PROCEDURES FOR ESTIMATING PARK-AND-RIDE DEMAND IN LARGE TEXAS CITIES

By

Lisa G. Nungesser
Research Associate
and
Nancy P. Ledbetter
Research Assistant

Research Report 339-7

Improving Urban Mobility Through Application of High-Occupancy
Vehicle Priority Treatments
Research Study Number 2-10-84-339

Sponsored By

State Department of Highways and Public Transportation
in Cooperation with
U.S. Department of Transportation
Federal Highway Administration

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

February 1987

TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA/TX-87/24+339-7		

4. Title and Subtitle	5. Report Date
Procedures for Estimating Park-and-Ride Demand in Large Texas Cities	February 1987
	6. Performing Organization Code
7. Author(s)	8. Performing Organization Report No.
Lisa G. Nungesser and Nancy P. Ledbetter	Research Report 339-7
9. Performing Organization Name and Address	10. Work Unit No.
Texas Transportation Institute The Texas A&M University System College Station, Texas 77843	11. Contract or Grant No. Study No. 2-10-84-339
	13. Type of Report and Period Covered
12. Sponsoring Agency Name and Address Texas State Department of Highways and Public Transportation; Transportation Planning Division P. O. Box 5051 Austin, Texas 78763	Interim - September 1983 February 1987
	14. Sponsoring Agency Code

15. Supplementary Notes

Research performed in cooperation with DOT, FHWA.
Research Study Title: Improving Urban Mobility Through Application of High-Occupancy Vehicle Priority Treatments.

16. Abstract

Numerous park-and-ride lots are being developed in Texas. This report develops techniques to estimate the ranges in ridership that will likely occur at park-and-ride lots in large urban areas. The data base employed to develop these techniques uses the experiences of 16 park-and-ride lots in Houston, Texas. Several of these models are then applied to Dallas park-and-ride lots. The demand estimation techniques presented are intended to be relatively easy and inexpensive to apply and use only data that are readily available for Texas urban areas. These techniques are also developed to estimate the impact of high-occupancy vehicle lanes, also called authorized vehicle lanes, on park-and-ride lot utilization.

17. Key Words	18. Distribution Statement
Park-and-Ride, Modal Split, Transit Demand Estimation, Change of Mode Facilities, Bus Rapid Transit, Terminal Design.	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	100	

Form DOT F 1700.7 (8-69)

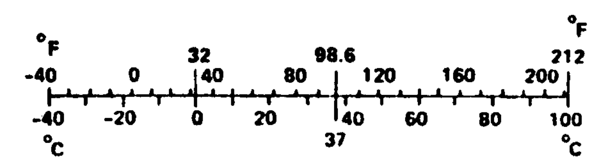
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

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ACKNOWLEDGEMENTS

The Texas Transportation Institute received assistance from the following transit properties:

Capital Metro Transportation Authority - Austin, Alan Wulkan
Corpus Christi Regional Transportation Authority - Corpus Christi, Christie Posey
Dallas Area Rapid Transit - Dallas, Loraine G. Lee
Dallas Transit System - Dallas, Cliff Franklin
Fort Worth Transportation Authority, Linda Watson
Metropolitan Transit Authority - Houston, Chuck Fuhs
Sun City Transit System - El Paso, Manny Escontrias
VIA Metropolitan Transit Authority - San Antonio, Debra Astin

The Institute would like to acknowledge gratefully their contributions.

ABSTRACT

Numerous park-and-ride lots are being developed in Texas. This report develops techniques to estimate the ranges in ridership that will likely occur at park-and-ride lots in large urban areas. The data base employed to develop these techniques uses the experiences of 16 park-and-ride lots in Houston, Texas. Several of these models are then applied to Dallas park-and-ride lots. The demand estimation techniques presented are intended to be relatively easy and inexpensive to apply and use only data that are readily available for Texas urban areas. These techniques are also developed to estimate the impact of high-occupancy vehicle lanes, also called authorized vehicle lanes, on park-and-ride lot utilization.

SUMMARY

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

Park-and-ride lots draw their demand from a watershed or market area. In Houston, this market area is generally parabolic in shape, with a vertex 0.5 to 1.0 mile downstream of the lot, an axis of 7 miles in length following the major artery upstream of the lot, and with a chord of 8 miles in length.

A summary of the demand estimation techniques considered follows:

- **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. As a "ballpark" indicator of park-and-ride demand, ridership is generally 0.5% to 2.0% of market area population.

- **Modal Split**: The percentage of the person trips (either all purposes or work trips only) 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. Modal splits typically range between 15% and 35%.

- **Regression Equations:** The data base containing variables which offer exploratory power in forecasting park-and-ride demand are evaluated with various variable combinations to develop equations useful in estimating park-and-ride patronage. Several equations are presented subsequently in this summary.

- **Institute of Transportation Engineers Model:** Park-and-ride demand at a given lot is equal to some percentage of peak period trips on adjacent streets that can be diverted into the lot.

- **GOPARK:** Developed in Georgia, examines only work trips bound for specified destinations and assumes that demand for park-and-ride comes from two sources; commuters from external areas passing the lot on the prime facility, and commuters from the lot's surrounding service area.

- **GOPARK II:** Same as GOPARK except that this model assumes that, within the service area, the closer a commuter lives to the park-and-ride lot, the more likely the individual is to use it. The service area is divided into three zones: the area within five minutes travel time, five to ten minutes from the lot, and the area ten to fifteen minutes from the lot.

This overview of selected demand estimation techniques used for park-and-ride facilities shows the variety of approaches currently used in practice. In recognition of the uncertainty surrounding park-and-ride project planning, demand estimates desirably should be expressed as ranges rather than point estimates or values. For this reason, transportation planners should employ several (three or more) of the outlined procedures in investigating any particular site for potential park-and-ride development. Table S-1 summarizes the estimating techniques and their data requirements.

Distinctive differences in ridership exist for those park-and-ride lots served by authorized vehicle lanes (AVL's) and those without AVL service. Ridership growth at lots with AVL's appears to be affected most by congestion on the freeway and employees in the park-and-ride market area destined to the

Table S-1. Summary Overview of Park-and-Ride Demand Estimation Techniques

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

CBD. Specifically, the average of congestion indices encountered along the freeway portion of the trip and CBD-destined employees in the market area emerged as good ridership predictor variables.

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

Several one- and two-variable models emerged as especially useful in projecting park-and-ride demand. Different models emerged for estimating ridership at lots served by AVL's and those not given priority treatment.

With or Without Priority Service

1. Riders = -1355 + 520.8 (ICI_B) + .07 (CBD_EMP) + 240.3 (AVL) + 6.52 (MO)
   R^2 = .49, RMSE 284.81
2. Riders = -1425.10 +605.08 (ICI_B) + 4.74 (MO) +.095 (CBD_EMP)
   R^2 = .40, RMSE = 299.15
3. Riders = -273.59 + 253.72 (ICI_B) + 5.21 (MO)
   R^2 = .24, RMSE = 315.17

Without AVL Service

1. Riders = 16.13 + 4.85 (MO) + 12.89 (DIST)
   R^2 = .89, RMSE = 58.19
2. Riders = 284.1 + 4.18 (MO) - 7.92 (ICI_B)
   R^2 = .67, RMSE = 99.68

With AVL Service

1. Riders = -4280.5 + 1675.75 (ICI_B) + .23 (CBD_EMP)
   R^2 = .76, RMSE = 241.16

2. Riders = -5351.3 + 1957.86 (ICI_B) + .0156 (MAPOP)

R^2 = .70, RMSE = 271.63

3. Riders = -4969.46 + 1866.33 (ICI_B) + .0056 (MAPOP) + .17 (CBD_EMP)

R^2 = .78, RMSE 249.24

4. Riders = -3786.7 + 1326.79 (ICI_B) + 8.75 (MO) + .246 (CBD_EMP)

R^2 = .84, RMSE = 212.28

where:

- MO = Months of lot's operation
- DIST = Road mileage to activity center
- AVL = Presence (1) or absence (0) of authorized vehicle lane
- ICI_B = Average of freeway congestion indices encountered on freeway portion of trip
- CBD_EMP = Employees residing in the market area destined for the central business district (CBD)
- MAPOP = People residing in market area of park-and-ride lot
- RMSE = Root Mean Squared Error

It appears that provision of an authorized vehicle lane increases park-and-ride utilization by between 60% and 100%. In addition, a one-variable model emerged as a good predictor of the percent of the market area population served by a lot with AVL service. The model follows:

Proportion MAPOP Served = -.031 + .0166 (ICI_B)

R^2 = .72, RMSE = .0036

The report includes other two- and three-variable models as well as calibrations of ITE and GOPARK models. None of these models, however, improve the projection accuracy or ease of utilization over the models discussed above.

IMPLEMENTATION STATEMENT

Texas continues to develop numerous large park-and-ride facilities in major cities. To date, limited Texas data have been available to assist in sizing and locating these facilities. This report expands this data base.

This report presents information that can be used by transportation planners in sizing and locating park-and-ride lots in large urban areas. This report, which provides guidelines for park-and-ride demand estimation, complements the following reports published by the Texas Transportation Institute.

"Park-and-Ride Facilities: Preliminary Planning Guidelines," Research Report 205-2, 1975.

"Design Guidelines for Park-and-Ride Facilities," Research Report 205-3, 1978.

"Development of Preliminary Congestion Indices for Urban Freeways in Texas," Research Report 205-7, 1979.

"Factors Influencing the Utilization of Park-and-Ride--Dallas/Garland Survey Results," Research Report 205-11, 1980.

"Houston Park-and-Ride Facilities, An Analysis of Survey Data," Research Report 205-15, 1981.

"Guidelines For Estimating Park-and-Ride Demand," Technical Report 1064-1F, 1981.

"Guidelines For Planning, Designing and Operating Park-and-Ride Lots in Texas," Research Report 205-22F, 1983.

"Alternative Mass Transportation Technologies Technical Data," Research Report 339-4, 1985.

DISCLAIMER

This report was prepared by the Texas Transportation Institute for the Texas State Department of Highways and Public Transportation in cooperation with the U.S. Department of Transportation, Federal Highway Administration.

The contents of this report reflect the views of the authors who are responsible for the opinions, findings and conclusions presented herein. The contents do not necessarily reflect the official view or policies of the sponsors. This report does not constitute a standard, specification or regulation.

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INTRODUCTION

During the past 10 to 12 years, development of park-and-ride lots has become a significant part of transit development plans in major Texas cities. Presently, about 80 park-and-ride lots operate in seven metropolitan areas in Texas. These metropolitan areas include Austin, Corpus Christi, Dallas, El Paso, Fort Worth, Houston and San Antonio. Several of these cities are actively pursuing the development of additional park-and-ride facilities. In essence, park-and-ride has proven to be a popular travel alternative (1).*

Because park-and-ride service is rapidly being developed in Texas, it is desirable to develop techniques to estimate demand for this service. These demand estimation techniques would be most applicable if they utilize available data, do not require large-scale computer modeling, and are able to predict with relative ease ridership at alternative park-and-ride sites. This study's objective is the development of such prediction techniques.

Chapter 2 presents the historical development of park-and-ride service in the United States, Texas, and, more specifically, Houston, Texas. The study presents several types of demand estimation models in Chapter 3. Not only are the Texas Transportation Institute demand estimation models (market area analysis, modal split and regression analysis) presented, but also alternative models such as the Institute of Transportation Engineers (ITE) model and the Georgia Department of Transportation models, GOPARK and GOPARK II, are discussed. The report applies the six demand estimation methodologies to Houston' park-and-ride lots to develop a series of techniques calibrated for large urban areas. The calibrated models are then applied to several of the park-and-ride lots in the Dallas area.

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*Denotes number of reference listed at the end of the report.

HISTORICAL DEVELOPMENT, CURRENT STATUS AND IMPACT

United States

The park-and-ride concept has existed in the United States since the late 1930's. The City of Detroit was a park-and-ride pioneer, opening eight small park-and-ride lots at gasoline stations located along existing transit lines. Because all of the lots were considered unsuccessful, they were subsequently discontinued (1).

In 1939, the Long Island Railroad developed a large park-and-ride lot on the grounds of the World's Fair. That facility was expanded over the years to a capacity of 3,500 cars by 1974 (2).

By the mid 1940's, many of the transit companies in the major cities had implemented park-and-ride programs, then referred to as "fringe lots". Boston, Philadelphia, Cleveland, St. Louis, Hartford, Atlanta, and Richmond were noted as some of the leaders in fringe parking (2).

In 1953, the first major U.S. bus park-and-ride facility was a 1,000-space lot located in the St. Louis suburb of Forest Park. Transit service linked the lot to the St. Louis Central Business District (CBD) located about five miles away (1).

The Port Authority of New York and New Jersey implemented a 1600-space park-and-ride facility two years later providing transit service to Manhattan. The Washington, D.C. metropolitan area also began park-and-ride service in 1955. The 900-space lot located at the Carter Barron Amphitheater in northwest Washington, D.C. provided bus service from the lot to the downtown area (1). Boston implemented park-and-ride service in the late 1950's (3).

By the middle 1960's, approximately 36 U.S. cities had implemented some form of park-and-ride service. At least 28 of those cities continue to operate the service (1, 3). Texas saw its first park-and-ride facility in

1963. Leonard's Department Store operated a lot located one mile outside of the Fort Worth CBD at the terminus of the subway.

During the 1970's and early 1980's, several additional cities followed with park-and-ride service (1). In 1975, over 60,000 park-and-ride spaces were available in Cleveland, over 22,000 spaces in Chicago, and more than 17,000 spaces existed in Boston, mainly to serve rail transit (3). The number of park-and-ride spaces available continues to increase.

In many cities, individual lot sizes have increased to capacities of over 1000 spaces. North Bergen, New Jersey; Cleveland, Ohio; Chicago, Illinois; Boston, Massachusetts; Cincinnati, Ohio; and Houston, Texas are typical cities with individual lots having a capacity greater than 1200 spaces. One of the largest lots in the country, with 2552 spaces, is the Lake Shore and Ninth Street facility in Cleveland, Ohio (2).

Many of the first park-and-ride facilities differed from those being implemented today. The level of planning is a key difference. A major emphasis of the earlier lots was on accommodating existing demand rather than on generating new demand. Today, park-and-ride programs comprise significant parts of many major highway and transit improvement plans and are implemented to attract people out of their automobiles into buses or other high-occupancy vehicles (1).

Texas

During the last several decades, the intensity of development in the central business district (CBD) and other major activity centers in the larger Texas cities has continued to increase. During this time, relatively low land costs and the widespread use of the private automobile have caused low density residential development to occur farther from these centers of business activity. This pattern of development has resulted in increasingly larger number of commuters traveling increasingly longer distances to reach their place of work.

Along with the growth of the major activity centers and the outward movement of residential development has come the need for increasing the peak-period capacity of the transportation facilities which link these areas together. During the 1950's and 1960's, the need for increased vehicular capacity along heavily traveled corridors was generally met by constructing new roadway facilities. By the 1970's, however, the construction of new facilities had been greatly curtailed because of cost considerations, land availability and environmental and energy concerns. As a result, considerable effort is now being concentrated in the area of increasing the person-movement capacity of the existing transportation systems (1).

Current Status

By 1982, six major Texas cities (Fort Worth, Dallas, Houston, San Antonio, El Paso, and Austin) had implemented park-and-ride service with a total of 68 lots statewide (1). As of 1985, 80 park-and-ride lots were located throughout the state in seven major cities including Corpus Christi, with parking spaces totaling over 28,000 (4, 5). A brief description of the existing services in these urban areas follows.

Austin

The City of Austin initiated its park-and-ride service in March 1974 as part of a transportation energy conservation program (1). As of 1985, Austin had 8 park-and-ride lots providing 435 spaces to patrons. The January 1985 creation of Capital Metro, Austin's Public Transportation Authority, has resulted in commitments to expand existing park-and-ride lot service. As presented in Table 2.1, the percent utilization of Austin's park-and-ride lots is approximately 47%.

Table 2.1 Characteristics of Austin Park-and-Ride Lots, 1985

Park-and-Ride Lot	Lot Location	Parking Spaces	Spaces Used	Percent Utilized
North #1	Rutland at Ledgewood	40	NA	NA
North #2	Lamar at Rundberg	25	15	60
US 183 N. #1	Research at Spicewood Springs	50	30	60
US 183 N. #2	Research at Balcones Wood Dr.	40	30	75
Fox Theatre	Airport at Pampa	100	70	70
Southwest	US 290W at Toney Burger Ctr.	100	10	10
N.W. Hills	7017 Hart Lane	30	NA	NA
TOTAL		435	173	47(1)

(1) Excludes data from lots; North #1 and N.W. Hills

Source: Capital Metro.

Corpus Christi

The Corpus Christi Transit System recently implemented park-and-ride service with the opening of three joint-use lots. Joint-use lots are typically lots constructed to serve retail/commercial activities but are also used to accommodate commuter vehicles parked from the morning peak period until the evening peak period. The location of the lots and the number of spaces used are presented in Table 2.2 below.

