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In the third phase, the characteristics of the cities identified in Phase I were matched with the characteristics of the transportation systems described in Phase II. The phases were synthesized through a matrix which gives a rating of each transit option for each type of city. General guidelines for estimating costs and revenues were also developed in this phase.

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EVALUATION OF VARIOUS APPROACHES TO PROVIDING PUBLIC TRANSPORTATION SERVICE IN AREAS LESS THAN 200,000 POPULATION

by

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Technical Report Number 1051-1F
Technical Study Number 3-10-76-1051

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Texas State Department of Highways and Public Transportation
in cooperation with the
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by the

CENTER FOR TRANSPORTATION RESEARCH
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PREFACE

This is the final report on Technical Study 3-10-76-1051, "Evaluation of Various Approaches to Providing Public Transportation Service in Areas Less Than 200,000 Population." The objective of this study is to provide data and information on feasible service approaches to satisfying local public transportation needs. This report presents the results of a three-phase study which included the development of a classification scheme for Texas cities within the scope of the project, identification and description of public transportation alternatives, and the evaluation of a means of linking city characteristics to appropriate public transportation systems. The resultant report is presented in a form to facilitate its use by professionals and lay people. The report is not intended as a technical manual for final evaluations but as a guide to foster decision making pertinent to public transportation options for Texas cities with under 200,000 population.

The authors wish to acknowledge and extend their appreciation to the many professionals who have assisted in providing information, data, and technical guidance. Special recognition is extended to Mr. Don Dial (D-10M), Mr. Russell Cummings (D-18S and formerly of D-10M), Mr. Ray Quay of the City of Galveston Planning Department, and Mr. John Pester, Center for Transportation Research, The University of Texas at Austin. To all these individuals and others we are greatly indebted.

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ABSTRACT

The study was divided into three phases. The first two phases were carried out simultaneously, while the third phase involved a synthesis of findings.

Phase I identifies the geographic, social, and economic characteristics of Texas cities relevant to mass transit use. The cities were then classified according to the observed characteristics, to provide assistance in choosing from among the available options. The pertinent characteristics were identified through a regression analysis of census data. The classification was made by using the statistical technique factor analysis. The research was limited to cities with at least 10,000 population in 1970. Cities smaller than this are unlikely to have sufficient demand to warrant transit service and they generally lack the administrative capacity to initiate public service in a new field.

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In the third phase, the characteristics of the cities identified in Phase I were matched with the characteristics of the transportation systems described in Phase II. The phases were synthesized through a matrix which gives a rating of each transit option for each type of city. General guidelines for estimating costs and revenues were also developed in this phase.

SUMMARY

This study examines various transit alternatives, combinations of alternatives, and their ability to meet local public transportation demand in Texas cities with populations less than 200,000. The anticipated transit needs of various cities are catalogued and the operational characteristics and costs of each alternative are defined, in an effort to give local community officials and decision makers a means of evaluating the appropriate transit alternatives for their community.

The study was divided into three phases. The first two phases were carried out simultaneously, while the third phase involved a synthesis of findings:

Phase I. Classification of Texas Cities
Phase II. Public Transportation System Characteristics
Phase III. Linking City Characteristics to Appropriate Public Transportation Systems

The report is structured into six chapters with chapter 1 presenting the background material pertinent to defining the issue and outlining the study approach.

Chapter 2 summarizes the results of Phase I. The classification of Texas cities involved four steps:

(1) an investigation of the literature to summarize the characteristics of cities and their inhabitants that are associated with public transportation usage;

(2) a determination of the characteristics found in the literature that are relevant to transit usage in Texas through a regression analysis of 1970 census data from the 27 urbanized areas in Texas.

(3) the identification of six independent factors through a factor analysis of the 1970 census data and characteristics of the 121 cities in Texas with at least 10,000 population; and

(4) the classification of the 121 cities into six types, according to their factor scores on the six dimensions.

Chapter 3 discusses the Phase II findings of the transit alternatives. The presentation of each transit type begins with a discussion of major users

and demand characteristics. Routing and scheduling, operation and management techniques, hardware and personnel requirements, and system costs are also covered.

Chapter 4 introduces Phase III, the matching of city types with transit system types. It discusses the salient characteristics of each transit alternative which should be considered in making a modal selection for a particular city. Special categories of users are also identified. The findings are summarized in matrix form. A suitability rating for each transit type, according to city type, is given.

Chapter 5 presents information to make preliminary estimates of costs and revenues for fixed-route and demand-responsive systems. The level-of-service concept is the key to estimating capital and operating costs.

Chapter 6 concludes the report with a summary of the findings and recommendations.

The intention of this document is to array and describe the public transportation options available to small and medium-sized cities in Texas and to assist State and local officials in making a preliminary selection of the most attractive alternatives for further study. It is not a planning manual, and no community should commit itself to new transit service without detailed feasibility and planning studies performed by qualified professionals.

IMPLEMENTATION STATEMENT

The availability of reference material that provides public officials and transportation professionals with public transportation alternatives including their planning, design, operations, maintenance, and financial characteristics is essential. Characteristics such as relevant costs should be of considerable value to decision makers who are attempting to establish, reestablish, or improve public transportation in their respective communities. Only recently has the provision of sufficient information of existing systems been an objective of the U.S. DOT. Much of the information remains inconsistent and therefore difficult to use as a basis for pertinent local decisions. This report is designed to provide a framework for local use as a guide in assessing the utility of various public transportation systems for a variety of city forms or classes.

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CHAPTER 1. INTRODUCTION

BACKGROUND

In the thirty years prior to 1974, transit ridership in Texas consistently declined. During that period, transit service ended in many smaller cities. The remaining services survived by shifting from private to public ownership and from profitable to subsidized operation. The factors contributing to this trend are well known and have been widely discussed elsewhere; important among them were increasing automobile ownership, rapid suburban growth, and the development of an outstanding highway system.

This trend did not go wholly unnoticed or unopposed. Early in the period, some planners and politicians sought to preserve mass transit as an urban transportation alternative. The Federal government first provided aid for mass transportation in the 1961 Housing Act and its financial commitment to transit has continued to increase. The expenditures of the Urban Mass Transportation Administration of the Department of Transportation currently exceed one billion dollars a year. The State of Texas, through the State Department of Highways and Public Transportation, currently provides financial assistance to the cities as matching funds for Federal capital grant applications. This is a further recognition of the need to foster alternatives to the automobile in urban areas.

Many communities of all sizes are considering initiating new transit systems or improving existing services. The Federal government presently provides 80 percent of the cost of capital transit improvements (including rolling stock); the Texas public transportation fund provides 13 percent of the capital transit improvements; and the locality must provide the remaining seven percent. The Federal government also finances up to 50 percent of the operating deficit of local transit systems.

OBJECTIVE

Although the basic historical trend in Texas has been similar to experiences in most other areas of the United States, the experience in

Texas has always been different from the states in the Northeast and Midwest. The majority of Texas' urban growth has occured since 1920, during the era of auto-highway expansion. Texas cities are generally characterized by lower population densities, excellent highway systems, and lower per capita transit usage. The resulting low transit demand makes it difficult for private transit systems to be profitable, especially in smaller cities. Of the 24 Standard Metropolitan Statistical Areas designated in Texas in the 1970 census, seven presently do not have any regularly scheduled bus service. All of the existing systems are now operating at a deficit.

In 1969, the Texas Legislature created the Texas Mass Transportation Commission. The Commission was assigned the task of evaluating public transportation in Texas and alternative roles for the state government. In 1975 the Commission was absorbed into the Highway Department which then became the State Department of Highways and Public Transportation (SDHPT). In the same year, the Legislature created the public transportation fund to help localities match federal grants for transit capital improvements. The State Legislature has continued the previous appropriation level of $15 million per year. The fund, allowing for discretionary use by the State Highway and Public Trnasportation Commission, was established to promote public transportation systems throughout the state, including the smaller cities with less than 200,000 population.

Despite the success of the auto-highway system in catering to the needs of the vast majority of Texans, there remains a substantial minority who are "transportation disadvantaged." These include people who do not have any auto available, those prevented from using one by infirmity or handicap, and those too young or too old to drive. The prevalence of this problem is illustrated by the following statistics. In 16 of the 121 cities in Texas with over 10,000 population, at least 20 percent of the households were without an auto in 1970. In 40 of the cities, at least 15 percent were carless.

In the meantime, there has been considerable experimentation throughout the country with "paratransit" modes. Many of these modes operate in a demand-responsive fashion rather than following fixed routes on fixed schedules. The major form of paratransit, the taxi, is already common in Texas cities. Other forms, including Dial-A-Ride options, jitneys, and shared taxis, may offer opportunities for transit mobility to many areas. For example, paratransit currently services the needs of the handicapped, a specialized client group. It is also possible that paratransit services may be a viable alternative in low-density, low-demand situations (including smaller cities) where conventional bus service would be very costly.

This study examines various transit alternatives, combinations of alternatives, and their ability to meet local public transportation demand in Texas cities with populations less than 200,000. The anticipated transit needs of various cities are catalogued and the operational characteristics and costs of each alternative are defined, in an effort to give local community officials and decision makers a means of evaluating the appropriate transit alternatives for their community.

DESIGN OF THE STUDY

The study was divided into three phases. The first two phases were carried out simultaneously, while the third phase involved a synthesis of findings. Each phase is summarized below.

Phase I. Classification of Texas Cities

This phase identified the geographic, social, and economic charasteristics of Texas cities relevant to mass transit use. The cities were then classified according to the observed characteristics to provide assistance in choosing from among the available options. The pertinent characteristics were identified through a regression analysis of census data. The classification was made by using the statistical technique factor analysis. The research was limited to cities with at least 10,000 population in 1970. Cities smaller than this are unlikely to have sufficient demand to warrant transit service and they generally lack the administrative capacity to initiate public service in a new field.

Phase II. Public Transportation System Characteristics

The different types of transit-paratransit alternatives suitable for Texas cities were identified in the second phase. Information on the operating, managerial, legal, and economic aspects of the alternatives was also assembled. The alternatives examined were conventional fixed-route bus, jitney, Dial-A-Ride, subscription bus, vanpooling and carpooling, taxi and shared taxi, and, briefly, bicycles.

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In this phase, the characteristics of the cities identified in Phase I were matched with the characteristics of the transportation systems described in Phase II. The phases were synthesized through a matrix which gives a rating of each transit option for each type of city. General guidelines for estimating costs and revenues were also developed in this phase.

REPORT OUTLINE

Chapter 2 summarizes the results of Phase I. The classification of Texas cities involved four steps:

(1) an investigation of the literature to summarize the characteristics of cities and their inhabitants that are associated with public transportation usage;

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CHAPTER 2. A CLASSIFICATION OF TEXAS CITIES

INTRODUCTION

This chapter presents a classification of Texas cities based upon characteristics that are relevant to public transportation usage. The viability of a particular transit mode for a city considering service implementation is partially dependent upon the type and nature of the city, although there are many considerations involved in the choice of alternative transit or paratransit systems. The characteristics of public transportation modes vary and so do city characteristics. Therefore, the characteristics of cities related to public transportation usage should be identified to aid cities in choosing appropriate public transportation systems. The identification of cities according to these characteristics should assist in the matching of particular transit modes with types of cities.

There have been numerous efforts to classify cities into relatively homogeneous types. Many of the published city classifications have been national in scope and have tended to classify cities into functional types based upon their economic specialties (Refs 20,26). Classification systems involving only Texas cities identified cities either in terms of geographic location or population sizes (Refs 29,66). No classifications dealing solely with transportation or public transportation characteristics of cities and their inhabitants were discovered in the literature.

This chapter describes a classification system for Texas cities developed for this study. Four major questions guided the system development:

1. What characteristics of cities and their inhabitants have been previously associated with public transportation usage?
2. What characteristics of Texas cities and their inhabitants have a relationship with public transportation usage?
3. How can the significant characteristics of public transportation usage (flowing from answers to the above questions) be analyzed for cities in Texas?

4. How can Texas cities be classified into groups based upon relevant public transportation characteristics?

The following tasks were identified as a feasible approach to answering the above questions: (1) a review of the literature concerning mass (public) transit usage and city characteristics, (2) multiple regression analysis of transit usage in urbanized areas in Texas, (3) factor analysis to determine the basic underlying dimensions of 121 cities in Texas, and, finally, (4) the classification or grouping of cities into city types.

This methodology employed the use of census data and the statistical techniques of multiple regression analysis and factor analysis. The following sections summarize each step of the research. The classification of Texas cities is presented in the last section of this chapter.

REVIEW OF THE LITERATURE

The characteristics of cities and their inhabitants previously associated with public transportation usage were identified in the first task. During a review of published and documented transit relationships, particular attention was given to variables that could be applied to further research on Texas cities.

Although much has been written on transit and paratransit usage, only a few studies have actually produced quantitative results. Most of the studies that have produced quantitative results have dealt mainly with conventional transit modes. These studies have usually compared different cities or have analyzed travel behavior within a single city (Ref 16).

The literature review revealed numerous spatial, social, and economic characteristics commonly associated with transit usage. The review culminated in a list of approximately 40 variables, grouped into eleven major categories (Table A-1, Ap. A). These eleven categories fell into two groups: structural characteristics of cities and characteristics of individuals.

Structural characteristics of cities were generally found to be more important than the characteristics of individuals. The three major structural characteristics were age, size or total population, and population density. Although different studies varied in ordering the importance of the structural components, all three were consistently significant in affecting transit use. A fourth characteristic, housing, was also included in this group. Specific housing measures (e.g., percent of units owner-occupied or percent in one-unit structures) reflect density to a considerable extent, but also reflect income.

The second general group, characteristics of city inhabitants, contained seven major categories: automobile ownership, income, race, employment, education, age, and sex. In the literature, automobile ownership emerged as the most important socioeconomic characteristic, and in some cases it was more important than any of the structural characteristics. However, the other socioeconomic characteristics of individuals cannot be discounted. All of these characteristics, including housing, can be highly interrelated and interdependent. For example, transit usage can depend upon automobile ownership. Auto ownership can depend upon income, which can, in turn, depend upon types of employment and education levels.

Most of the studies were national in scope and were heavily weighted by cities in the Northeast and Midwest, where transit use tends to be higher than elsewhere in the United States. It is well known that Texas cities, particularly small and medium-sized cities, differ in many respects from the cities covered in the literature. In general, Texas cities are younger, less dense, and more automobile-oriented. Therefore, the next research task identified the variables specifically associated with transit usage in Texas.

REGRESSION ANALYSIS INVOLVING TEXAS CITIES

The second task determined the characteristics of Texas cities and their inhabitants that are related to mass transit usage. This phase of the research essentially replicated the types of studies examined in the literature review. A description of the study design and the pertinent results of the analysis are presented in the following sections to provide an understanding of the evolution of the city classifications (Ref 8).

Design of the Study

The statistical technique of multiple regression analysis was employed and the dependent variable was defined as the percent of work trips by transit. The data source was the 1970 U.S. census for the 27 urbanized areas in Texas. An urbanized area was the standard unit of observation, as opposed to Standard Metropolitan Statistical Area (SMSA), county, or city, because this unit closely approximates the actual extent of the service area of a transit operator. These urbanized areas are listed in Table A-2, Ap. A, along with relevant information on population and transit use.

Initially over 40 city characteristics or variables were examined as potential independent variables. A preliminary computer analysis highlighted 25 significant variables that were, consequently, selected for the final analyses. These variable code names are listed in Table 2-1. The 25 variables cover all of the 11 categories in the previous section. The computer analysis utilized the SPSS packaged program for multiple regression analysis specifically "stepwise regression analysis" (Ref 48).

Results of the Analyses

The first findings were the degrees of correlation between transit use and the independent variables. The simple (or zero-order) correlation coefficients between TRANSIT, the dependent variable, and each of the 25 independent variables are listed in Table A-3, Ap. A. The findings indicate that OWNER, NOCAR, POP1920, SINGLE, and CCDENS are the most important variables. These are the only variables with a coefficient greater than .5, meaning that these five variables, taken alone, are the only ones which explain at least 25 percent of the variation in TRANSIT.

The objective of multiple regression analysis is to find the best set of variables to form an estimating equation. Therefore, numerous analyses were conducted, leading to four final equations for four sets of cases: all 27 areas, non-Valley areas (which excluded Brownsville, Harlingen, Laredo, and McAllen), only areas with transit (which excluded areas with less than five buses in 1970, including Bryan, Harlingen, McAllen, Midland, Odessa, Sherman, Texas City, and Tyler), and smaller areas (which excluded Houston, Dallas, San Antonio, Fort Worth, El Paso, Austin, and Corpus Christi). The latter three analyses were conducted to see if the inclusion of a particular set of areas distorted the overall pattern for transit use in Texas. The resulting equations are presented in Tables A-4 thru A-7 in Ap. A.

The results indicated that transit use for the journey to work was strongly related to the social, economic, and geographic characteristics of Texas urbanized areas. These results can only be briefly summarized here. In all cases, a multiple regression equation, significant at the 0.1 percent level, was obtained (explaining at least 90 percent of the variation in the dependent variable).

TABLE 2-1. TRANSIT VARIABLES USED FOR REGRESSION ANALYSIS

Code Name	Definition
BLACK	Percentage of total population that is black.
CCDENS	Population density of central city (persons per square mile).
DISABLED	Percentage of persons, aged 16 to 64 years, who are disabled or handicapped.
EDUC	Percentage of employed persons, 16 years and over, in educational services.
EDUC5YRS	Percentage of adult population with less than five years of education.
EDERLY	Percentage of total population aged 65 years or older.
FEMALE	Percentage of civilian labor force (male and female, 16 years and over) that is female.
FEMWORK	Percentage of females, 16 years and over, who are in the labor force.
FOREIGN	Percentage of total population that is foreign born.
GOVT	Percentage of employed persons, 16 years or older, who are government workers.
HHSIZE	Average number of persons per household.
MEDAGE	Median age of the total population.
MILITARY	Percentage of the male labor force, 16 years and over, in the armed forces.
NEWHOUSE	Percentage of housing units built in 1960 or later.
NOCAR	Percentage of households with no automobile available.
OWNER	Percentage of housing units occupied by the owner.
INCOM	Percentage of families with low income (as defined by the Census Bureau).
POP	Total population.
POPCHA	Percentage change in total population from 1960 to 1970.
POP1920	Population of central city in 1920.
SINGLE	Percentage of housing units in single-unit structures.
SPANISH	Percentage of total population consisting of persons of Spanish heritage.
UNEMPLOY	Percentage of male civilian labor force, 16 years and over, that is unemployed.
WHITECOL	Percentage of employed persons, 16 years and over, in white collar occupations.
YOUNG	Percentage of total population less than 18 years of age.

However, there were differences in the occurrences and significance of specific independent variables among the four sets of cases. These results are summarized in Table 2-2, which provides a rating system of the variables. An insignificant variable in the equation is rated with one star. The ratings increase to five stars, an indication of a significant variable at the 0.1 percent level. A blank indicates that the variable was not included in the final equation obtained.

The results indicate that the most important variables in Texas urbanized areas are OWNER, UNEMPLOY, POP1920, and YOUNG. OWNER turned out to be the strongest single variable in all of the tests. Since it had the highest simple correlation with TRANSIT, it was always the first variable to enter the equation. In addition, it continued to be the dominant variable after others were added. For example, in a long equation run it had the highest F value (87.60) out of the 12 variables in the equation. Generally, the higher the F value, the greater the level of significance. The direction of this relationship was as expected: the higher the percentage of homes occupied by their owners, the less the transit usage.

UNEMPLOY is highly significant, with a F level of 17.16. The interpretation of significance is circuitous, since, by definition, people who are unemployed do not ride transit to work. However, areas with high unemployment tend to be areas with considerable poverty, and these also tend to be areas where transit use is high.

POP1920 entered at an early step in most of the runs. It remained very significant after other variables were entered. In the long equation, its F level of 40.20 was second only to that of OWNER. The direction of the relationship was as expected: the larger a city was in 1920, the greater the transit use in 1970. This variable basically reflects the age of a city. Similar variables were found to be important in other studies. If a city went through its major growth period in the pre-automobile era, then it developed around a transit system, with high densities, and the people acquired a "transit habit" which has persisted over the years. However, there is a substantial association between population in 1920 and 1970 (the correlation coefficient is .881), because cities which were large then continue to be large today.

YOUNG has a positive relationship and is quite significant (F level = 15.27). YOUNG is moderately correlated with FOREIGN, EDUC5YRS, and UNEMPLOY.

TABLE 2-2. SUMMARY OF OCCURRENCE OF VARIABLES IN REGRESSION EQUATIONS

Variable	All Areas	Non-Valley Areas	Areas With Transit Service	Smaller Areas
BLACK		****		*
CCDENS				***
DISABLED	**	*****		**
EDUC				***
EDUC5YRS	****			*****
ELDERLY		*****		
FEMALE				***
FEMWORK	**			
FOREIGN	*	**	*****	
GOVT				
HHSIZE				
MEDAGE	*****		*****	
MILITARY	**			
NEWHOUSE	*		**	*
NOCAR			*	***
OWNER	*****	*****	*****	*****
INCOM		****		
POP			***	
POPCHA				
POP1920	*****	*****	*****	
SINGLE	***		****	***
SPANISH				
UNEMPLOY	*****	*****	****	***
WHITECOL			****	
YOUNG	****	*****	****	

Key:

*	In equation but not significant
**	Significant at 10 percent level
***	Significant at 5 percent level
****	Significant at 1 percent level
*****	Significant at 0.1 percent level

Moderately important variables are DISABLED, EDUC5YRS, FOREIGN, MEDAGE, and SINGLE.

At a 10 percent level, DISABLED has an F value of 4.00. The relationship is negative, meaning that the higher the percentage of disabled and handicapped persons in the working years (ages 16 to 64), the lower the transit use. It may be that while disabled people are less likely to drive a car, they are more likely to be driven by someone else. Until very recently, transit operators in Texas made no special provision to accommodate the handicapped.

EDUC5YRS tends to be confused with that of other highly intercorrelated variables.

FOREIGN entered at an early stage (usually the third step) on most of the tests. However, it was reduced to insignificance by other variables entered later (as shown by its F level of only 1.40). This indicates that it is intercorrelated with other added variables. FOREIGN has high values in urban areas along the Mexican border. These areas also have higher-than-average transit use. However, there are several other characteristics which tend to take on extreme values in this group of cities in relation to other Texas cities.

MEDAGE has a positive relationship with TRANSIT and is highly significant (F level = 22.33). MEDAGE tends to be low in areas with many children (as in the Valley) and high in areas with relatively older populations. The result indicates that the latter type of area relies on transit, and that this effect is independent of the poverty-transit relationships.

SINGLE has an unexpected relationship: a high percentage of single family homes is associated with high transit use. This variable is significant at the 5 percent level, with an F value of 6.35. This seems to be another case of confusion of variables, since this has a correlation of .808 with OWNER.

These findings deviate somewhat from those reported in the literature. Overall, the previous studies found that the structural or geographical characteristics of cities (i.e., city age, population size, and population density) were the most significant in affecting transit usage. Of the two highly significant variables in this study, POP1920 and OWNER, one relates to structural and the other to socioeconomic characteristics. For the most part, structural characteristics were secondary, with the exception of

POP1920, POP, and CCDENS. The other independent variables that were highly or moderately significant were socioeconomic in nature (including OWNER, SINGLE, and NOCAR).

Thus, there was some question as to whether the highly and moderately significant variables identified in this research were actually the basic underlying causes of transit use. Theoretically, the variables in a regression equation should be independent of each other. This was not the case in this set of independent variables. There was a high degree of intercorrelation among many of them.

Due to the intercorrelations among the variables, the statistical technique of factor analysis was utilized. Factor analysis has the advantage of identifying clusters of interrelated variables which are independent of each other, and it is frequently used to classify cases into separate categories.

A FACTOR ANALYSIS OF CHARACTERISTICS OF TEXAS CITIES

This section describes the factor analysis used to classify the 121 Texas cities with a population of over 10,000 in 1970, based on major geographic, social, and economic dimensions. A brief description of the factor analysis technique and the design of the analysis is presented first, followed by a discussion of the results (Ref 15).

Factor Analysis

Factor analysis is a rather complex statistical technique which reduces a large number of manifest variables (describing various characteristics for the units of interest to the researcher) to a small number of implicit, underlying dimensions, or "factors." In this application, the manifest variables were data items taken from Texas census reports. Factors are statistical constructs which are not directly observable in the real world. However, they are often interpreted as the "true" dimensions of data variations——dimensions which are only imperfectly represented by easily measurable, intercorrelated variables.

One advantage of factor analysis (as used here) is that the computed factors are independent of each other (or uncorrelated). This is frequently not true of manifest variables; in this case, there were high intercorrelations among the census data items. This increases the difficulty of identifying the most important variables. Factor analysis extracts the key dimensions in a data set, which can normally be identified with a cluster of the original variables.

For readers unfamiliar with factor analysis, a further description of the technique——its uses and procedures——is provided in Table A-8, Ap. A. However, the terms factor, factor loading, and factor score are defined here since the discussion of the analytical results uses these to render findings.

The number of factors in an analysis is the number of substantively meaningful patterns of independent relationships formed from the input variables. A factor loading may be interpreted as a correlation coefficient between variable and factor. Loadings vary between variable and factor. A positive loading implies a direct relationship, while a negative one implies an inverse relationship. The higher the absolute numerical value, the stronger the degree of association between each variable and the factor. Importance is attached to variables scoring either very high or very low. Factor scores, the standardized measures of a city on a particular factor pattern, indicate the importance of a factor for a particular city.

Design of the Study

The units of observation for both the factor analysis and the subsequent classification of cities were the 121 incorporated cities in Texas with a population of 10,000 or more in 1970. Table 2-3 lists the cities and their 1970 populations. An impression of the various city sizes can be gleaned from the grouping of the cities by population ranges. Twenty-three variables were selected for the final analysis and one was redefined. These variables are listed in Table 2-4 with their computer code names and definitions.

The analysis, employing the SPSS subprogram FACTOR, was performed using PA2 factor extraction (principal factoring with iterations) with the default specifications operational. The principal axes were rotated to an orthogonal simple structure using the varimax criterion.

The major output of the factor analysis included a correlation matrix of all the variables, unrotated and varimax rotated factor loadings, and factor scores for each city on each factor. The meaningful results of the analysis are presented here.

