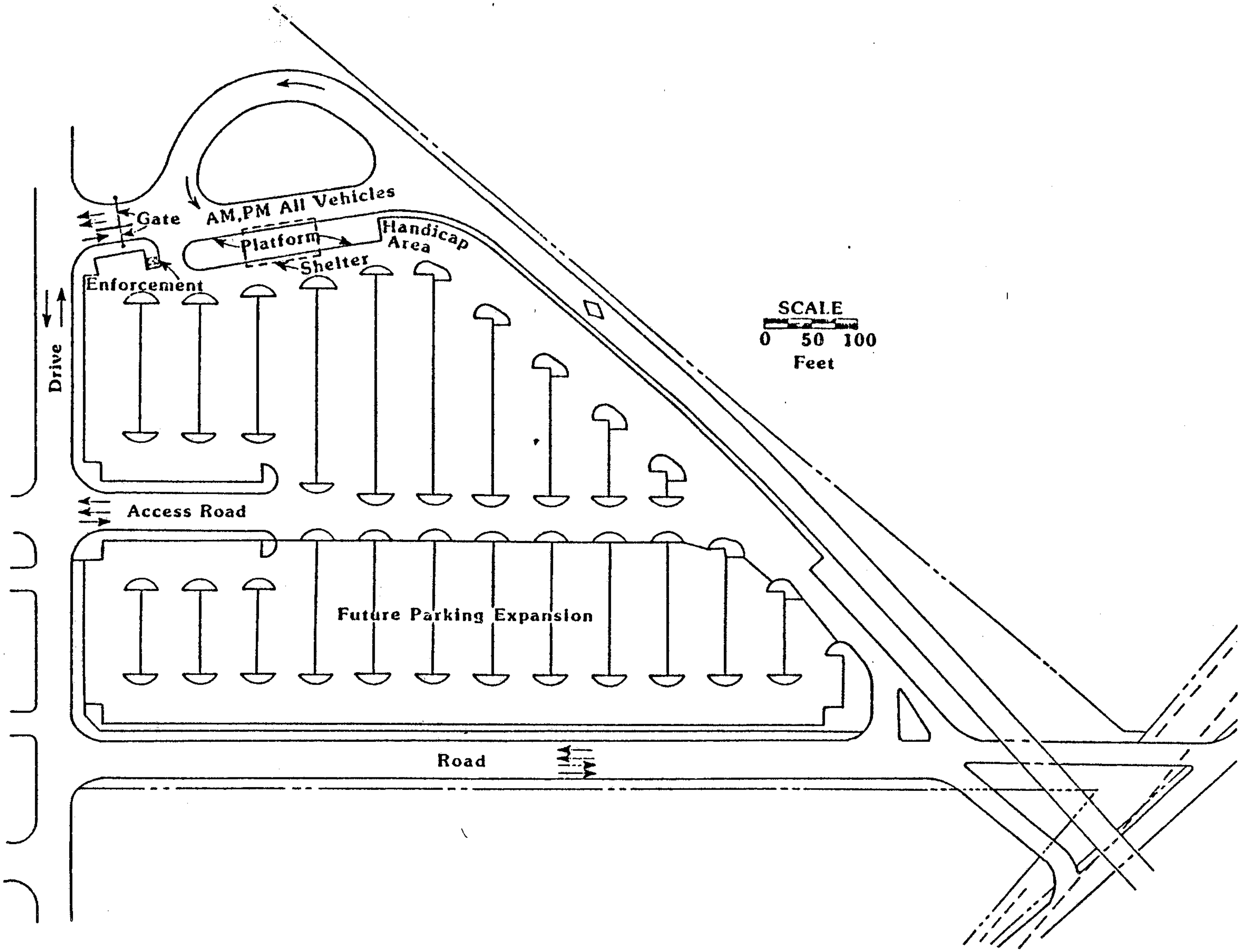


Figure 3-15. Example Layout of Park-and-Pool Area

Figure 3-16. Park-and-Pool Signing

3.5 REFERENCES

1. Texas Transportation Institute. Park-and-Ride Facilities. Res. Rept. 205-2, 1975.

2. ________. Design Guidelines for Park-and-Ride Facilities. Res Rept. 205-3, 1978.

3. ________. Factors Influencing the Utilization of Park-and-Ride; Dallas/Garland Survey Results. Res. Rept. 205-11, 1980.

4. ________. Park-and-Pool Facilities: Survey Results and Planning Data. Res. Rept. 205-13, 1981.

5. ________. Houston Park-and-Ride Facilities: An Analysis of Survey Data. Res. Rept. 205-25, 1981.

6. ________. Techniques for Estimating Vanpooling Demand. Res. Rept 205-17, 1982.

7. ________. Park-and-Pool Lots: Demand Estimation and Survey Results, Dallas-Ft. Worth. Res. Rept. 205-18, 1982.

8. ________. Guidelines for Planning, Designing and Operating Park-and-Ride Lots in Texas. Res. Rept. 205-22F, 1983.

9. Levinson, H.S., C.L. Adams and W.F. Hoey. Bus Use of Highways: Planning and Design Guidelines. NCHRP Rept. No. 155, 1975.

10. Levinson, H.S. and Texas Transportation Institute. Lockwood Transit Center Conceptual Planning Design. Prepared for Metropolitan Transit Authority of Harris County, 1983.

11. Schneider, J.B. et al. Planning and Designing a Transit Center Based Transit System: Guidelines and Examples from Case Studies in Twenty-Two Cities. UMTA-WA-11-0007-81-1, 1980.

12. American Association of State Highway and Transportation Officials. Guide for the Design of High Occupancy Vehicle and Public Transfer Facilities, 1983.

13. Sussman, E.D. and L.G. Richards. Transit Station Security. In Planning and Development of Public Transportation Terminals. Rept. No. DOT/RSPA/DPB-50/81/19, 1981.

14. U.S. Dept. of Transportation. Manual on Uniform Traffic Control Devices for Streets and Highways. Federal Highway Administration, 1978.