Table 2.2 Characteristics of Corpus Christi Park-and-Ride Lots, 1985

Park-and-Ride Lot	Lot Location	Parking Spaces	Spaces Used	Percent Utilized
Calallen	US 77	NA	35	NA
Portland Baptist Church	1305 Wildcat	NA	30	NA
Mission Shopping Center	4977 Ayers St.	NA	17	NA
TOTAL		NA	82	NA

Source: Corpus Christi Transit System

Dallas Area

In November 1973, Dallas opened its initial park-and-ride facility on the North Central Expressway (US 75) as part of an Urban Corridor Demonstration Project (1). As of 1985, the Dallas Transit System provided a total of 6,229 parking spaces at the 15 Dallas/Garland park-and-ride facilities. Approximately 67% of the total number of park-and-ride spaces are utilized as shown in Table 2.3.

Table 2.3 Characteristics of Dallas Area Park-and-Ride Lots, 1985

Park-and-Ride Lot	Lot Location	Parking Spaces	Spaces Used	Percent Utilized
Plano Drive Inn	Hwy. 75 at Parker	600	496	83
North Central	Coit Rd. at Churchill Way	945	70[1]	7
Pleasant Grove	Seaford at Maddox	710	200	28
Redbird	Redbird Airport	302	310	103
Garland North	Fifth at 5th	315	248	79
Garland South	NW Hwy at Jackson Drive	542	550	101
Las Colinas North	SH 114 at O'Connor Road	229	223	97
Las Colinas South	Bowie Street	440	178	40
Reunion	Memorial Drive at Sports St.	1,500	1,100	73
Loos Stadium	Spring Valley Road	150	90	60
Forneaux Creek Mall	Trinity Mill at Denton	50	188	376
Word of Faith	I-35 at Valley View	100	46	46
Beltline	I-35 at Beltline	58	76	131
Richardson Terrace Ctr.	Greenville at Beltline	100	159	159
First Baptist Church	Greenville at Phillips	188	233	124
TOTAL		6,229	4,167	67

[1]North Central park-and-ride was under construction to expand the 482 space lot to 945 spaces; it opened in May, 1985. During construction, the spaces used dropped from 400 (in 1982) to 70.

Source: Dallas Transit System and Dallas Area Rapid Transit.

El Paso

In December 1978, Sun City Area Transit opened a 76-space lot at Montwood Square Shopping Center at the east end of town (1). As of 1985, the system operates four park-and-ride lots with a total of 286 spaces. Data are presented in Table 2.4

Table 2.4 Characteristics of El Paso Park-and-Ride Lots, 1985

Park-and-Ride Lot	Lot Location	Parking Spaces	Spaces Used	Percent Utilized
Vista Hills	Montwood at Bobby Jones	73	112	100
Mount Hope Lutheran	9640 Montwood	40	NA	NA
Northgate	Diana at Joe Herrera	100	44	25
Rusfair	Rushing at Fairbanks	73	NA	NA
TOTAL		286	156	90[1]

[1]Excludes data from lots Mount Hope Lutheran and Rusfair.

Source: Sun City Transit.

Fort Worth

Fort Worth was the first city to implement park-and-ride service in Texas and refers to its service as "Park-and-Go". This name was selected to distinguish the type of transit service (local, generally non-express) provided by Fort Worth's CITRAN from the express service initially provided by the Dallas Transit System (DTS) in Dallas and Garland (1). A total of 24 park-and-go facilities were in operation as of 1985. Characteristics of these lots are presented in Tables 2.5. In addition, the Fort Worth Transit Authority (FWTA) provides 11 lots for carpoolers and vanpoolers to meet, park extra vehicles, and consolidate their travel in one vehicle. Table 2.6 presents data on these lots. During special events, FWTA, also known as the "T", offers express buses to and from some of these lots.

Table 2.5 Characteristics of Fort Worth Park-and-Go Lots, 1985

Park-and-Ride Lot	Lot Location	Parking Spaces	Spaces Used	% Full
Springdale Baptist Church	3016 Selma	N/A	2	N/A
Seminary South Mall	Bolt Street	N/A	N/A	N/A
First United Meth. Church	Bedford Rd. at Airport Fwy.	N/A	77	N/A
Will Rogers Coliseum	3301 West Lancaster	N/A	N/A	N/A
Brentwood Bible Church	6917 Brentwood Stair	N/A	N/A	N/A
Ft. Worth Bible Church	Terbert at Brentwood Stair	N/A	10	N/A
Jefferson Unitarian Church	1950 Shady Lane	N/A	10	N/A
Handley Methodist Church	2929 N. Forest Street	N/A	71	N/A
Handley Baptist Church	6800 Church Street	N/A	2	N/A
Herman E. Clark Stadium	TCJC Folwell/Eastside	N/A	12	N/A
Ed. K. Collett Park	4800 West Vickery	N/A	N/A	N/A
K-Mart	4812 South Freeway	N/A	15	N/A
Bethel United Meth. Church	5000 Southwest Blvd.	N/A	N/A	N/A
St. Mark's Meth. Church	6250 South Freeway	N/A	10	N/A
St. Luke's Pres. Church	1404 Sycamore School Rd.	N/A	1	N/A
Edgepark Meth. Church	5616 Crowley Rd.	N/A	59	N/A
K-Mart	6300 McCart	N/A	22	N/A
Western Hills Meth. Church	2820 Laredo	N/A	N/A	N/A
Altamesa Church of Christ	4600 Altamesa	N/A	6	N/A
Hulen Mall	4800 South Hulen	N/A	N/A	N/A
Tanglewood Village	3100 South Hulen	N/A	71	N/A
Levitz Furniture	7100 Camp Bowie Blvd.	N/A	6	N/A
Ridglea Baptist Church	6037 Calmont	N/A	51	N/A
Arlington Hts. Christ Church	4629 Bryce	N/A	5	N/A
	TOTAL	N/A	430+	N/A

Source: Fort Worth Transit Authority

Table 2.6 Characteristics of Fort Worth Carpool and Vanpool Lots, 1985

Park-and-Ride Lot	Lot Location	Parking Spaces	Spaces Used	Percent Utilized
N.E. Sub-Courthouse	645 Grapevine Hwy.	NA	NA	NA
Safeway	6605 Forest Hill Dr.	NA	NA	NA
Crowley	Main at Hampton	NA	NA	NA
First Baptist Church Euless	Hwy. 157 at Airport Fwy.	NA	31	NA
Arlington Stadium	Randol Mill Road	NA	135	NA
Six Flags Mall	411 Six Flags Mall	NA	129	NA
Brentwood Church of Christ	6516 Brentwood Stair	NA	90	NA
Northwest Sub-Courthouse	6713 Telephone Road	NA	NA	NA
1st Baptist Church, Lakeside	8801 Jacksboro Hwy.	NA	NA	NA
Edisons	303 at Park Springs Blvd.	NA	NA	NA
Northeast Mall	Loop 820 at Hwy. 183	NA	25	NA
TOTAL		NA	410+	NA

Source: Fort Worth Transit Authority

Houston

Park-and-ride service was initiated in the Houston Metropolitan area in March 1977 with the opening of a lot in southeast Houston at a Sage Department Store (1). Currently, the Metropolitan Transit Authority (METRO) of Harris County operates 17 park-and-ride lots with over 19,300 spaces. Table 2.7 presents the characteristics of Houston's park-and-ride lots. Additional information on Houston's park-and-ride service is presented later in this chapter.

Table 2.7 Characteristics of Houston Park-and-Ride Lots, 1985

Park-and-Ride Lot	Lot Location	Parking Spaces	Spaces Used	% Full
S.W. Freeway	Bellaire at Rookin	125	160	128
N. Shepherd	7821 N. Shepherd	1,605	754	47
Kuykendahl	12920 Kuykendahl	2,246	1,595	71
Spring	17444 Carlsway Rd.	1,280	1,031	81
Kingwood	3210 Lake Houston Pkwy.	940	504	54
Eastex	1440 Old Humble Rd.	930	296	32
West Belt	Katy Freeway at West Belt	1,111	147[1]	13
Seton Lake	7555 Seton Lake	1,286	665	52
N.W. Station	18502 Hempstead Hwy.	1,222	290	24
Kingsland	Old Katy Rd.	1,300	225	17
Addicks	14230 Old Katy Rd.	1,119	550	49
Edgebrook	9524 Edgebrook	1,000	628	63
Bay Area	801 Bay Area Blvd.	1,165	519	45
West Loop	S. Post Oak at S. Braeswood	639	477	75
Westwood	9900 S.W. Freeway at Bissonnet	1,213	500	41
Alief	8901 Boone Rd.	1,377	328	24
Missouri City	13849 Fondren	799	270	35
	TOTAL	19,337	8,939	46

[1]The West Belt usage was based on 2 months operating experience after opening. Park-and-ride usage increased to 264 after 14 months.

Source: Metropolitan Transit Authority.

San Antonio

The City of San Antonio implemented its first park-and-ride facilities in 1974 with the opening of two lots (1). VIA Metropolitan Transit currently operates 9 park-and-ride lots with a total of 1,475 parking spaces with a utilization rate of 46%. Table 2.8 presents the characteristics of San Antonio's lots.

Table 2.8 Characteristics of San Antonio Park-and-Ride Lots, 1985

Park-and-Ride Lot	Lot Location	Parking Spaces	Spaces Used	Percent Utilized
Windsor Park Mall	I-35 at Walzem	170	123	72
McCreless	S. New Braunfels at Ada	75	31	41
South Park Mall	S.W. Military at Zarzamora	70	24	34
Kel-Lac	Hwy. 90 at Military Dr.	173	94	54
Wonderland	Gill at Wonderland	322	285	89
University	Loop 1604 at 1-10	152	41	27
Broadway/Value Club	Broadway at Gulfmart	63	3	5
Ingram	Ingram at Wurzbach	150	51	34
I-35 - I-410	I-35 at I-410	300	20	7
	TOTAL	1,475	672	46

Source: VIA Metropolitan Transit

Summary

In 1985, a total of 80 lots in seven major cities in Texas offered park-and-ride service. This represents an increase of 24,000 spaces over ten years, which is a 623 percent increase. In 1985, at least 28,000 spaces were available, with nearly 15,000 vehicles parked daily at the lots. This represents approximately 19,000 daily park-and-ride patrons. Figure 2.1 graphically presents the historic growth of park-and-ride spaces available in Texas cities. Table 2.9 shows the changes in park-and-ride lot spaces over the last decade. Table 2.10 summarizes the current status of park-and-ride lots in Texas.

Houston, Texas

In March 1977, park-and-ride service was introduced to the Houston metropolitan region with the opening of a 225-space lot at a Sage Department

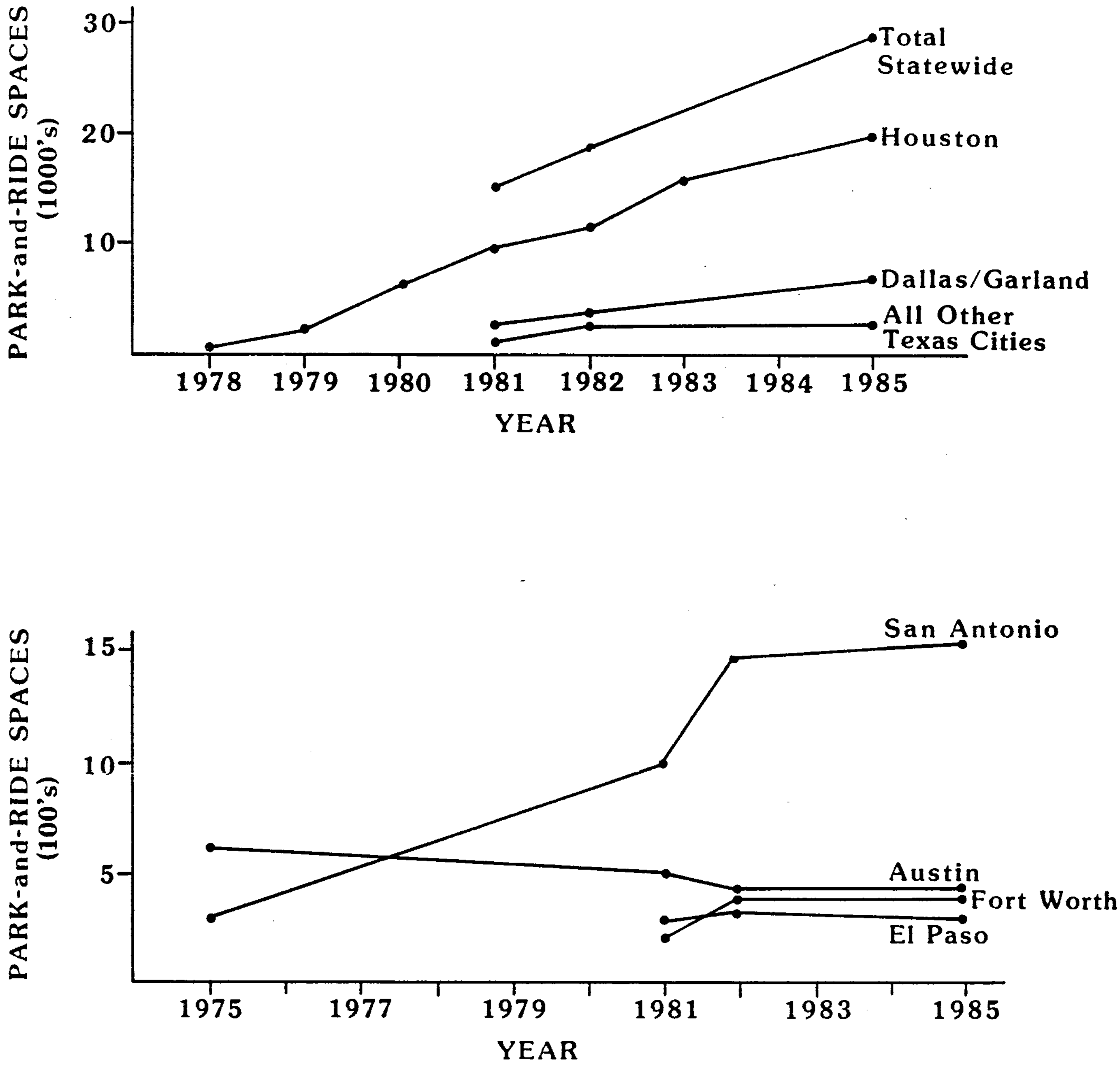


Figure 2.1: Park-and-Ride Spaces in Texas Cities

Table 2.9 Changes in Texas Park-and-Ride Lot Spaces for 1975, 1981, 1982, and 1985

City	1975 Spaces	1981 Spaces	% Change	1982 Spaces	% Change	1985 Spaces	% Change
Austin	600	499	-17%	435	-13%	435	0%
Corpus Christi	-----	-----	-----	-----	-----	N/A	-----
Dallas	2,972	3,149	6%	3,935	20%	6,229	58%
El Paso	-----	284	-----	374	32%	286	-24%
Fort Worth	N/A	210	N/A	430	105%	430	0%
Houston	-----	9,140	-----	11,539	26%	19,337	68%
San Antonio	329	933	184%	1,398	50%	1,475	6%
TOTAL	3,901	14,215	264%	18,111	27%	28,192	56%

---- indicates that park-and-ride service was not in operation.

N/A indicates that park-and-ride was in operation but data not available.

Table 2.10 Park-and-Ride Lots in Texas, 1985

City	Number of Lots	Number Of Spaces	Spaces Used	Daily R.T.[1] Riders
Austin	8	435	173+	282
Corpus Christi	3	N/A	82	135
Dallas/Garland	15	6,229	4,167	6,292
El Paso	4	286	156+	242
Fort Worth[2]	24	N/A	430+	615
Houston	17	19,337	8,939	10,395
San Antonio	9	1,475	672	1,095
TOTAL	80	27,762+[3]	14,619+	19,056

[1]R.T. means round-trip.

[2]Excludes Fort Worth carpool lots.

[3]This excludes an estimated 82 spaces for Corpus Christi and 430 spaces for Fort Worth.

Store in the I-45 (Gulf) Freeway corridor. The success of the service encouraged Houston's Office of Public Transportation to expand park-and-ride service (1, 6). Three months later, the city opened two additional lots in southwest Houston (1).