TABLE 2-3. CITIES EXAMINED IN FACTOR ANALYSIS

Greater than 200,000 (7)

1.	Houston	1,232,802
2.	Dallas	844,401
3.	San Antonio	654,153
4.	Fort Worth	393,476
5.	El Paso	322,261
6.	Austin	251,808
7.	Corpus Christi	204,525

100,000 to 200,000 (3)

8.	Lubbock	149,101
9.	Amarillo	127,010
10.	Beaumont	117,548

50,000 to 100,000 (17)

11.	Irving	97,260
12.	Wichita Falls	96,265
13.	Waco	95,326
14.	Arlington	89,723
15.	Abilene	89,653
16.	Pasadena	89,277
17.	Garland	81,437
18.	Odessa	78,380
19.	Laredo	69,024
20.	San Angelo	63,884
21.	Galveston	61,809
22.	Midland	59,463
23.	Tyler	57,770
24.	Port Arthur	57,371
25.	Mesquite	55,131
26.	Brownsville	52,522
27.	Grand Prairie	50,904

25,000 to 50,000 (18)

28.	Richardson	48,582
29.	Longview	48,547
30.	Baytown	43,980
31.	Victoria	41,349
32.	Denton	39,874
33.	Texas City	38,908
34.	McAllen	37,636
35.	Killeen	35,507
36.	Bryan	33,719
37.	Harlingen	33,503
38.	Temple	33,431
39.	Texarkana	30,497
40.	Sherman	29,061
41.	Kingsville	28,915
42.	Big Spring	28,735
43.	Haltom City	28,127
44.	Farmers Branch	27,492
45.	Hurst	27,215

10,000 to 25,000 (76)

46.	Denison	24,923
47.	Orange	24,457
48.	University Park	23,498
49.	Paris	23,441
50.	Lufkin	23.049
51.	Marshall	22,937
52.	Nacogdoches	22,544
53.	Greenville	22,043
54.	Pampa	21,726
55.	Del Rio	21,380
56.	Alice	20,121
57.	Corsicana	19,972
58.	Euless	19,316
59.	Plainview	19,096
60.	Bellaire	19,009
61.	San Marcos	18,860
62.	Mineral Wells	18,411
63.	Groves	18,067
64.	Plano	17,872
65.	New Braunfels	17,859
66.	College Station	17,676
67.	Huntsville	17,610
68.	Brownwood	17,368
69.	Edinburg	17,163
70.	Nederland	16,810
71.	North Richland Hills	16,514
72.	La Marque	16,131
73.	Cleburne	16,015
74.	Seguin	15,934
75.	Pharr	15,829
76.	Eagle Pass	15,364
77.	Weslace	15,313
78.	McKinney	15,193
79.	San Benito	15,176
80.	Palestine	14,525
81.	Borger	14,195
82.	Terrell	14,182
83.	Duncanville	14,105
84.	Carrellton	13,855
85.	Gainesville	13,830
86.	Beeville	13,506
87.	Waxahachie	13,452
88.	White Settlement	13,449
89.	Hereford	13,414
90.	Lake Jackson	13,376
91.	West University Place	13,317
92.	Mission	13,043
93.	Deer Park	12,773
94.	Pecos	12,682
95.	Kerrville	12,672
96.	Rosenberg	12,098
97.	Sweetwater	12,020
98.	Freeport	11,997
99.	Conroe	11,969
100.	Weatherford	11,750
101.	Bay City	11,733
102.	Lamesa	11,559
103.	South Houston	11,527
104.	Vernon	11,454
105.	Levelland	11,445
106.	Robstown	11,217
107.	Snyder	11,171
108.	Ennis	11,046
109.	Port Neches	10,894
110.	Copperas Cove	10,818
111.	League City	10,818
112.	Uvalde	10,764
113.	Alvin	10,671
114.	Sulphur Springs	10,642
115.	Lancaster	10,522
116.	Port Lavaca	10,491
117.	Galena Park	10,479
118.	Balch Springs	10,464
119.	Henderson	10,187
120.	Highland Park	10,133
121.	Bedford	10,049

Source: U.S. Census, 1970

TABLE 2-4. VARIABLES USED IN FACTOR ANALYSIS

Code Name	Definition
BLACK	Percentage of total population that is black.
CCDENS	Population density of city (persons per square mile).
EDUC	Percentage of employed persons, 16 years and over, employed in educational services.
EDUCYEAR	Average number of school years completed.
ELDERLY	Percentage of total population aged 65 years or older.
FEMALE	Percentage of civilian labor force (male and female, 16 years and over) that is female.
FEMWORK	Percentage of females, 16 years and over, who are in the labor force.
FOREIGN	Percentage of total population that is foreign born.
GOVT	Percentage of employed persons, 16 years and over, who are government workers.
HHSIZE	Average number of persons per household.
MEDAGE	Median age of the total population.
NEWHOUSE	Percentage of housing units built in 1960 or later.
NOCAR	Percentage of households with no automobile available.
OWNER	Percentage of housing units occupied by the owner.
INCOM	Percentage of families with low income (as defined by the Census Bureau).
POP	Total population.
POPCHA	Percentage change in total population from 1960 to 1970.
POP1920	Population of city in 1920.
SINGLE	Percentage of housing units in single-unit structures.
SPANISH	Percentage of total population consisting of persons of Spanish heritage.
UNEMPLOY	Percentage of civilain labor force, that is unemployed.
WHITECOL	Percentage of employed persons, 16 years and over, in white collar occupations.
YOUNG	Percentage of total population less than 18 years of age.

Factor Analysis Results

Six factors resulted from the analysis of the 23 variables for 121 cities. In effect, the analysis indicated that the 23 variables may be reasonably reduced to six dimensions of variation in Texas cities. The extracted factors accounted for 84.5 percent of the variance. Table 2-5 presents a description of these factors.

Each factor is defined and labeled by the principal loadings of the variables. Principal loadings are factor loadings for the variables of .5 or above with no higher loading for a variable on any other factor. As each of the variables loaded .5 or above on at least one factor, no variables were excluded from the identification of the factors.

Tables 2-6 through 2-11 indicate the dimensions and the principal loadings of the variables that were used in defining the factors. The variables are identified by their computer code names (Table 2-4 should be consulted for definitions). The tables also list the ten highest and ten lowest scoring cities, accompanied by their scores, for each factor. These cities are presented here for illustrative purposes; the last section is devoted to a fuller discussion of the cities.

Factor 1. The first dimension was defined by the principal loadings of seven social and economic variables (Table 2-6).

Income and minority variables form the factor pattern. Three of the variables are representative of low incomes, particularly the highest loading variable, the percentage of families with low incomes (INCOM); the others are percentage of households with no automobile (NOCAR) and the percentage of the labor force unemployed (UNEMPLOY). Two expected associations were a high number of person per household (HHSIZE) and below average number of years of schooling (EDUCYEAR). Minority variables, SPANISH and FOREIGN, loaded high on this factor.

A community scoring high on this dimension may be characterized as one with residents of relatively low incomes and below average years of schooling. A high number of persons per household and a high percentage of Spanish or foreign-born residents can also be expected. The cities that scored highest on this dimension are mostly in the Rio Grande Valley.

The lowest scoring cities are presented to provide a contrast with the highest scoring cities. The lowest scoring cities tend to have the opposite characteristics. The residents have high incomes and high educa-

TABLE 2-5. FACTOR DESCRIPTIONS AND CORRESPONDING TYPES OF CITIES

Factor No.	Factor Description	City Classes
1	Low socioeconomic status of city residents	Class 1
2	Stage in life cycle--Disadvantaged residents	Class 2
3	Multi-unit dwelling pattern	Class 3
4	Size and age of city	Class 4
5	Recent growth experience of city	Class 5
6	High population density and white-collar employment	Class 6

TABLE 2-6. FACTOR 1

Variable Code Name	Loadings
POOR	.940
SPANISH	923
EDUCYEAR	-.888
FOREIGN	.832
NOCAR	.649
HHSIZE	.647
UNEMPLOY	.614

Highest Scoring Cities			Lowest Scoring Cities		
City No.		Score	City No.		Score
32	Eagle Pass	4.065	111	University Park	-1.472
87	Pharr	3.196	51	Highland Park	-1.423.
98	San Benito	2.865	119	West University Park	-1.278
118	Weslaco	2.826	83	Pampa	-1.040
63	Laredo	2.823	59	Lake Jackson	-1.004
16	Brownsville	2.798	92	Port Neches	-1.004
75	Mission	2.568	46	Groves	-1.001
33	Edinburg	2.414	15	Borger	- .992
69	McAllen	2.017	13	Bellaire	- .922
94	Robstown	1.877	30	Denton	- .911

tional levels. There are also a low number of persons per household and a low percentage of Spanish or foreign-born residents. Many of the low-scoring cities are suburbs or bedroom communities of larger cities.

Factor 2. The second dimension was defined by the stage in the life cycle of the residents and the presence of "disadvantaged" residents. The variables with principal loadings on factor 2 (Table 2-7) represent a later stage in the life-cycle pattern. Three of the variables (ELDERLY, MEDAGE, and YOUNG) compose an age category. Both the percentage of the population over 65 years and the median age of the population indicate a relatively large number of elderly residents. In addition YOUNG loaded negatively, indicating a low percentage of the population under eighteen years of age. FEMALE, the percentage of the labor force that is female, was the second highest variable. A possible interpretation may be that the women have passed through child-rearing stages and have entered the labor force.

Three additional variables loaded highly on this factor, but they loaded even more highly on other factors. These three variables, noted in parentheses in Table 2-7, are HHSIZE, NOCAR, and BLACK. The first, the average number of persons per household, loaded high and negative (-.619), which was very close to its loading on factor 1 (.647). Small households would be in keeping with the elderly community structure defined by the first four variables.

In transportation planning, there are residents who are termed the "transportation disadvantaged." These are usually residents with no automobiles; typically these are elderly, female, minority, or disabled persons. The principal loadings of ELDERLY and FEMALE, along with the high loadings on NOCAR and BLACK, appeared to delineate a pattern of transportation disadvantaged residents. This pattern, though, appears to be secondary to the stage in life cycle pattern. Most of these cities were located in Northeast Texas, with a few scattered in Central and North Texas.

Factor 3. The third most important dimension was identified by a multiunit dwelling pattern. The variables with principal loadings on this factor (Table 2-8) represent apartment living and employment of residents in government and educational services. The high negative loadings on two housing variables, the percentage of owner-occupied housing units (OWNER) and the percentage of single-unit housing structures (SINGLE), clearly denote an apartment or multiunit dwelling pattern. The positive loadings

TABLE 2-7. FACTOR 2

Variable Code Name	Loadings
ELDERLY	.864
FEMALE	.856
MEDAGE	.727
YOUNG	-.668
(HHSIZE)	(-.619)
(NOCAR)	(.509)
(BLACK)	(.433)

Highest Scoring Cities			Lowest Scoring Cities		
City No.		Score	City No.		Score
56	Kerrville	2.946	23	Copperas Cove	-2.404
107	Terrell	2.032	27	Deer Park	-1.868
119	West University Place	1.986	59	Lake Jackson	-1.761
111	University Park	1.899	67	Killeen	-1.605
25	Corsicana	1.853	77	Nederland	-1.594
113	Vernon	1.708	46	Groves	-1.544
17	Brownwood	1.698	36	Euless	-1.367
51	Highland Park	1.482	91	Port Lavaca	-1.254
49	Henderson	1.470	11	Bedford	-1.120
104	Sulphur Springs	1.464	92	Port Neches	-1.114

TABLE 2-8. FACTOR 3

Variable Code Name	Loading
OWNER	-.822
GOVT	.802
EDUC	.781
SINGLE	-.730
(YOUNG)	(-.496)

Highest Scoring Cities			Lowest Scoring Cities		
City No.		Score	City No.		Score
21	College Station	5.436	7	Balch Springs	-1.818
53	Huntsville	3.821	62	Lancaster	-1.339
57	Killeen	2.853	72	Mesquite	-1.183
30	Denton	2.395	11	Bedford	-1.135
76	Nacogdoches	2.370	77	Nederland	-1.104

on the employment variables, the percentage of workers employed by government (GOVT), and the percentage of workers employed in educational services (EDUC) aid in identifying this factor.

Although somewhat unexpected, the housing and employment variables coupled together delineate a single dimension for Texas cities. The highest scoring cities are those with colleges or military bases, where a high percentage of the population reside in multiunit structures. It also might be noted that the relatively high loading of YOUNG on this factor (-.496) is in keeping with the overall pattern. These cities generally have a low percentage of residents under 18 years of age.

Factor 4. The fourth factor, defined by size and age of city, had principal loadings on only two variables: total population (POP) and the total population of the city in 1920 (POP1920). The extremely high positive loadings on only these two variables (Table 2-9) clearly indicate that Texas cities may be arrayed along a size and age continuum.

Those Texas cities that are either large, old, or both can be expected to score high on this dimension. Table 2-9 indicates that the highest scoring cities include the six largest cities in the state. The remaining four cities on the list are not overly large in current population. Three medium-size cities——Beaumont, Galveston, and Waco——had relatively large populations in 1920. Orange is neither particularly large nor old, which is reflected in its lower score.

Factor 5. In contrast to the last dimension, factor 5 represents a dimension of recent growth experience. Three variables had principal loadings on this factor (Table 2-10). The high positive loadings of two of the variables, the percentage of housing units built in 1960 or later (NEWHOUSE) and the percentage change in population from 1960 to 1970 (POPCHA), delineate a distinct growth pattern. The third variable, the percentage of women in the labor force (FEMWORK), loads just above the minimum level for a principal loading.

The Texas cities which have experienced both a growth in population and new housing units and have a significant percentage of women in the labor force can be expected to score high on this dimension. Table 2-10 indicates that the ten highest scoring cities are suburbs. Therefore, the dimension of recent growth appears to be a pattern most characteristic of large city suburbs.

TABLE 2-9. FACTOR 4

Variable Code Name	Loading
POP	.928
POP1920	.908

Highest Scoring Cities

City No.		Score
52	Houston	6.332
26	Dallas 5.152	5.152
97	San Antonio	4.140
38	Ft. Worth	2.579
34	El Paso	2.228
42	Galveston	1.179
6	Austin	.928
10	Beaumont	.682
115	Waco	.600
81	Orange	.438

Lowest Scoring Cities

City No.		Score
21	College Station	-1.154
56	Kerrville	- .967
53	Huntsville	- .886
119	West University Place	- .645
79	North Richland Hills	- .644
99	San Marcos	- .623
65	Levelland	- .607
58	Kingsville	- .606
11	Bedford	- .605
78	New Braunfels	- .596

TABLE 2-10. FACTOR 5

Variable Code Name	Loading
NEWHOUSE	.804
POPCHA	.717
FEMWORK	.526

High Scoring Cities

City No.		Score
89	Plano	2.663
31	Duncanville	2.648
93	Richardson	2.280
19	Carrollton	2.240
37	Farmers Branch	2.100
54	Hurst	2.046
11	Bedford	2.043
36	Euless	2.040
43	Garland	1.972
72	Mesquite	1.872

Lowest Scoring Cities

City No.		Score
46	Groves	-1.770
15	Borger	-1.750
90	Port Arthur	-1.650
41	Galena Park	-1.484
119	West University Place	-1.273
102	Snyder	-1.258
39	Freeport	-1.251
121	Wichita Falls	-1.199
83	Pampa	-1.183
12	Beeville	-1.149

Factor 6. The sixth factor in the analysis describes high population density and white-collar employment. The highest loading variable in this dimension (Table 2-11) is the population density of the city (CCDENS). The second highest variable is the percentage of the labor force in white-collar occupations (WHITECOL). WHITECOL, coupled with a negative loading on the percentage of the population which is black (BLACK), clearly delineates a community with a low number of black residents.

Texas cities scoring high on this dimension may be characterized as dense, white cities. The five highest scoring cities all have particularly high population densities and some of the other cities have low black populations.

A CLASSIFICATION OF CITIES

The results of the factor analysis indicated that there are six uncorrelated dimensions accounting for a large proportion of the variability among Texas cities. Based upon these dimensions, six classes of cities were identified. In order to develop a classification system which did not include the same city in different groups, each city was placed in a single class. The 121 cities were assigned to a class based on the factor score with the highest positive loading. Thus, all the 121 cities were classified into only one of the six city classes.

The classification of the cities is presented in Table Figs. 2-1 thru 2-6 showing the locations of cities in each of the six classes. A separate listing of the cities within each class, along with factor scores, is given in Tables 9-14 of Appendix A. The following sections describe the six city classes.

Class 1

The cities comprising this class have a very definite geographical manifestation. Figure 2-1 indicates the cities are predominantly located in South Texas along the Rio Grande Valley. The cities extend from Del Rio to Brownsville and then up the Gulf Coast to Rosenberg. While the mapping of these cities shows a definite regional component, they were included in this class mainly because of socioeconomic characteristics.

Two cities in West Texas, Lamesa and Pecos, do not conform with the otherwise regional grouping. These cities have high Spanish populations,

TABLE 2-11. FACTOR 6

Variable Code Name	Loading
CCDENS	.652
WHITECOL	.629
BLACK	-.558

Highest Scoring Cities

City No.		Score
119	West University Place	4.081
111	University Park	3.919
51	Highland Park	3.260
13	Bellaire	2.475
32	Eagle Pass	1.743
56	Kerrville	1.671
34	El Paso	1.492
69	McAllen	1.418
93	Richardson	1.116
37	Farmers Branch	.887

Lowest Scoring Cities

City No.		Score
81	Orange	-1.704
84	Paris	-1.499
107	Terrell	-1.435
7	Balch Springs	-1.425
70	McKinney	-1.374
90	Port Arthur	-1.351
108	Texarkana	-1.255
71	Marshall	-1.222
116	Waxahachie	-1.191
42	Galveston	-1.177

TABLE 2-12. FACTOR CLASS FOR SELECTED TEXAS CITIES

			Class
Greater than 200,000 (7)			
1.	Houston	1,232,802	4
2.	Dallas	844,401	4
3.	San Antonio	654,153	4
4.	Fort Worth	393,476	4
5.	El Paso	322,261	4
6.	Austin	251,808	3
7.	Corpus Christi	204,525	6
100,000 to 200,000 (3)			
8.	Lubbock	149,101	3
9.	Amarillo	127,010	4
10.	Beaumont	117,548	4
50,000 to 100,000 (17)			
11.	Irving	97,260	5
12.	Wichita Falls	96,265	3
13.	Waco	95,326	2
14.	Arlington	89,723	5
15.	Abilene	89,653	3
16.	Pasadena	89,277	5
17.	Garland	81,437	5
18.	Odessa	78,380	6
19.	Laredo	69,024	1
20.	San Angelo	63,884	6
21.	Galveston	61,809	4
22.	Midland	59,463	6
23.	Tyler	57,770	2
24.	Port Arthur	57,371	4
25.	Mesquite	55,131	5
26.	Brownsville	52,522	1
27.	Grand Prairie	50,904	5
25,000 to 50,000 (18)			
28.	Richardson	48,582	5
29.	Longview	45,547	2
30.	Baytown	43,980	6
31.	Victoria	41,349	1
32.	Denton	39,874	3
33.	Texas City	38,908	4
34.	McAllen	37,636	1
35.	Killeen	35,507	3
36.	Bryan	33,719	3
37.	Harlingen	33,503	1
38.	Temple	33,431	2
39.	Texarkana	30,497	2
40.	Sherman	29,061	2
41.	Kingsville	28,915	3
42.	Big Spring	28,735	3
43.	Haltom City	28,127	6
44.	Farmers Branch	27,492	5
45.	Hurst	27,215	5
10,000 to 25,000 (76)			
46.	Denison	24,923	2
47.	Orange	24,457	4
48.	University Park	23,498	6
49.	Paris	23,441	2
50.	Lufkin	23,049	2
51.	Marshall	22,937	2
52.	Nacogdoches	22,544	3
53.	Greenville	22,043	2
54.	Pampa	21,726	6
55.	Del Rio	21,330	1
56.	Alice	20,121	1
57.	Corsicana	19,972	2
58.	Euless	19,316	5
59.	Plainview	19,096	2
60.	Bellaire	19,009	6
61.	San Marcos	18,860	3
62.	Mineral Wells	18,411	3
63.	Groves	18,067	6
64.	Plano	17,872	5
65.	New Braunfels	17,859	2
66.	College Station	17,676	3
67.	Huntsville	17,610	3
68.	Brownwood	17,368	2
69.	Edinburg	17,163	1
70.	Nederland	16,810	6
71.	North Richland Hills	16,514	5
72.	La Marque	16,131	4
73.	Cleburne	16,015	2
74.	Seguin	15,934	1
75.	Pharr	15,829	1
76.	Eagle Pass	15,364	1
77.	Weslaco	15,313	1
78.	McKinney	15,193	2
79.	San Benito	15,176	1
80.	Palestine	14,525	2
81.	Borger	14,195	4
82.	Terrell	14,182	2
83.	Duncanville	14,105	5
84.	Carrollton	13,855	5
85.	Gainesville	13,830	2
86.	Beeville	13,506	1
87.	Waxahachie	13,452	2
88.	White Settlement	13,449	4
89.	Hereford	13,414	5
90.	Lake Jackson	13,376	6
91.	West University Place	13,317	6
92.	Mission	13,043	1
93.	Deer Park	12,778	5
94.	Pecos	12,682	1
95.	Kerrville	12,672	2
96.	Rosenberg	12,098	1
97.	Sweetwater	12,020	2
98.	Freeport	11,997	3
99.	Conroe	11,969	2
100.	Weatherford	11.750	2
101.	Bay City	11,733	3
102.	Lamesa	11,559	1
103.	South Houston	11,527	5
104.	Vernon	11,454	2
105.	Levelland	11,445	6
106.	Robstown	11,217	1
107.	Snyder	11,171	6
108.	Ennis	11,046	2
109.	Port Neches	10,894	6
110.	Copperas Cove	10,818	3
111.	League City	10,818	5
112.	Uvalde	10,764	1
113.	Alvin	10,671	3
114.	Sulphur Springs	10,642	2
115.	Lancaster	10,522	5
116.	Port Lavaca	10,491	1
117.	Galena Park	10,479	4
118.	Balch Springs	10,464	5
119.	Henderson	10,187	2
120.	Highland Park	10,133	6
121.	Bedford	10,049	5

Source: U.S. Census, 1970.

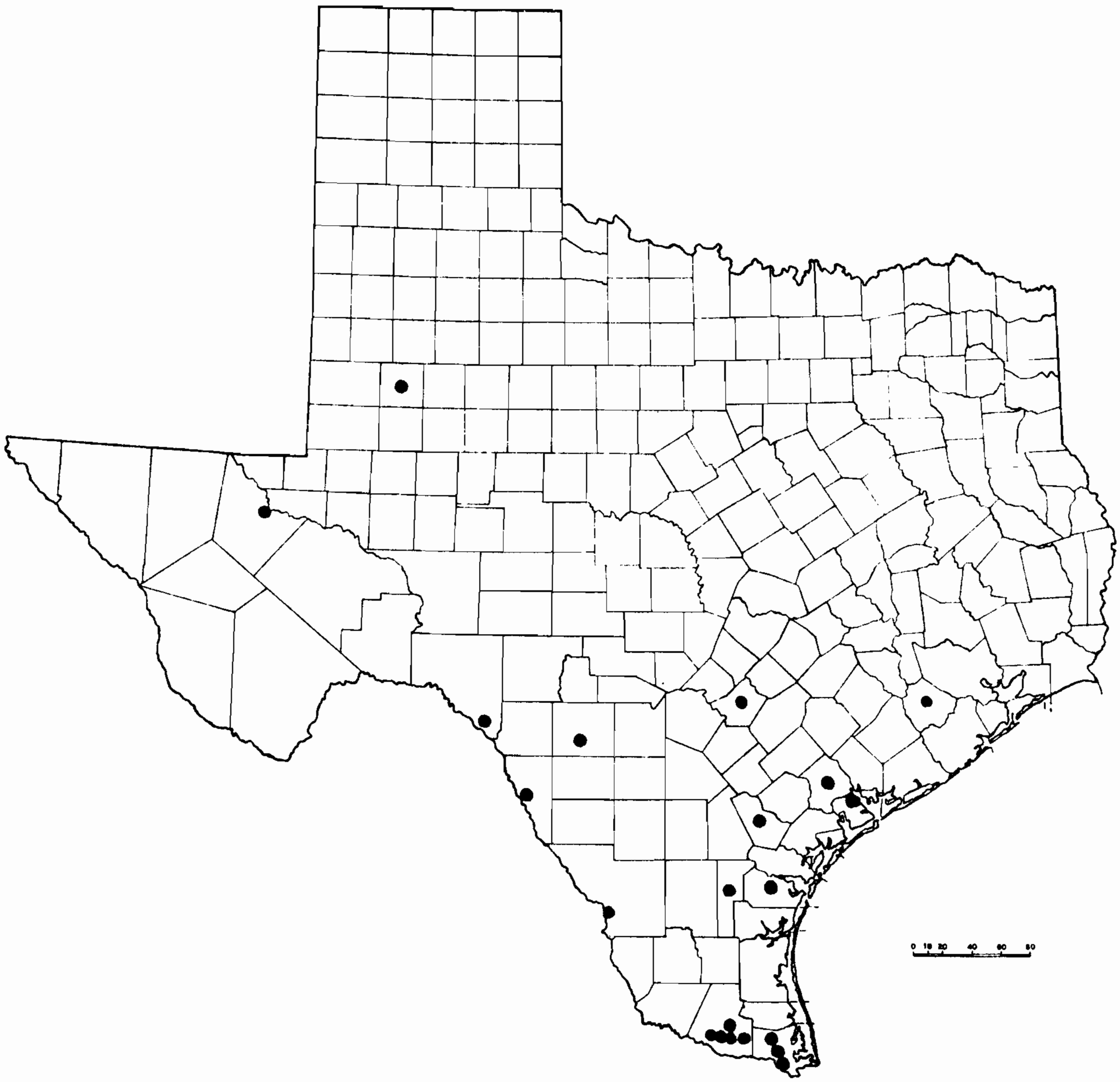


Fig. 2-1. Class 1 cities

which accounts for their inclusion. This is also true of Seguin, a non-"Valley" city.

Class 2

The cities comprising this class are predominantly Northeast Texas cities. The regional manifestation, however, is not as distinct as for the Class 1 cities. Figure 2-2 reveals these cities are located in Northeast and Northcentral Texas and extend south as far as New Braunfels and Conroe.

The chief characteristics of this class are a large percentage of elderly residents and a high percentage of residents who are "transportation disadvantaged." The first characteristic, a high percentage of elderly, apparently accounts for the inclusion of the cities that are exceptions to the otherwise quasi-regional grouping.

These exceptions include: Plainview in West Texas; Brownwood, Sweetwater and Vernon in West Central Texas; and Kerrville and New Braunfels in South Central Texas. Plainview, Sweetwater, and New Braunfels all have low factor scores, but they have a moderately high percentage of elderly residents.

Class 3

Cities of this class, identified as college/government towns (Fig. 2-3), do not comprise a regional cluster. Rather, they are scattered throughout the state. This can be expected, given the characteristics upon which the grouping is based. Those characteristics are, primarily, a multiunit dwelling pattern and high percentages of the labor force in educational and government services.