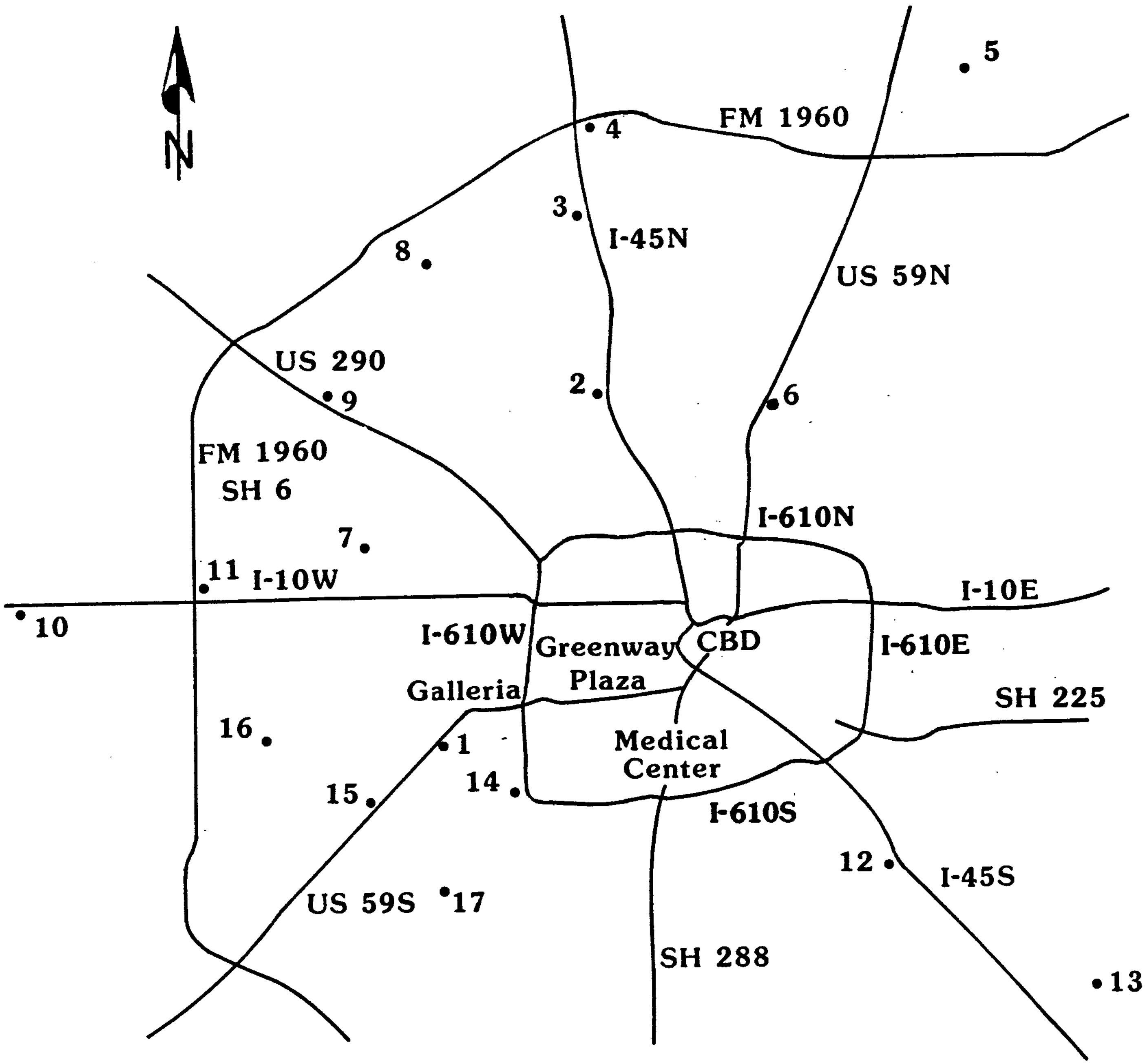
Harris County voters passed the Metropolitan Transit Authority (MTA) referendum on August 12, 1978 (7). It created Texas' second MTA, each having its own dedicated sales tax base. Responsibility for Houston's transit system, HouTran, shifted to MTA (Metro). This included the transfer of approximately 1000 park-and-ride spaces throughout the region (6).

Park-and-ride played an important role in the Metro Plan adopted by voters during the MTA formation. This service provides a mechanism for quickly supplying the growing unserved MTA region with transit service, where demand for service had been demonstrated (6).

During the first year of operation, Metro aggressively pursued the expansion of park-and-ride through leasing lots. Typically, these lots were located in portions of retail or church parking lots and, by 1979, Metro added nearly 1100 additional spaces to the park-and-ride inventory (6).

Demand for park-and-ride was overwhelming, with several leased lots filling quickly; however, problems arose from the overcrowded conditions at the leased lots. In lots where only a portion of spaces were leased, parkers began spilling over into areas not designated for park-and-ride. At other lots, bus patrons parked in grassy areas, in circulation aisles, and on neighborhood streets. At churches, park-and-ride patrons were occupying the few designated staff spaces or blocking access to these spaces. Metro recognized that permanent park-and-ride lots were needed to replace the leased lots. The process to replace the leased lots began. A combination of local, state, and federal funds helped pay for the park-and-ride lot construction (6).

By the end of 1982, Houston had the most extensive park-and-ride program in the state, with 15 different lots containing more than 10,700 spaces (4). By 1986 this increased to 17 lots with over 19,300 spaces. Figure 2.2 shows



LEGEND

1. Southwest Freeway
2. North Shepherd
3. Kuykendahl
4. Spring
5. Kingwood
6. Eastex
7. West Belt
8. Seton Lake
9. Northwest Station
10. Kingsland
11. Addicks
12. Edgebrook
13. Bay Area
14. West Loop
15. Westwood
16. Alief
17. Missouri City

Figure 2.2: Houston Area Park-and-Ride Lots

the locations of the park-and-ride lots. Seven of these lots utilize transitways for the line-haul portion of their trips. Metro's program is the only one in the state to offer priority treatment using exclusive bus lanes on freeways to selected lots (1).

The number of people taking advantage of Houston's park-and-ride service on a typical day varies from a low of about 158 riders at the West Belt lot, the newest facility, to a high of 1,689 at the Kuykendahl lot. The total number of daily riders at all 17 lots averages nearly 10,400 (5). This number represents about 55% of the State's 19,000 daily park-and-ride patrons (4). Table 2.11 presents more detailed 1985 ridership and operation information for the Houston lots.

Table 2.11 Houston Park-and-Ride Service, March 1985

Lot Name	Lot Number	Began	Lot Capacity	Daily Parked Cars	Daily Round-Trip Riders
S.W. Freeway	59	6/1977	125	160	190
N. Shepherd	201	4/1980	1,605	754	905
Kuykendahl	202	1/1980	2,246	1,595	1,689
Spring	204	10/1982	1,280	1,031	919
Kingwood	205	11/1979	940	504	653
Eastex	206	7/1983	930	296	334
West Belt	210	1/1985	1,111	147[1]	158
Seton Lake	212	4/1983	1,285	665	801
N.W. Station	214	4/1984	1,222	290	336
Kingsland	221	9/1980	1,300	225	370
Addicks	228	1/1982	1,119	550	580
Edgebrook	245	3/1977	1,000	628	726
Bay Area	246	3/1980	1,165	519	629
West Loop	261	6/1977	639	477	543
Westwood	262	5/1979	1,213	500	509
Alief	263	4/1981	1,377	328	427
Missouri City	270	10/1981	779	270	326

[1]The West Belt ridership was based on two months operating experience after opening. Ridership increased to 242 after 12 months and to 282 after 14 months.

Source: Reference 5.

Analysis of these data on Table 2.11 shows all of the lots to have capacity for additional cars, except lot 59, Southwest Freeway. It is approximately 30 percent over-capacity. Lots 201, 202, 204, 210, 212, 221 and 228 use transitways, or authorized-vehicle lanes (AVL), to reach their destination, the central business district (CBD).

Park-and-Ride Concept

The park-and-ride concept is an effective way of combining the private automobile and public transit by using each mode in the geographic area to which it is best suited. The automobile collects riders in the low density residential areas and then funnels them by public transit along existing transportation corridors. Park-and-ride is thus able to draw trips from a relatively large market area to a point where there is a sufficient concentrated demand to support public transit. For this reason, park-and-ride is especially suited to low density areas which may not otherwise be able to support fixed-route transit service. The bus service can increase the efficiency of the highway for moving people (8).

The efficiencies fostered by the park-and-ride mode are not limited to the transportation network alone. Land use efficiencies may be realized because of a decentralization of parking demand at the activity center where land values are high. When large numbers of drivers leave their autos at park-and-ride facilities and take the bus, they reduce the demand for parking in the higher density core areas (9). The park-and-ride lots that serve Houston's authorized vehicle lane on I-45 reduce the demand for downtown parking by over 4,000 spaces, which is roughly equivalent to 20 to 40 acres of downtown parking in Houston (5), if those spaces were developed as surface lots. A benefit is realized because of the diversion of parking to areas of lower land use density and, hence, lower land values.

Park-and-ride service can also achieve reductions in energy consumption and air pollution. Because of the relatively low percentage of total trips that can be accommodated by park-and-ride service, however, the relative magnitude of park-and-ride fuel savings is low relative to total state and national transportation fuel consumption. By reducing vehicle-miles traveled, park-and-ride commuters also decrease air pollution. Studies show, however, that a vehicle with a cold engine emits more pollution than a warmed-up engine; therefore, air pollution emissions increase from vehicles making short trips. This tends to offset slightly the expected reduction in air pollution. Table 2.12 shows the air pollution and energy impact of a park-and-ride lot along a congested six- and eight-lane freeway for anorigin to destination distance of 10 miles (8).

Table 2.12 Impact of a Park-and-Ride Lot on Freeway Energy Consumption, Air Quality, and Congestion Per 3-Hour Peak Period

	Freeway Conditions	
Freeway Evaluation Factor	Without Park-and-Ride	With Park-and-Ride
Person-hours of travel	6,029	4,754 (-21%)
Average speed (mph)	43	53 (+23%)
Gasoline consumption (gals)	11,037	10,630 (- 4%)
Pollutants emitted (kilograms)		
Hydrocarbons	536	475 (-11%)
Carbon Monoxide	3,552	2,872 (-19%)
Nitrous Oxide	746	759 (+ 2%)

Notes: Based on implementing a 1200-space, fully-utilized park-and-ride lot along a congested six- and eight-lane freeway a distance of 10 miles from downtown. Based on FREQ computer simulation analysis.

Source: Reference 8.

Park-and-ride service shares operational attributes and impacts common to local bus operations. Not only using the freeway itself, park-and-ride service utilizes the local arterial street network for collection, distribution and terminal access. It can operate in a variety of modes: from high-speed line-haul service on exclusive bus lanes to collection and distribution functions on local arterial street network. Because motor bus modes possess the capability to utilize so many street and network configurations, bus operations can benefit from staged improvements with increasingly capital intensive projects being phased in as demand and congestion warrant. Bus operations in mixed traffic on freeways from park-and-rides exhibit the following characteristics (8).

- Because existing vehicles service park-and-ride lots, initial capital costs consist of vehicle acquisition, maintenance and storage. Joint-use lot costs typically are limited to lease arrangement and passenger shelter/terminal area costs. Owned or exclusive use lots include the former costs plus rights-of-way and lot design, and construction.

- Because fixed facility construction is minimal, the service may be implemented in a relatively short time.

- Service initiation involves little or no community disruption.

- Because it provides for a convenient mode, this service can provide a single transfer ride to concentrated destinations. For local park-and-ride service, the bus can provide collection and distribution functions.

- Freeway operating speeds limit operating speeds for buses serving park-and-ride lots and traveling in mixed-flow traffic.

- Because of the ability to use under-utilized parking lots, the park-and-ride mode has an inherent flexibility. As demand increases, owned or exclusive lots can replace joint-use lots.

- Some park-and-ride lots sustain all day transit service. Buses usually serve commuters during peak traffic hours. Some lots do have limited midday service available (8).

A concern for future urban mobility will be the ability to predict reasonably well the demand for park-and-ride facilities. Chapter 3 presents several methods to estimate park-and-ride demand as well as applications of the models to park-and-ride lots in Houston, Texas.

DEMAND ESTIMATION MODELS AND APPLICATIONS

Using information generally available for Texas' urban areas, researchers have developed and evaluated six different procedures to estimate potential park-and-ride utilization. The last procedure, GOPARK II Model, proved too cumbersome to use. In evaluating a potential site, planners should use at least three of these procedures to provide a range of demand estimates. That range provides a basis for decision-making.

- **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.

- **Modal Split.** The percentage of the person trips (either all purposes or work trips only) 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 containing variables which offer exploratory power in forecasting park-and-ride demand are evaluated with various variable combinations to develop equations useful in estimating park-and-ride patronage.

- **Institute of Transportation Engineers Model.** Park-and-ride demand at a given lot is equal to some percentage of peak-period trips on adjacent streets that can be diverted into the lot.

- **Georgia GOPARK Model.** Examines only work trips bound for specified destinations and assumes that demand for park-and-ride comes from two sources: commuters from external areas passing the lot on the prime facility, and commuters from the lot's surrounding service area.

- **Georgia GOPARK II Model.** Assumes that demand comes from the same sources as GOPARK; however, this model assumes that within the service area the closer a commuter lives to the park-and-ride lot, the more likely the individual is to use it. The service area is divided into three zones: the area within five minutes travel time, five to ten minutes from the lot, and the area ten to fifteen minutes from the lot.

Based on survey work and operational experience with park-and-ride service, TTI developed lot location guidelines. It is recommended that these guidelines be employed in conjunction with the demand estimation models presented in this report. The lot location guidelines follow (1).

- Lots should be located at least 4 to 5 miles from the activity center served.

- The more successful lots occur along freeway corridors with daily traffic volumes per lane in excess of 15,000.

- Lots should be able to intercept traffic upstream of congestion.

- Lots should be developed with both good access and accessibility.

- Parking at the lot should be free.

- Park-and-ride service should not be expected to compete with local routes, especially if fare differentials exist.

In 1979 through 1980, Texas Transportation Institute developed a data base in order to calibrate the three demand estimation procedures for Texas. These are market area population, modal split, and regression equations. Since the 1981 report Guidelines for Estimating Park-and-Ride Demand, Houston Metro has expanded their service and opened authorized vehicle lanes (AVL) on North Freeway (I-45N) and Katy Freeway (I-10W). Additional census data on

CBD-employment have also been released. Together, these considerations made updating the 1981 park-and-ride demand estimation guidelines timely. The following describes the models and results of these calibrations.

Market Area Population

Analysis of data indicates that the population in the park-and-ride lot's watershed or market area can be used to gain an estimate of potential park-and-ride utilization. While many factors may influence its shape, the market area is typically parabolic in shape, with a vertex 0.5 to 1.0 mile downstream of the lot, an axis of 5 to 7 miles in length following the major artery upstream of the lot, and with a chord of 6 to 8 miles in length (2, 9). The presence of several park-and-ride lots in a single corridor will impact the parabolic shape since service areas should not overlap.

Survey work performed by TTI suggested that, in Houston, the "characteristic" market area was somewhat larger than the average shape in other Texas cities. Figure 3.1 presents the suggested market area size, having an axis of 7 miles in length and a chord of 8 miles in length. About 75 percent of total patrons live within five miles of the lot, and about 95 percent live within seven miles of the lot (10).

The percentage of the market area population represented by park-and-ride patronage varies between Texas cities; however, within Texas cities, for those lots located in accordance with the lot location guidelines, a "ballpark" range appears to exist (9). Table 3.1 summarizes these data (1). Ridership appears to correlate with variables such as congestion and intensity of activity center development. Figures 3.2, 3.3, and 3.4 also show the correlation with freeway congestion in Houston.

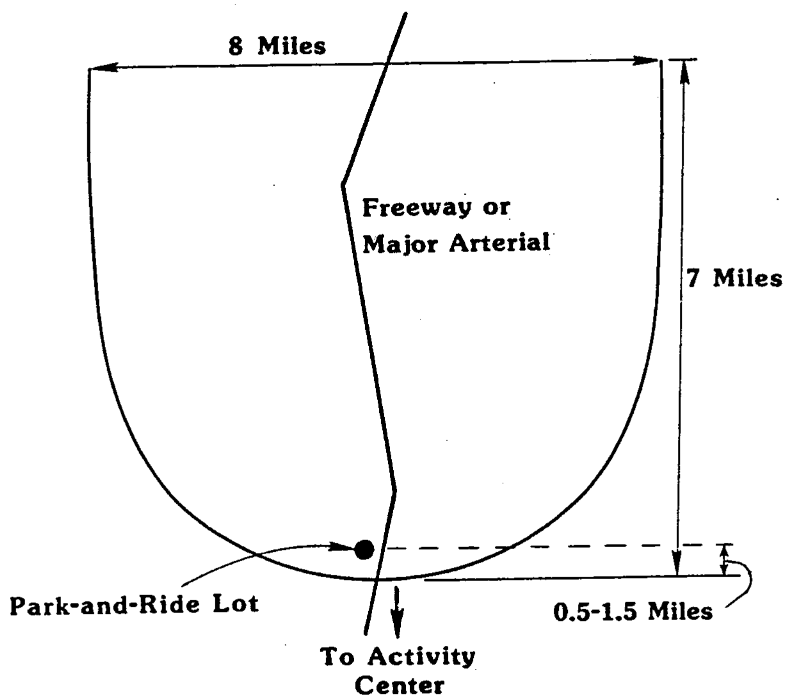


Figure 3.1: General Shape of "Typical" Park-and-Ride Market Area for Houston Lots

Table 3.1 Ridership as Related to Market Area Compared to Other Indicators of Park-and-Ride Potential, by City, 1983

City	Ridership as a % of Market Area Population	"Representative" Congestion Index[1]	Activity Center Size	
			Monthly Pkg. Cost	Employment
Houston	0.7 to 2.0[2]	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

[1]A "representative" value for the urban area as selected from reference (9). In actuality, considerable variation also occurs between corridors within a given urban area. (The congestion index is discussed more in the subsequent regression analysis method.).

[2]In general, the Houston percentages are constrained by parking spaces available.

Source: Reference 1.

Analysis of Figures 3.2, 3.3 and 3.4 shows that the percent of market area population served by a park-and-ride facility is generally related to the average of the congestion indices encountered on the freeway portion of the trip. This is especially true of the relationship between congestion index and park-and-ride lots served by an authorized vehicle lane (Figure 3.3).

Table 3.2 shows the independent variables considered to predict percent of market area population served by a park-and-ride lot.

Table 3.2 Independent Predictor Variables Considered in Regression Analysis

Variable	Description
Distance	Road mile distance from the park-and-ride lot to the activity center.
ICI	Individual Congestion Index (see text).
ICI-B	Average of the congestion indices encountered on the freeway portion of trip.
SCI	Societal Congestion Index equals ICI weighted by daily traffic (see text).

The use of the congestion indices merits further description. This index presents a method to define quantitatively freeway traffic congestion. The formulation of the indices follows:

$$ICI = \frac{\text{Travel Delay Time In Minutes}}{\text{10 minutes}} + \frac{\text{AADT/Lane}}{20{,}000}$$

$$SCI = ICI \times \frac{AADT}{100{,}000}$$

where: AADT = Average Annual Daily Traffic

ICI-B represents a different emphasis on the ICI. ICI-B is the average of all of the congestion indices on the freeway portion of the trip. While

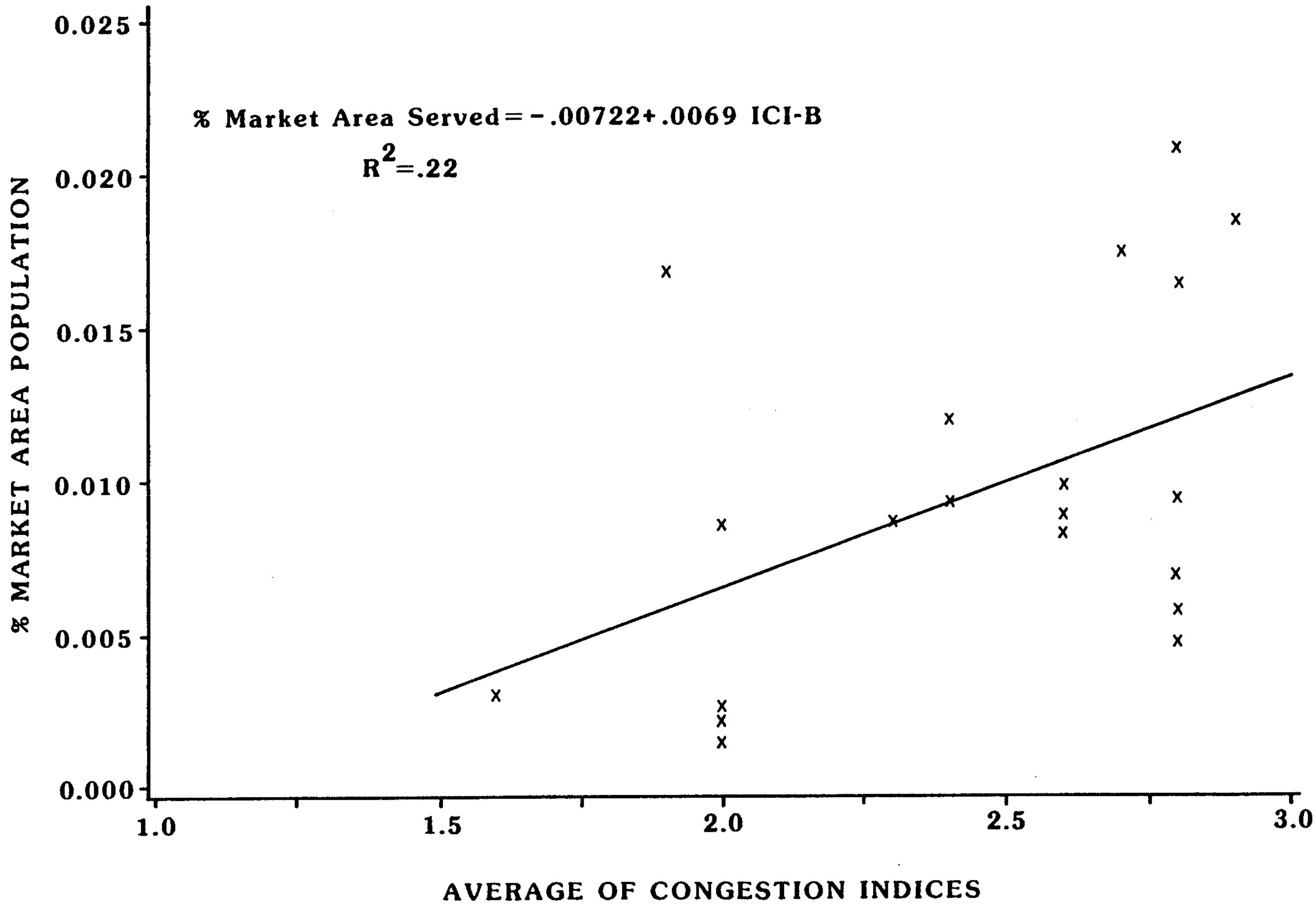


Figure 3.2 Relationship of Variables to Riders

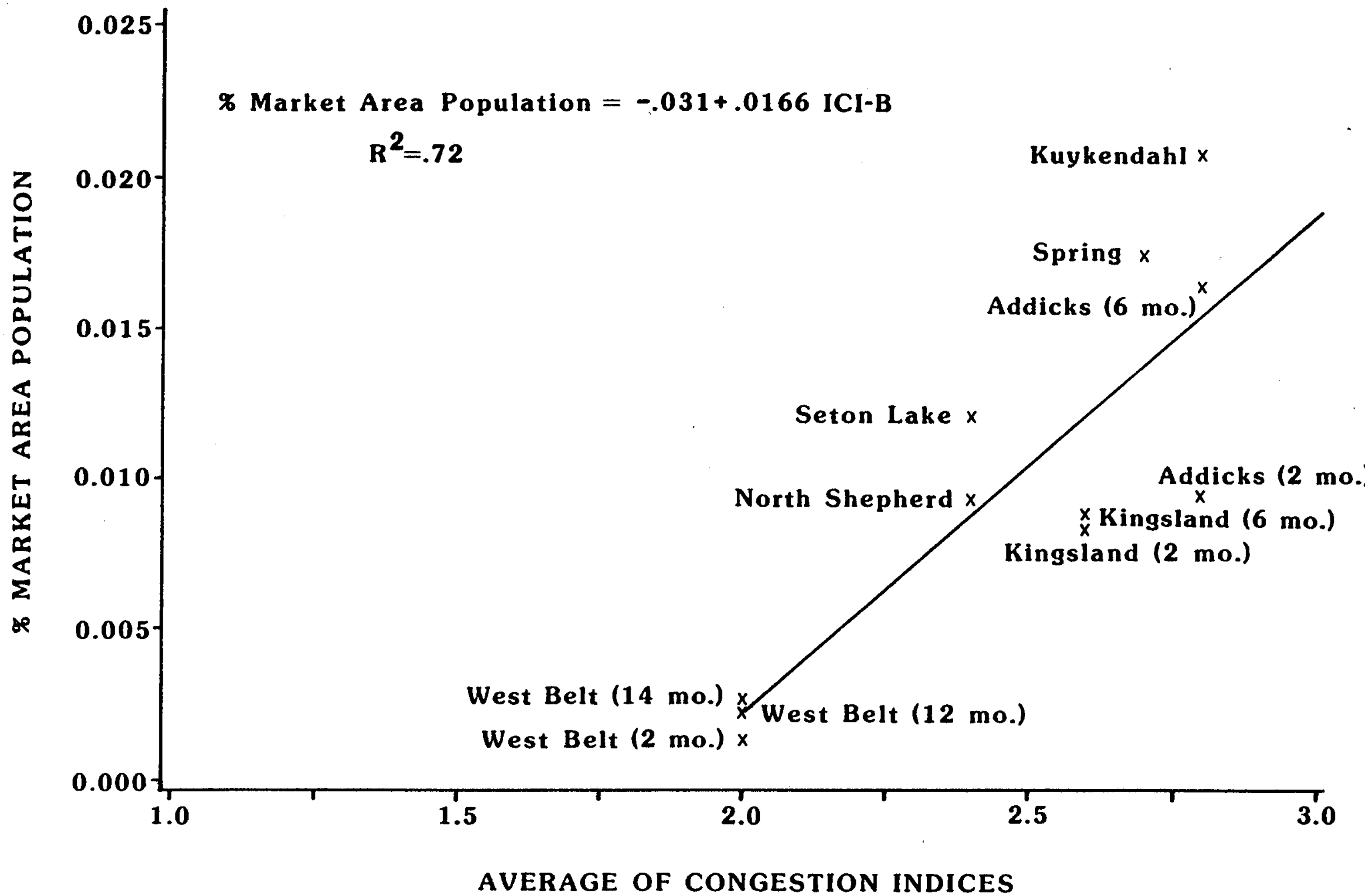


Figure 3.3 Relationship of Variables to Riders, AVL = 1

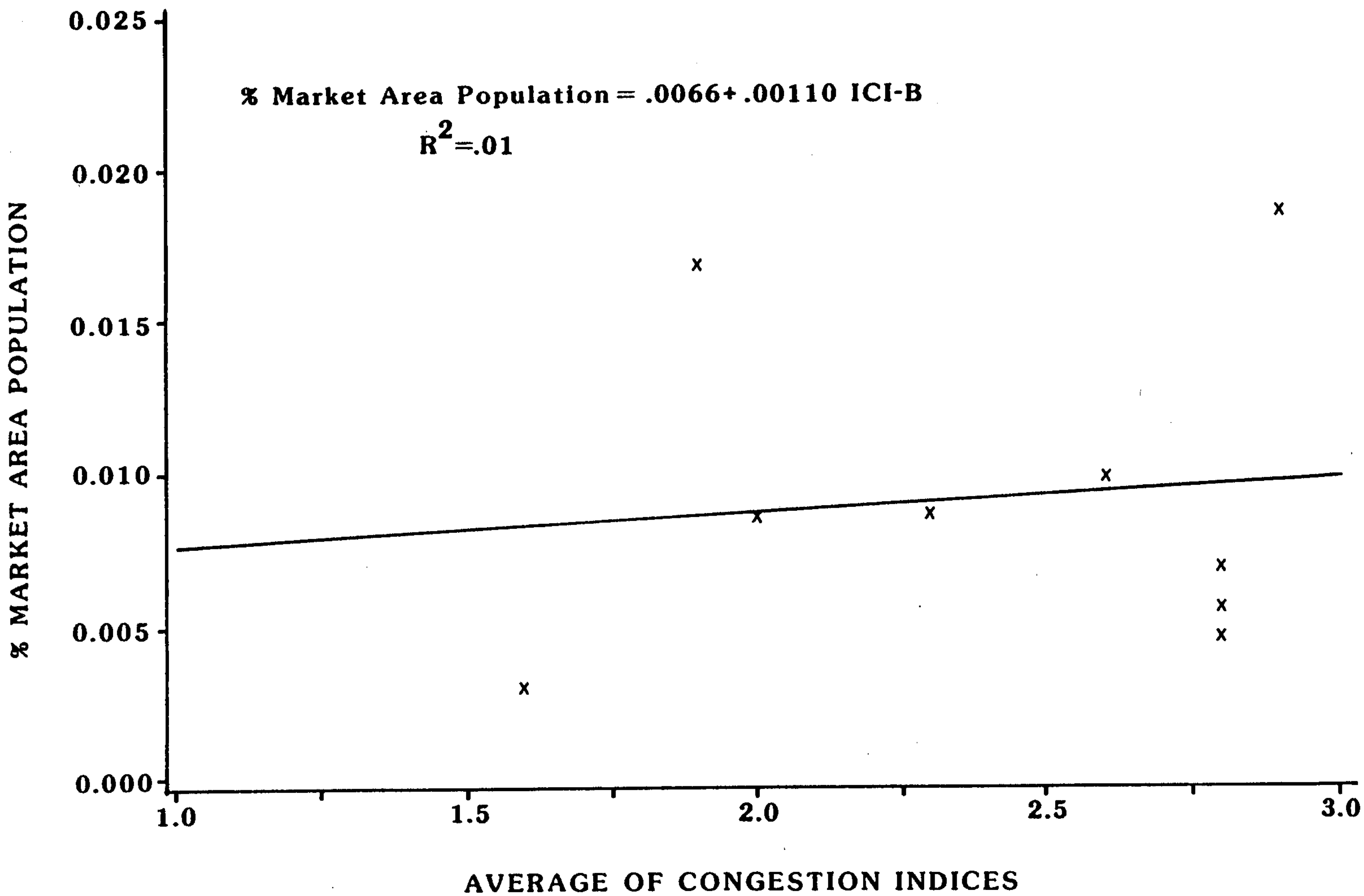


Figure 3.3 Relationship of Variables to Riders, AVL = 0

both ICI and SCI may be calculated manually, these values come from published TTI reports (see references 11 and 12).

Testing the predictive power of a one variable model to project the percent of market area population served by a park-and-ride lot resulted in identification of one model. To project percent of market area population served by a park-and-ride lot that uses an authorized vehicle lane, the model is as follows:

Population Served = -.031 + .0166 ICI_B

Where: ICI_B = Average of congestion indices encountered on freeway portion of trip.

R^2 = .72, RMSE = .0036

Table 3.3 shows the actual percent market area population served, predicted percent, residual and percent error. For the Houston data, this

Table 3.3 Market Area Population Regression Results Related to Freeway Congestion, Park-and-Ride Lots Served by Transitways

Lot Name	MAPOP Served	Predicted MAPOP served	Residual	% Error
N. Shepherd	.0094	.0089	5.1E-04	- 5.4
Kuykendahl	.0209	.0155	.00538	-25.7
Spring	.0175	.0138	.00365	-20.9
West Belt[1]	.0014	.0022	-8.0E-04	+57.1
West Belt	.0022	.0022	-4.2E-05	+ 1.9
West Belt	.0025	.0022	3.2E-04	-12.8
Seton Lake	.0121	.0089	.00325	-26.9
Kingsland	.0083	.0122	-.00387	+ .5
Kingsland[2]	.0088	.0122	-.00337	+38.3
Addicks	.0095	.0155	-.00603	+63.5
Addicks[3]	.0165	.0155	.00101	- 6.1

[1]Data are for West Belt at 2, 12 and 14 months.

[2]Kingsland data are for 2 and 6 months after AVL opening.

[3]Addicks data are for 2 and 6 months after AVL opening.

Source: TTI data.

model predicted on the average within 6.3 percent. At its worst, it underpredicted the Addicks lot by 64 percent (that data is prior to the growth in ridership experienced since the AVL opened). As a predictive tool, the model provides an estimate ± .0071 percent at the 95 percent confidence level. For a ballpark estimate, this model is useful; the required data are not difficult to obtain.

To re-evaluate the market area population technique for Houston, planners developed an updated data base. Drawing the parabolic-shaped service area on census block group maps, planners aggregated the 1980 population block group data into these service areas (13, 14). Calculating the percentage of the service area lying within individual 1980 census tracts, they determined the 1990 service area population (15). The 1990 data are population projections provided by the area Metropolitan Planning Organization, the Houston-Galveston Area Council. Service area population for 1985 was interpolated. Table 3.4 shows the resulting 1985 market area population and ridership as a percentage of this population for each park-and-ride lot.

The market area analysis 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 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 (9).

Analysis of Table 3.5 suggests that, with time, the provision of an AVL to park-and-ride lots increases the percentage of the market area population by perhaps as much as two-thirds or 67% in corridors where a priority lane has operated for a considerable time (like 7 years on North Freeway). In that case, the percentage of market area population served is 1.5%. On the Katy AVL, which had operated for less than 6 months, data show the percent market area population served is 0.7%. Based on 1986 data, this has already increased by nearly 30% to 0.9%. The only lot which is presently undercapacity (Southwest Freeway) exhibits unusually low ridership compared

Table 3.4 Ridership Related to Market Area Population For Houston Park-and-Ride Lots, 1985

Lot	Market Area Population, 1985	Ridership as % of Population	AVL Service
S.W. Freeway[1]	204,400	0.1%	No
N. Shepherd	96,700	0.9%	Yes
Kuykendahl	80,900	2.1%	Yes
Spring	52,600	1.8%	Yes
Kingwood	35,100	1.8%	No
Eastex	33,700	1.0	No
West Belt	111,500	0.2%[2]	Yes
Seton Lake	66,200	1.2%	Yes
Northwest Station	38,300	0.9%	No
Kingsland	44,500	0.8%	Yes
Addicks	61,300	1.0%	Yes
Edgebrook	83,900	0.9%	No
Bay Area	37,000	1.7%	No
West Loop	178,600	0.3%	No
Westwood	89,200	0.6%	No
Alief	91,500	0.5%	No
Missouri City	47,100	0.7%	No

[1]The Southwest Freeway is constrained by available capacity.