This group includes three types of cities: college towns, military bases, and two small cities in Southeast Texas near the Gulf Coast. The college towns are Abilene, Austin, Bryan, College Station, Denton, Huntsville, Kingsville, Lubbock, Nacogdoches, and San Marcos. Military bases are located in or near Big Spring, Copperas Cove, Killeen, Mineral Wells, and Wichita Falls. Alvin has a Junior College and is located near NASA. The inclusion of Bay City and Freeport, which are neither college nor government towns, may be due to a higher than average percentage of their housing units being rented as multiunit dwellings. While three sub-groups have been identified within this one city type, they are all in keeping

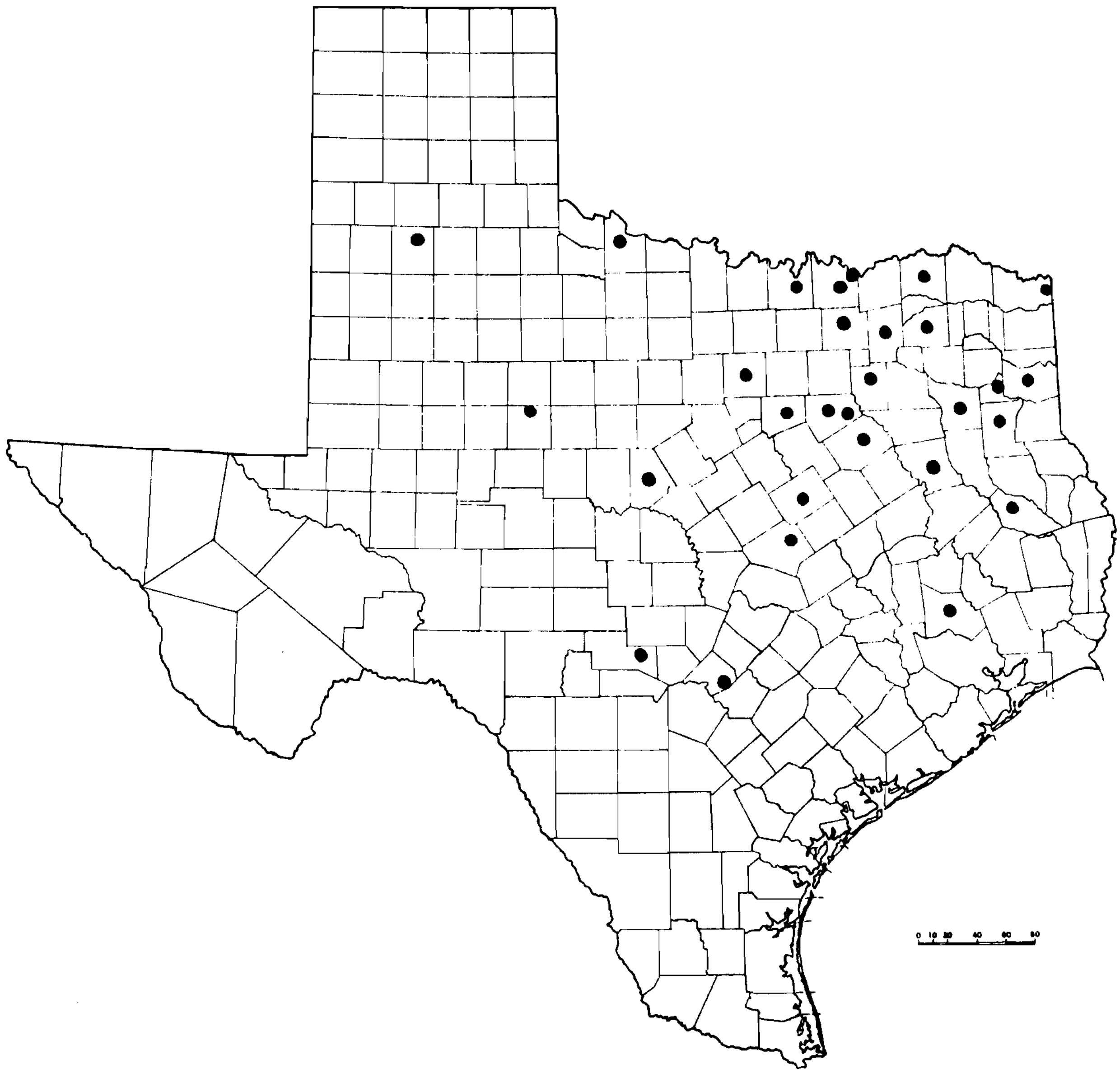


Fig. 2-2. Class 2 cities

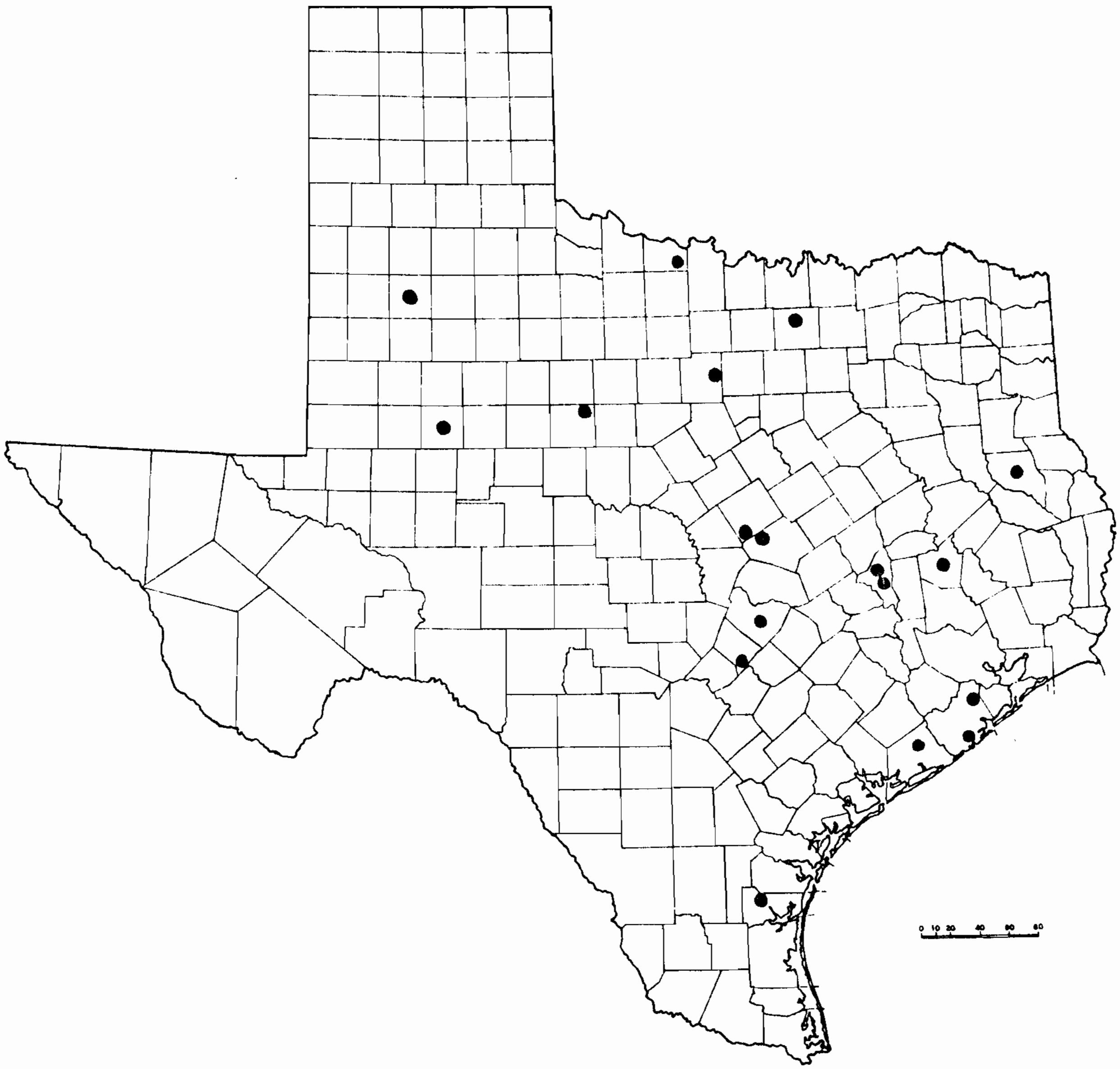


Fig. 2-3. Class 3 cities

with a multiunit dwelling pattern.

Class 4

The locations of the cities comprising this class are presented in Fig. 2-4. The grouping characteristics are high total population and high population in 1920. In keeping with these characteristics, the five largest cities in Texas are included in this group (Dallas, El Paso, Fort Worth, Houston, and San Antonio). In addition, Amarillo and Beaumont, medium-size cities, are included.

Aside from the larger cities, a regional sub-group exists. These are the cities in Southeast Texas including Beaumont, Galena Park, Galveston, La Marque, Orange, Port Arthur and Texas City. This may reflect the fact that Southeast Texas experienced considerable development prior to 1920, following discovery of the Spindletop oil field in the vicinity of Beaumont in 1901.

Two other small cities are included in the group——Borger in West Texas and White Settlement near Fort Worth. Both Borger and White Settlement have negative factor scores, along with La Marque and Galena Park. An examination of the data for all four negative scoring cities reveals that none of them are particularly old or large. However, they are more representative of this city type than the other five, as they scored even lower on the other dimensions. While this is a mixed class of cities, it is significant that the five largest cities were classified into the same group.

Class 5

The cities defined by recent growth comprise the most compact geographical grouping. As Fig. 2-5 indicates, these cities are primarily suburbs of Dallas-Fort Worth or Houston, a fact that is consistent with the defining characteristics: a high percentage of population growth, new houses, and working women.

The one exception to the suburban grouping is Hereford in West Texas. It is apparently included within the recent growth cities because it experienced a very high rate of population growth from 1960 to 1970 and a substantial increase in new houses since 1960.

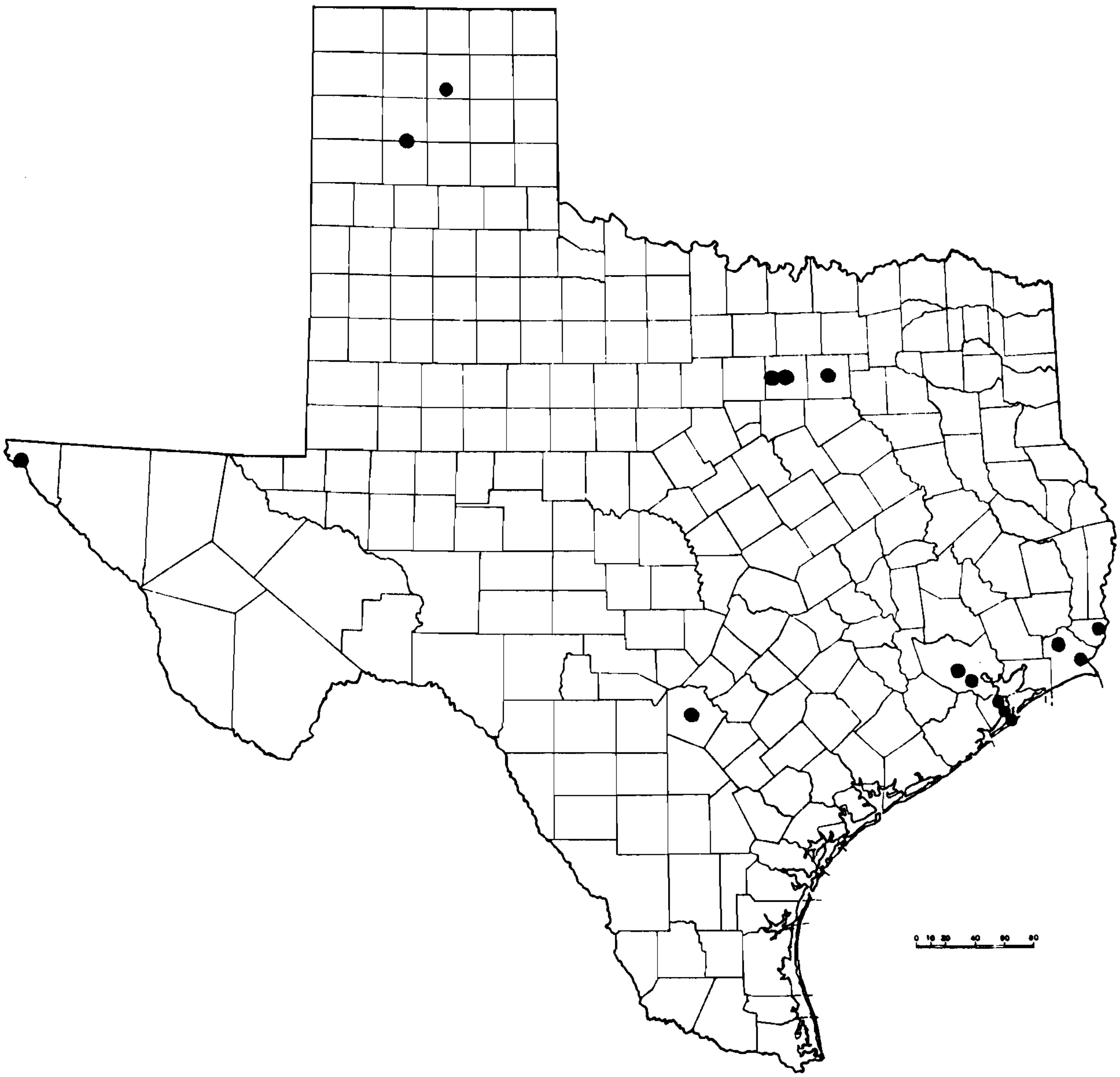


Fig. 2-4. Class 4 cities

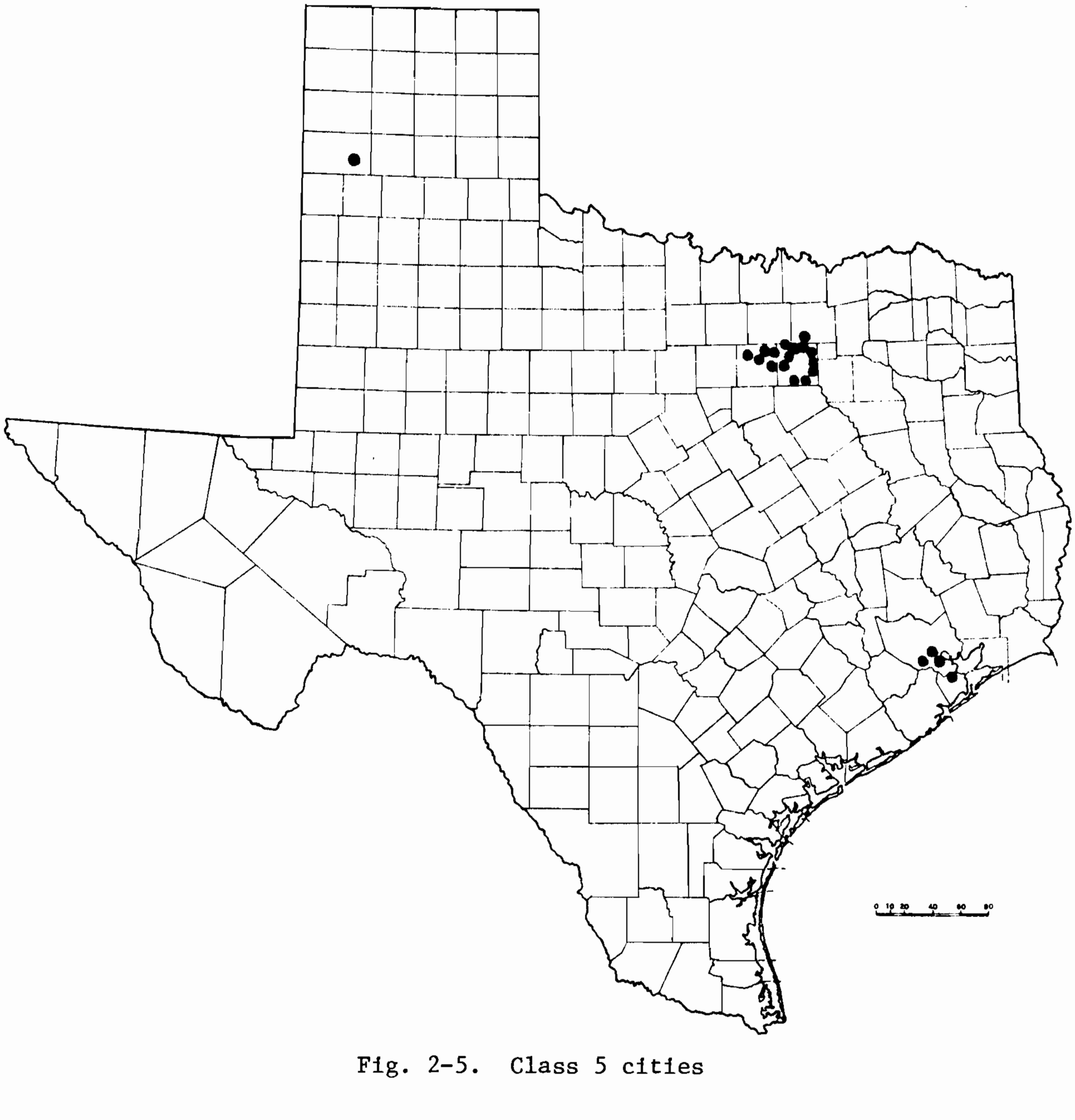


Fig. 2-5. Class 5 cities

Class 6

Although the cities of this class are scattered over the state, as shown in Fig. 2-6, they appear to comprise several distinct groups.

First, there is a group of old, densely populated areas around Dallas-Fort Worth, and Houston. These are Baytown, Bellaire, Groves, Haltom City, Highland Park, Nederland, Port Neches, University Park, and West University Place. Many of these older suburbs have passed their period of major growth and, hence, do not fall under Class 5.

The second group consists of cities in West Texas and is the largest occurrence of West Texas cities in all the categories. The group includes Levelland, Midland, Odessa, Pampa, San Angelo, and Snyder. Odessa and Pampa have higher than average population densities. All of the six cities have a low percentage of Spanish and black populations. Since this grouping is based upon the characteristics of high density, high white-collar employment, and a low black population, the inclusion of these cities is consistent with the class characteristics.

In addition, two older towns along the Gulf Coast are included within this category——Lake Jackson and Corpus Christi. Both have low black populations and Lake Jackson has a high number of white-collar workers.

SUMMARY AND CONCLUSIONS

This classification of Texas cities was not a modification of any existing city classification but resulted from a sequence of four research steps. A literature review established the characteristics of cities and their inhabitants that have previously been related to transit usage. The variables emerging from the review were then examined as to their relationship with transit usage in Texas urbanized areas. Numerous multiple regression analyses identified several significant characteristics affecting transit use for these areas.

Twenty-three of these characteristics were then utilized in a factor analysis for 121 cities in Texas. The results indicated that the 23 characteristics could be reduced to six uncorrelated dimensions of variability among the cities. The identification of the six dimensions, along with the scores for the cities on each of the dimensions, resulted in classifying each of the cities into one of six classes.

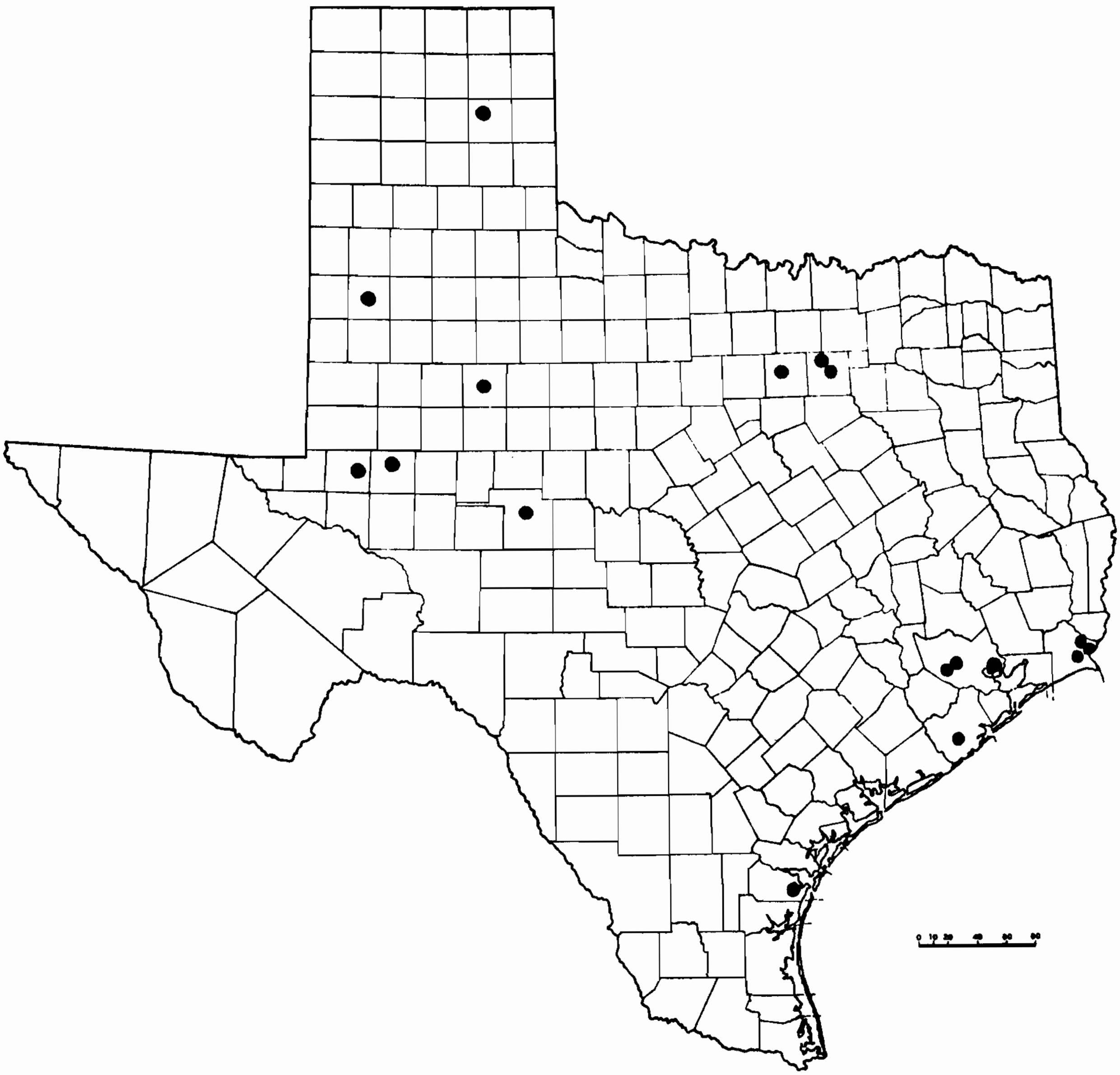


Fig. 2-6. Class 6 cities

The classification of any city into a particular city type is difficult given the natural multi-dimensional composition of a city. On the other hand, there appear to be certain characteristics that are more significant for some cities than for others. This element of significant characteristics was utilized in this classification system.

Most importantly, this classification scheme, based on transportation related characteristics, provides a basis by which transit and paratransit options may be recommended for different types of cities.

CHAPTER 3. TRANSIT OPTIONS

INTRODUCTION

Today, a host of available public transportation alternatives have evolved throughout the U.S. and Europe to suit the particular needs of cities with a population of less than 200,000. A broad classification of the different forms of systems is: (1) conventional fixed route bus transportation, (2) paratransit, and (3) vehicles which operate on a fixed guideway.

It is generally accepted that fixed guideway systems (light rail, rapid rail, monorail, etc.) are not feasible for cities having a population of less than 200,000 persons because of the low to medium density, dispersed trip ends, and limited financial resources. Therefore, this study is limited to conventional fixed route bus systems and various paratransit alternatives. This chapter provides an overview of these alternatives along with their management techniques, primary users, service patterns, costs, and previous experience.

Initially, the different forms of transit systems can be divided into three categories: (1) fixed route (where vehicles traverse a designated route and users must provide their own means of access to and from stops), (2) demand responsive ("door to door" service), and (3) paratransit options. The first category consists of the conventional fixed route bus systems and the informal operator (e.g., jitney). The second category, demand responsive transportation, is defined in this study to include Dial-A-Ride systems, taxis, and shared taxis. The last includes vanpools, carpools, subscription buses, and bicycles. There also exists a wide range of combinations and variations of these options (route deviation, car rental, park-and-ride, etc.).

CONVENTIONAL FIXED ROUTE BUS SYSTEM

A conventional fixed route bus system operates on fixed routes with fixed schedules and generally employs the use of large, 30 to 55 seat buses. This is the oldest and most traditional form of bus system and still foremost in the number of operations in the U.S. and Europe. This is the form that is most often identified by the general public as "mass or public transit."

Users and Demand Characteristics

The number and type of clients utilizing any form of transit depends on the fare, level of service, and degree of area coverage provided. Work trips are the primary trip purpose served, but many of the other types of trips made in the community (shopping, school, personal business, recreation, etc.) are also served.

The fixed route system, because of its relatively low fare and wide coverage, can be a viable option for the transportation disadvantaged (elderly and poor). However, because of the inherent limitations of this form, the needs of the handicapped may not be completely met. This clientele segment may require a door-to-door service with modified vehicles to allow entry of wheelchairs, etc.

Organization, Operation, and Management Techniques

The organization of a transit system can be classified as private or public. In a private system, service is provided by a private entrepeneur, as compared with a public system, in which service is provided by a governmental based unit, such as a city, county, or regional authority.

When a need for a transit system is identified or expressed by a special interest or civic group, it is generally brought to the attention of someone within the local government, perhaps the city manager, city engineer, a city councilman, or a county commissioner. It may be taken before the city council or county board to obtain permission for an initial feasibility study to be conducted internally by either the engineering or planning staff. The study should include estimates of demand, costs, and revenues. Upon completion of a preliminary assessment, the governing body must decide whether a more in-depth study is warranted, internally or externally. If a second study is undertaken, an organizational chart should be developed to indicate the different departments involved and the chain of command. In the case of private systems, this should designate which city departments will periodically review the agreement with the private operator.

Many management options are available to a city, such as providing the entire transit service, contracting out vehicle maintenance only, and contracting out the entire operation. Many private transit operators also provide management services for a predetermined fee.

There is no one universal method for structuring and managing a transit company. Each system must be structured and organized to fit local needs and conditions. Figure 3-1 provides two typical structures for existing small-scale transit firms. The figure indicates the different jobs which must be performed and an appropriate chain of command. In smaller operations several of these functions may be performed by one individual or may be contracted out to other companies.

Routing

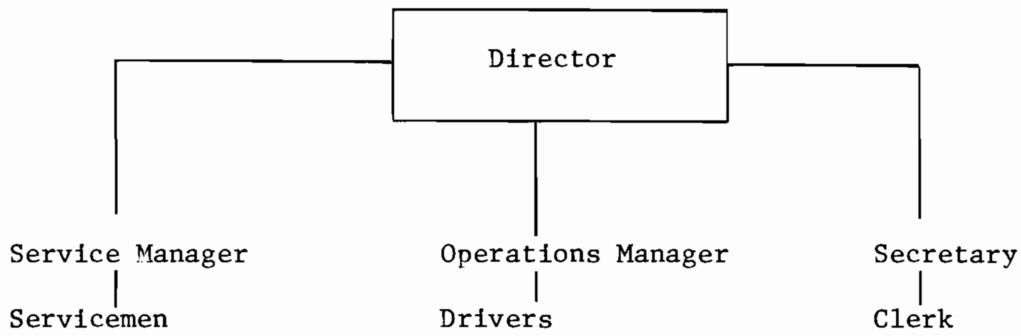
Routing and scheduling are two of the fixed route transit manager's primary responsibilities. Through careful route layout and proper scheduling techniques, the transit manager must minimize delay to patrons, fuel consumption, and operating costs. At the same time, service and revenues need to be maintained at acceptable levels.

Before routes and schedules can be determined, an estimate of demand must be forecast. This can be facilitated by locating all major traffic generators: high-density residential areas, CBD and shopping locations, industrial and employment centers, hospitals, schools, and recreation areas. From these estimates, routes can be planned to link areas of concentrated demand.

In residential areas, the traditional guide has been to space routes no closer than a half-mile. However, two separate and independent studies have shown that ridership drops off sharply beyond one block (Ref 32). For a transit operation to attract patrons, particularly automobile owners, the routes should be spaced as close as possible, given financial and operational constraints. Appendix B gives further guidance for determining the location of routes.

There are four common types of routes: through-routing, cycle-routing, reverse-routing, and balloon-routing (see Fig. 3-2). In through-routing, the vehicles pass through the CBD while going from one end of town to the other. This scheme minimizes the number of passengers who must transfer between buses. Cycle-routing involves moving buses into the CBD and back out again on the same route. This method simplifies scheduling but requires more transfers to be made, particularly if through traffic is heavy (Ref 32).

System A - Less than 15 buses



System B - 15 buses or more

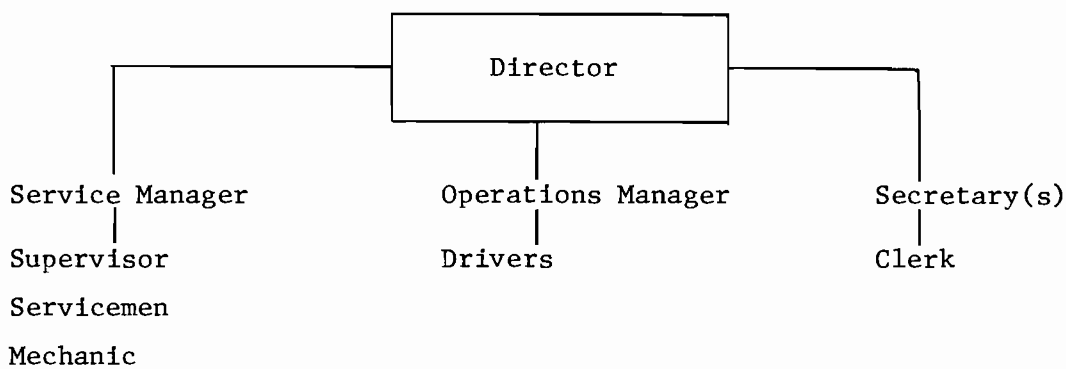


Fig. 3-1. System organization

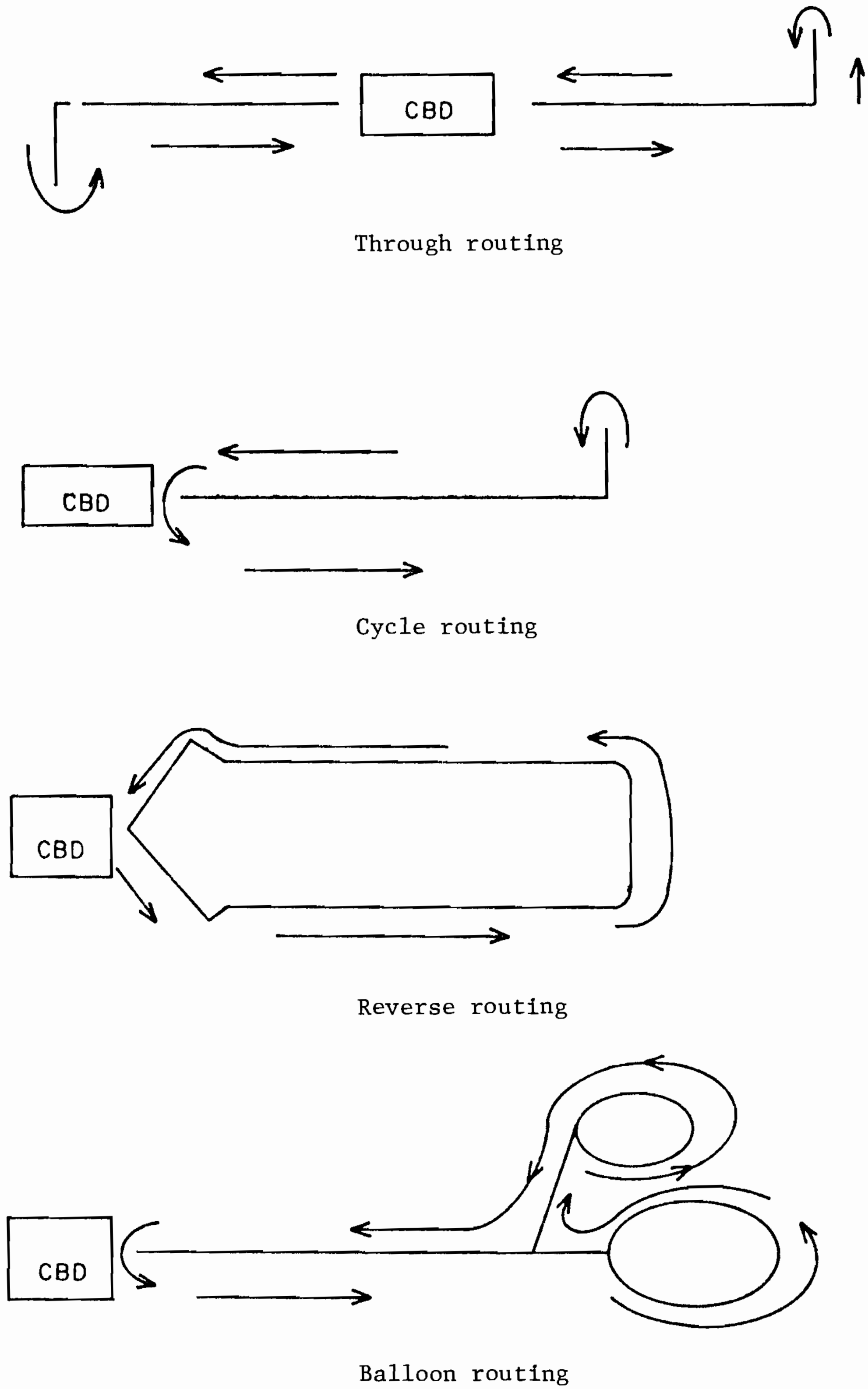


Fig. 3-2. Bus routing patterns

Two variations of cycle-routing which can be used are reverse-routing and balloon-routing. Reverse-routing is similar to cycle-routing except that different routes are used for going toward and going away from the CBD. This method allows more area of coverage per bus, but it also means any passenger boarding on the outbound route, destined for the CBD, must also travel the outer portion of the loop before reaching the CBD. Balloon-routing is often employed at the outlying end of a line to serve residential areas. This method consists of loops at the outlying end of the routes for better coverage of residential areas. This is very desirable from a consumer viewpoint and is recommended where feasible (Ref 32).