[2]The West Belt data are two months after opening. Estimated February 1986 ridership is 280, for a revised ridership as a percentage of population of 0.3%.

to its market area population (0.1%). If ample parking exists, all other things being equal, priority treatment appears to increase the percent of market area population served by about 67%.

Modal Split

To use the modal split procedure, one must identify the component of the market area population that works in the activity center served by park-and-ride bus service. This information is not always readily available and, as a

Table 3.5 Possible Impacts of Priority Treatment of Park-and-Ride Utilization Based on Market Area Population Analysis, Houston, Lots, 1985

Houston Park-and-Ride Lots	% of Market Area Population Using Park-and-Ride[1]	Available Parking Spaces per person in Market Area Population	Park-and-Ride Patrons per Avail. Parking Space
Lots with Priority Treatment[2]			
North Frwy., 4 lots	1.5%	0.022	0.64
Katy Frwy., 3 lots	0.7%	0.019	0.32
Lots without Priority Treatment	0.9%	0.011	0.50

[1]Percent Market Area Population is the mean of the percentages.

[2]North Freeway Contraflow Lane opened in August 1979 while the Katy AVL opened in October 1984. Thus, the operating data for Katy are based on two months of priority treatment.

result, the attractiveness of this approach is diminished. In some instances it becomes necessary to use census data (9) or population data maintained by the Metropolitan Planning Organizations. Table 3.6 summarizes the available modal split data for Houston park-and-ride lots for 1983, while Table 3.7 updates these data for 1985. The 1985 analysis used the 1980 journey-to-work information to identify CBD-workers. Specifically, for each service area, the 1980 CBD-workers as a percentage of population by tract was calculated. This percentage was then applied to the 1985 population data, presented in Table 3.4.

Table 3.6 Estimated Modal Split for Houston Park-and-Ride Lots, 1981

Lot	Modal Split[1]	Procedure to Estimate Modal Split[2]
Clear Lake City	52%	Census Analysis
Gulf Edgebrook	24%	Census Analysis
Westwood	10%	TTI Surveys (Research Report 205-15)
Champions	23%	TTI Surveys (Research Report 205-15)
N. Shepherd	27%	TTI Surveys (Research Report 205-15)
Kuykendahl	22%	TTI Surveys (Research Report 205-15)
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 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: Reference 1.

Table 3.7 Estimated Modal Split for Houston Park-and-Ride Lots, 1985

Lot	Modal Split[1]	Procedure to Estimate Modal Split[2]	1985 CBD Workers in Service Area
N. Shepherd	30%	Census Analysis	3000
Kuykendahl	33%	Census Analysis	5100
Spring	37%	Census Analysis	2500
Kingwood	38%	Census Analysis	1700
Eastex	33%	Census Analysis	1000
West Belt[3]	3%	Census Analysis	5500
Seton Lake	21%	Census Analysis	3800
N.W. Station	26%	Census Analysis	1300
Kingsland	25%	Census Analysis	1500
Addicks	24%	Census Analysis	2400
Edgebrook	33%	Census Analysis	2200
Bay Area	n/a[4]	---------------	----
West Loop	7%	Census Analysis	7900
Westwood	16%	Census Analysis	3100
Alief	14%	Census Analysis	3100
Missouri City	32%	Census Analysis	1000
Average, All Lots	25%	---------------	----

[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 number and percent of the population working in the CBD were obtained from 1980. These percentages were applied to 1985 population estimates.
[3]This is based on 2 months operating data. One year later, the mode split increased to 5% (ridership from 158 to 282).
[4]Since the Bay Area lot's market area includes part of Galveston County and census data for employment at Houston's CBD are not available, these data were excluded from the analysis.

Source: TTI data.

Table 3.8 Possible Impacts of Priority Treatment on Park-and-Ride Utilization Based on Modal Split Analysis, Houston Lots 1985 (Weighted Modal Splits)

Houston Park-and-Ride Lots	Modal Split[1]	Available Parking Spaces per Market Area Population	Park-and-Ride Patrons per Avail. Parking Space
Lots with Priority Treatment			
North AVL	30%	0.022	0.64
Katy AVL	9%[2]	0.019	0.32
Lots without Priority Treatment	15%	0.011	0.50

[1]Modal Split values shown are weighted averages for the lots shown in Table 3.7. This calculation takes the ridership for lots that use one freeway and sums the ridership. This total is divided by the total CBD employment for residents in the market areas for those lots. Limited available data suggest that with time the provision of priority treatment may increase modal split by as much as 100%.

[2]The longer the Katy AVL has been open, the larger the modal split has been. Two months after opening, the unweighted modal split was 2.8%; one year after opening it was 4.4%; and 5.1% fourteen months after the AVL opened.

Tables 3.9 and 3.10 present the estimated modal split according to priority treatment of each park-and-ride lot.

Table 3.9 Estimated Modal Split For Houston Park-and-Ride Lots, 1985 by Priority Treatment

Priority Treatment Lots

Lot	Number	Modal Split[1]	Procedure to Estimate Modal Split[2]
North AVL			
K. Shepherd[3]	201	30%	Census Analysis
Kuykendahl	202	33%	Census Analysis
Spring	204	37%	Census Analysis
Seton Lake	212	21%	Census Analysis
Mean		30%	(Non-weighted)
Katy AVL			
West Belt	210	3%[4]	Census Analysis
Kingsland	221	25%	Census Analysis
Addicks[3]	228	25%	Census Analysis
Mean		18%	(Non-weighted)

[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 number and percent of the population working in the CBD were obtained from 1980. These percentages were applied to 1985 population estimates.

[3]A previous TTI research report (16) found a 33% modal split at North Shepherd and a 15% at Addicks. The lower modal split at Addicks reflects ridership before the AVL opened.

[4]The West Belt ridership was based on two months operating experience after opening; one year later it was 5%.

Table 3.10 Estimated Modal Split For Houston Park-and-Ride Lots, 1985 (No Priority Treatment)

Non-Priority Treatment Lots

Lot	Lot Number	Modal Split[1]	Procedure to Estimate Modal Split[2]
Kingwood	205	38%	Census Analysis
Eastex	206	33%	Census Analysis
N. W. Station	214	26%	Census Analysis
Edgebrook	245	33%	Census Analysis
Bay Area	246	n/a[3]	---------------
West Loop	261	7%	Census Analysis
Westwood	262	16%	Census Analysis
Alief	263	14%	Census Analysis
Missouri City	270	32%	Census Analysis
Mean		25%	

[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. This is a weighted mean.

[2]In using census data, the number and percent of the population working in the CBD were obtained from 1980. These percentages were applied to 1985 population estimates.

[3]Since the Bay Area lot's market area includes part of Galveston County and census data for employment at Houston's CBD are not available, this calculation was excluded from analysis.

Regression Analysis

Researchers found average daily ridership to be the best measure of demand, or the dependent variable, for the regression analysis. In order to determine the best set of independent variables to use for predicting park-and-ride patronage, a series of routines were run on numerous potential variables using Statistical Analysis System (SAS). Researchers recognized that minimizing the number of variables would improve the ease of using any resulting demand prediction models. Table 3.11 shows the independent variables considered for the independent predictor variables. A complete list of the variables and values used is in Appendix A. Since the models are developed using Houston data, researchers omitted using some variables other researchers found to be good predictors. For example, downtown employment and parking costs were excluded because, for Houston, these variables would be the same for all lots. In developing models from statewide data, researchers may want to include additional variables to those shown in Table 3.11. The importance of this cannot be overemphasized in applying these models to cities other than Houston.

Table 3.11 Independent Predictor Variables Considered in Analysis

Variable	Description
Distance	Road mile distance from the park-and-ride lot to the activity center.
ICI	Individual Congestion Index (see text).
ICI-B	Average of the congestion indices encountered on the freeway portion of trip.
SCI	Societal Congestion Index equals ICI weighted by daily traffic (see text).
Months	Number of months of operation of park-and-ride lot.
MAPOP	Market area population of park-and-ride service area.
Emp-CBD	Number of employees residing in park-and-ride service area working in the Central Business District.
Emp-All	Total number of employees who reside in park-and-ride service area.

The use of the congestion indices is discussed previously. This index presents a method to define quantitatively freeway traffic congestion. The formulation of the indices follows:

$$ICI = \frac{\text{Travel Delay Time in Minutes}}{\text{10 minutes}} + \frac{\text{AADT/Lane}}{20{,}000}$$

$$SCI = ICI \times \frac{AADT}{100{,}000}$$

where: AADT = Average Annual Daily Traffic

ICI-B represents a different emphasis on the ICI. ICI-B is the average of all of the congestion indices on the freeway portion of the trip. While both ICI and SCI may be calculated manually, these values come from published TTI reports (see references 11 and 12).

Plotting the relationships between the dependent variable, riders, and the independent variables contained in Table 3.11 showed that predictor variables for park-and-ride lots with AVL service and for those without priority treatment may be different. Employing a SAS routine, researchers identified those two and three variable model combinations producing the highest coefficients of correlation (R^2) and lowest root mean square error (RMSE). Based on a limited data base, the variables of ICI_B, MO, DIST, ICI, CBD_EMP and MAPOP proved to be the best predictor variables. The data set is limited and, as more lots are opened and data are collected over time, other predictor variables may prove significant. For example since congestion indices in Houston are all fairly high, this variable does not prove to be a very good predictor variable by itself for park-and-ride service within Houston. Statewide, however, congestion indices vary and so the variable may be a good predictor for statewide park-and-ride demand estimations; indeed, previous TTI research has found that to be true (1, 10).

Having identified those variable combinations which produce high R^2 and lower RMSE, researchers used a SAS routine to produce linear regression equations. With the first sets of regression equations, researchers attempted to identify one model to predict ridership, including whether the low would be served by an authorized vehicle lane. The results follow.

For Park-and-Ride Lots - Regardless of Priority Treatment - Model 1

$$\text{Ridership} = -1355 + 520.8\,(ICI\_B) + .07\,(CBD\_EMP) + 240.3\,(AVL) + 6.52\,(MO)$$

where: ICI_B = Average of congestion indices encountered on freeway portion of trip.

CBD_EMP = Number of employees in market area destined for CBD.

AVL = Presence (1) or absence (0) of authorized vehicle lane.

MO = Months of operation.

R^2 = .49, RMSE = 284.81

Model statistics indicate the coefficients to be statistically significant at the 82 percent level of confidence. Table 3.12 shows the actual ridership, predicted value, residuals and percent error. The predictive power of the model indicates that the estimate will be ± 558 riders at the 95 percent level of confidence. Applied to the Houston data set, this model predicted riders generally within 50% (Table 3.12). For some lots, the model overpredicted riders by as much as 107%. The simple distinction of the categorical "yes" or "no" variable (whether served by an authorized vehicle lane) results in a useful model that will predict within about 300 riders at the 67 percent confidence level.

Next, researchers attempted to calibrate models containing the predictor variable combinations first with the combined data set and next with two distinct data sets: those lots served by an AVL and those lots not served by an AVL. Model 2 is for the combined data set, while Model 2.1 and 2.2 are for the separated data sets.

Table 3.12 Regression Results For Park-and-Ride Lots - Regardless of Priority Treatment - Model 1

$$Ridership = -1355 + 520.8\ (ICI\_B) + .07\ (CBD\_EMP) + 240.3\ (AVL) + 6.52\ (MONTHS)$$

Lot Name	Actual Riders	Predicted Riders	Residual	% Error
N. Shepherd	905	733.2	171.8	-19.0
Kuykendahl	1689	1107.4	581.6	-34.4
Spring	919	657.0	262.0	-28.5
Kingwood	653	692.9	-39.9	+6.1
Eastex	334	200.2	133.8	-40.1
West Belt[1]	158	326.9	-168.9	+106.9
West Belt[2]	242	392.1	-150.1	+62.0
West Belt[3]	282	405.1	-123.1	+43.7
Seton Lake	801	554.1	246.9	-30.8
N.W. Station	336	4.8	331.2	-98.6
Kingsland[4]	370	696.8	-326.8	+88.3
Kingsland[5]	392	709.9	-317.9	+81.1
Addicks[6]	580	758.0	-178.0	+30.7
Addicks[7]	729	726.6	2.4	-.3
Edgebrook	726	467.7	258.3	-35.6
Bay Area	629	------	------	-----
West Loop	543	638.1	-95.1	+17.5
Westwood	509	781.2	-272.2	+53.5
Alief	427	627.0	-200.0	+46.8
Missouri City	326	442.2	-116.2	+35.6

[1]West Belt 2 months after opening.

[2]West Belt 12 months after opening (12/85).

[3]West Belt 14 months after opening (2/86).

[4]Kingsland (12/85).

[5]Kingsland (2/86).

[6]Addicks (12/85).

[7]Addicks (2/86).

Source: TTI Data.

For Park-and-Ride Lots - Regardless of Priority Treatment - Model 2

Ridership = -1425.10 + 605.08 (ICI_B) + 4.74 (MO) + .095 (CBD_EMP)

where: ICI_B = Average of congestion indices encountered on freeway portion of trip.

MO = Months of operation.

CBD_EMP = Number of Employees in market area destined for CBD.

R^2 = .40, RMSE = 299.15

Model statistics indicate that the coefficients of the variables are statistically significant at the 10 percent level of significance. As a predictor, the model yields an estimate plus or minus 586 riders at the 95 percent confidence level. Table 3.13 shows the actual and predicted ridership, residuals and percent error. Analysis of Model 2 suggests that not dividing the data into two sets (AVL and no AVL service) reduces the model's power to predict ridership accurately.

Recalibrating Model 2 for the lots served by an AVL and those not served by an AVL results in two different models 2.1 and 2.2.

Model 2.1 AVL: Riders = -3786.7 + 1326.79 (ICI_B) + 8.75 (MO) + .246 (CBD_EMP)

where: R^2 = .84, RMSE = 212.28

Model 2.2 No AVL: Riders = 337.5 - 28.64 (ICI_B) + 5.38 (MO) - .031 (CBD)

where: R^2 = .83, RMSE = 85.09

To determine possible impacts of an AVL's impact on ridership by using Models 2.1 and 2.2, researchers input typical variable values. Table 3.14 shows resulting predicted ridership while holding two variables constant and varying the other. For example, Table 3.14 shows that if one assumes a lot to be in operation for 36 months, to have CBD employment of 2000 within its market area and a freeway congestion index of 2.6, Model 2.1 projects ridership of 470 with an AVL and Model 2.2 estimates 395 riders for an AVL

Table 3.13 Regression Results For Park-and-Ride Lots - Regardless of Priority Treatment - Model 2

Ridership = -1425.10 + 605.08 (ICI_B) + 4.74 (MO) + .095 (CBD_EMP)

Lot Name	Actual Riders	Predicted Riders	Residual	% Error
N. Shepherd	905	596.7	308.3	-34.1
Kuykendahl	1689	1051.8	637.2	-37.7
Spring	919	586.0	333.0	-36.2
Kingwood	653	796.5	-143.5	+22.0
Eastex	334	339.0	-5.0	+1.5
West Belt[1]	158	320.5	-162.5	+102.9
West Belt[2]	242	367.9	-125.9	+52.0
WestBelt[3]	282	377.3	-95.3	+33.8
Seton Lake	801	501.6	299.4	-37.4
N.W. Station	336	141.3	194.7	-58.0
Kingsland[4]	370	547.3	-177.3	+47.9
Kingsland[5]	392	556.8	-164.8	+42.0
Addicks[6]	580	675.8	-95.8	+16.5
Addicks[7]	729	625.0	104.0	-14.3
Edgebrook	726	451.0	275.0	-37.9
Bay Area	629	------	------	-----
WestLoop	543	736.1	-193.1	+35.6
West Wood	509	902.1	-393.1	+77.2
Alief	427	787.2	-360.2	+84.4
Missouri City	326	560.8	-234.8	+72.0

[1]West Belt 2 months after opening

[2]West Belt 12 months after opening

[3]West Belt 14 months after opening (2/86)

[4]Kingsland (12/85)

[5]Kingsland (2/86)

[6]Addicks (12/85)

[7]Addicks (2/86)

Source: TTI Data

impact of +75 riders. The average shown at the bottom of Table 3.14 is the average impact and ridership that an AVL has, using the variables shown and the Models 2.1 and 2.2 depicted.