Routing is essentially concerned with providing access and can take many different forms. Routing should be considered as a dynamic process with periodic reviews to insure an efficient and economical service. User and potential user surveys are an aid to monitoring and evaluating existing service. One element of caution——frequent changes in service (routes or schedules) can have an adverse effect on patronage.

Scheduling

There are two basic types of scheduling: cycle operation and non-cycle operation (Ref 32). In a cycle operation, all buses leave and return to the CBD at approximately the same time, making transfers more convenient. This implies that there is one bus per route and all routes are approximately the same length. Once the routes have been selected and the round trip times equalized, the departure time from the CBD is used as a base to fix the schedule. This is a basic technique and appropriate for smaller cities.

Non-cycle operation involves scheduling each route separately. The difficulty implicit in this method is the coordination of transfers. The main advantage is increased flexibility since the routes do not need to have the same length, headway, or general operational characteristics. This general approach is used for most bus systems in larger urban areas.

Several guidelines for establishing schedules are presented below (Ref 32):

1. Schedules should be simple and easy for patrons to use and remember.
2. Schedules should be coordinated so that transferring is as convenient as possible.
3. Schedules and schedule changes should be widely publicized.

4. Schedules attempting to attract specific patrons should be coordinated as much as possible, e.g., the work commuters need to arrive at their destinations at the designated times.
5. Schedules should be continually reviewed as part of the ongoing activities of management.

System Costs

The major costs involved in a fixed route system can be separated into five basic groups:

1. personnel wages (drivers, maintenance workers, etc.),
2. transportation costs (fuel, oil, tires, etc.),
3. vehicle related costs (insurance, license, etc.),
4. overhead (administrative and utility costs, etc.), and
5. capital cost (bus, equipment, building, etc.).

These costs vary with the size and variety of functions performed. As previously mentioned, maintenance activities can be performed by the operator or by contractual agreement. Personnel requirements depend on the size of the bus system. The personnel of existing departments can also be utilized in the transit system for certain services, such as purchasing, accounting, etc. The number and type of buses required depend on service requirements of the system, such as average operating speed, scheduling specifications (the bus frequency or headway), and the maintenance program, based upon performance standards.

Chapter 5 provides more detailed information for estimating fixed route transit costs. Tables 3-1 and 3-2 provide a review of costs and operating characteristics for Texas and out-of-state transit systems. These are intended to give a range or order of magnitude for estimates.

INFORMAL OPERATORS

An informal public transportation system, the type of service normally associated with "jitney" service, may provide a flexible and convenient means of transportation to the public by running privately owned and operated vehicles along fixed routes according to demand. The vehicles are generally of the 4 to 12 passenger size and operate on headways determined either by demand or other arrangements. Today, as a result of restrictive legislation in the early 1900s, there are only a few legal jitney services still operating in the U.S., such as those in San Francisco and Atlantic City.

TABLE 3-1. FIXED ROUTE BUS STATISTICS FOR SELECTED TEXAS CITIES, ANNUAL FIGURES FOR 1978

	Pass./ Veh. Mi.	Veh. Mi./ Bus	Rev./ Pass.	Rev./ Veh. Mi.	Oper./ Pass.	Oper./ Veh. Mi.	Cost/ Rev.
Abilene	0.9	26,472	$ .17	$ .15	$ .83	$ .76	$5.02
Amarillo	0.7	24,148	.40	.30	1.21	.89	3.00
Austin	2.1	37,928	.17	.36	.61	1.28	3.57
Beaumont	2.2	22,457	.21	.47	.53	1.18	2.50
Brownsville	1.6	28,718	.45	.74	.52	.85	1.40
Corpus Christi	1.4	26,666	.59	.83	1.06	1.50	1.82
Dallas	2.4	31,477	.40	.96	.59	1.40	1.46
El Paso	2.2	44,760	.33	.72	.47	1.02	1.41
Fort Worth	1.7	29,148	.56	.95	.79	1.34	1.41
Galveston	2.5	35,558	.28	.70	.48	1.21	1.74
Houston	2.6	33,816	.31	.79	.84	2.15	2.73
Laredo	3.8	38,646	.22	.82	.37	1.41	1.72
Lubbock	2.4	25,257	.17	.39	.43	1.01	2.56
San Angelo	1.0	27,255	.19	.20	.72	.75	3.78
San Antonio	2.1	35,507	.26	.52	.67	1.38	2.63
Waco	1.2	30,135	.35	.41	.98	1.15	2.83
Wichita Falls	0.9	29,177	.44	.39	1.05	.93	2.40

Source: 1978 Texas Transit Statistics, State Department of Highways and Public Transportation, Austin, Texas, October 1979.

TABLE 3-2. BUS SERVICE IN SMALL URBAN COMMUNITIES

Name	Vehicles Type and Number	Daily Vehicle Miles	Operations Cost Per Vehicle	Cost/ Revenue Ratio	Pass. Per Weekday	Fare	Pop. of Area	Density	Driver Wages
Eugene-Springfield, OR County Wide Transit 1970	60 Buses	Not Available	Mi --- Hr $16.90	4.3	10,500	Not Available	169,000	1,690	$5.25
Amherst, MA Student 1971	16-35 pass. Buses	2,450	Mi 52¢ Hr $7.74	∞	15,200	No Fare	17,000	1,000	$3.00/hr
Evansville, IN Transit Service 1971	19-19 pass.	2,541	Mi 50¢	1.3	3,500	50¢	138,700	3,855	$5.00
Chapel Hill, NC Public Transit- University Town 1974	22-45 pass. Buses	4,123	Mi 93¢ Hr $11.08	2.1	7,960	Not Available	32,000	3,300	$3.80/hr, benefits
East Chicago, IL Freefare transit 1974	5-25 pass. Buses; 4- Vans special	1,500	Mi 39¢ Hr $14.50	∞	1,050	No Fare	46,966	4,000	$4.00/hr
Westpoint, CT Suburban Transit 1974	8-16 pass. Minibuses; 1-33 pass Bus	1,347	Mi 72¢ Hr $11.53	3.7	1,400	50¢	28,000	1,300	$4.40
Bremerton, WA Private Subscription Bus Service 1975	28-41 pass. Buses	1,120	Mi 34¢ Hr $9.16	.8	2,240	35-50¢	35,000	3,600	$10/day
Xenia, OH 1975	9-19 pass. Minibuses; 1-12 pass. Minibus	960	Mi 93¢ Hr $11.67	8.9	900	10-50¢ Avg of 15¢/pass.	27,600	3,070	$3.71

Source: Small City Transit Characteristics: An Overview, U.S. DOT, 1976 Report No. UMTA-MA-06-0049-76-1. Information was also gathered from a series of reports detailing the transit characteristics for each of the small urban communities listed, UMTA Reports 06-0049-76-2-15.

The service is characterized by a fixed fare or "flat rate," which applies regardless of the distance traveled by each of the passengers sharing the ride. Typically this fare ranges from 25¢ to 50¢.

In other countries, those with low automobile ownership, jitney services are extensively utilized. Mexico City has a registered taxicab fleet of 33,000, of which 5,000 units are designated as operating jitneys, each working 18 hours per day and carrying about 400 passengers per day.

Users and Service Characteristics

User groups are essentially the same as for a conventional fixed route bus system. However, because of the small vehicle size, a jitney service can also be a viable substitute for a conventional bus system where patronage potential may be insufficient to warrant the large buses. One factor which influences the success or failure of a jitney service is the vehicle headway. Experience has shown that small headways are of great importance in attracting patrons, as is, also, extending hours of service at night, when the public transit may be out of service or be on reduced service. Several years ago when jitneys were in widespread use throughout the U.S., the lower headways associated with jitneys were a major element in attracting passengers away from existing streetcar services. These smaller headways were directly related to the smaller size of the vehicle, enhanced flexibility in a traffic stream, and deadheading on the quickest route possible (as in San Francisco, where the return trip is made on a freeway) (Ref 5).

In general, any route which has regular demand patterns of 10 to 12 riders every 15 minutes is a potential jitney route. This will allow headways to be no more than 15 minutes and the jitney to operate at capacity. As demand increases, more jitneys can be added.

Routes and Scheduling

Although many jitney operations may operate in designated corridors, it may be necessary to regulate their operation. The major control, which is often self regulating, is vehicle headway, or time between successive jitneys. Control may be obtained in three ways: first, fixing the maximum number of vehicles allowed in service on a particular route at any one time; second, controlling the length of the route; third, having a starter at the beginning of the route to dispatch vehicles at given intervals, eliminating bunching or platooning of the jitney.

The two largest formal jitney operations in the U.S. operate differently. In San Francisco during peak hours, headways are regulated by the number of vehicles in service and the route length. During off-peak hours they are regulated by a starter. In Atlantic City the headways are regulated throughout the entire day by the length of the route and number of vehicles in service (Ref 38).

Although the jitney is basically a corridor operation, operators may deviate slightly from their basic route to provide more direct service. An extra fare is often charged for this additional service.

Operation and Management Techniques

The use of jitneys has been limited in the U.S. for many years and little information is available concerning different operational and managerial methods. This section details the two primary U.S. systems mentioned in the preceding section, San Francisco and Atlantic City.

In San Francisco the Board of Supervisors, through the Commissioner of Police, regulates the owner-operated jitneys. Each owner-operator is required to pay an annual license fee and carry minimum levels of public liability insurance. In addition, certification of the vehicle's road worthiness and the fitness of the driver to operate a public service vehicle is required. Police codes limit the total number of licenses issued and regulate the fare structure.

Service is provided twenty-four hours a day, seven days a week, subject to municipal regulations and the working rules developed by the voluntary driver association. Each driver may work up to ten hours per day. A driver is not allowed to work between 9:00 a.m. and 4:00 p.m. one day a week (Ref 5).

As mentioned earlier, peak hour headways are regulated by the number of vehicles in service and the route length, with service during off-peak hours regulated by a starter. An operational strategy is available for shortening the routes of some vehicles. For example, on even-numbered days of the month, even-numbered jitneys may turn around approximately three miles earlier than the odd-numbered ones and vice versa (Ref 5). This provides an additional element of flexibility to the service.

In Atlantic City, the City Department of Revenue and Finance, by virtue of city ordinances, sets fare, route, and general operating procedures. Annually the city routinely issues licenses, provided the driver has not committed any major traffic violations during the previous year. The driver must conform with state laws relevant to a public conveyor. These include minimum levels of liability insurance, omnibus tags, and an annual state safety inspection.

There is no fixed schedule of service, only the frequency associated with headways, which are controlled by the route length and the number of vehicles in service. In addition, a Jitneymen's Association has been founded, which further regulates work rules. However, each jitneyman is characterized as a private entrepeneur who owns and operates his own vehicle, retains his own passenger receipts, and works when he wishes within the confines of the association's schedule (Ref 53).

In addition to the two major operations, there are an undetermined number of illegal or non-regulated jitney operations. In Chicago and Pittsburgh, illegal jitney operations exist in many areas, such as the black neighborhoods, which receive little regular taxi service. Another form of quasi-jitney service occurs in low income areas, where the services are provided by neighbors who own automobiles. Often regular shopping or medical trips for the poor, elderly, or handicapped are rendered by the providers for a small fee.

Operating Costs

Jitneys offer low cost service due to the inherent advantage of low overhead and operating expenses. For the basic operation, there is no need for a manager, dispatchers, or supervisors; and, therefore, labor and personnel costs are at a minimum. The major costs associated with jitneys are the initial cost of the vehicle, operating cost, and some type of wage or salary for the driver. Table 3-3 gives several costs and operating characteristics.

DIAL-A-RIDE

Demand responsive transportation encompasses a host of public transportation services which can be characterized by the flexible routing and scheduling of either smaller buses or vans. The basic concept involves dispatching a vehicle in response to either a telephone request or a scheduled appointment by a traveler for transportation to a particular destination. Normally door-to-door service is provided, and the traveler may share

TABLE 3-3. COST ESTIMATION FOR JITNEY SERVICE (1977)

Type of Vehicle	No. of Seats	Maximum Estimated No. of Pass. Per Day*	Cost of Vehicle (incl. Tax), $	Cost/ Veh. Mile, $	Cost/ Veh. Hour, $	Cost/ Pass., $	Average No. of Vehicle Miles Per Hour	Average No. of Pass./ Vehicle Hour	Revenue Per Pass., $	Average Revenue Per Veh. Hr., $
Passenger Car	5	213	5,000	0.314	5.69	0.379	18	15	0.40**	6.00
Van	9	384	10,495	0.347	6.25	0.231	18	27	0.25**	6.75
Minibus	18	502	23,000	0.670	8.04	0.223	12	36	0.25**	9.00

*in a 14-hr period, considered to be from 6:00 A.M. to 8:00 P.M.

**proposed fare

the vehicle with other passengers.

Dial-A-Ride or Dial-A-Bus is a type of demand responsive transportation which is characterized by the vehicle's simultaneous accommodation of patrons whose requests for service are temporarily and geographically compatible. Thus, the actual number of stops made between a person's origin and destination will be a function of the intensity and location of demand, the number of vehicles in service, and the number and location of trip attractions.

Users and Potential Service Scenarios

The Dial-A-Ride configuration, because of its door-to-door service, is able to provide transportation not only to the average citizen but also to the very young, the elderly, and the handicapped, all of whom would be left less mobile or otherwise disadvantaged by a conventional, fixed-route bus system. Vehicles have been designed and are now in operation which can accommodate wheelchairs or other special equipment for the disabled. Many elderly persons who cannot negotiate the required walk to a conventional transit system bus stop, cannot afford the expense of a taxi, or do not have an automobile at their disposal will find a Dial-A-Ride system ideal. Parents, desiring to send small children to a particular location will also find this system ideal because door-to-door service allows the driver to insure a child's arrival at the proper destination.

The Dial-A-Ride can also be a viable feeder service for linehaul transit, which is not normally applicable to most cities under 200,000, if there is sufficient travel between bedroom communities and a regional CBD to warrant the feeder line. A major factor is its ability to more easily and efficiently serve the "transportation disadvantaged" than conventional transit systems. Many transit systems provide a comprehensive mix of service options in an attempt to satisfy a wide variety of trip purposes and clientele.

Route and Scheduling Configurations

In its purest sense, routing and scheduling of Dial-A-Ride service is a dynamic operation. The central dispatcher continually updates the routing of the vehicles in an attempt to conform with a schedule determined by arriving service requests. The transit vehicle will provide transportation between any origin and destination pair within the service area. However, there are several modifications of this which have been successful in certain situations.

The first is a many-to-one system, which provides transportation from various origins (homes) to a single destination (CBD, shopping center, or a central transfer point). The second is a many-to-few system, providing transportation from multiple origins to just a few major activity centers. A final alternative, suited to either large, narrow, or elongated cities, involves vehicle circulation through particular service areas, determined by service requests, for set periods of time. Then, at a predetermined time, all vehicles can converge at a common point, preferably a major attraction, to allow for transfers (Ref 71).

The scheduling and routing procedures are the most important part of a demand responsive system. Efficient scheduling of incoming transit requests will result in less waiting and riding time for the passengers and more economical operating cost.

Several methods can be used to route the vehicles, varying from manual routing boards to sophisticated computer algorithms. Communications between the dispatcher and the driver are also important. The communication equipment can vary from two-way radios (e.g., CB's) to digital sending and receiving equipment.

Operation and Management Techniques

There are several ways in which Dial-A-Ride service can be operated and managed. Management of a system may be handled by a public agency, such as a city's Urban Transportation Department, Department of Public Works, community development agency, or transit authority. Service may be contracted out to a private enterprise with the public management aspect simply consisting of a periodic review of the goals and objectives and the degree of their fulfillment. The other end of the spectrum would be continuous day-to-day management of a municipally owned and operated service, involving a rather extensive chain of command and functional organization. If the service is municipally owned and operated, responsibility for the provision of the best possible service should start with a transit manager and end with the city council, with intermediate steps at the appropriate city department directorate and city manager's office.

Fleet sizes and configurations must be determined in conjunction with a service pattern and level of service. If a high level of service is to be offered, the system will probably require many smaller, van type, vehicles rather than a few of the larger, 50-70 passenger, buses. However, if the service pattern calls for all buses to interface periodically, larger buses may prove to be more efficient to accommodate anticipated transfers.

Hardware and Personnel Requirements

When determining hardware requirements for Dial-A-Ride systems, the first decision is whether vehicles will be manually or computer dispatched. Manual dispatching would probably be more cost effective for cities under 200,000 population in Texas. Extensive studies have been conducted to develop algorithms for computerized dispatching. There is still some question as to the point where computerized dispatching becomes more efficient and economical than manually controlled routing and scheduling of vehicles. Experience indicates that 15-20 vehicles providing many-to-many service, with about 100 demands per hour, is the approximate limit for manual control (Ref 17). When the volume of activity exceeds this level, there are two options:

1. install a computerized scheduling and dispatching system or
2. divide the region into discrete service areas, each handled by one dispatcher.

There are also several types of communication equipment that can be used. Two-way radios can be used, allowing the dispatcher to relay a route schedule to the driver. This is the least expensive technique and can be used for any size of system.

Digital readout equipment can also be used. This system sends a route schedule to the vehicle. It is then printed out for the driver. This works well with computer scheduling systems, providing fast and efficient scheduling. This type of system can also keep track of regular passengers and send reminder messages (such as providing information on the disability of a particular patron scheduled for pick up and on special attention required).

System Costs

The basic costs for a Dial-A-Ride system will, with minor changes, be similar to those associated with fixed route systems. If the service is to be conducted by an existing transit system, then maintenance, administration, and dispatching may be done in existing facilities. If there are inadequate facilities to handle the new system, facilities for maintenance, service dispatching, and administration will be required. It will also be necessary to purchase vehicles and to hire operating and administrative employees. Chapter 5 discusses in more detail demand responsive cost estimating. Table 3-4 gives a state-of-the-art review of costs and operating characteristics for several systems.

TAXI SERVICE

Taxi service represents a very flexible and convenient mode of transportation. In Texas some 145 cities are being served by taxi operations. The services range from single taxis in very small communities to large fleets serving the metropolitan areas. In many instances the local taxi service may be the only form of public transportation service in the area (Ref 12).

In the analysis described in chapter 3, 121 Texas cities of at least 10,000 population were identified and used in the evaluation of public transportation options. This indicates that at least 24 Texas cities under 10,000 population are currently served by taxi operations.

The nationwide trend toward subsidizing public transit systems with federal, state, and local funds has placed taxi operations at a competitive disadvantage. Federally sponsored programs are being reviewed and modified to develop a balanced program between private and public transportation operations. Understandably the role of taxi operation in Texas cities is essential to thousands of users in a wide range of city sizes.

In general taxi service in Texas is provided by private companies regulated by city ordinances. Most taxi companies are structured and operate in the following manner:

- There is a general manager——usually the owner of the company.
- There are three radio dispatchers, each working eight hours a day, to provide 24-hour service.
- There is a core group of drivers working a daily average of nine hours, six days a week.
- The drivers are normally compensated on a commission basis, 40-50 percent of the daily fare income. Gasoline, oil, maintenance, insurance, taxes, and any other expenses are paid by the owner.
- Companies with more than ten vehicles may have a full-time mechanic to take care of maintenance and repair of the units.

Auxiliary facilities which are required in the normal provision of service are

TABLE 3-4. DEMAND RESPONSIVE STATE OF THE ART

Name of System	Type of Demand Serviced	Number of Vehicles	Pass. per Veh/hr	Pass. Weekday	Operating Cost per Vehicle Hour	Operating Cost per Vehicle Mile	Operating Cost per Pass.	Capital Cost	Driver Wage	Fare	Revenue Pass	Yearly Cost	Yearly Revenue	Cost/ Rev. Ratio	Population	Density
Ann Arbor, Michigan	Many to Many	3-10 pass. 6-15 pass. 12-23 pass.	6	180	$19.97	$ .83	$1.67	$35,000	$6.00 hr.	60¢	47¢	$2,157,000	$398,000	3.7	178,561	7,100
Merrill, Wisconsin	Route Deviation		10	150	$ 9.50		$ .99	$95,000	$4 00/ hr.	25¢	26¢			3.8		
Merced, California			12	340	$ 9.70 [2]		$ .84	$65,000	$3.75	25¢	25¢			3.4		
Model Cities Columbus, Ohio		4-19 pass.		350	$12.00				$8.00						37,000	[3]
Senior Citizen's Transportation Rhode Island	Many to Many	19-15 pass. 13-12 pass.				$ .63	$2.72			Free	$4.11 $ .92/ veh mi					
Richmond, California	Many to Many					$3.89	$3.98				25¢ 24¢/ veh mi					
Santa Barbara, California	Many to Few					$ .43	$1.60				$1.00 27¢/ veh mi				129,873	
Batavia B-Line	Many to Many	4-19 pass.	13	340 44/veh	$10.00				$3.50	60¢	50¢	$225,000	$ 53,000		18,000	3,300/ mi^2
Haddonfield Dial & Ride New Jersey	Many to Many	12-17 pass. 7-10 pass. wheelchair	5.4	925 51/veh	$21.66				$6.00	80¢	68¢	$1,200,000	$150,000		40,000	1,400/ km^2
La Habra Dial-A-Ride California	Many to Many	6-19 pass. 1- 8 pass.	6	450 75/veh	$10.00				$3.12	50¢	39¢	$ 225,000	$ 50,000		47,000	2,600/ km^2
La Mirada Dial-A-Ride California	Many to Many	3-18 pass. 3-14 pass.	6	70	$ 8.00				$3.00	25¢	22¢	$ 150,000	$ 24,000		32,000	2,100/ km^2
Dover Senior Survey Delaware	Many to Many	4	7	43	$ 3.40				$3.80	Free	0	$ 63,000	0		27,000	500/ km^2
Regina Telebus Saskatchewan, Canada		6-14 pass. 4-22 pass. 7-42 pass.			$13.43	$1.19	$ .71				29¢					

- office space,
- telephone service,
- two-way radio system,
- a parking lot, and
- a maintenance area.

Nationally the average trip length is approximately 2.13 miles; the average is probably higher in Texas (Ref 81).

Taxi Fares and Shared Taxi Concept

Taxi service is provided in return for a fare structure approved by the City Council. This fare is proposed to the authorities by the owner or franchiser of the company and must be ratified by the City government.

The average fare for Texas cities under 200,000 population is $0.70 for the first 1/4 of a mile and $0.60 for each mile thereafter (or $0.20 per 1/3 mile). In small towns most taxi companies operate with a fixed or "flat" fare ranging from $1.00 to $1.50. This means that the person hiring the taxi is able to travel anywhere within the municipal limits for the standard price for one ride (Ref 67).

Another type of taxi service is the shared taxi concept. This concept refers to a patron sharing a ride with another passenger or passengers with similar or close destinations. This type of operation (which is prohibited by most Texas municipal ordinances) can function well at shopping centers, bus terminals, airports, and any other place where the demand for taxis often exceeds the number available.

Often the taxi driver will group passengers with similar destinations in his taxi. This matching of potential shared taxi riders can also be done by the dispatcher, by advanced scheduling of demands, or by grouping calls as they are received, into sections such as neighborhoods.

Overall, approximately 50 percent of the total recorded vehicle miles are "empty" or "non-paid" miles for everyday taxi operations. The "shared-taxi" concept enhances the opportunity to decrease operating costs and contribute to the improvement of the service. This could enhance the ability of the operator to service a higher level of demand with lower operational costs and less waiting time. The gain in efficiency and economy should be passed on to the patrons in terms of lower fares.

There are several obstacles that must be overcome before a shared taxi service can be implemented. The allocation of fares among patrons is a major problem which must be resolved and well publicized in advance of initiating service. One approach is to divide the total fare by the number of passengers to yield an average fare. Another approach is to charge a flat rate fare and divide the fare by the total number of passengers each passenger has ridden with, regardless of distance.

Another problem to be addressed concerning the "shared taxi" concept is the legality under local city ordinances. A review of existing taxi regulatory ordinances in many Texas cities indicates the need for revision before the shared taxi concept can be implemented.

Users and Demand

Taxi service can be used for a variety of trip types; however, several trends are apparent for Texas localities:

- Few work or school trips utilize taxi service.
- Non-automobile-owners use the taxi for shopping, medical, and personal business trips.
- Out-of-town visitors who arrive by plane, train, or bus frequently rely on the taxi for much of their local transportation needs.
- A surprisingly large number of poor and elderly use taxi service, despite the high cost.

Taxi service experiences high demands during the traditional peak periods. The wait can range from 20 minutes during the peak to 10 minutes during the off peak time. Demand for taxi service is higher during week days than week-ends,providing an opportunity to utilize various operating strategies to meet varying demand periods.

Operating Costs

Taxi operating costs vary from operator to operator and depend on such factors as the vehicle fleet size, composition, age, proper preventive maintenance, and average daily mileage. Table 3-5 shows some of the average costs of four taxi services in Texas, and Table 3-6 shows a typical cost scenario for a shared taxi service.

CARPOOLING

Ridesharing may not be a publicly operated form of transit but it can be a viable means of transportation for those who previously had no form of transportation available or for those who wish to economize through use

TABLE 3-5. AVERAGE COSTS OF FOUR TAXI SERVICES IN TEXAS (1977)

	Avg No. of Pass per Day	Avg No. of Pass per Shift	Avg Lgt. of Trip Mi.	Avg No. of Pass per Trip	Avg No. of Veh Mi. per Shift	Fare	Avg Rev-enue per Trip	% of Pd. Mi.	Avg Rev-enue per Veh Mi.	Avg Rev-enue per Veh Hr.	Operating Cost: Veh, per Hour	Operating Cost: Veh, per Mi.	Operating Cost: Trip	Driver Wages ($/hr)	Dis-patcher Wages	Me-chan-ic Wages	Ins. (per yr.)	Lic. Fee (per yr.)	Fuel Con-sump-tion	Oil Con-sump-tion (per mon.)	Pop.	Density
A	50	25	4.56	1.3	86.8	$0.70 first 1/4 mi + $0.60 each mile	$1.92	47	42¢	$3.95	$2.61	24¢	83¢	$1.78	$2.75	$3.75	$645	$140	13	6 qts	300,000	3,492
B	55	30	4.30	1.4	72.0	$0.70 first 1/4 mi + $0.60 each mile	$1.90	48	42¢	$3.95	$2.65	25¢	84¢	$1.95	$2.75	N.A.	$638	$140	12.5	6.5 qts.	300,000	3,492
C		43	5.0				$2.20							$4.00			$900		12	5 qts	N.A.	N.A.
D		22	5.85	1.3	106.7		$1.95	49.5		$4.13		30¢		$1.79					11.45		N.A.	N.A.

Table 3-6. AVERAGE OF PRINCIPAL OPERATING COSTS OF A TAXICAB (1977)

Item	Operating Cost Per Mile	Operating Cost Per Working Hour
Gasoline	$0.0414	$0.621
Oil	$0.0024	$0.036
Tires	$0.0032	$0.049
Tune-up	$0.0040	$0.060
Brake relining	$0.0025	$0.037
Other maintenance expenses, washes, etc.	$0.0047	$0.070
Depreciation and amortization	$0.0201	$0.300
Insurance, permit fee, & other expenses	$0.0095	$0.014

Assumptions: Six-cylinder engine (14 mpg)

Average mileage per hour → 15.0 miles

Average working hours per day → 16.0 hours

Number of working days per year → 312

One gallon of oil per 159 gallons of gasoline.

Gasoline price of $0.58 per gallon

Life span of the car → 6 years

Tires are replaced at → 40,000 miles.

of this alternative. The energy efficiency of a mode may be improved and the emission level of in-use vehicles can be reduced if the load factor per trip is increased. Peak-hour congestion may also be relieved. Though ridesharing is basically a private and personal venture, there are means by which municipalities can promote and implement ridesharing activities.

Carpools represent the most familiar and widespread form of ridesharing, and work trip carpooling is the most effective use of the technique. Carpooling generally consists of a driver/operator and one to five riders commuting to and from work. The driving can be a shared responsibility among the carpoolers or one person may provide the vehicle and perform the driving while the other(s) pay for the services.

Major Users and Potential Scenarios

The major patrons of carpooling operations are commuters. Carpooling can be organized for a single employment location or implemented on a city-wide scale.

The basic characteristics of carpooling are (Ref 69):

1. The ride is shared with other travelers.
2. There is some route deviation to pick up and drop off individual travelers.
3. Access to the service is determined by prior agreement with a program coordinator.
4. The schedule is fixed by agreement among the participants and is essentially inflexible from the point of view of the individual traveler.

Route deviation, which accounts for only a small percentage of the total trip, is generally limited to relatively minor collection and distribution patterns at the beginning and end of the trip. Although the service is similar to regular transit service in its rigidity of schedule, it provides additional benefits. The service is door-to-door and the major portion of the trip is essentially express. Its primary use is for commuting and, therefore, it is of particular interest to communities seeking alternatives that affect traffic congestion during peak travel hours (Ref 69).

An individual carpool will succeed only if (Ref 69):

1. Both origins and destinations are concentrated within relatively small areas, with a long-line haul trip in between.

2. Arrival and departure times are concentrated within a fairly short interval.
3. Deterrents to private auto travel are present, or, conversely, incentives to form and maintain carpools are provided.

There is clearly some loss of independence and privacy entailed in carpooling, a loss that many will not accept at the current relative low costs associated with driving their private automobiles.

Routes, Scheduling and Matching Programs

Generally, routes and scheduling are determined by the carpool participants. A comprehensive carpool involving an information service matching commuters travel needs can be provided to assist those interested in exploring the potential of this alternative. The carpool information service can bring together commuters sharing similar travel needs by enlarging the number of potential matches to all the employees in one area or all the potential users within a city.

Operation and Management Techniques

In most carpooling programs, privately owned and maintained automobiles are used. The major role of employers and municipal agencies is to initiate and maintain a program bringing potential carpoolers together and to promote advantages of carpooling through marketing activities and/or through various incentives, such as parking and pricing mechanisms.

The initiation and maintenance of a program can be handled in several ways, all of which center around an information collection, matching, and dissemination format. Information collection generally entails the use of a questionnaire which solicits information from potential carpoolers. This may vary from an information board for people to post their carpooling interests to a citywide questionnaire placed in the newspaper or included with utility bills. Once the information is collected, several matching methods can be used. These vary from simple manual methods (usually with 1,000 persons or less) to automated systems using computer programs (used with 1,000 or more persons) (Ref 73). Once potential carpoolers have been matched, communication among interested parties must be initiated. Usually, once potential carpoolers have been notified of others near them who are interested in carpooling, only individual initiative is required to organize the carpool. A program similar but on a smaller scale can be used to maintain the pooling program as others become interested or individuals drop out and need to be replaced (Refs 69,70,72,73,74).

Selection and implementation of a matching method does not guarantee that a program will succeed. Incentives may greatly enhance the success of a carpooling program. Carpool incentives can be categorized in terms of the basic determinants of travel behavior (Ref 40), which are

- travel cost,
- travel time,
- convenience, and
- intangible, non-travel related factors

Travel cost is a significant factor in the decision to form or join a carpool. Economic incentives can be devised to reduce vehicle parking costs, ownership costs, operating costs, or a combination. Conversely, economic disincentives can be devised to increase the cost to non-carpoolers (Ref 78).

Various types of traffic control techniques can be applied to give priority or preferential treatment to high occupancy vehicles, such as buses, carpools, and vanpools (Ref 79). The basic intention of all these techniques is to reduce travel time for high occupancy vehicles, typically during peak travel demand periods.

Convenience-related incentives can increase the relative attractiveness of carpooling. An example is reserving the most convenient spaces in a parking lot for carpools. There is some overlap between convenience incentives and economic or temporal incentives since cost and time are often elements of "convenience" (Ref 78).

Hardware and Personnel Requirements

Hardware and personnel requirements depend on the size of the carpooling program and implementing organization. If implementation is performed by a small employer, the requirements may be only for a set of cards, a bulletin board, and a person working a few hours a week. A large, citywide program may require several people, such as an accountant, administrator, and secretary, augmented by computer capability to utilize the federally provided computer programs. These requirements need to be scaled to the local situation, but it is not considered a difficult task for a small city or employer to initiate a carpooling program.

Operating Costs

Costs for carpooling can be separated into two groups: (1) costs incurred by the carpoolers themselves and (2) costs associated with organization of the carpooling program. The costs associated with operating an automobile will vary with the characteristics of the vehicle and local operating circumstances. This has posed a problem for many carpoolers attempting to estimate a fare and cost structure. Generally, the organizing agency or employer may wish to provide guidelines in defining average operating cost estimates by vehicle type.

Costs associated with carpooling organization will vary with the size of the program and techniques used. Tables 3-7 and 3-8 list some average costs for a manual matching method and a computer-based method. In both methods the personnel used would be existing employees or part-time help.

VANPOOLING

Vanpooling is very similar to a subscription bus service in that it operates on the principle of transporting a regular group of patrons to and from one or several nearby origins and destinations. The primary differences lie in possible methods of ownership, operation, and management and the size of the vehicle. Subscription bus services generally operate 40 to 50 passenger buses, and vanpools use nine to twelve-passenger vehicles. This allows the potential for door-to-door service while maintaining a sufficiently high level of average speed. It also means they are suitable for shorter trips because their lower collection and distribution time need not be offset by such a long express run.

Major Users and Potential Service Scenarios

Again the most common patron of this type of service is the work trip commuter. Vanpooling was initially developed as a means of conveying neighborhood groups of fellow workers. Any group of nine to twelve employees from one or several closely spaced employment locations, working similar hours and living close together, provides a basis for a viable vanpooling operation. The riders can come from a variety of backgrounds and income levels.

Other potential market segments serviceable by vanpooling operations are the transportation disadvantaged, including school-aged children. The presence of a van, used primarily for work trip commuting, provides an

TABLE 3-7. COST FOR MANUAL CARPOOL PROGRAM (1977)

OPERATION	
Personnel	
Program Coordinator	64 hours initially per 500 users—$6/hr.
	8 hours/month maintenance per 500 users—$6/hr.
Secretary	40 hours initially per 500 users—$5/hr.
	8 hours/month maintenance per 500 users—$5/hr.
Matching Personnel	40 hours/initially per 500 users—$4/hr.
Supplies	
Questionnaires	2.5¢ per person
Lists	1.3¢ per person
Mailing	8¢ questionnaire
	13¢ list
	13¢ return postage
Total Mailing	34¢ per person
Locator Board*	$300.

*Locator board optional in some techniques

Source: Manual Carpool Matching Methods, U.S. DOT, January 1974.

TABLE 3-8. COST OF COMPUTER MATCHED CARPOOL PROGRAM (1977)

OPERATION	
Personnel	
Program Coordinator	64 hours initially per 500 users—$6/hr.
	8 hours/month maintenance per 500 users—$6/hr.
Secretary	40 hours initially per 500 users—$5/hr.
	8 hours/month maintenance per 500 users—$5/hr.
Key Punching	8 hours initially per 500 users—$5/hr.
	2 hours/month maintenance per 500 users—$5/hr.
Supplies	
Questionnaires	2.5¢ per person
Maps	3¢ per person
Mailing	13¢ questionnaire and map
	13¢ return mail
	13¢ listings
Total Mailing	39¢ per person
Computer Cards	6¢ per person
Computer Time*	$15 per 1,000 persons

*This cost assumes use of an "inhouse" computer, excludes cost of the program itself, and includes cost of list printing.

Source: Carpooling Case Studies, U.S. DOT FHWA, January 1974.

opportunity for other mobility services during time periods when it would otherwise be idle. For example, it can be used as an inter-office shuttle, rented out as a Dial-A-Ride service, or simply used as a delivery vehicle.

Routes and Scheduling

Routes may be determined two ways: (1) identifying demand on a door-to-door basis and routing the van by the most efficient method (time-wise) of picking up and transporting the patrons to their destination or (2) identifying a number of collector points and routing the van by starting at the farthest point and proceeding in the quickest manner to the destination(s) while stopping at all the pick up points (Ref 56).

Scheduling is determined by required arrival and travel times plus a time allowance for the degree of daily traffic fluctuations. There are several extensions of this which deserve mentioning, especially if the service is being promoted by the employer. Work hours can be staggered enough to allow the van to be used for two sets of trips, or work hours can be adjusted in conjunction with alternative uses for the vans during the day, such as being leased to community groups, or as Dial-A-Ride service.

Operation and Management Techniques

There are many different facets associated with organizing, operating, and managing a vanpooling program. Organization involves bringing together the initial group of riders to begin the program. To date employers have been the largest initiators or promoters of vanpooling programs. This has been encouraged for a variety of reasons, ranging from improving work schedule adherence to relieving parking problems. A program may begin by someone's, such as a person in the personnel department, taking the initiative to circulate questionnaires or post a signup sheet to determine the number of potential users and their home locations. Once this is performed, a "go" or "no go" decision about initiating a program can be made.

Programs may be initiated by the local transit organization, which can follow the same procedures as those initiated by employers except that the questionnaires would require wide circulation via the local newspaper or by enclosure with city utility bills.

Another method of organization, particularly where long commuting trips are involved, is for a group of employees to buy or lease, manage, and operate a van themselves. Similarly, a neighborhood group may form their own vanpool in the same manner as employee based groups.

Operational decisions concerning details, such as vehicle leasing, operator assignments, service and maintenance responsibilities, record keeping, and report forms, must be formulated and approved prior to implementation. The responsibilities can be rotated among the pool participants or one person may be elevted to direct the activities. Generally, if one person accepts responsibility for the operation and maintenance of the van, he or she is rewarded by being allowed to ride free or use the vehicle on weekends or possibly by being paid a fee for these services. Fare determination and collection procedures should be structured and approved prior to initiation of service (Ref 56).

Maintenance can be provided by private service stations, particularly if the pool is employee-founded. If it is managed by an employer, municipality, or local transit company, maintenance may be included in the lease agreement.

The management of a vanpooling project is a dynamic operation. The system must be constantly monitored to determine necessary route and schedule updating. Management is also responsible for deciding when and where new vehicles should be added and when old vans should be replaced. It must make all the general policy decisions and then continually monitor the project to insure they are carried out. Such things as incentives, use of matching techniques, promotional schemes, fares, buying or leasing of the vehicle, accounting, insurance, driver selection, financing, and maximizing van utilization are administrative and management responsibilities which are essential to an efficient and successful program.

If the project is initiated by an employee or neighborhood group, operating policies and individual responsibilities must be decided prior to starting service. If a municipality-sponsored, citywide effort is being undertaken, management responsibilities should be (1) placed on an existing city transit authority, (2) placed on the city traffic engineering, engineering, or personnel department, or (3) administered under contract to a private agency subject to review by the city council, city manager, or director of public works.

Hardware and Personnel Requirements

Hardware and personnel requirements are obviously tied to the scope of the project. If it is a large, citywide project, several persons (such as an accountant, administrator, and secretary) may be required in addition to the drivers. In a smaller operation, these jobs could be combined under a single individual or handled by part-time help. This area is very flexible and should be adapted to local requirements. A relatively large program might require the following types of personnel (Ref 56): accountant, administrator-coordinator, secretary, payroll clerk (if fares are paid via payroll deductions), and drivers.

Operating Costs

Costs and the corresponding methods of financing are dictated by both the size of the project and the organizing and operating methods. Costs range from initial investment, or capital outlays, to periodic operation and maintenance costs for a single employee-based van and the costs for an operation which includes a number of vans and extensive overhead costs (administrative costs, advertising and promotion, matching, etc.). Table 3-9 shows some average costs for a vanpooling program. This estimation does not include administrative or matching costs and will vary according to commuting distance. Table 3-10 gives several examples of vanpool programs.

SUBSCRIPTION BUS

Subscription buses operate on the principle of transporting a regular group of riders to and from one or several proximate origins and destinations. There is a certain degree of overlap with vanpooling or a prearranged shared taxi. For clarity, a substription bus service is defined as one which (1) uses the larger, 40 to 60 seat, buses, (2) follows a fixed route and a fixed schedule with predetermined patrons, and (3) does not necessarily provide door-to-door service.

Users and Potential Service Scenarios

The most common patron of this transit service is the commuter. Peak-hour travel to and from work provides an ideal market for subscription bus service (Ref 56). This service works best when a large group of people travel to and from as few origins and destinations as possible; for example, between several park-and-ride lots and a single employer or industrial complex. Kirby and Blatt state that "carefully tailored subscription bus services can attract riders from all levels of income" (Ref 38). Another

TABLE 3-9. VANPOOL COSTS ESTIMATE (1977)

Initial Costs		
1977 Dodge Sportsman Van, 15-passenger		$ 6,700+
Texas sales tax		499
Total		$ 7,199
Yearly Costs		
Texas license		$ 29
Insurance		250
Total		$ 279
Mileage Costs		
Gas - 12 mi/gal $.60/gal		$ .050/mi
Oil & lube*		.003/mi
Tires		.005/mi
Other maintenance*		.005/mi
Total		$ .063/mi
Average miles/commuter round trip		40 miles**
Number of working days/month		21 days
Number of miles per month		840 miles
Estimated value of van - 15% depreciation/year		
After 48 months		$3,997
After 36 months		5,496

Total Overall Cost

	36 months	48 months
Initial costs	$ 7,199	$ 7,199
Yearly costs	837	1,116
Mileage costs	1,905	2,540
Sub total	9,941	10,845
Resale value of van	-3,015	-2,680
	$ 6,926	$ 8,165
Monthly cost	$192.40	$170.00
Cost per passenger/mo***	$ 19.24	$ 17.00

+Assumed buyer will get preferential rate.

*Assuming $1800 oil change and lube every 6,000 mi.; assuming tune-up and other maintenance $40.00 every 10,000 mi., derived from Dodge suggested maintenance.

**Based on average figures in "Commuter Van Programs: An Assessment," Gerald K. Miller and Melinda A. Green, Traffic Quarterly, 31(1):33-57, January 1977.

***Assume ten passengers plus driver - driver rides free.

TABLE 3-10. STATE OF THE ART - VANPOOLS

Operation & Location	Date Started	# Vans	# Riders	Employees or pop. ride area	Average trip length	Van Cost	Fuel/mile	Main./mile	Total/mile	Type Van	Operator Wages	Insurance
Chrysler Vanpooling	6/74	6	60			lease @ $175/mo. & misc. 209.6/mo.	.075	.025/mi	.10/ mi.	12-pass.	Fare $26-29/ mo.	
3-M Vanpooling	4/73	75	780	10,000	5-150	Purchased $5,400	.06/mi	.0224	.085	12-pass.		
Caltrans Sacramento, California	9/74	3	30		100-120	License $171/mo			.08/ mi.		Fare $28.80 to $35.40/ mo.	$22/mo.
Utah County Vanpooling Provo, Utah	11/74	2	24	120	40-45	$1,133/ year			.057/ mi.	12-pass.	2	$25/year
Cenex St. Paul	10/73	21	175	620	10-100	Lease			.085	12-pass.	$.085/ mi.	
A.M. Voorhees	1/74				Fixed Cost 9/day				.09/ mi.	12-pass.	$20/mo.	

potential source of riders is school children. The problem of multiple origins can be overcome by using several centralized pickup points.

Experience to date indicates that in an effective operation the trips are fairly long (between 10 and 50 miles). Trip lengths in Reston, Virginia, average 22 miles. Com-Bus in Los Angeles has patrons traveling from 20 to 65 miles (Ref 38).

The attractiveness of this service is that a regular, reliable, and comfortable mode of transportation is offered, one which will assure the patron of arriving at his destination on time while providing some free time to read, sleep, etc.

Routes and Scheduling

Routes and scheduling must be convenient to the patron. Routes are assigned by having buses pass through one or more centralized trip origins and then proceed via the quickest route to the destination. Scheduling is determined by the patrons' work schedules. However, it should be stressed that this phase should be dynamic and include a periodic survey of both users and non-users to insure a convenient and satisfactory service.

When demand is light and dispersed, a few large buses may not be able to provide the quality of service characteristic of small vehicles. In this case, vanpooling should be considered as a possible alternative.

Operation and Management Techniques

The manner in which a subscription bus service is organized plays a key role in the methodology of management, while the operating procedure stays more or less constant.

A subscription bus service transports a predetermined group of patrons from a few origins to one or several destinations on a regular basis. This can involve commuting to work or school, shopping trips, visits to medical services, etc. A main point is that demand is predetermined, with routes and schedules established to insure financially viable service. Experience to date indicates that there are four key operating characteristics: reliability, trip length and speed, fare, and comfort.

Reliability is mandatory since experience has shown that most trips are for work purposes. Therefore, backup buses and drivers, along with a closely watched maintenance schedule, are required.

Experience also indicates that subscription bus services are better suited to long trips, the major part being an express, line haul service. Service standards which will make the bus more attractive than travel by private automobiles should be attempted, which in turn necessitates limiting the number of stops. Residential collection and distribution on a door-to-door basis will result in excessive travel times for many riders. Therefore, feeder services from the sparsely populated residential areas to centralized transfer points or park-and-ride lots may be required.

Fare is an important element in providing incentives to potential patrons. As a guide, the fare should be less than commuting costs by private auto, including carpooling. Other service attributes, such as comfort, safety, and frequency, are important and should be taken into account.

There are several groups who can manage this type of service: the riders, private entrepreneurs, employers, or a transit agency. A private enterprise, if already existing, may provide the least costly arrangement.

Hardware and Personnel

In addition to the buses, shelters and park-and-ride facilities may be needed. Personnel requirements include drivers (and backup drivers), a manager, and an accountant. In small operations, the backup driver, manager, and accountant could each be one of the riders. In the usual case of contract services, these requirements are filled by the transit operator. The cost of service normally reflects true costs, except for some subsidized operations.

Operating Costs

Costs for a subscription bus service will be similar to those for fixed route systems, and the tables for fixed route costs should be used to calculate an estimate. The major costs will be for the driver, the bus, and operating costs. Since 40-60 passenger buses cost from $90,000 to $140,000, it is normally more economical to lease the bus. Maintenance can be included in the lease, leaving only the cost of fuel and driver, or it is possible to contract for the entire service. Table 3-11 shows some rough estimates of cost for various subscription bus systems.

TABLE 3-11. SUBSCRIPTION BUS SERVICE SAMPLE COST (1977)

<u>GMC Twin Coach 45-passenger</u>	
Operating Cost	$.1036/vehicle mile
Leasing Cost	$1,200/month*
Total Commuting Mileage 40 passengers	40 miles/day**
1 Driver at $25 a day 4 hours	$6/hour
Total Operating Cost/Month	$1,900
Cost Per Passenger	$48/month

*Estimate from Austin Bus System, including servicing— charter rates

**Arbitrary figure

BICYCLES

Information

Bicycles are being recognized by an increasing number of Americans as a viable transportation alternative to the auto for short distance commuting and recreation trips. The bicycle provides several benefits to the user and society, such as low acquisition and usage costs, a healthy form of exercise, and reduction of air and noise pollution, energy consumption, and traffic congestion. Since 1972 the bicycle has outsold the automobile, resulting in an estimated 100 million bicycle riders in the United States (Ref 38). These riders are creating a new transit option, which planners are beginning to recognize as a viable part of the community transportation system.

Users and Demand Characteristics

There are three basic types of bicycle users who use public facilities; those who cycle for touring, for commuting, or for recreation. The touring cyclist rides long distances (hundreds of miles), sometimes camping, backpacking, or vacationing in motels along the way (Ref 18).

The second type of cyclist, the commuter, uses his bicycle for more utilitarian purposes, such as work or school trips and shopping or social trips. This type of cyclist makes short trips, rarely over four miles, and often travels regular routes. These cyclists are the most active in bicyling issues but their special interests do not often represent the majority (Ref 37). A recent study by the Iroquois Research Institute has shown that the average rider in this group is 39 to 40 years old and has average or above average income and education (Ref 37). A result of a 1975 nationwide Gallup poll was the report that 5 percent of all work trips were made by bicycle (Ref 22).

The last group, those who cycle for recreation, is the largest, consisting of millions of cyclists. They come in all ages, sizes, and abilities and form the silent majority. They need very little space, do not go very far, and do not require special facilities (Ref 51).

The cyclist's trip characteristics and needs vary with each group. The commuter travels short distances and usually takes the shortest route. Destinations are usually areas of high vehicle concentration, such as the central business district, schools, and shopping centers. This group has the highest interaction with motor vehicles. Safe, fast routes to high demand locations are needed. Also, secure temporary storage facilities are important to commuters.

Although in Europe the bicycle is heavily used for work commuting, there is considered to be very little potential for the number of bicycle trips to work in the United States to be substantially increased. However, the potential for an increase in bicycle commuting to school (elementary to college) is considered to be very large. In Davis, California, location of a major branch of the University of California, 40 percent of all trips during the rush hours are by bicycle (Ref 37).

There are three basic types of recreational bicycle trips: (1) trips to recreation sites, such as parks or public beaches, (2) leisure-time riding along linear parks or other parks and open spaces that have either special trails for bikes or roads of low traffic volume, and (3) leisure-time riding for exercise along various streets with no definite destination. Though this is the largest cycling group, facilities constructed for their needs and benefits are hard to identify or justify (Ref 18).

Routes and Facilities

Planning of bikeway facilities will vary from community to community, depending on perceived needs. There are no set planning procedures, and a variety of methods is used. However, there are certain considerations that should be included in any plan (Ref 18).

First, an examination of need should be made. This can be done through a survey or by examining potential generation and destination locations, such as schools, shopping centers, and parks.

Next, an examination should be made of existing and potential barriers to bicycle usage. Some potential barriers include expressways, railroads, waterways, streets with high traffic volume, steep areas, areas where water collects after rain, and streets in poor condition. Locations where these barriers can be crossed safely should be noted.

Standard specifications for bike lane widths, signing, storage, etc. can be found in the following publications:

- Bicycle Transportation, Bicycle Transportation Committee, ASCE, 1979.
- Planning and Design Criteria for Bikeways in California, California State Dept. of Transportation, June 1978.

- Bikeway Design, Oregon Highway Division, January 1974.
- Guide for Bike Routes, Standing Committee on Engineering Operations, American Association of State Highway and Transportation Officials.
- Planning Criteria for Bikeways, American Automobile Association Traffic Engineering and Safety Department, Falls Church, Virginia, 1973.

While there is a wide variety of designs for specific bicycle facilities, all fall into several categories. Three basic bikeway options are discussed below (Refs 7,50):

1. Class I bikeways are facilities with exclusive rights-of-way, with cross flows by motorists minimized. They are for the exclusive use of bicycles and pedestrians. However, if significant pedestrian use is anticipated, separate facilities for pedestrians are necessary to minimize conflicts.
2. Class II are preferential bike lanes for use within the paved area of highways. Bike lane stripes promote an orderly flow of traffic by establishing specific lines of demarcation between areas reserved for bicycles and lanes to be occupied by motor vehicles.
3. Class III bikeways are shared facilities, either with motor vehicles on the street or with pedestrians on sidewalks, and, in either case, bicycle usage is secondary. These facilities are established by placing Bike Route signs along the roadway.

Street traffic volumes, parking locations, and street widths are also critical. High volume streets should either be provided with a Class I or II bikeway or not be available for bicycles at all. Street width determines the types and sizes of bike routes that can be designated. Parking conditions along a street should be noted for possible conflict between bicycles and vehicles entering or leaving parking spaces.

Lastly, locations for bicycle storage facilities should be considered. Areas of concentrated bicycle destinations (shopping centers, schools, etc.) and areas of low security should be provided with adequate, secure storage facilities. The bicycle, like other private vehicles, needs to be stored during periods of non-use and this storage should be near the rider's destination. There are two major location considerations, security and weather.

Temporarily, 12-15 bicycles can be stored in an average automobile parking space. However, security is a problem. There are three major options to make bicycle storage more secure:

1. increased awareness on the owner's part,
2. increased number of and improved bicycle storage facilities, and

3. citywide bicycle registration program.

As bicycle owners become more aware of the threat of bicycle theft and make use of the products available to provide adequate protection, security will improve. However, there will be a need for some form of storage facility where large volumes of bikes can be secure. There are three types of bike storage facilities (Ref 43):

1. bicycle rack——a rack structure which the bike can be locked in or clamped to;
2. bicycle hitching post——a solid structure, such as a post or concrete column, allowing the cyclist to secure the bike with chains; and
3. bicycle locker——a key-operated locker, similar to a baggage locker, in which the bicycle can be locked.

Costs

Costs for the installation of bicycle facilities vary with the type of facility and location. Several factors which need to be considered are: (1) earthwork and pavement, (2) land acquisition, (3) drainage, (4) barrier curbs and fences, (5) sign/pavement markings, and (6) bridges, retaining walls, and landscaping (Ref 7). Table 3-12 gives estimated cost figures for various facilities. Projects completed in Austin during the summer of 1977 showed the following average values.

Type	Price
Ramps and sidewalks	$ 1.82 per sq ft
Signs and installation	$ 12.00 per sign
Bike racks	$ 5.00 per bike
Striping, nonreflective	$ 30.00 per mile
Striping, reflective	$200.00 per mile

TABLE 3-12. EXAMPLES OF BIKEWAY COSTS (1977)

Item and Source	Short Block	Long Block	Mile
A. PAVEMENT (including preparation)	(250')	(600')	(continuous)
4" concrete, 6' wide	$800	$2,000	$17,000
3" asphalt, 6' wide	$600	$1,400	$12,000
B. BARRIER			
6" asphalt (extruded curbing)	$225	$ 550	$ 4,800
C. EDGE LINE MARKINGS*			
Single 4" skip stripe (to denote two-way bike lane)	$ 30	$ 65	$ 550
4" solid reflectorized line	$ 45	$ 105	$ 900
6" solid reflectorized line	$ 75	$ 180	$ 1,600
Removal of painted stripe	$ 75	$ 180	$ 1,600
D. REFLECTORIZED SIGNING	(2 per block)	(4 per block)	(20 per mile)
Bikeway sign on existing post	$ 20	$ 40	$ 200
Installed on wooden post	$ 50	$ 100	$ 500

*Wet reflecting lane tape

Source: Bikeways, Waco Urban Transportation Study, Bikeway Technical Committee, 1975, p. 31.

CHAPTER 4. TRANSIT OPTION APPROPRIATENESS

INTRODUCTION

A significant task in considering the feasibility of public transportation service for a given community is identifying and evaluating the possible supply options. The basic supply options, discussed in the previous chapter, must be considered in view of the inherent characteristics of each individual community and the demand (existing and potential) for transit service.

In deciding what transit options are best suited for a certain community, two basic elements should be examined:

1. the ability of the transit option (or options) to meet the community's needs and
2. the ability of the transit option to be economically feasible.

Each of the city classifications defined in chapter 1 has been categorized on the basis of similar transit needs; correspondingly, each of the options presented in chapter 3 assists in matching transit types with city needs. The purpose of this chapter is to examine both of these elements and to provide an evaluation of the transit options on the basis of anticipated effectiveness and efficiency.

First, transit options are examined in relation to the transit characteristics of each city type. Suitable options are then presented for each city type. Last, the overall efficiency of the two major options, fixed route and demand responsive service, is considered in a general overview.

SERVICE CHARACTERISTICS

Each transit option satisfies certain transit needs because of its inherent service characteristics. These characteristics relate to the type of vehicle used, fare structure, route schedule, level of service, and coverage. A city's transit system, however, is not limited to one option but will probably consist of a combination of options. By combining the options that best meet the transit requirements of the community, a more comprehensive service can be achieved. The following sections provide a discussion of the levels of service of each option and an evaluation of their associated service potentials.