Table 3.14 Application of Models 2.1 and 2.2 to Variable Data

Riders		%	Variable Values		
AVL	No AVL	Difference	Months	CBD Employ	ICI_B
470	395	19	36	2000	2.6
716	364	97	36	3000	2.6
1208	302	300	36	5000	2.6
1454	271	436	36	6000	2.6
965	166	481	6	4000	2.8
1015	199	410	12	4000	2.8
1123	263	327	24	4000	2.8
1438	456	215	60	4000	2.8
326	280	16	24	4000	2.2
724	271	167	24	4000	2.5
1122	262	328	24	4000	2.8
Average 960	294	227	29	4000	2.6

Source: TTI Data.

Analysis of variables used in equations 2.1 and 2.2 specified in Table 3.14 shows that the models predict the average impact of an AVL is to increase ridership by about 227 percent. With the root mean squared error high in Model 2.1, the actual impact may be less than this. Analysis of Houston ridership data suggest the impact of an AVL is less, more in the range of 100%. As more data for operating park-and-ride lots served by an AVL are available, these models can be recalculated to assess more accurately the impact of an AVL on park-and-ride usage.

To assess more accurately the impact of providing an authorized vehicle lane to a park-and-ride lot based upon available data, researchers investigated the ridership at lots over different periods of time. The data base includes lots which do not have and have not had AVL service, lots previously without AVL service but now which have AVL service, and lots which have always had AVL service. Park-and-ride lots with AVL service have significantly higher daily ridership than those which do not. The average daily ridership for AVL served lots was 832 versus 411 for lots without. This is about a 100 percent difference in ridership. A one-way analysis of variance found these means to be statistically different. Thus, the provision of an AVL causes enough difference in the resulting ridership to be considered statistically different, i.e. coming from two different data bases (statistical samples).

The recalibration of both models 2 and 3 by whether they are served by an authorized vehicle lane shows that making this distinction results in separate models with better predictive power than when the park-and-ride lots are combined. With this in mind, researchers developed sets of models for lots served by an AVL and not served by an AVL. The results follow.

<u>For Park-and-Ride Lots - Regardless of Priority Treatment - Model 3</u>

Ridership = -273.59 + 253.72 (ICI_B) + 5.21 (MO)

where: ICI_B = Average of congestion indices encountered on freeway portion of trip.

MO = Months of operation.

R^2 = .24, RMSE = 315.17

This model offers the least reliable of the three models for park-and-ride demand estimation. The coefficients of the variables are statistically significant at the 20 percent level of significance. Using it as a predictor, the model yields an estimate $\pm$ 618 riders at the 95 percent confidence level. Table 3.15 shows the actual and predicted ridership, residuals and percent error.

Table 3.15 Regression Results For Park-and-Ride Lots - Regardless of Priority Treatment - Model 3

Lot Name	Actual Riders	Predicted Riders	Residual	% Error
N. Shepherd	905	642.6	262.4	-29.0
Kuykendahl	1689	759.7	929.3	-55.0
Spring	919	562.5	356.5	-38.8
Kingwood	653	795.5	-142.5	+21.8
Eastex	334	490.2	-156.2	+46.8
West Belt[1]	158	244.3	-86.3	+54.6
West Belt[2]	242	296.3	-54.4	+22.5
West Belt[3]	282	306.8	-24.8	+8.8
Seton Lake	801	455.1	345.9	-43.2
N.W. Station	336	367.3	-31.3	+9.3
Kingsland[4]	370	667.3	-297.3	+80.4
Kingsland[5]	392	677.7	-285.7	+72.9
Addicks[6]	580	634.7	-54.7	+9.4
Addicks[7]	729	645.1	83.9	-11.5
Edgebrook	726	733.8	-7.8	+1.1
Bay Area	629	520.9	108.1	-17.2
West Loop	543	616.7	-73.7	+13.6
Westwood	509	801.4	-292.4	+57.5
Alief	427	681.6	-254.6	+59.6
Missouri City	326	650.4	-324.4	+99.5

[1]West Belt 2 months after opening.

[2]West Belt 12 months after opening (12/85).

[3]West Belt 14 months after opening (2/86).

[4]Kingsland (12/85).

[5]Kingsland (2/86).

[6]Addicks (12/85).

[7]Addicks (2/86).

Source: TTI Data.

Recalculating Model 3 for lots served by an AVL and not served by an AVL changes the equation's coefficients and increases the models predictive power.

Model 3.1 Riders = -962.62 + 570.85 (ICI_B) + 5.62 (MO)
<u>AVL</u>
where: R^2 = .42, RMSE = 374.43

Model 3.2 Riders = 284.10 + 4.18 (MO) - 7.92 (ICI_B)
<u>No AVL</u>
where: R^2 = .67, RMSE = 99.68

To determine possible impacts of an AVL's impact on ridership by using these Models 3.1 and 3.2, researchers input typical variable values. Table 3.16 shows the results of using the models to predict ridership with varying variable values. For example, Table 3.16 shows that if one assumes a lot to be in operation for 36 months, to have CBD employment of 2000 within its market area and a freeway congestion index of 2.6, Model 3.1 projects ridership of 498 with an AVL and Model 2.2 estimates 289 riders for an AVL impact of +209 riders. The average shown at the bottom of Table 3.16 is the average impact and ridership that an AVL has, using the variables shown and the Models 3.1 and 3.2 depicted.

Table 3.16 Applications of Models 3.1 and 3.2 to Variable Data

Riders		%	Variables	
AVL	No AVL	Difference	Months	ICI_B
498	289	72	6	2.5
532	314	69	12	2.5
599	365	64	24	2.5
667	415	61	36	2.5
802	515	56	60	2.5
656	364	65	24	2.6
771	362	113	24	2.8
Average 646	375	72	27	2.6

Analysis of Table 3.16 illustrates the estimated impact of the provision of an AVL to the park-and-ride lot which increases ridership by about 70 percent. This figure tends to underestimate actual findings in Houston where the AVL increases ridership over those lots without AVL service by 100%.

For Park-and-Ride Lots - No Priority Treatment-1

Ridership = 16.13 + 4.85 (MO) + 12.89 (Dist)

where: MO = months of lot operation

Dist = road distance to activity center in miles

R^2 = .89, RMSE = 58.19

Model statistics indicate a .01 probability that the coefficients have nonzero values. Table 3.17 shows the actual ridership, predicted values, residuals and percent error. The model successfully predicted ridership in all cases within 20 percent. Interpretation of the model's predictive powers means that the park-and-ride estimate will be plus or minus 114 riders 95 percent of the time.

Table 3.17 Regression Results For Park-and-Ride Lots - No Priority Treatment Model - 1

Ridership = 16.13 + 4.85 (MO) + 12.89 (Dist)

Lot	Actual Riders	Predicted Riders	Residual	% Error
Kingwood	653	679.4	-26.4	+4.0
Eastex	334	288.3	45.7	-13.7
N.W. Station	336	320.1	15.9	-4.7
Edgebrook	726	633.5	92.5	-12.7
Bay Area	629	597.5	31.5	-5.0
West Loop	543	597.1	-54.1	+10.0
Westwood	509	533.9	-24.9	+4.9
Alief	427	445.1	-18.1	+4.2
Missouri City	326	388.2	-62.2	+19.1

For Park-and-Ride Lots - No Priority Treatment Model 2

Ridership = 284.1 + 4.18 (MO) - 7.92 (ICI_B)

where: MO = Months of park-and-ride lot operation.

ICI_B = Average of congestion indices encountered on freeway portion of trip.

R^2 = .67, RMSE = 99.68

The model statistics show the coefficients to be statistically significant as a forecasting tool; the model yields an estimate ± 195 riders at the 95 percent level of confidence. Table 3.18 shows the actual and predicted ridership, residuals and percent error. The model successfully predicted Houston ridership within 33 percent. The negative sign of the coefficient for the congestion index merits explanation. Freeway congestion appears to have a negative impact on ridership for park-and-ride lots without priority treatment. Without service by an authorized vehicle lane, the park-and-ride patrons do not have a travel time advantage by using the bus. Instead, they sit on a bus with the rest of the traffic in congestion. Thus, the coefficient's sign may make sense.

Table 3.18 Regression Results For Park-and-Ride Lots - No Priority Treatment Model 2

Ridership = 284.1 + 4.18 (MO) - 7.92 (ICI_B)

Lot	Actual Riders	Predicted Riders	Residual	% Error
Kingwood	653	528.6	124.4	-19.1
Eastex	334	347.1	-13.1	+3.9
N.W. Station	336	311.9	24.2	-7.2
Edgebrook	726	669.5	56.5	-7.8
Bay Area	629	519.8	109.2	-17.4
West Loop	543	660.1	-117.1	+21.6
Westwood	509	554.5	-45.5	+8.9
Alief	427	458.3	-31.4	+7.3
Missouri City	326	433.3	-107.3	+32.9

Since analysis of predictor variables with ridership suggested the predictor variables change between lots served by an AVL and those without the AVL, researchers developed a second set of models for lots with priority treatment. The results follow:

<u>For Park-and-Ride Lots - Priority Treatment Model - 1</u>

Ridership = -4280.5 + 1675.75 (ICI_B) + .23 (CBD_EMP)

where: ICI_B = Average of congestion indices encountered on freeway portion of trip.

CBD_EMP = CBD employees residing in park-and-ride service area.

R^2 = .76, RMSE = 241.16

Model statistics indicate a .005 probability that the coefficients have nonzero values. Table 3.19 shows actual ridership, predicted ridership, residuals, and errors. The model does not predict Houston ridership as

Table 3.19 Regression Results For Park-and-Ride Lots - Priority Treatment Model - 1

Ridership = -4280.5 + 1675.75 (ICI_B) + .23 (CBD_EMP)

Lot	Actual Riders	Predicted Riders	Residual	% Error
N. Shepherd	905	437.3	467.7	-51.7
Kuykendahl	1689	1584.8	104.2	-6.2
Spring	919	820.0	99.1	-10.8
West Belt	158	333.3	-175.3	+111.0
West Belt[1]	242	333.3	-91.3	+37.7
West Belt[2]	282	333.3	-51.3	+18.2
Seton Lake	801	618.6	182.4	-22.8
Kingsland	370	420.3	-50.3	+13.6
Kingsland[3]	392	420.3	-28.3	+7.2
Addicks	580	955.4	-375.4	+64.7
Addicks[4]	729	810.6	-81.6	+11.2

[1] West Belt after 12 months

[2] West Belt after 14 months

[3] Kingsland with AVL after 12 months (2/86)

[4] Addicks with AVL after 12 months (2/86)

closely as the non-priority treatment models. This is due mainly to the recent opening of the Katy AVL. Analysis of the table shows the error to decrease for West Belt, Kingsland and Addicks over time. Using the 1986 ridership data, the model predicts the Katy AVL lots within 20 percent. The North Shepherd lot remains the outlier with a 50 percent error. The model will predict ridership within ± 463 riders 95 percent of the time.

For Park-and-Ride Lots - Priority Treatment Model - 2

Ridership = -5351.3 + 1957.86 (ICI_B) + .0156 (MAPOP)

where: ICI_B = Average of congestion indices encountered on freeway portion of trip.

MAPOP = Market area population of service area.

R^2 = .70, RMSE = 271.63

Model statistics indicate greater than a 0.1 probability that the coefficients have nonzero values. Table 3.20 shows actual ridership, predicted ridership, residuals and percent error. As with the previous model, this model's predictive power increases with increased operating experience with the Katy AVL. By eliminating ridership data less than 12 months, the model successfully predicts within 18 percent for all lots.

Interpretation of the second model indicates that, as a predictive tool, the model will forecast ridership within ± 532 riders 95 percent of the time.

Models 1 and 2 are the best two variable models. The following are the best three variable models.

For Park-and-Ride Lots - Priority Treatment Model - 3

Ridership = -4969.46 + 1866.33 (ICI_B) + .0056 (MAPOP) +.17 (CBD_EMP)

where: ICI_B = Average of congestion indices encountered on freeway portion of trip.

MAPOP = Market area population of service.

CBD_EMP = CBD employees residing in park-and-ride service area destined for the CBD.

R^2 = .78, RMSE = 249.24

Table 3.20 Regression Results For Park-and-Ride Lots - Priority Treatment Model 2

Ridership = -5351.3 + 1957.86 (ICI_B) + 0.156 (MAPOP)

Lot	Actual Riders	Predicted Riders	Residual	% Error
N. Shepherd	905	855.5	49.5	-5.5
Kuykendahl	1689	1392.5	296.5	-17.6
Spring	919	754.8	164.2	-17.9
West Belt[1]	158	303.8	-145.8	+92.3
West Belt[2]	242	303.8	-61.8	+25.6
West Belt[3]	282	303.8	-21.8	+7.7
Seton Lake	801	380.0	421.0	-52.6
Kingsland[4]	370	433.6	-63.6	+17.2
Kingsland[5]	392	433.6	-41.6	+10.6
Addicks[6]	580	1086.2	-506.2	+87.3
Addicks[7]	729	819.4	-90.4	+12.4

[1]West Belt 2 months after opening.

[2]West Belt after 12 months.

[3]West Belt after 14 months.

[4]Kingsland (12/85).

[5]Kingsland with AVL after 12 months (2/86).

[6]Addicks (12/85).

[7]Addicks with AVL after 12 months (2/86).

Analysis of the model statistics indicate the coefficients of the variables are statistically significant at the .01 probability level. Table 3.21 shows the predicted and actual ridership, residuals and percent error. As with the other two models, this model's predictive power increases when the latest ridership data for lots served by the Katy AVL are used. As a predictor, the model will yield a ridership estimate $\pm$ 489 riders 95 percent of the time.

Table 3.21 Regression Results For Park-and-Ride Lots - Priority Treatment Model 3

Lot	Actual Riders	Predicted Riders	Residual	% Error
N. Shepherd	905	572.6	332.4	-36.7
Kuykendahl	1689	1584.8	104.2	-6.2
Spring	919	794.3	124.7	-13.6
West Belt[1]	158	330.7	-172.7	+109.3
West Belt[2]	242	330.7	-88.7	+36.7
West BeElt[3]	282	330.7	-48.7	+17.3
Seton Lake	801	535.4	265.6	-33.2
Kingsland[4]	370	389.8	-19.8	+5.4
Kingsland[5]	392	389.8	2.2	-.6
Addicks[6]	580	1006.1	-426.1	+73.5
Addicks[7]	729	801.9	-73.0	+10.0

[1]West Belt 2 months after opening.

[2]West Belt after 12 months.

[3]West Belt after 14 months.

[4]Kingsland (12/85).

[5]Kingsland with AVL after 12 months.

[6]Addicks (12/85).

[7]Addicks with AVL after 12 months (2/86).

For Park-and-Ride Lots - Priority Treatment Model - 4

Ridership = -3786.7 + 1326.79 (ICI_B) + 8.75 (MO) +.246 (CBD_EMP)

where: ICI_B = Average of congestion indices encountered on freeway portion of trip.

MO = Months of operation.

CBD_EMP = Number of employees in the service are destined for the CBD.

R^2 = .84, RMSE = 212.28

The model statistics indicate that the variables coefficients are statistically different from zero at the 90 percent level of confidence. As a predictor, the model will yield a ridership estimate within ± 416 riders at the 95 percent confidence level. Table 3.22 shows the actual and predicted ridership, residuals and percent error. The model replicated the Houston data within 50 percent. Using the latest ridership data for lots served by the Katy Freeway and the North AVL data shows the model to predict within 34 percent.

Table 3.22 Regression Resulting For Park-and-Ride Lots - Priority Treatment Model 4

Ridership = -3786.7 + 1326.79 (ICI_B) + 8.75 (MO) + .246 (CBD_EMP)

Lot	Actual Riders	Predicted Riders	Residual	% Error
N. Shepherd	905	659.2	245.8	-27.2
Kuykendahl	1689	1727.4	-38.4	+22.7
Spring	919	666.3	252.7	-27.5
West Belt[1]	158	236.5	-78.5	+49.7
West Belt[2]	242	324.0	-82.0	+33.9
West Belt[3]	282	341.5	-59.5	+21.1
Seton Lake	801	538.6	262.4	-32.8
Kingsland[4]	370	503.7	-133.7	+36.1
Kingsland[5]	392	521.1	-129.1	+33.0
Addicks[6]	580	843.2	-263.2	+45.4
Addicks[7]	729	705.6	23.4	-3.2

[1]West Belt 2 months after opening.

[2]West Belt after 12 months.

[3]West Belt after 14 months.

[4]Kingsland (12/85).

[5]Kingsland with AVL after 12 months (2/86).

[6]Addicks (12/85).

[7]Addicks with AVL after 12 months (2/86).

Considering the improvement in each model's predictive power when one restricts ridership data to the latest available figures for lots served by the Katy AVL, researchers feel that separate models can be developed for lots that have AVL service. Existing data are presently limited, and Models 1 through 4 lack strong predictive accuracy. As more recent ridership data become available for lots served by the Katy AVL, the models could be recalibrated to yield better predictive tools.

Relationship of Ridership and Variables - Summary

Distinctive differences in ridership for park-and-ride lots with and without AVL's exist. Growth in ridership of those with AVL's appears to be affected most by the variable ICI_B, average of freeway congestion indices, and by the variable CBD_EMP, CBD-bound employees in the park-and-ride service area. Growth of non-AVL park-and-ride lots is more dependent upon the months the lots have been in operation and their distance to the activity centers.

In addition to the work performed by the Texas Transportation Institute, researchers identified two other sources for park-and-ride demand estimation models. The Institute of Traffic Engineers (ITE) developed one model. The Georgia Department of Transportation uses two models: GOPARK and GOPARK II. A description of these three models follows.

Institute of Transportation Engineers Model

The Institute of Traffic Engineers' (ITE) model assumes that park-and-ride demand is a direct function of peak-period traffic on adjacent travel facilities. Other assumptions include: 1) commuters will not divert from their normal travel routes to reach the park-and-ride lots; and 2) users consist solely of commuters who were already passing the park-and-ride site along their normal travel routes. Thus, park-and-ride demand at a given lot is equal to some percentage of peak-period trips on adjacent streets that can be diverted into the lot (17).

According to the model, most of the park-and-ride demand will be diverted from the prime facility or major arterial used by commuters as part of their usual travel route (there can be more than one primary facility, such as when a lot is located at the intersection of two major arterials) (17). A lesser amount of demand comes from the adjacent non-prime facilities.

The formula for the ITE model follows: DEMAND = a(PEAK) + b(PRIME) where:

- PEAK = total peak period traffic on adjacent facilities (including the prime facility);
- PRIME = peak period traffic on the prime facility; and,
- a,b = diversion factors for total traffic and prime facility traffic, respectively.

ITE recommends the diversion factors of one percent (1%) for the total area traffic (PEAK) and an additional three percent (3%) for traffic on the prime facility (PRIME). According to the literature, the primary advantage of the ITE technique is in the extreme simplicity in its use, requiring only peak-period traffic volumes on adjacent travel facilities. The primary limitations of the model are that it makes no attempt to distinguish among trips by destination. It treats all trips as equal candidates for park-and-ride. As a result, unrealistically high demand projections can result when applying this technique in areas with diverse trip purposes and destinations (17).

ITE Calibration

The original ITE model was not validated or tested. Thus, the inclusion of this model is based solely on the literature review. Assuming the original formulation is correct, researchers calibrated the ITE model for Houston park-and-ride lots. Planners used twenty-four hour traffic counts adjusted for 1985 traffic and peak-period conditions. Lots for which no additional traffic counts besides the prime facility were available were omitted from the calibration. Using a SAS procedure, planners calibrated the model with the following results:

$$\text{Ridership} = .083\ (PR) - .036\ (PE)$$

where: PR = prime facility peak traffic

PE = peak traffic (including prime)

$R^2 = .76$, RMSE = 422.51

Model statistics indicate greater than a .20 probability that the coefficients have nonzero values. Thus, a twenty percent chance exists that the coefficient of the variable "peak traffic" is zero, or meaningless. Moreover, multicollinearity exists between the two predictor variables. The variable peak includes prime traffic plus area traffic; prime traffic is counted twice. Table 3.23 shows the actual ridership, predicted values and residuals for the eleven park-and-ride lots used to calibrate the model. It replicated the Houston data within 93 percent. While the coefficients of determination is good, the root mean squared error term suggests a large error, ± 828 riders 95 percent of the time. The coefficients of 8.3 percent prime and -3.6 percent peak differ greatly from the ITE's recommended 3 percent prime and 1 percent peak.

Table 3.23 ITE Model Calibration Results Ridership = .083 (PR) - .036 (PE)

Lot	Actual Riders	Predicted Riders	Residuals	% Error
Eastex	334	522.4	-188.4	+54.4
N.W. Station	336	249.9	86.1	-25.6
Kingsland[1]	392	552.7	-160.7	+41.0
Alief	427	402.1	24.9	-5.8
Westwood	509	485.3	23.7	-4.7
Bay Area	629	1,210.2	-581.2	+92.4
Kingwood	653	176.6	476.4	-73.0
Addicks[2]	729	648.9	80.1	-11.0
N. Shepherd	905	1,070.0	-165.0	+18.2
Spring	919	632.0	287.0	-31.2
Kuykendahl	1,689	763.9	925.1	-54.8

[1]Kingsland (2/86).

[2]Addicks (2/86).

Possible reasons for the differences in the coefficients are the use of 24-hour traffic counts factored to the a.m. peak period. This includes traffic in both directions. For Houston, the percentage of average daily traffic in the a.m. peak is 16.4 percent for the county (18). This factor was applied to all of the 24-hour counts used in the calibration. Another possible explanation lies in the use of traffic data from the years 1980 through 1985. For each lot, the percentage growth in traffic occurring on the prime facility was applied to adjacent arterial and collector streets counted as peak facilities. This percentage growth may not be an accurate expansion factor for the peak facilities. Because of the possibilities of non-meaningful variables, difficulty in obtaining accurate data, presence of multicollinearity, and high error in predicted results, use of this model is not recommended.

Researchers attempted to calibrate the ITE model in a formulation which would eliminate the problems with multicollinearity. In this formulation, peak traffic excluded prime traffic; prime traffic is not counted twice. The reformulated model follows:

Ridership = .047 (PR) - .036 (PE)

where: PR = prime facility peak traffic

PE = peak traffic (excluding prime)

R^2 = .76, RMSE = 422.51

As with the originally formulated model, model statistics indicate less than a .20 probability that the coefficients have zero volumes, or in other words an 80 percent chance that the coefficients of the variables are non-zero. This formulation eliminates the previous model's problem with multicollinearity. Table 3.23 also shows actual and predicted ridership, residuals and percent error. The root mean squared error remains large so, as a predictor, this model produces ridership that will be within ± 828 riders 95 percent of the time. The coefficients of 4.7% prime and -3.6% peak differ from the ITE values of 3% prime and 1% peak. Again, these differences are most likely due to the use of bi-directional, peak-traffic volumes, one peak-hour factor for all facilities, and limited non-peak value data.

The problems with attempting to calibrate the ITE model for Houston reflect the problems transportation professionals are likely to encounter in using this method. Limited peak-period traffic data collected during the same year, lack of peak-directional volume data, and problems appropriately identifying non-prime facilities from which to collect data all diminish the ability to easily apply this method. The lack of accuracy resulting from the predictor model also distracts from its desirability.

The Georgia Models-GOPARK

Georgia Department of Transportation (GDOT) developed a model called "GOPARK" to estimate demand in areas with diverse peak-period traffic patterns. This model examines only work trips bound for specified destinations and assumes that demand for park-and-ride comes from two sources (17,19):

1. Commuters from external areas passing the lot on the prime (major roadway) facility; and,

2. Commuters from the lot's surrounding service (market) area.

The GDOT's requirements used in developing their models for park-and-ride demand estimation techniques follow (17, 19):

1. Techniques must be easy to use and quick to apply yet yield reliable results;
2. Techniques must not require extensive new data collection, but must rely on readily available data;
3. Techniques must be capable of estimating park-and-ride demand for a variety of destinations; and,
4. Techniques should not be mode-specific; i.e. restricted to bus only operation.

The formula for the basic demand estimation model "GOPARK" is (19):

DEMAND = a(TSA) + b(TPRIME)

where:

TSA = candidate trips from the lot's service (market) area;

TPRIME = candidate trips on the prime (major roadway) facility; and,

a,b = attraction factors for candidate trips from the service area and prime facility.

For the Atlanta area, both a and b equal twelve percent (12%).

In this model, candidate trips both for the service area and the prime facility include those trips headed for destinations attracting a significant volume of the total trips, like the CBD. For the service area trips, planners can identify such destinations by examining a traditional origin-destination trip table. For the prime facility, planners can identify trip ends from an examination of traditional traffic assignment models for the roadway link adjacent to the lot. The GOPARK model works best in outlying areas where travel times to final commuting destinations are at least thirty, and preferably forty-five, minutes during the peak period. The model allows the separation of inbound trips, or those most likely to use park-and-ride, and bases the projections on those trips alone (17).

The chief drawback of GOPARK lies in its treatment of trips within the surrounding service area. It assumes commuters living fifteen minutes from the park-and-ride lot would be just as likely to use the lot as people living only one minute away; this may only be true in the far outlying areas where total travel times are long (17,19). To resolve this problem, GDOT developed a modified version of the original model called GOPARK II.

GOPARK Calibration

Calibration of GOPARK for Houston required the use of traffic counts and origin-destination data. The original GOPARK and GOPARK II Models were neither tested nor validated by TTI. As in the ITE Model calibration, planners used 24-hour counts adjusted for a.m. peak-period traffic (6-9 a.m.). To identify employees destined for the activity center (the CBD), planners identified the service area as the parabolic-shaped area identified in park-and-ride surveys (see Figure 3.1). Planners attempted to utilize 1975 and 1995 origin-destination work trip tables, but found the traffic serial zones in the service area aggregated into several sectors; sectors not coterminous with the park-and-ride lot market area. Attempting to identify the percent of the area contained in sector and service area and applying the re-sulting percentage to the trip interchange data proved too cumbersome and time-consuming. This percentage would have needed to be applied to both the 1975 and 1995 trip tables and results interpolated to develop 1985 data. Instead planners used the CBD employment data within the market area of the park-and-ride lots developed from the 1980 census (see Table 3.7). The results of the GOPARK Model calibration follow:

Rider = .0089 (TPRIME) + .121 (TSA)

where: TPRIME = Peak period traffic on prime facility

TSA = CBD workers in the market area

R^2 = .69, RMSE = 432.42

While the F-test for the model shows it to be statistically significant, the coefficients of the variables have statistical significance at the .5 level. The coefficient for TPRIME is most suspect, while TSA has a t-test showing significance at the 90 percent level of confidence. While the co-efficient of determination is relatively high, the root mean squared error is also high. When using this model for prediction, 95 percent of the time the model will produce ridership estimates of about ± 840 riders. Compared to the Atlanta coefficients (both 12 percent), the Houston coefficients for candidate trips (TSA) in service area matches closely. The .89 percent coefficient for Houston's trips on prime facility is lower than Atlanta's 12 percent. This difference probably results from the use of factored peak traffic for both directions rather than use of traffic generated from a selected link procedure to identify CBD-destined trips on the facility as was used in Atlanta. Table 3.24 shows the actual versus predicted riders and residuals from this model calibration. The model replicated rather poorly Houston's data (within 227 percent). As calibrated, the model lacks accurate predictive power.

Table 3.24 GOPARK Calibration Results

Ridership = .0089 (TPRIME) + .121 (TSA)

Lot	Actual Riders	Predicted Riders	Residuals	% Error
West Belt[1]	282	921.0	-639.0	+226.6
Missouri City	326	320.6	5.4	-1.7
Eastex	334	251.8	82.3	-24.6
N.W. Station	336	207.7	128.3	-38.2
Kingsland[2]	392	320.1	71.9	-18.3
Alief	427	570.9	-143.9	+33.7
Westwood	509	578.3	-69.3	+13.6
West Loop	543	1,196.8	-653.8	+120.4
Kingwood	653	247.7	405.3	-62.1
Edgebrook	726	442.2	283.8	-39.1
Addicks[3]	729	377.0	352.0	-48.3
Seton Lake	801	510.4	290.6	-36.3
N. Shepherd	905	908.6	-3.6	+.4
Spring	919	433.6	485.4	-52.8
Kuykendahl	1,689	765.8	923.2	-54.7

[1]West Belt lot data based on 14 months after opening (2/86).

[2]Kingsland lot data from 2/86.

[3]Addicks lot data from 2/86.

GOPARK II

The GOPARK II model also assumes that demand is a function of work trips from within the lot's surrounding service area and those passing the lot on the prime facility from other areas. This model assumes that, within the service area, the closer a commuter lives to the park-and-ride lot, the more likely the individual is to use it. The service area is divided into three zones (17,19):

(a) the area within five minutes travel time;
(b) the area within five minutes to ten minutes from the lot; and,
(c) the area ten to fifteen minutes from the lot.

This is illustrated in Figure 3.5:

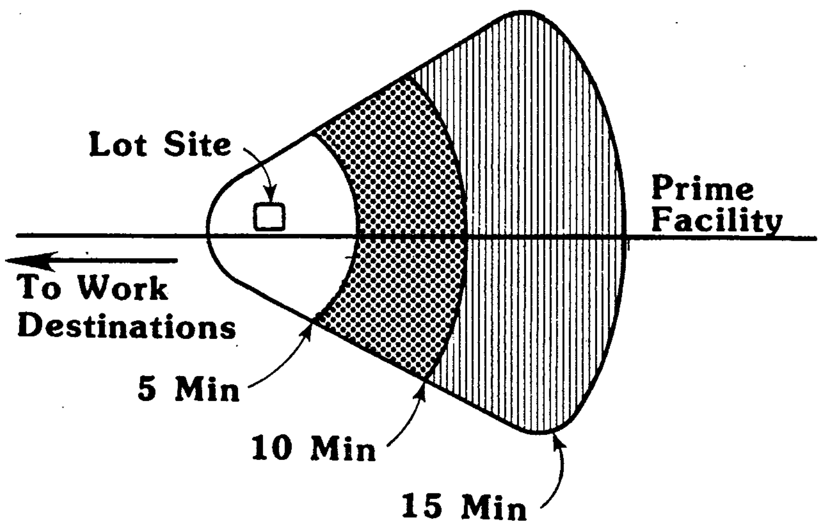


Figure 3.5: Park-and-Ride Lot Service Area Stratified By Travel Times To Lot

Each area has a separate attraction factor for the lot, which decreases as time from the lot increases. The formula for this technique is as follows (17,19):

DEMAND = a(T5) + b(T10) + c(T15) + d(TPRIME)

where:

T5 = candidate trips by service area residents living within five minutes of the lot;

T10 = candidate trips by service area residents living five to ten minutes from the lot;

T15 = candidate trips by service area residents living ten to fifteen minutes from the lot;

TPRIME = candidate trips on the prime (major roadway) facility; and,

a,b,c,d, = attraction factors.

For the Atlanta area, a = 0.175, b = 0.125, c = 0.100 and d = 0.100.

Georgia now uses GOPARK as the principal planning technique for demand estimation at most urban park-and-ride lots (17). In applying the Georgia techniques, some additional considerations need to be taken into account, particularly in corridors where commuters may have a choice of several park-and-ride lots. In spite of close spacing of lots, service areas in the Georgia models must not overlap. Instead, an area will fall in the service area of the closest park-and-ride lot that does not require considerable backtracking or diversion out of normal travel routes. Otherwise, a double counting of commuter trips from the service areas and an over estimation of demand would result. Also, for commuters on the prime facility, the probability of using park-and-ride diminishes as they get closer to their work destinations. Thus, if a commuter passes up the first park-and-ride lot encountered, it is extremely doubtful a second lot closer to the final destination will be utilized. Therefore, prime facility trips are considered as park-and-ride candidates only for the first available lot they encounter (17).

Candidate trips for a second, closer-in lot would include only trips which gain access to the prime facility or major roadway after passing the first lot within a travel corridor. If, however, the first lot reaches capacity and is unable to satisfy total demand, the excess demand can divert to a second, closer-in lot. A percentage of candidate prime facility trips equal to the percentage of demand unsatisfied at the first lot is still considered a candidate for park-and-ride at the second lot (17).

GOPARK II Calibration

GOPARK II calibration also required use of traffic counts and origin-destination data in the form of work trip tables. To identify candidate trips going to the activity center, planners need to identify those traffic serial zones 5-, 10-, and 15-minutes from the park-and-ride lot. In the absence of detailed travel time data, planners must identify those zones. The aggregation of resulting 5-, 10-, and 15-minute zones into traffic sectors results in confusing overlaps between zones and sectors. Because of the problem of non-coterminus boundaries between falling in 5-, 10-, and 15-minute areas and sectors, this model requires the assumption that the percent of zone's areas which fall in a sector approximates the percent of the trips generated from that area. Thus, one could aggregate trips into the 5-, 10-, and 15-minute service areas. An attempt to do this proved very time-consuming, subjective and cumbersome. In light of other easier-to-use models, planners decided against calibrating GOPARK II. In the future, however, the serial zone structure could be construed to allow the designation of 5-, 10-, and 15-minute zones into their own sectors. From this, planners could more easily calibrate the GOPARK II model.

Lot Sizing

The six methods described in this section provide a range of park-and-ride service patronage planners can anticipate. How do these relate to sizes of park-and-ride lots one needs to construct? Most park-and-ride service patronage results from a combination of park-and-ride where one parks his or her car and rides the bus, as well as kiss-and-ride where one drops off the bus rider on his or her way to another destination. Table 3.25 shows the ratio of riders to parked vehicles for each lot in Houston. The unexpectedly low ratio at the Spring lot of .92 suggests that some people may be using the park-and-ride lot for carpool and/or vanpool staging areas. The extent to which the parked cars include vehicles of people who do not use the transit service is not yet fully known. Thus, in estimating parked car spaces from the modeled park-and-ride service ridership, one must use caution.