Conventional Fixed Route Bus

A fixed route system consists of medium to large buses (averaging from 23 to 55 seats) which travel along one or more fixed routes on a predetermined schedule. The fare is generally affordable and typically averages 30 to 50¢. The level of service is limited by the fixed route concept because routes normally are a minimum of 1/2 mile apart.

Optimally, this system better serves areas and corridors of high population densities with concentrated destinations. Examples include work commuting to the central business district, shuttle service to schools and military bases, and express park-and-ride service. This is usually the least expensive means of providing broad transit coverage to a community.

Jitney

A jitney system, usually consisting of an 8 to 12 passenger vehicle or a 4 to 6 passenger car, operates along a fixed linear route. The fare may vary from 25 to 50 cents. The level-of-service is generally high, comparable to that of a taxi. Typically a jitney provides service in areas having frequent, short linear trips and high demand (such as tourist or CBD trips). The jitney service may deviate slightly from its fixed route. The jitney best satisfies demand that occurs in linear areas such as major arterial corridors in large metropolitan areas and tourist areas of all sizes.

Dial-A-Ride

A demand responsive Dial-A-Ride system generally operates with either a 10 to 15 seat van or a small bus (23 seats). The level-of-service is considered high because door-to-door service is an inherent characteristic of this mode, but waiting time can be long. The fare can range from a small subsidized fare to $2.00 or $3.00 per trip.

Dial-A-Ride systems respond to most types of demand with a high level-of-service, but there is a correspondingly high cost for service. Dial-A-Ride has been widely used where other forms of transit were unavailable or impractical, such as service to the transportation disadvantaged, most notably the handicapped or very young.

Taxi

A taxi service generally operates with a 4 to 6 passenger car. The level-of-service provided by a taxi operation is considered the highest of all transit options. The fare is a function of distance and ranges from 70 to 90 cents a mile. It can also be based on zone changes rather than distance.

Traditionally, the taxi has provided for all types of transit needs. Though the fare is normally higher than that for other options, it is used by a cross section of all socioeconomic population groups. The taxi best meets transit needs where a high level-of-service is desired. Taxi service is usually not used for commuting.

Taxi service has been financially successful in small towns and suburbs. Taxi operations are common in most cities over 10,000 in population. The sizes of these fleets range from 2 to 3 in the smaller cities to 500 in the larger cities.

Pooling Methods

The various pooling methods involve the shared use of vehicles (either vans, 9-15 passengers; cars, 2-5 passengers; or buses, 20-55 passengers) which are leased or owned by the users. The level-of-service is considered high. The fare, often paid on a monthly basis, is usually lower than taxi service and may be only enough to cover operating expenses.

These pooling methods are best for work commuting. The density of demand and trip lengths are used in determining the feasibility of transit service and the type of vehicle best suited for the demand. For example, automobiles may be best suited for dispersed origins and destinations and short trip lengths, vans for higher demand densities, and buses for high demand densities and long trip lengths. Large employment and activity centers are prime locations for vehicle pooling methods, and programs in various cities have demonstrated the feasibility of this concept. There are federal government incentives for this option, if program feasibility can be demonstrated.

Bicycles

The bicycle, though only recently regarded in the U.S. as a viable transportation option, may be used for a variety of trip types, the major ones being work commuting, school commuting, and recreation. Construction of special facilities for bicycles greatly enhances usage because of their inherent operating characteristics. Average bicycle costs range from $100 to $300. The level-of-service is limited because of speed and susceptibility to the weather.

TRANSIT NEEDS

The transit needs of a community depend in large part on its spatial form and the socioeconomic characteristics of its residents. These needs can be characterized by a variety of trip types, such as medical, social, shopping, work, and school commuting. Therefore, a combination of mobility programs and services is normally required to satisfy these needs. The typical transit needs of each city type defined in chapter 2 are reviewed below.

Class I

The residents of Class I communities usually have limited access to or use of an automobile. Many family units do not have access to a second automobile. In these communities there is a sufficient demand for an inexpensive and reliable source of transportation, fulfilling a variety of trip purposes and providing extensive coverage of the urban area. A high level-of-service is not as necessary as accessibility.

Class II

Many residents of these communities have limited access to any form of transportation or are physically unable to use the options that are available. The handicapped and the elderly are major population groups comprising these communities and they require a transit option with a high level-of-service. Specially equipped vehicles with wheelchair lifts and drivers who can help riders on and off the vehicle are necessary to serve the disabled patrons. Door-to-door service or a short walking distance to stops is an important service feature of this option.

Class III

Communities classified in this group have a high number of multiunit dwellings and a large proportion of one- and two-person households. In Texas these tend to be communities with large government employment centers or a college or university. These communities have a primary demand for a transit option which can service work and school commuting trips. Origins and destinations tend to be concentrated; as a result, the level-of-service is not as critical as overall accessibility. However, fare structure is a major consideration because these are daily trips.

Class IV

In Texas, most of these cities have a population over 200,000 persons, and thus lie outside the major emphasis of this report. They usually experience all the transit needs discussed in this chapter. Often the need for public transit in these cities is relatively high, since traffic congestion problems in the CBD and other areas make travel by auto unattractive, particularly at peak hours. Most of these cities already have some type of transit system, and their need is for expanded and improved services.

Class V

Typically, these suburban communities have recently experienced a high rate of growth. Most of the families living in these communities are relatively affluent and have two or more cars available. The majority of the transportation trips are made with these private automobiles. The demand that does exist for public transportation is highly dispersed. These situations are suited for demand responsive service, where fare structure is not as important as level-of-service.

Class VI

These communities are characterized by a relatively high level of population density and white collar employment. These communities have a broad spectrum of transportation needs. The majority of the transit trips relate to work commuting. The demand in these communities is less dispersed than in the other classes of communities.

PRELIMINARY EVALUATION

The main objective in the classification of cities by transit determinants and the review of possible transit options is to facilitate the matching of appropriate transit options with city types. Tables 4-1 and 4-2 show possible transit scenarios which are immediately identifiable as candidates for further consideration. Table 4-1 presents the appropriate transit options for cities with a population less than 50,000. Table 4-2 provides an indication of appropriate options for cities with populations between 50,000 and 200,000.

These two tables relate the appropriateness of each option in meeting the needs of the six different community classes. The purpose of this concept is to identify the options which should be initially examined. The first step is to identify the city class which best represents the community. Based on city size, proceed to the appropriate table for an indication of the relative ranking of options. The ranking of viable options is recommended for the preliminary assessment. For example, a user whose interest is in a community which has a population of 75,000 and has recently experienced a large amount of growth (Class V) would look on Table 4-2 on the Class V line and examine each of the options. In this case it is shown that carpooling and taxi service (and bicycles for minor effects) should be explored further as an option best suited for this community's particular transit needs. Of the remaining options, the jitney is considered a poor alternative and all others are ranked as fair.

There are several special transit scenarios which may be appropriate for different communities. They, however, may not be obvious from an examination of the two tables. These are marked on the tables with arterials, and are discussed below.

Communities containing a major university have the possibility for several unique transit options. In a fixed route shuttle system servicing the areas adjacent to the university, the use of less expensive buses (similar to school buses) is common and effective. This type of system can be expanded and developed into a community-wide system. The use of the bicycle for school commuting is becoming increasingly popular. Facilities constructed near schools for bike users can become the initial segment for a community-wide system. These facilities may also qualify for federal support.

In communities with a high concentration of tourist facilities, excellent opportunities are provided for the operation of taxis and jitneys. Taxis and jitneys can meet the highly concentrated, short-trip needs of the tourist.

TABLE 4-1. TRANSIT ALTERNATIVES FOR CITIES WITH LESS THAN 50,000 POPULATION

City Classification	Fixed Route Bus	Demand Responsive	Buspooling*	Vanpooling*	Carpooling	Taxi	Jitney*	Bicycle
Class I	1	2	2	2	2	1	2	2[1]
Class II	2	1*	2	2	2	1	2	3
Class III	2*	2	2	2	1	1	2	1
Class IV	2	2	2	2	2	1	2	2[1]
Class V	2*	2*	2*	2	1	1	3	1
Class VI	2	2	2	2	2	1	2	2[1]

Key: 1 - Excellent
2 - Fair
3 - Poor

*Possible special scenario, see text.

1. Street conditions make use hazardous; use can be improved by providing special bikeway facilities.

TABLE 4-2. TRANSIT ALTERNATIVES FOR CITIES WITH POPULATION RANGE OF 50,000 to 200,000

City Classification	Fixed Route Bus	Demand Responsive	Buspooling*	Vanpooling*	Carpooling	Taxi	Jitney*	Bicycle
Class I	2	3	3	3	2	1	2	2[1]
Class II	3	1*	3	3	2	1	3	3
Class III	2*	2	3	2	2	1	2	1*
Class IV	2	2	3	3	2	1	2	1[1]
Class V	3*	2*	2*	2	2	1	3	1
Class VI	2	2	3	2	2	1	2	1[1]

Key: 1 - Excellent
2 - Fair
3 - Poor

*Possibility of special scenario, see text.

1. Street conditions make use hazardous; bicycle facilities would be helpful.

Communities with large military bases located in town or nearby are also excellent areas for taxis and jitneys. Jitneys, for example, could act as an express service between the bases and the CBD.

Areas with a large employment center, such as a manufacturing plant or refinery, are a good location for some form of pooling, either municipal or employer operated. These vehicles could also be used in off-hours for other community needs.

Bedroom communities can initiate park-and-ride express bus service to the CBD of the metropolitan area. Garland is an example of a community that offers such a service. The highly dispersed demand for other trips within these suburbs may be met by a demand-responsive system. Cost considerations are pertinent to the effectiveness of these options.

The elderly and handicapped require special services. The required high level-of-service is available in a Dial-A-Ride system. Although the cost of these systems is high, many potential funding or cost sharing sources for capital and operating cost subsidization are available. Recently the Texas legislature passed enabling legislation to encourage the use of school buses. The legislation allows eligible school districts to lease their school buses to non-profit and government agencies to provide transportation for the elderly and handicapped (HB 884, passed May 27, 1977). This may offer many communities the opportunity to serve their elderly and handicapped citizens at a relatively low cost.

TRANSIT COSTS

Another factor which should be considered when selecting transit options is the associated costs. Figures 4-1 thru 4-8 give a general overview of the costs associated with the two major options discussed in this report, conventional fixed route and Dial-A-Ride.

Figure 4-1 shows the operating cost range for a demand responsive system which contracts out all maintenance and service to an outside agency. Figure 4-2 includes the capital costs of new administration facilities. Figure 4-3 shows the cost range for a demand responsive system which performs inhouse maintenance. In Fig. 4-4, the capital costs include administrative and maintenance facilities. Figure 4-5 shows the operating cost range for a demand responsive system which does not include the administrative facilities and maintenance. Figure 4-6 adds in the capital costs for the same system.

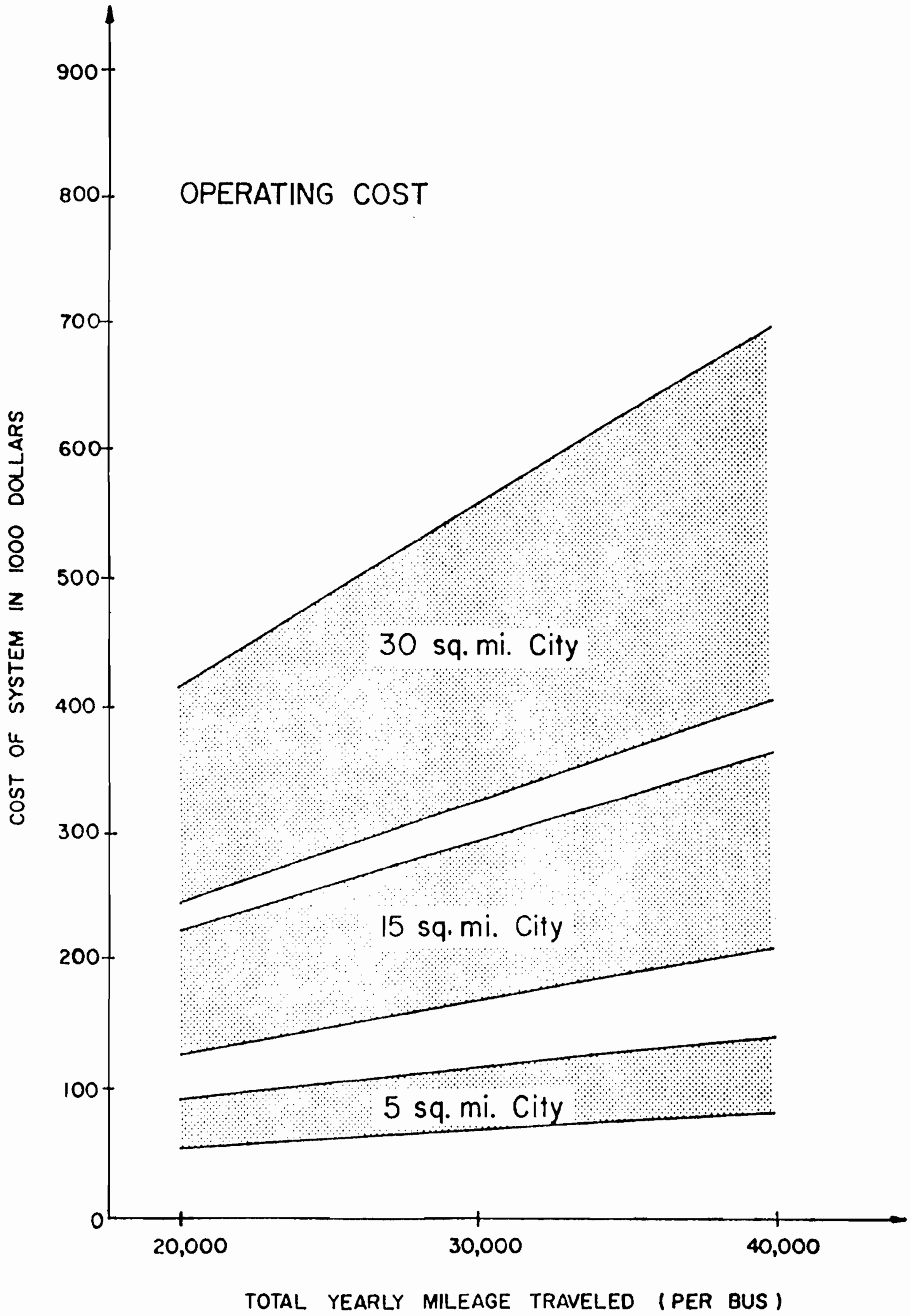


Fig. 4-1. Demand responsive system costs, service contracted out (1977 base)

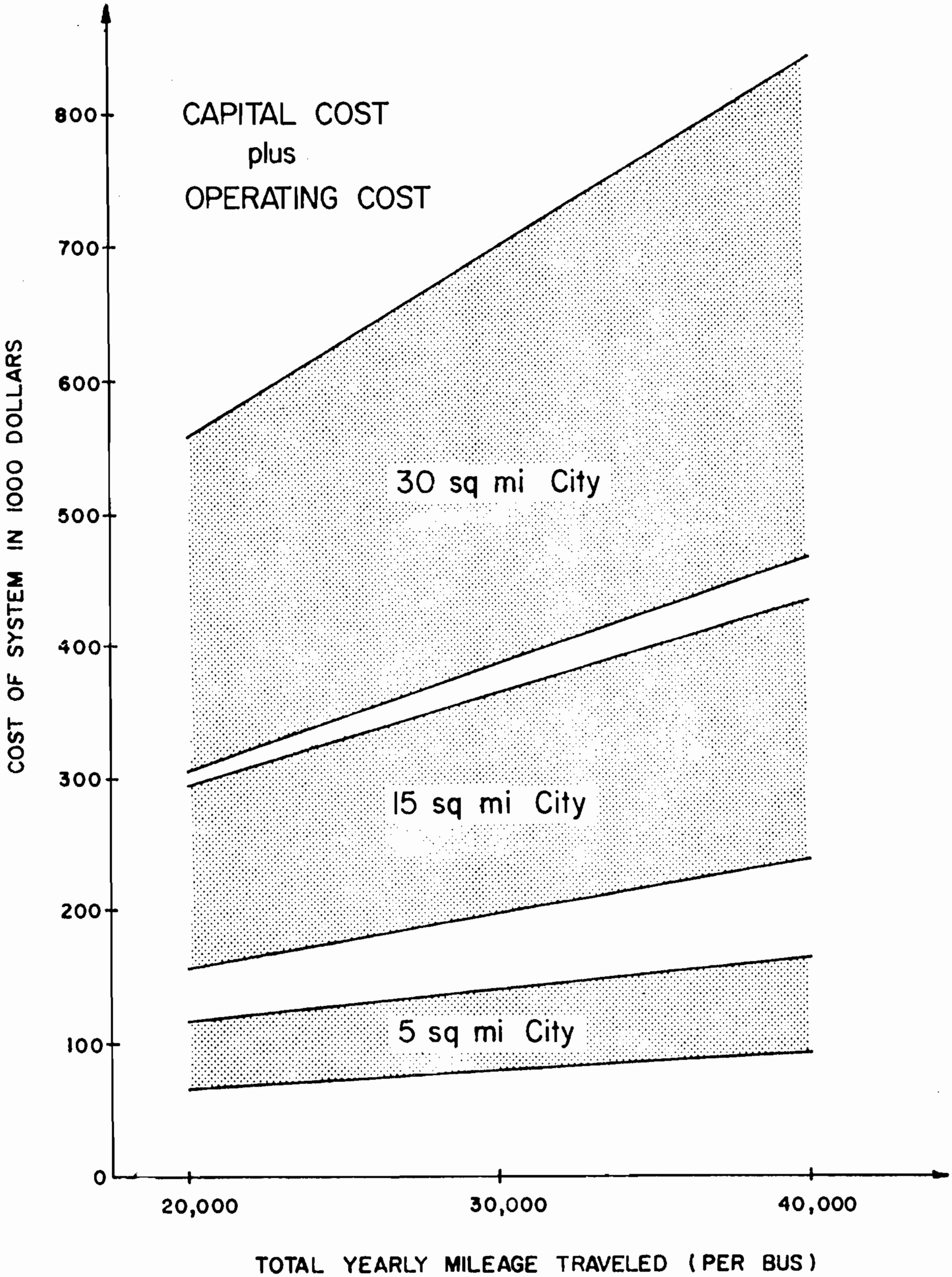


Fig. 4-2. Demand responsive system costs, administrative facilities built, service contracted out (1977 base)

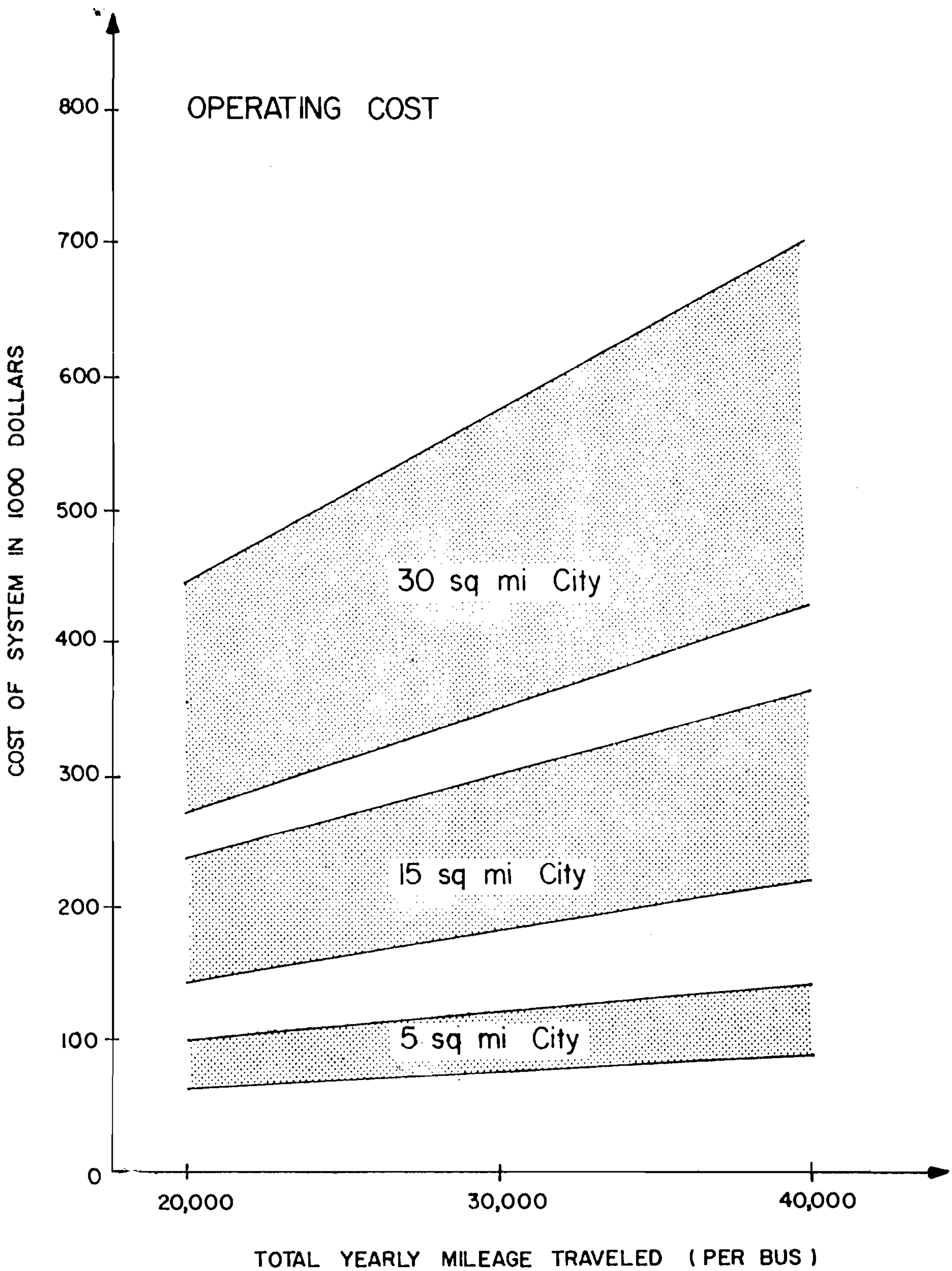


Fig. 4-3. Demand responsive system costs, service done inhouse (1977 base)

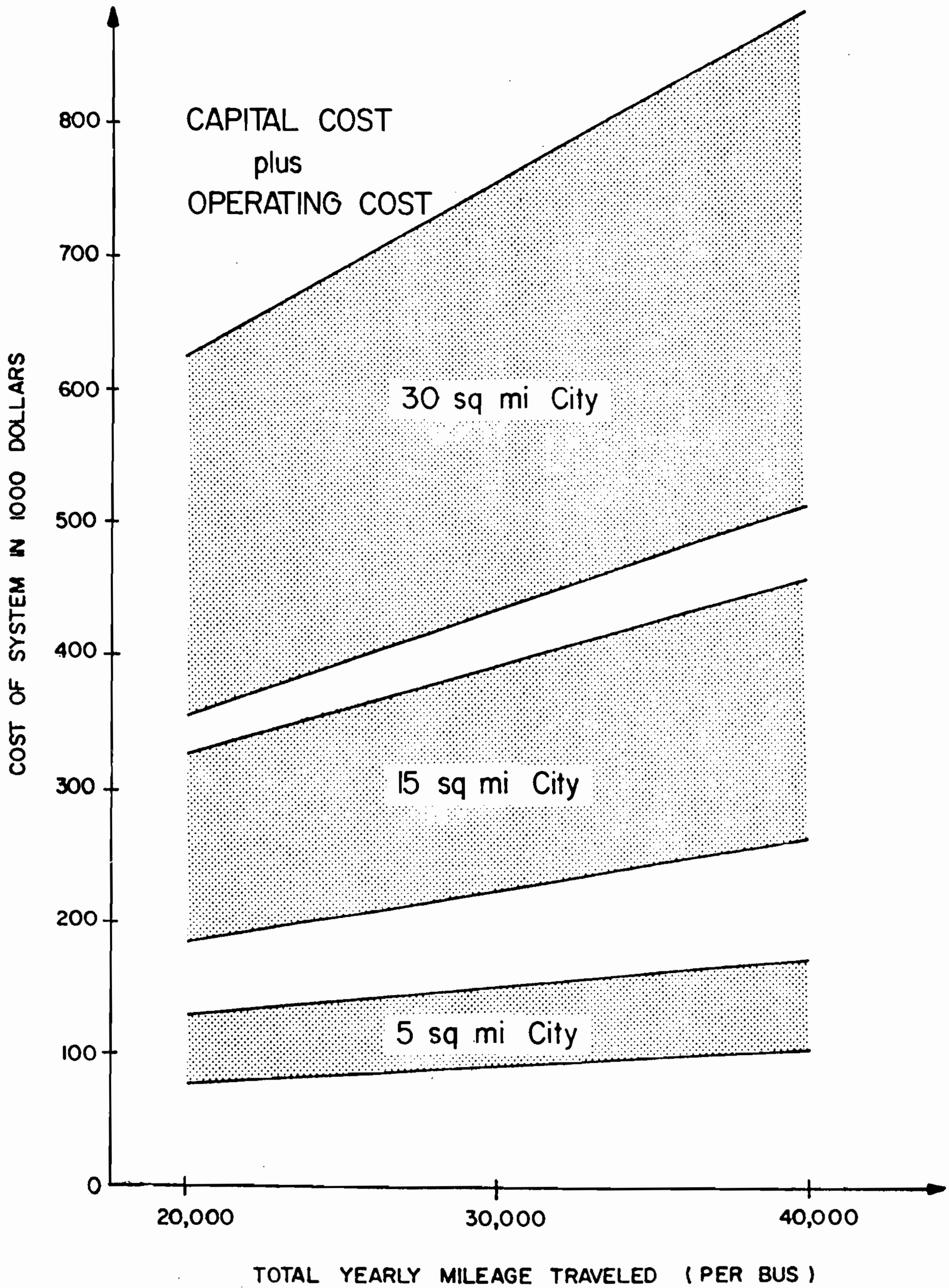


Fig. 4-4. Demand responsive system costs, administrative and maintenance facilities built, service done inhouse (1977 base)

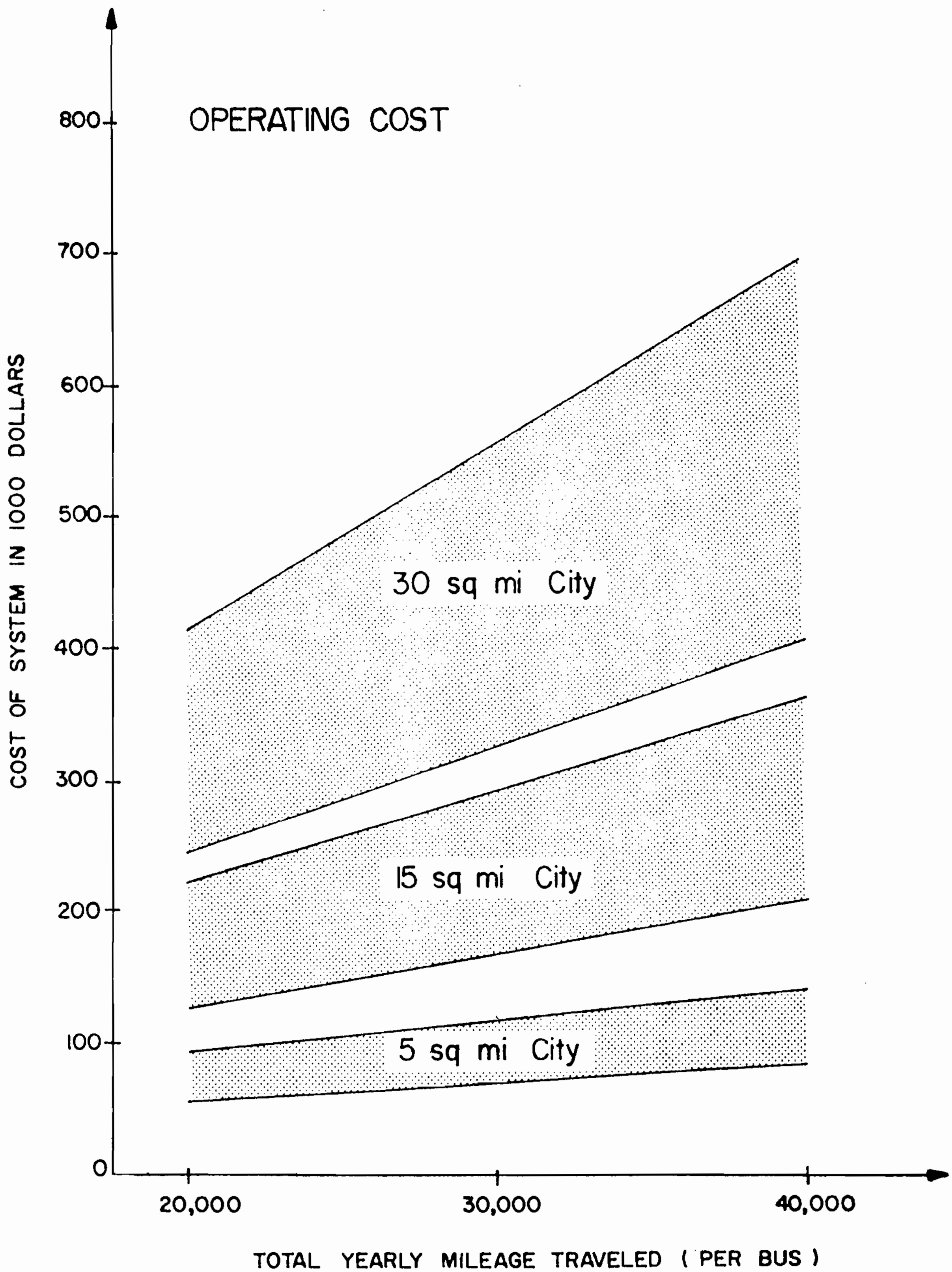


Fig. 4-5. Demand responsive system costs, administrative facilities not built, service contracted out (1977 base)