The mean ratio of riders to parked vehicles is 1.17 riders per parked vehicle, or eliminating Spring, it is 1.18. Earlier TTI research had found this ratio to be 1.4 (10). Thus, to plan the number of parking spaces needed at a park-and-ride lot, analysts need to take the range of ridership estimates derived from the demand estimation methodologies and take from 75 to 85 percent of the ridership numbers to arrive at a range of parking spaces required. To relate parking spaces to actual lot size, one generally needs to multiply spaces by approximately 450 square feet per space (roughly 100 spaces per acre). This 450 square feet per space is greater than normal parking lot design standards, but the 450 square feet per space includes areas for kiss-and-ride drop off, bus loading areas, passenger terminal, circulation areas and areas for other activities associated with the provision of park-and-ride service (1).

Table 3.25 Park-and-Ride Patrons to Parked Vehicles, Houston, Texas - 1985

Lot	Ratio of Riders/ Parked Vehicles
S.W. Freeway	1.19
N. Shepherd	1.20
Kuykendahl	1.06
Spring	0.92[1]
Kingwood	1.30
Eastex	1.13
West Belt	1.07
Seton Lake	1.20
N.W. Station	1.16
Kingsland	1.49
Addicks	1.05
Edgebrook	1.16
Bay Area	1.21
West Loop	1.14
Westwood	1.02
Alief	1.30
Missouri City	1.20
Mean	1.17

[1]This low ratio probably results from carpool and/or vanpool riders using the lot as a staging area. The revised mean without this lot is 1.18.

Transferability of Models to Other Large Texas Cities

Since Houston is, to date, the only Texas city providing authorized vehicle lanes to serve park-and-ride lots, the models to project ridership to lots served by AVL's remain applicable only to Houston. Do the models calibrated for lots without AVL service project daily ridership well in other Texas cities? To test the models applicability, two models were applied to a sample of Dallas area park-and-ride lots. Specifically the models below were applied to four Dallas lots: Redbird, Plano, Garland South and Pleasant Grove park-and-ride lots. Figure 3.6 shows these lot locations.

Model 1

Ridership = 16.13 + 4.85 (MO) + 12.89 (Dist)

where: MO = Months of lot operation

Dist = Road distance to activity center in miles

R^2 = .89, RMSE = 58.19

Model 2

Ridership = 284.1 + 4.18 (MO) - 7.92 (ICI_B)

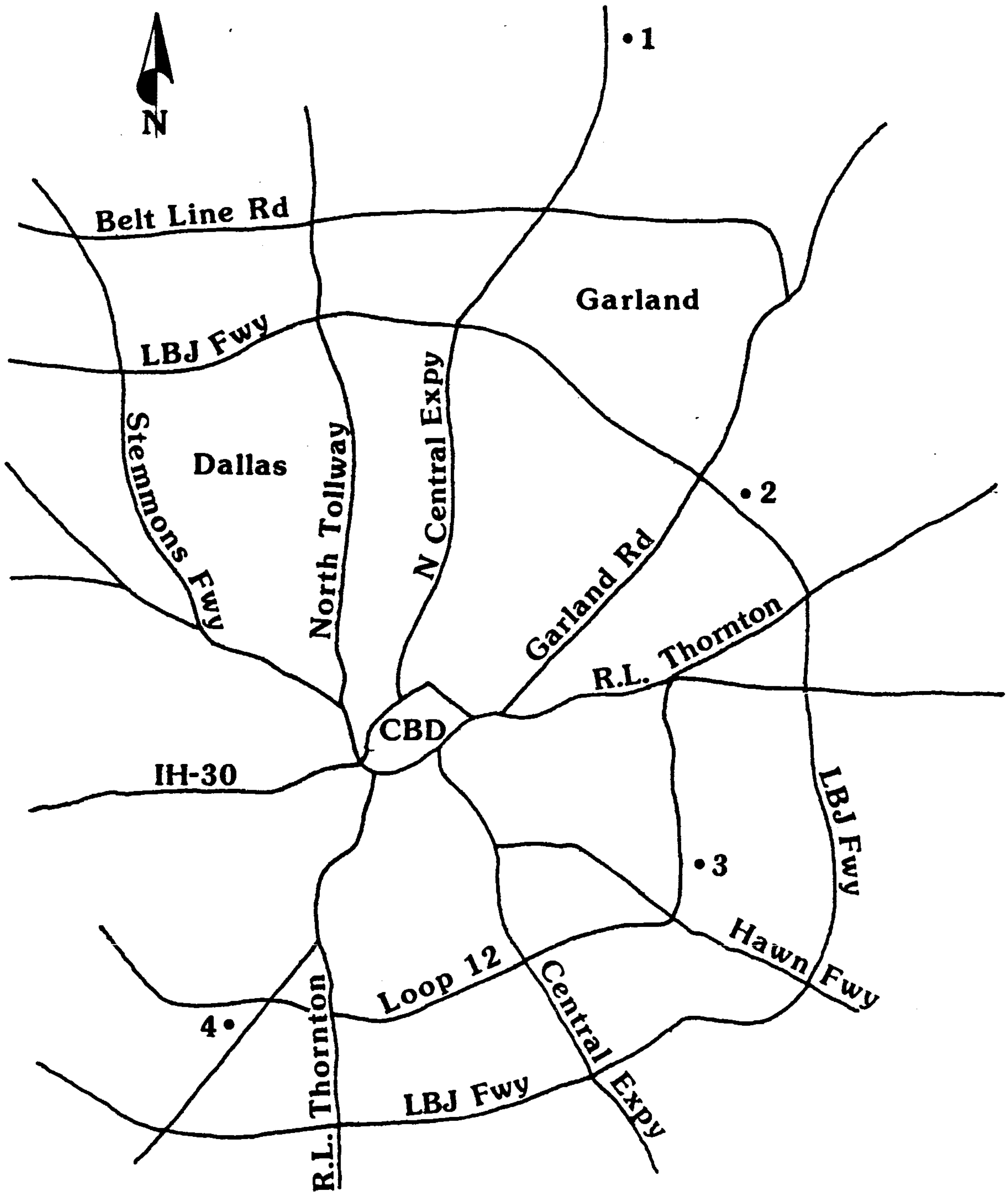
where: MO = Months of lot operation

ICI_B = Average of congestion indices encountered on freeway portion of trip.

R^2 = .67, RMSE = 99.68

Table 3.26 shows the results of applying these models to Dallas data. It also shows the percent error between predicted and actual ridership and the interval estimate of the projection at the 95 percent confidence level.

Except for the Red Bird lot, model 1 generally projects ridership $\pm$ 40 percent for the Dallas sample; however, the actual ridership falls outside of the interval estimate. Model 2, on the other hand, projects ridership within the interval estimate. Again the Red Bird lot differs most from the ridership prediction. The limited application of the non-AVL models to four Dallas lots shows them to project ridership generally $\pm$ 40 percent, except for the Red Bird lot. Model 2 provides the best interval estimate. For



LEGEND

1. Plano	3. Pleasant Grove
2. Garland South	4. Red Bird

Figure 3.6 Dallas Area Park-and-Ride Lots

Table 3.26 Projected Ridership at Dallas Park-and-Ride Lots Using Non-AVL Models

Lot	1985 Actual Riders	Model 1 Project. Riders	Model 1 % Error	Model 1 Model Interval Estimate[1]	Model 2 Project Riders	Model 2 % Error	Model 2 Model Interval Estimate
Red Bird	310	651	+110.0	537-765	720	+132.3	525-916
Plano	496	296	-40.3	182-410	271	-45.4	76-466
Garland South	550	770	+40.0	656-884	738	+34.2	543-933
Pleasant Grove	200	194	-3.0	80-308	324	+62.0	129-520

[1]At the 95 percent confidence level, the true ridership will fall within the interval estimate (1.96 x RMSE).

greater predictive power, planners may want to calibrate the models for their particular city. Both models applied to Dallas can be used since they require congestion indices data, distance to activity center and months of operation.

Conclusion

This section has presented six alternative techniques for estimating the potential utilization of park-and-ride service in Houston. These will need to be calibrated for other Texas cities. Each technique has certain limitations, and all assume that the proposed lot is situated in accordance with the lot location guidelines presented earlier in this report. In planning for new park-and-ride facilities, it is recommended that, where time and data permit, all six of the demand estimation techniques outlined be applied in order to obtain a range of estimates of potential lot utilization. That range, along with lot sizing information and knowledge of the local area, can be used to estimate the size of the new park-and-ride facility (1). Also, by only analyzing the Houston lots, potentially important predictive variables are not necessarily included since, in any one city, they may not vary significantly between lots (e.g., downtown parking costs).

CONCLUSIONS

Distinctive differences in ridership exist for those park-and-ride lots served by authorized vehicle lanes (AVL's) and those without AVL service. Ridership growth at lots with AVL's appear to be affected most by freeway congestion and employees in the park-and-ride market area destined to the CBD. Specifically, the average of congestion indices encountered along the freeway portion of the trip and CBD-destined employees in the market area emerged as good ridership predictor variables.

For lots without AVL service, growth in ridership is more dependent upon the months the lots have been operating and on the distance of the lot from the activity center. Based on the available data, there appears to be no upper limit on the months of operation variable. Those lots with the greatest ridership increases were located at least 11 miles from the activity center, with the mean distance being 20 miles.

Based on this finding, researchers constructed several models to project park-and-ride lot ridership. Several one- and two-variable models appear to be the most useful in projecting ridership. Different models emerged for estimating ridership at lots served by AVL's and those not given priority treatment.

With or Without Priority Service

1. Riders = -1355 + 520.8 (ICI_B) + .07 (CBD_EMP) + 240.3 (AVL) + 6.52 (MO)

   R^2 = .49 RMSE = 284.81

2. Riders = -1425.10 + 605.08 (ICI_B) + 4.74 (MO) + .095 (CBD_EMP)

   R^2 = .40, RMSE = 299.15

3. Riders = -273.59 + 253.72 (ICI_B) + 5.21 (MO)

   R^2 = .24, RMSE = 315.17

Without AVL Service

1. Riders = 16.13 + 4.85 (MO) + 12.89 (DIST)
   R^2 = .89, RMSE = 58.19
2. Riders = 284.1 + 4.18 (MO) - 7.92 (ICI_B)
   R^2 = .67, RMSE = 99.68

With AVL Service

1. Riders = -4280.5 + 1675.75 (ICI_B) + .23 (CBD_EMP)
   R^2 = .76, RMSE = 241.16
2. Riders = -5351.3 + 1957.86 (ICI_B) + .0156 (MAPOP)
   R^2 = .70, RMSE = 271.63
3. Riders = -4969.46 + 1866.33 (ICI_B) + .0056 (MAPOP) + .17 (CBD_EMP)
   R^2 = .78, RMSE = 249.24
4. Riders = -3786.7 + 1326.79 (ICI_B) + 8.75 (MO) + .246 (CBD_EMP)
   R^2 = .84, RMSE = 212.28

where:

MO = Months of lot's operation

DIST = Road mileage to activity center

AVL = Presence (1) or absence (0) of authorized vehicle lane

ICI_B = Average of freeway congestion indices encountered on freeway portion of trip (discussed in more detail in previous sections of this report)

CBD_EMP = Employees residing in the market area destined for the central business district (CBD)

MAPOP = People residing in market area of park-and-ride lot

In addition, a one-variable model emerged as a good predictor of the percent market area population served by a lot with AVL service. The model follows:

$$\text{Proportion MAPOP Served} = -.031 + .0166\ (\text{ICI\_B})$$
$$R^2 = .72,\ \text{RMSE} = .0036$$

As a "ballpark" means of sizing lots, ridership typically ranges between 0.5% and 2% of market area population. Additional two- and three-variable models emerged as fairly good predictors of ridership. Each was neither easier to use nor a better predictor than the models discussed. Futhermore, these other models required data not as readily available as those above.

Although the ITE and GOPARK models were calibrated as part of this research effort for a large Texas city, researchers encountered problems with each. The ITE model suffers from multicollinearity. The predictor variables, peak and prime, are not independent since peak traffic includes traffic on the prime facility plus adjacent roadways. Reformulated to eliminate this colinearity, researchers calibrated the ITE model. The resulting coefficient of determination was an acceptable .76, but the root mean squared error is high (423). Thus, as a predictive tool, ITE will not be particu-larly helpful. Moreover, problems in quickly and easily obtaining peak-period traffic counts by direction for prime and adjacent roads further weakened the model's usefulness.

Georgia's GOPARK model was also calibrated resulting in a good coefficient of determination (.69) but a high root mean squared error (432). The high error term reduces the model's predictive value. Problems with obtaining peak-period, directional traffic and in using trip tables with traffic serial zones which were not designed to coincide with park-and-ride market areas further reduced the model's ease of use.

The park-and-ride analysis not only highlighted different variables for predictors of ridership at lots served by AVL's and those without service, but also revealed some quantitative impacts of AVL service on park-and-ride patronage. Based on limited experience, AVL service appears to increase ridership at park-and-ride lots by between 60% and 100%.

Operating data on the North Freeway (I-45) AVL has been available for over five years. The Katy AVL, however, has only been open since October 1985, so data are limited. With time, the provision of an AVL to park-and-ride lots increases the percentage of market area population served by about 67%. Modal split data support this finding; park-and-ride lots served by an AVL have modal splits of 30% to 33%. Analysis of the regression models shows the provision of AVL's to park-and-ride lots increases ridership significantly. One set of models shows the impact to increase patronage by 70 percent. Another set of equations estimates the impact to be closer to 225 percent. Operating data suggest the AVL equation in the pair (Model 2.2) may over-estimate the impact of AVL-provision, and the non-AVL equation (Model 2.1) may under-estimate ridership. As more operating data become available for park-and-ride service for those with and without an AVL, the ridership impact of an AVL to a park-and-ride lot can be assessed more accurately. Limited data suggest the impact increases ridership significantly.

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APPENDIX A

Appendix A

Relationships of Variables to Riders, 1985

Lot	Lot#	Riders	Dist	ICI_B	SCI	ICI	AVL	Mos.	MAPOP	ALL_EMP	CBD_EMP
N. Shepherd	201	905	9.35	2.4	5.7	3.0	1	59	96,684	40,345	3,032
Kuykendahl	202	1689	15.60	2.8	5.7	3.0	1	62	80,901	42,439	5,111
Spring	204	919	19.50	2.7	5.7	3.0	1	29	52,570	47,844	2,509
Kingwood	205	653	27.40	2.9	4.8	3.3	0	64	35,134	16,136	1,710
Eastex	206	334	13.60	2.6	4.8	3.3	0	20	33,749	14,471	1,005
West Belt	210	158	13.73	2.0	5.8	3.2	1	2	111,527	61,044	5,499
West Belt	210	242	13.73	2.0	5.8	3.2	1	12	111,527	61,044	5,449
West Belt	210	282	13.73	2.0	5.8	3.2	1	14	111,527	61,044	5,499
Seton Lake	212	801	16.70	2.4	5.7	3.0	1	23	66,200	38,052	3,822
N.W. Station	214	336	19.45	2.3	3.8	2.1	0	11	38,278	19,622	1,282
Kingsland	221	370	28.75	2.6	5.8	3.2	1	54	44,525	23,229	1,498
Kingsland	221	392	28.75	2.6	5.8	3.2	1	56	44,525	23,229	1,498
Addicks	228	580	18.66	2.8	5.8	3.2	1	38	61,263	21,830	2,369
Addicks	228	729	18.66	2.8	5.8	3.2	1	40	44,156	23,646	1,738
Edgebrook	245	726	11.80	2.0	5.2	2.4	0	96	83,908	46,522	2,205
Bay Area	246	629	22.55	1.9	5.2	2.4	0	60	37,039	------	-----
West Loop	261	543	10.10	1.6	3.5	1.6	0	93	178,603	103,262	7,865
Westwood	262	509	13.85	2.8	7.0	3.1	0	70	89,151	48,232	3,149
Alief	263	427	15.61	2.8	7.0	3.1	0	47	91,486	52,130	3,088
Missouri City	270	326	13.45	2.8	7.0	3.1	0	41	47,059	19,907	1,018

Riders = Average daily roundtrip riders (dependent variable).

Dist = Roadmile distance to activity center (CBD).

ICI_B = Average of congestion indices encountered on freeway-portion of trip.

SCl = Societal congestion index (reference 16).

ICI = Individual congestion index (reference 16).

AVL = Whether served by an authorized vehicle lane (1 if yes, 0 if no).

Mos = Number of months of operation.

MAPOP = Market area population of area served by park-and-ride.

ALL_EMP = Number of employees (over 16 years of age) residing in market area of park-and-ride.

CBD_EMP = Number of CBD-bound employees who reside in park-and-ride market area.