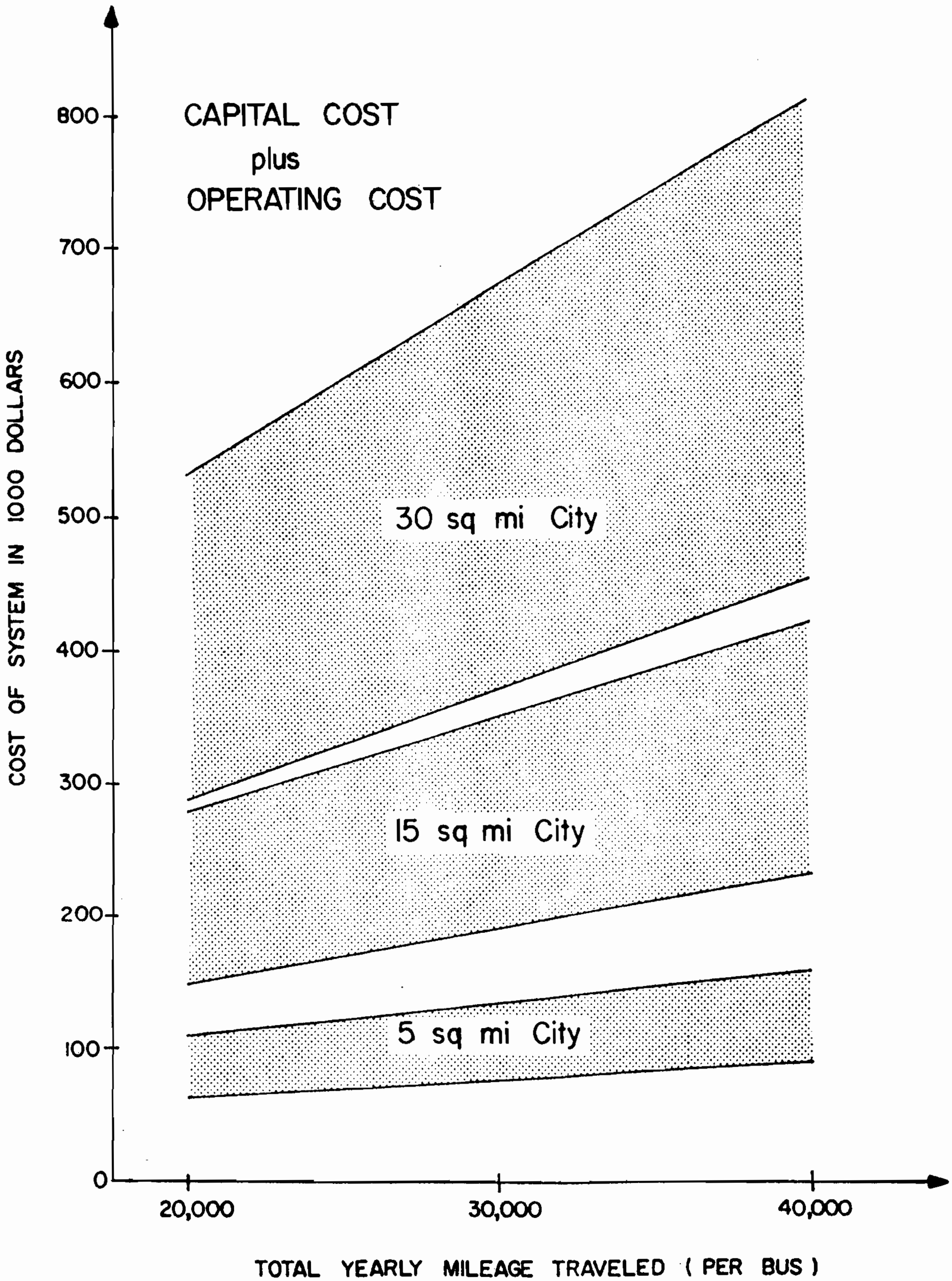


Fig. 4-6. Demand responsive system costs, administrative facilities not built, service contracted out (1977 base)

Figures 4-7 and 4-8 show the cost range for a fixed route system where the operating and capital cost includes administrative facilities and inhouse maintenance.

These graphs show typical ranges of operating and capital costs for different systems. These costs do not necessarily represent the actual encumbered cost which must be incurred by the community. There are a number of federal and state funding programs which can aid the community in financing a transit system. The following chapter presents a more detailed procedure for estimating the range of costs associated with each of the transit options.

SUMMARY

The transit alternative tables, by matching transit needs to transit characteristics, provide a preliminary assessment of possible viable transit options for different city types. By classifying itself according to one of the six city classes presented, a city can evaluate possible viable options.

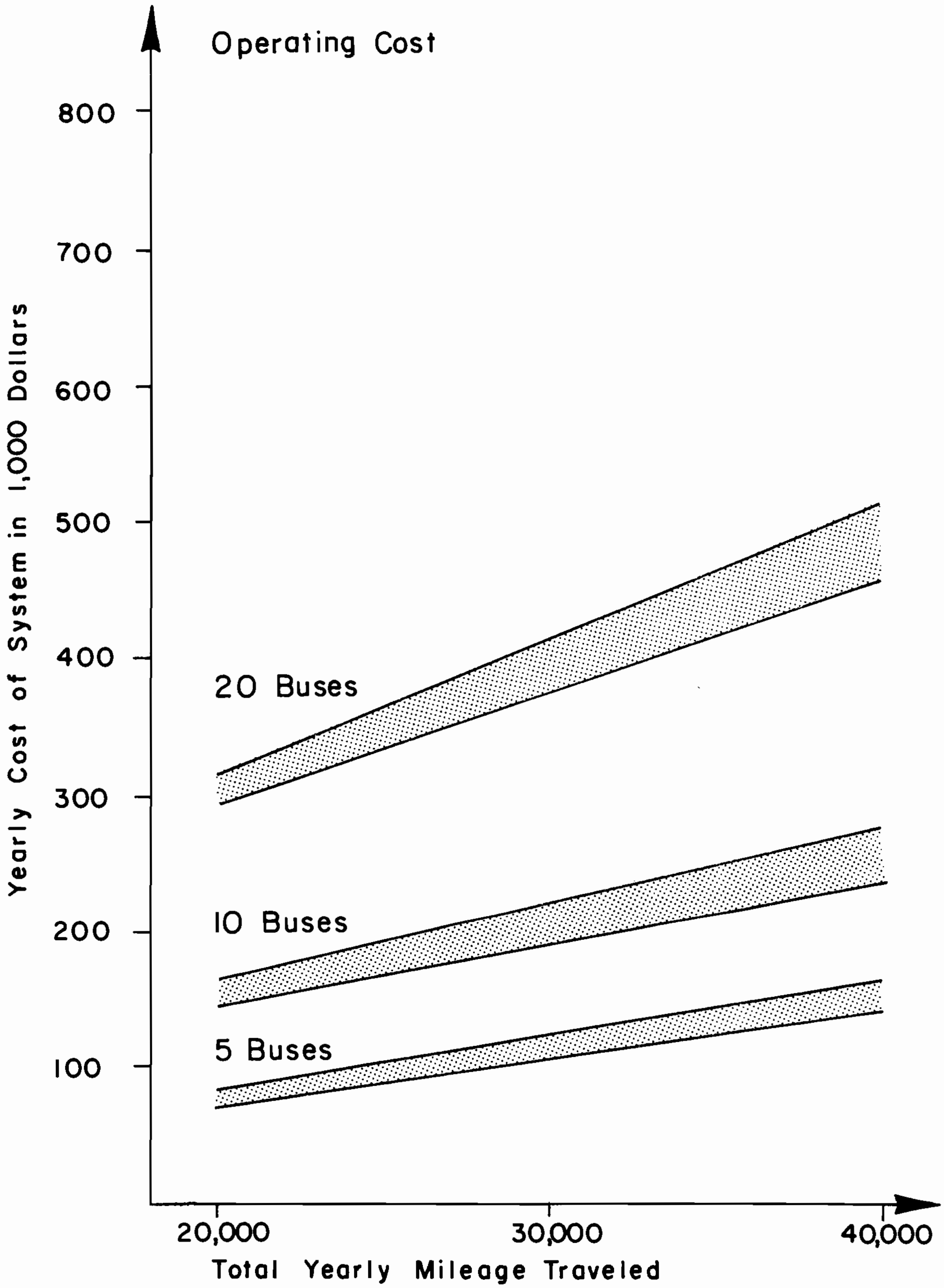


Fig. 4-7. Fixed route system operating costs (1977 base)

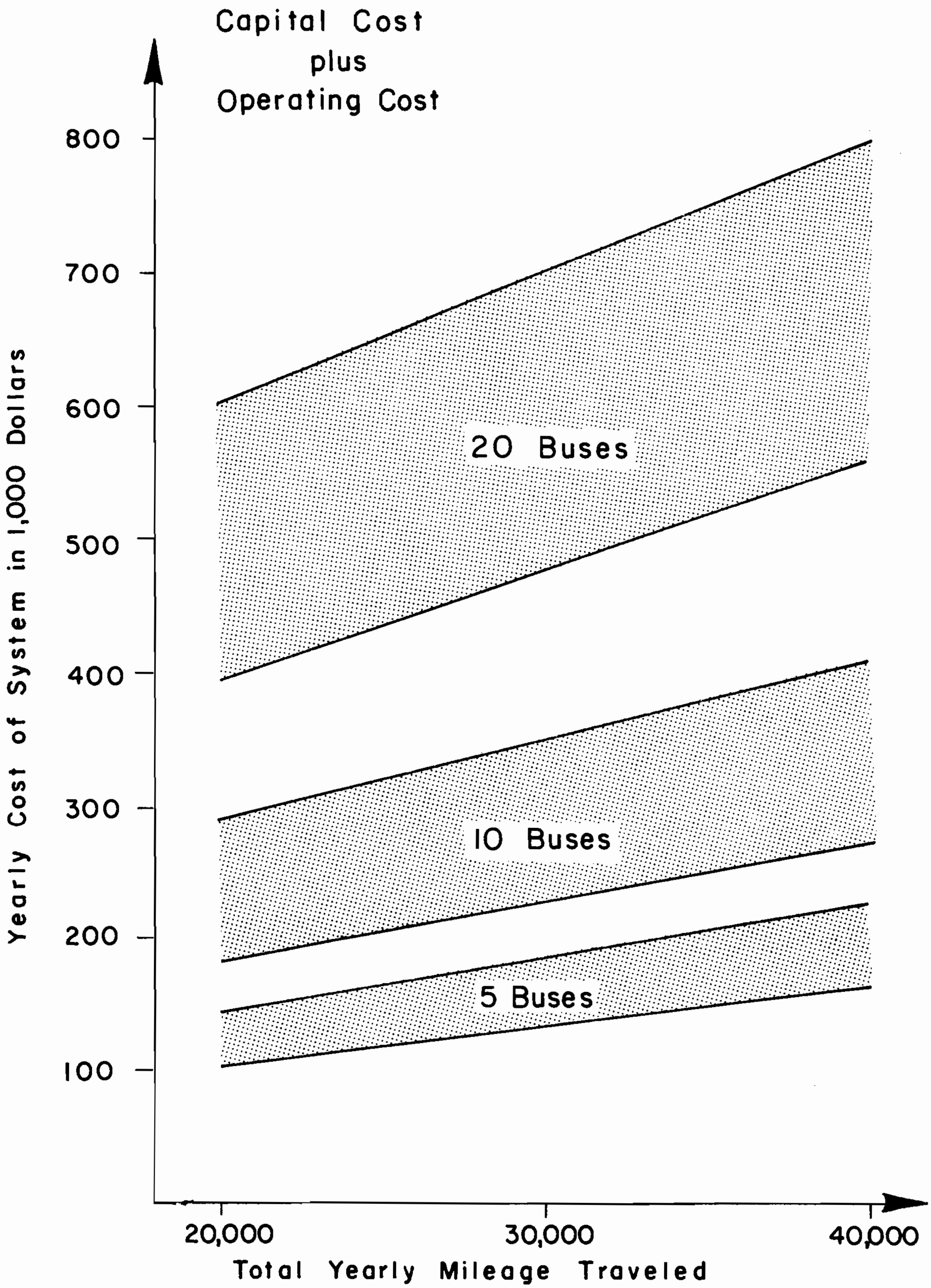


Fig. 4-8. Fixed route system operating and capital costs (1977 base)

CHAPTER 5. LEVEL OF SERVICE AND COST ESTIMATING TECHNIQUES

INTRODUCTION

As previously presented, there is a finite number of transit alternatives for small systems, although operational infrastructure may vary significantly. A small community would have little use for a heavy rail system, yet a taxi service may be essential. The options are rather clear; however, their viability is uncertain.

In this chapter, measures of transit system level of service will be reviewed. Each of the measures will be analyzed for its applicability to small city transit properties. A model to predict the service performance of a fixed route and demand responsive transit system is presented. Since route structure is a basis for evaluating transit coverage, a procedure for developing routes is outlined. The final output of this process is a set of number-of-vehicles vs. level-of-service curves that reflect a coverage measure. An example and preliminary cost model relating cost encumbrance estimates for a given transit system to the level of service is also included.

LEVEL OF SERVICE

Level-of-service (LOS) is a qualitative measure that represents the collective factors of speed, travel time, traffic interruption, freedom to maneuver, safety driving comfort and convenience, and operating costs provided by a highway facility under a particular volume condition (Ref 10). There are several ways to measure LOS. Common indicators include speed, delay, space, acceleration, temperature, ventilation, and noise (Ref 11). LOS indicators can motivate behavioral change in transportation made by potential users who have a choice of mode (Ref 2). There are four components of LOS that have a direct affect on modal choice: reliability, directness of service, frequency of service, and passenger density (Ref 2). Another suggested LOS measure is the ratio of total travel time to the direct auto travel time (Ref 19).

Level-of-service is defined as a transit travel time, measured by access to transit or wait time, ride time, reliability, transfers, and frequency of service, divided by auto travel time. Factors such as overcrowded buses, thus passenger density, and vehicle environmental conditions, thus space, acceleration, temperature, ventilation, and noise, are not considered as critical in measuring level-of-service.

Fixed Route System

To determine LOS for a fixed route system, certain variables such as the length and number of routes must be defined. Other variables include the number of buses used, the total vehicle miles traveled and total hours of operation. A suggested procedure to provide an assessment is to diagram a schematic routing system and calculate the statistics for each scheme. Appendix B outlines a simple procedure for determining route location and calculating the necessary data inputs.

Level-of-Service

To calculate level of service, transit trip time and auto trip time must be estimated. This consists of four elements: (1) the trip to the bus, (2) the wait time, (3) the ride time, and (4) the trip to the final destination.

The trip to the bus can be made in a variety of ways, such as walking, by automobile (park-and-ride), bicycle, or by other transit options. For this study the most likely method is by walking. The band of coverage for a fixed route is 1/2 or 1/4 mile wide on either side of the route. Barker and Krechner (Ref 4) found that on the average 50 percent of walking trips are less than 500 feet and 30 percent are between 500 and 1500 feet. With an average walk of 500 feet and an average walking rate of approximately 4 feet per second, the walk to a bus stop would be about two minutes (Ref 32).

The transit wait time is a function of the vehicle headway. Therefore, the average passenger is assumed to wait one-half of the time interval between transit vehicles, or one half of the headway. The probable wait time at a transit access point is considered to vary from 5 to 10 minutes. In small communities, the wait time will more closely approximate 10 minutes.

The ride time consists of two components: (1) the time to travel the desired route(s), which is dependent on trip length and average vehicle speed, and (2) the time required for transfers. In lieu of performing user surveys to estimate average trip lengths secondary data, such as previous studies provide reasonable estimation of average bus trip lengths and average auto trip lengths. Table 5-1 shows several typical estimates of trip lengths taken from surveys performed in three Texas cities.

Transfer time is considered a function of the number of trips actually requiring a transfer and the scheduling of the buses themselves. For example, if the transit system was comprised of one route which covered the entire community then no transfers are required. If the system has two routes then as many as 50 percent of the non-CBD trips may require a transfer. If 50 percent of the non-CBD riders must wait for a transfer, this is equal to all riders waiting 50 percent of the time required for a transfer. Given these assumptions, transfer time estimates can be computed by

$$\text{TRANSFER} = E\left(1 - \frac{1}{N_R}\right)W_T$$

where

TRANSFER = time required for transfer,

N_R = number of routes,

$$E = \frac{\text{No. of non-CBD places x 100}}{\text{No. places}}$$

W_T = wait time, minutes.

On-board ride time is made up of ride time and transfer wait time:

$$R_T = \frac{\text{average trip length}}{\text{average vehicle speed}} + E\left(1 - \frac{1}{N_R}\right)W_T$$

$$W_T = 1/2 \text{ headway} .$$

The trip-end time, or final walk to the destination, which is the usual case in this study, is assumed to be the same as for the means of travel to and from the transit access point. The trip will average about 500 feet in length, with a two-minute walk time.

The final equation for finding travel time by fixed route transit is

$$TT_{Transit} = 4 \text{ min} + 1/2 \text{ headway} + \frac{\text{ave. trip length}}{\text{ave. vehicle speed}} + E\left(1 - \frac{1}{N_R}\right)W_T$$

where

$TT_{Transit}$ = transit travel time estimates, in minutes.

TABLE 5-1. TYPICAL TRIP LENGTHS, THREE TEXAS CITIES

SAN ANGELO, TEXAS

Trip Purpose	Average Trip Length (Minutes)			
	1964	1970	1980	1995
Home Based Work	6.1	7.2	7.2	7.5
Home Based Non-Work	4.6	5.6	5.7	6.0
None Home Based	4.6	5.5	5.5	6.1
Truck & Taxi	5.0	5.2	5.2	5.9

WICHITA FALLS, TEXAS

Trip Purpose	Average Trip Length (Minutes)			
	1964	1970	1975	1990
Home Based Work	9.14	9.38	9.31	9.32
Home Based Non-Work	6.29	6.33	6.32	6.32
None Home Based	5.95	6.06	6.05	6.32
Truck & Taxi	6.06	6.06	6.20	6.24

TEXARKANA, TEXAS

Trip Purpose	Average Trip Length (Minutes)	
	1964	1970
Home Based Work	6.03	6.11
Home Based Non-Work	4.79	4.85
None Home Based	4.35	4.43
Truck & Taxi	4.87	4.87

Source: Texas Highway Department, PLANNING AND RESEARCH DIVISION, "Texarkana Urban Transportation Study - The Development of Trip Generation and Distribution Models 1964-1995."

The time for travel by automobile will be

$$TT_{Auto} = \text{(average trip length/average vehicle speed)} + 1 \text{ minute}$$

where the one minute represents the time to get the car started and the time to walk from the car to the destination. Level-of-service (LOS) is estimated by

$$LOS = \frac{TT_{Transit}}{TT_{Auto}}$$

To estimate the relative sensitivity of the transit analysis to the routing and scheduling assumptions, several different configurations of service should be examined, with a corresponding estimated LOS for each.

Fixed Route Procedure Example

To illustrate the fixed route procedure detailed in Appendix B, a typical community will be used. This community——Example, Texas——has a population of 50,000 and is located at the crossroads of two primary intercity highways. It has an average population density of 2,000 persons per square mile. A hypothetical map of major streets is shown in Fig. 5-1.

The socioeconomic study of the city found the city to be extremely heterogeneous, with few areas of either homogeneous social or economic groups. The CBD is the major trip destination, with other destinations evenly distributed throughout the city. Approximately 50 percent of the destinations are in the CBD.

Since data on an average trip length do not exist, Fig. 5-2 is used to estimate an average trip length, which is 2.5 miles.

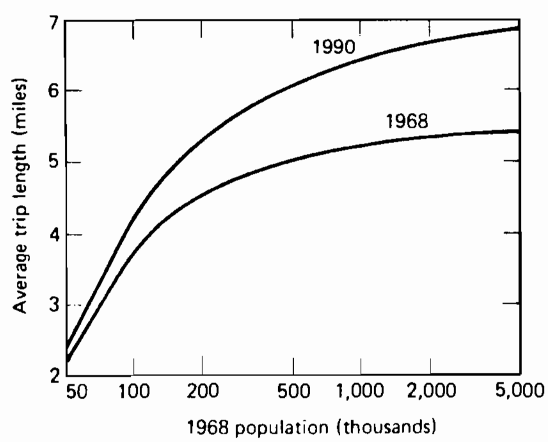


Fig. 5-2. Average trip length in urban areas (Ref 32)

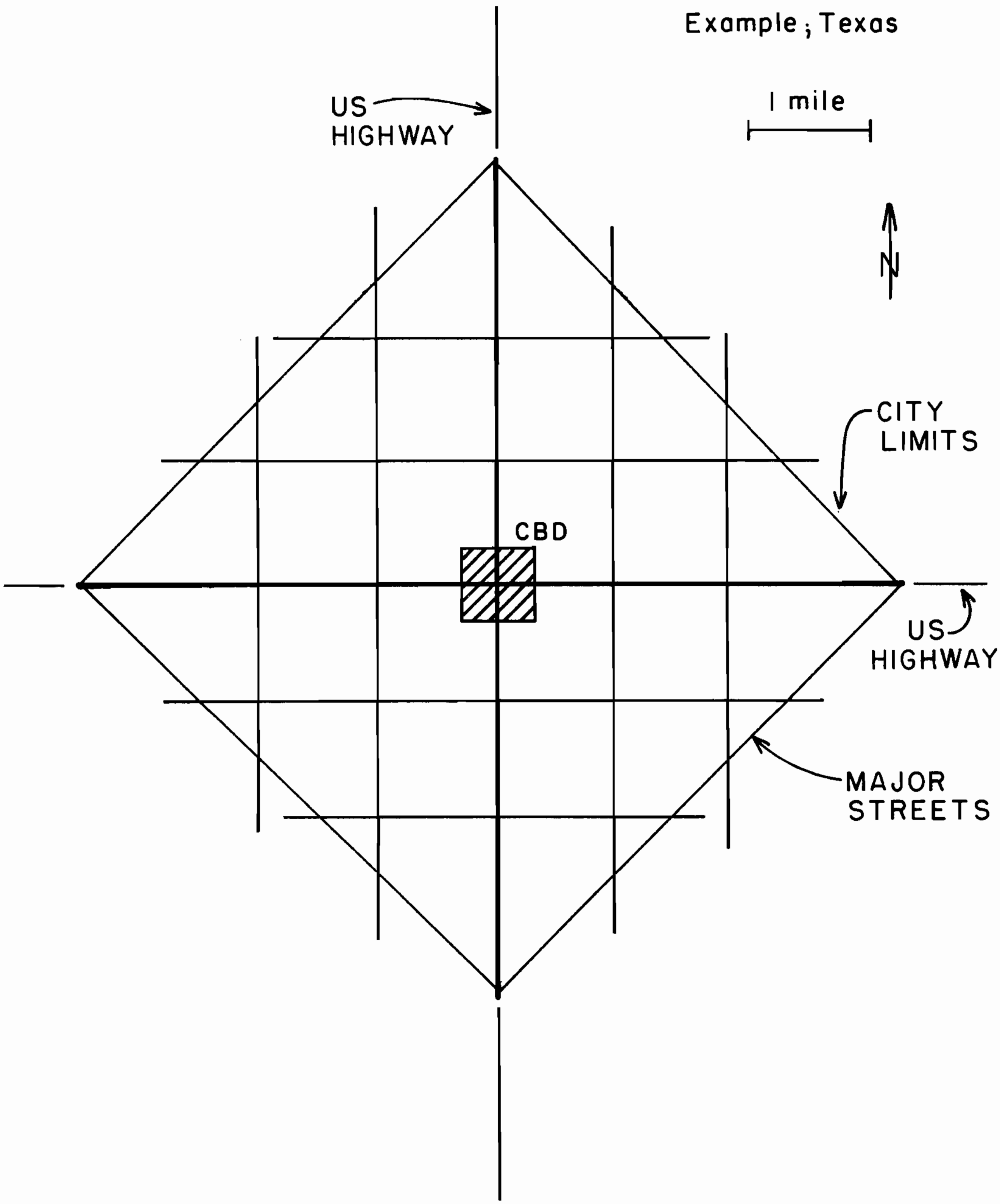


Fig. 5-1. Map of example community

Trial Routing. Two sets of routes are developed, as shown in Figs. 5-3 and 5-4. Route set number one consists of two routes which follow the U.S. highways and two routes which are designed to serve the four quadrants. Route set number two consists of the same basic routes extended to provide more coverage. Figures 5-5 and 5-6 show the coverages for route sets one and two respectively.

Route Coverage. The route coverage area measured for route set number one is 8.75 square miles. Out of a total area of 25 square miles, route set number one covers 35 percent of the community. Route set number two covers 11.75 square miles, or 47 percent of the community.

Number of buses vs. LOS

(1) Round-trip lengths

Average vehicle speed = 15 mph

	Length (miles)	
Route	Set No. 1	Set No. 2
E-W	8	12
N-S	8	12
NW-SE	8	12
NE-SW	8	12

8 miles at 15 mph = 32 minutes; use 35 minutes
12 miles at 15 mph = 48 minutes; use 50 minutes

(2) Sample calculation. The following is an example of the computation of LOS, given an assumed value of N:

Average trip length = 2.5 miles

Average vehicle speed = 15 mph

E = 50% Average auto speed = 25 mph

Number of routes, $(N_R) = 4$

$$\text{Headway, } H = \frac{\text{total round-trip length}}{\text{number of vehicles, } N}$$

$$TT_{Transit} = 2 \text{ min} + 1/2H + \frac{\text{average trip length}}{\text{average vehicle speed}}$$

$$+ E(1 - 1/N_R) + (1/2H) + 2 \text{ min.}$$

$$TT_{Auto} = 1 \text{ min.} + \frac{\text{average trip length}}{\text{average auto speed}}$$

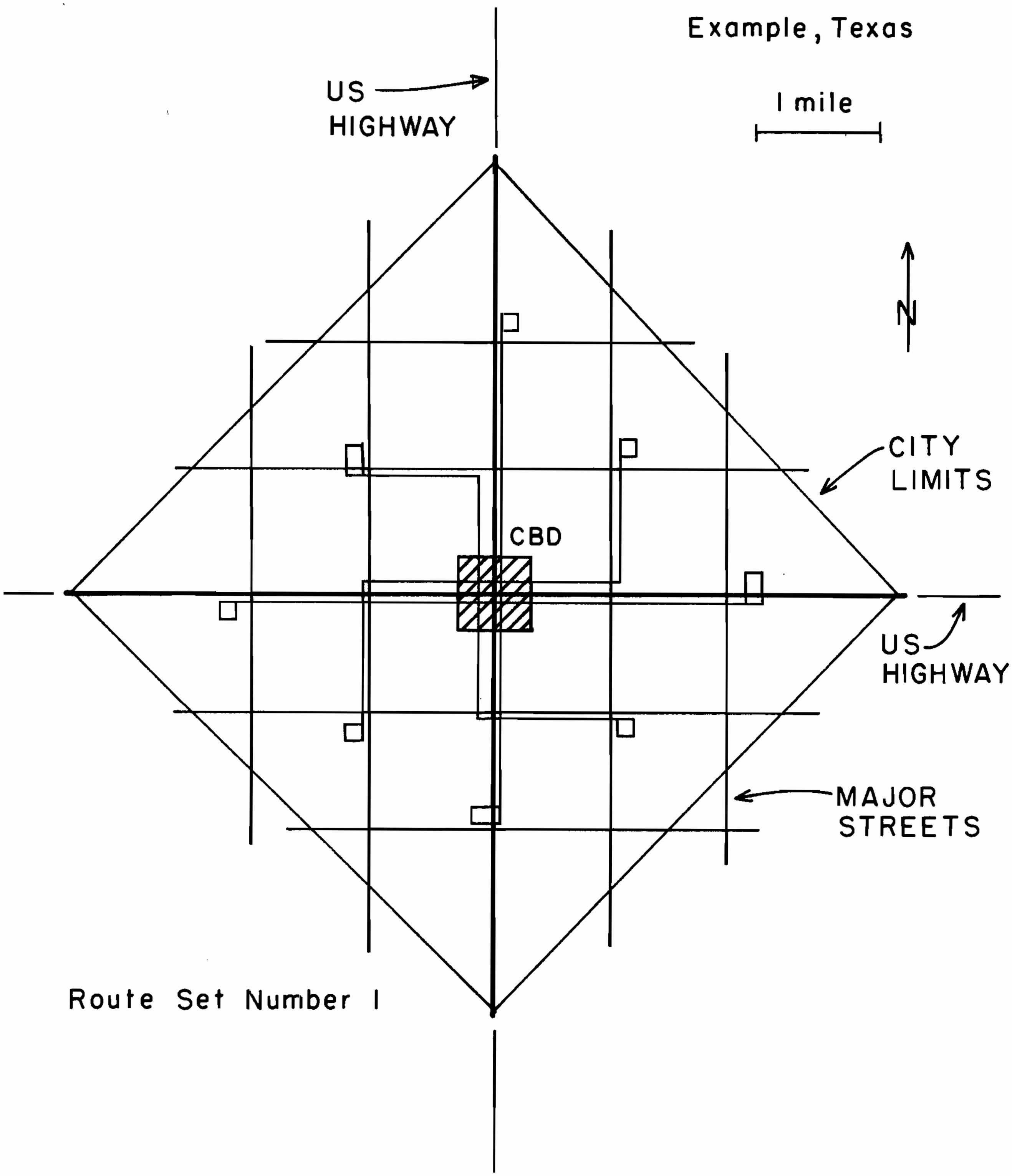


Fig. 5-3. Layout of Route No. 1

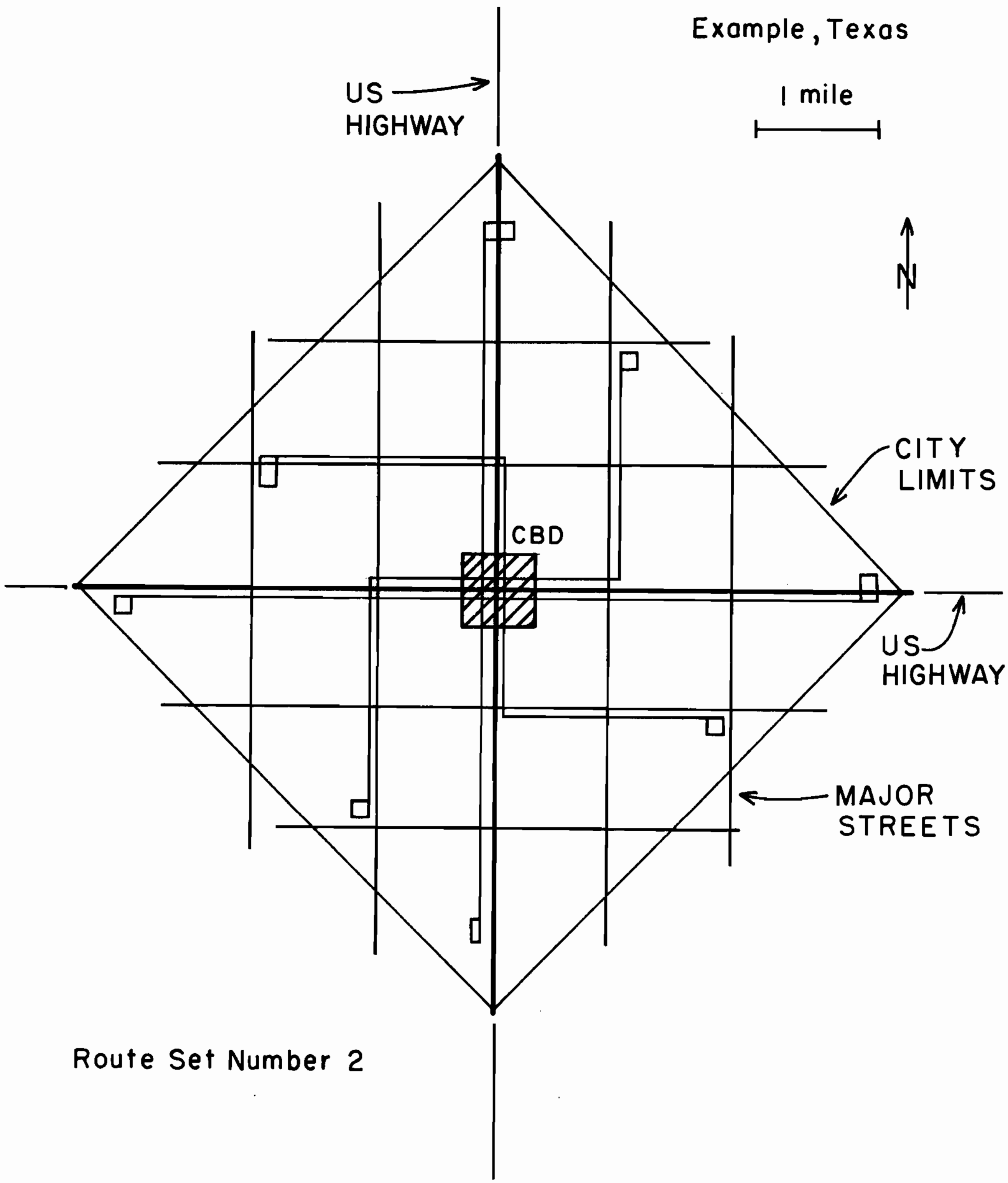


Fig. 5-4. Layout of Route No. 2

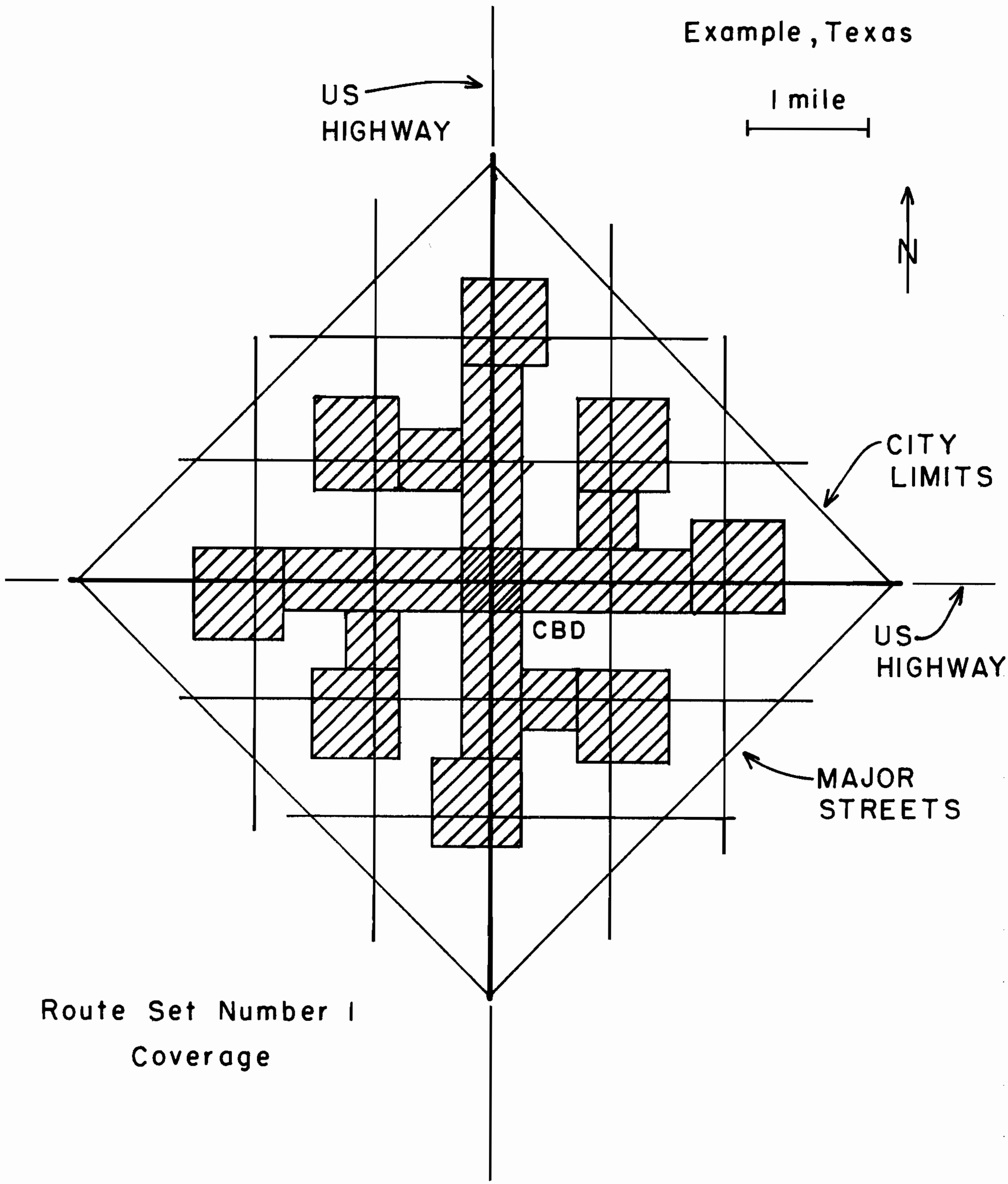


Fig. 5-5. Community coverage of Route No. 1

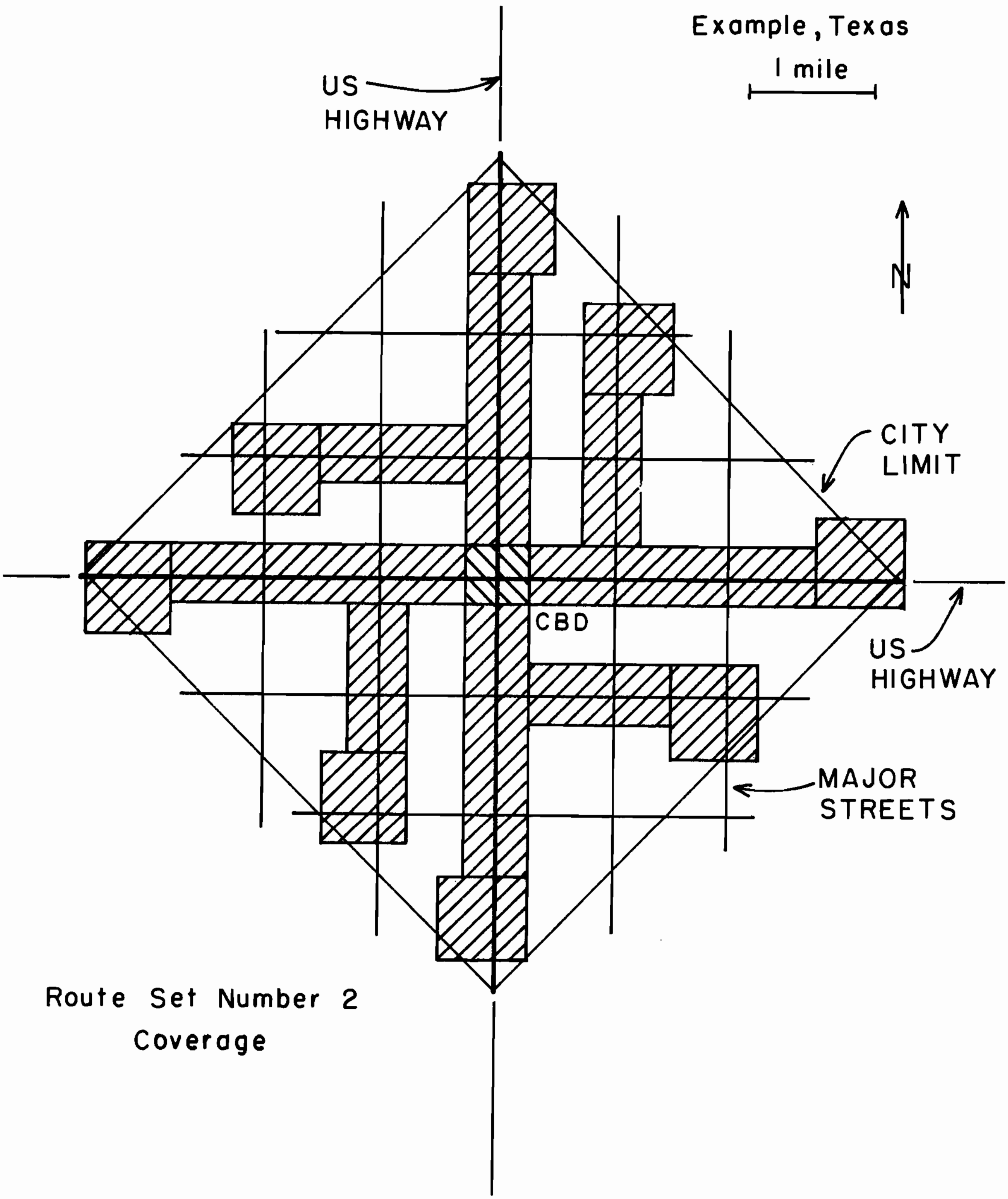


Fig. 5-6. Community coverage of Route No. 2

for Route Set No. 1, N = 4

Total round trip length = 140 minutes

$$H = \frac{140}{4} = 35 \text{ minutes}$$

$$TT_{Transit} = 2 + 1/2(35) + \frac{2.5(60)}{15} + 5.(1 = 1/4)\ 1/2(35 + 2 = 38.06 \text{ min.}$$

$$TT_{Auto} = 1 + \frac{2.5(60)}{25} = 7 \text{ minutes}$$

$$LOS_4 = \frac{TT_{Transit}}{TT_{Auto}} = \frac{38.06}{7} = 5.44$$

An iterative procedure is followed for both sets of routes resulting in sufficient data points (Tables 5-2 and 5-3) to develop the graphical relationship shown in Fig. 5-7.

Demand Responsive System

The relationship between LOS and transit costs is more complicated for demand responsive than for fixed route bus systems. Wait time for demand responsive systems is a function of the number of bus users who precede the rider, and ride time is a function of the number of bus users whose destinations precede that of the rider. Thus LOS, being transit trip time divided by auto trip time, is a function of the number of bus users rather than of the length of headway, as it is for fixed route.

Level-of-Service

There are several models available which relate LOS to the number of buses used in the system. These are summarized in Appendix C. The model here recommended is one developed by Flusberg and Wilson, which has been specifically developed as a sketch planning tool (Ref 19). This model was developed from the demand responsive simulation model at MIT. The mathematical model, developed using the boundary conditions for any system calibrated over variable ranges, is shown below. The model was checked against data for Haddonfield, New Jersey, and Rochester, New York, and in both cases predicted within 10 percent of the actual values.

The model consists of a set of equations that predict mean system wait and ride times for a DRT system:

TABLE 5-2. NUMBER OF VEHICLES VS. LOS FOR ROUTE LAYOUT NO. 1

Number of Vehicles	LOS
4	5.44
8	3.72
12	3.15
16	2.86
20	2.69
24	2.57
40	2.34

TABLE 5-3. NUMBER OF VEHICLES VS. LOS FOR ROUTE LAYOUT NO. 2

Number of Vehicles	LOS
4	6.91
8	4.46
12	3.64
16	3.23
20	3.00
24	2.82
40	2.50

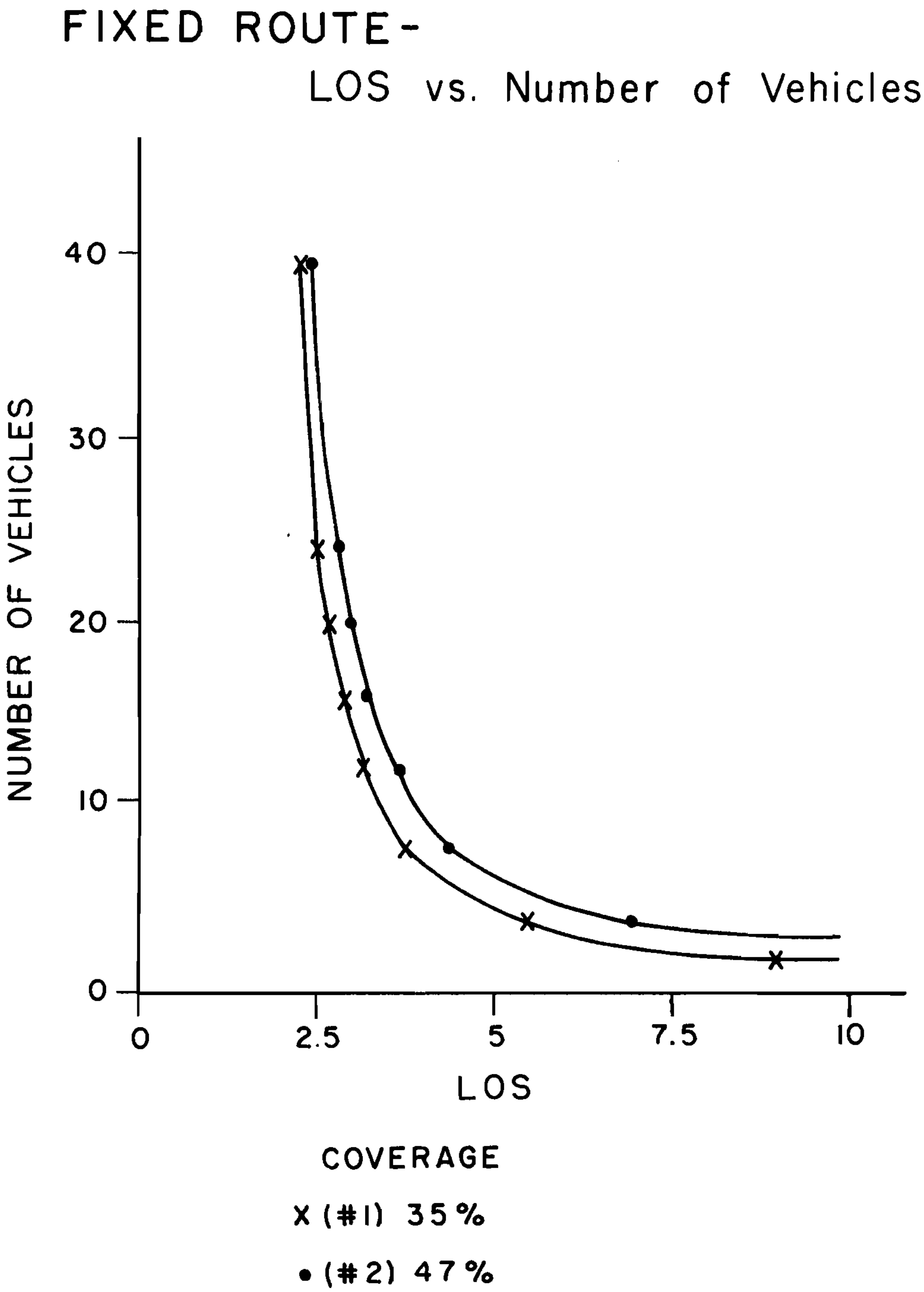


Fig. 5-7. Number of vehicles vs. LOS, fixed route example

$$TT_{Transit} = WT + RT$$

where

$$WT = \left(\frac{fa}{2 \cdot V_{eff}} \right) \left(\sqrt{\frac{A}{N}} \right) \exp \left[k_1 \cdot \left(\sqrt{\frac{A+4}{N+12}} \right) \quad k_2 \right]$$

$$RT = \left(\frac{fa \cdot L}{V_{eff}} \right) \exp \left[k_3 \left(\frac{A \cdot \lambda}{N} \right) \quad k_4 \right]$$

$$\lambda = \frac{D \cdot A}{N}$$

$$V_{eff} = \frac{(60-\lambda)(l+u)V}{60}$$

Variable definitions and calibration ranges are given as

A (area) = 4 mi^2 - 24 mi^2,

N (vehicle fleet size) = 4 - 34,

fa (street adjustment factor) = 1.2 - 1.4,

V (vehicle speed) = .20 mi/min - .30 mi/min,

l,u (load and unload time) = .375 min - 1.25 min,

D (demands per sq mi per hour) = 1 - 45,

λ (demands per vehicle per hour) = 4 - 12.7,

V_{eff} = effective vehicle speed.

The equation constant values developed during calibration are

k_1 = .22 for a bus system and .20 for a shared-ride taxi system,

k_2 = .9 for a bus system and 1.0 for a shared-ride taxi system,

k_3 = .084 for both bus and shared-ride taxi systems,

k_4 = .7 for both bus and shared-ride taxi systems.

The output of the model is travel time by transit. LOS measures are computed from the ratio of travel time by transit and automobile (same as fixed route). Although the mathematics of the DRT equations are more complex than those of previous models, the models are readily understandable and useable. This model is extremely flexible, not only in its ranges of variables but also in its adaptability to alternative system types.

Demand Responsive Procedure

The procedure for relating level of service to number of buses for demand responsive systems utilizes the following parameters.

Demand Density. Demand density, D, is measured in trip demands per unit area per hour. Most existing many-to-many systems operate in the range of 2-5 demands per square mile per hour (Ref 19). The model is calibrated over the range of 1-45 demands per square mile per hour.

Service Area Size. Area size, A, has been calibrated for areas of from 4 square miles to 24 square miles. This area does not have to include the entire community. As area increases, the trip length extends. (To keep times as short as possible, a very large city may require numerous demand responsive zones connected by high quality fixed route service.)

Load and Unload Times. Load and unload times, l and u, are related to the type of vehicle used and the type of fare to be collected. If the vehicle has wide doors and no fare, loading will be faster than for a vehicle which has narrow doors and a fare, for which the driver may have to give change. A typical value would be .5 minute, with the model being calibrated over the range of .375 minute to 1.25 minutes. The latter value would be related to boarding of handicapped and wheelchair users.

Street Network Characteristics. The street network characteristic, fa, is a measure of street travel distance to airline distance. A perfect grid system would have an "adjustment factor" of 1.273 (Ref 19). If the community has an irregular street network with many interruptions and barriers, the value would be higher. For a city with grid and radial streets such as Washington, D.C., the value may be lower.

Mean Direct Trip Length Between Origin and Destination. The average length of trip from the origin to the destination of the transit rider.

Vehicle Speed. The average operating speed, V, of the transit vehicle.

Demand Responsive System Type

The last input is the type of demand responsive system to test. This model has been calibrated for both Dial-A-Ride and shared-taxi operations. The main difference in the model is the size of vehicle used. Dial-A-Ride uses a small bus, one which seats 10 to 14 persons. Shared-taxi systems use large automobiles, which seat at most 5 to 6 passengers.

Once the input values have been determined, the second step in the procedure is to designate the service area. Using the maps developed for the fixed route model in chapter 3, areas where transit service is desirable are outlined. Scaling adjustments can be made as one gains experience with the procedure; therefore, a large scale system is recommended for the first trial. Areas of low potential usage (high income areas) may be excluded. This area, A, should be measured.

The third step is to estimate the demand density, D, of the community. Since precise values are not available, a range of values should be used. Since 2-5 demands per square mile per hour is the usual range, it is suggested that low, medium, and high values, such as 1, 3, and 6 demands per square mile per hour, be used.

The final step is an iterative one consisting of choosing the number of vehicles to be used in computing the corresponding LOS.

To relate demand density to the system another variable, called vehicle productivity, λ, is introduced:

$$\lambda = \frac{D \cdot A}{N} \quad \text{demands/vehicle/hour}$$

To modify vehicle speed, a variable, effective vehicle speed, V_{eff}, is used.

$$V_{eff} = \frac{(60-\lambda)(1+u)V}{60} \quad \text{miles/minute}$$

The final equations are

$$WT = \frac{fa}{2xV_{eff}} \sqrt{\frac{A}{N}} \quad \exp \quad (k_1) \sqrt{\frac{A+4}{N+12}} \quad \lambda^{k_2}$$

where

k_1 = .22 bus) and .20 (shared taxi)

k_2 = .90 (bus) and 1.0 (shared taxi)

and

$$RT = \frac{faxL}{V_{eff}} \quad \exp \left(k_3 \left(\frac{Ax\lambda}{N} \right) k_4 \right)$$

where

$k_3 = .084$

$k_4 = .7$

Travel time by bus equals wait time plus ride times:

$$LOS = \frac{TT_{Transit}}{TT_{Auto}}$$

Similar graphical representations as produced for the fixed route system are produced through sufficient iterations of LOS, computing for various numbers of vehicles and at respective demand densities.

Demand Responsive Procedure Example

To illustrate the demand responsive procedure, Example, Texas, is used. Its attributes have previously been enumerated in the fixed route example.

1. demand density, D - demands per square mile per hour of 3 and 10 are assumed, to bracket the anticipated values.
2. service area size, A - assumed to be the entire community, 25 square miles.
3. load and unload time, l and u - assume 1 minute.
4. street network characteristics, fa - a perfect grid renders a theoretical value of 1.273 city; assume a value of 1.25.
5. average trip length, L - from Fig. 5-2, use a value of 2.5 miles.
6. vehicle speed, V - use typical value, 25 mph.

A sample set of calculations is provided for reference:

$D = 3 \quad N = 20$

$$\lambda = \frac{D\ A}{N} = \frac{3.25}{20} = 3.75 \text{ demands/vehicle/hour}$$

$$V_{eff} = \frac{(60 - \lambda)(1+u) \quad V}{60}$$

$$= \frac{(60 - 3.75(L) \quad 25}{60} = .39 \text{ miles/min}$$

$$WT = \frac{fa}{2\ V_{eff}} \sqrt{\frac{A}{N}} \quad \exp\left(k_1 \sqrt{\frac{A+4}{N+12}} \quad \lambda^{k_2}\right)$$

$$\frac{1.25}{2.39} \sqrt{\frac{25}{20}} \quad \exp\left(.22 \sqrt{\frac{29}{32}} \quad 3.75^{.9}\right) = 3.57 \text{ minutes}$$

$$RT = \frac{fa(L)}{V_{eff}} \quad \exp \left(k_3 \left(\frac{A(\lambda^k)}{N} \right) \right)$$

$$= \frac{1.25(2.5)}{.39} \quad \exp \left(.084 \left(\frac{25}{20} \right) (3.75^{.7}) \right) = 10.44 \text{ minutes}$$

$$TT_{Transit} = 14.01 \text{ minutes}$$

$$TT_{Auto} = 7.0 \text{ minutes}$$

$$LOS_{20} = 2.0$$

A set of values for an assumed number of transit vehicles and computed LOS is developed for two demand density estimates. The results are shown in Tables 5-4 and 5-5. The results are graphically shown in Fig. 5-8.

COST ESTIMATES AND MODEL

The choice of a new alternative requires more than a description of level-of-service. A high LOS system costs more to operate than low LOS system. There is a tradeoff between LOS and system cost. Most alternative selection criteria represent this by either demanding the best service for a price or the lowest price for a level-of-service. A procedure is provided to estimate the cost of a transit system and facilitate an understanding of the tradeoff process. The number-of-buses vs. level-of-service curves are then converted to provide cost vs. LOS relationships. Following the curve conversion, a process to choose points on the curves and to obtain a description of alternatives is presented.

Cost Estimates

Annual system costs are dependent primarily on number and types of vehicles, hours and types of operation, labor agreement, system management organization, and similar variables. The number of possible combinations of these elements greatly compounds the difficulty in developing a cost model. Each aspect of the service must be viewed as to its affect on the total system cost. The costs associated with a transit system can be separated into four components.

Operators Wages and Benefits

These costs are variable and directly related to the number of revenue

TABLE 5-4. NUMBER OF VEHICLES VS. LOS WHERE DEMAND DENSITY EQUALS 3 PERSONS PER SQUARE MILE PER HOUR

D = 3

Number of vehicles	LOS
8	$3x10^5$
10	4.79
15	2.36
20	2.0
40	1.45

TABLE 5-5. NUMBER OF VEHICLES VS. LOS WHERE DEMAND DENSITY EQUALS 10 PERSONS PER SQUARE MILE PER HOUR

D = 10

Number of vehicles	LOS
18	6.22
20	4.81
25	3.14
30	2.46
40	1.91

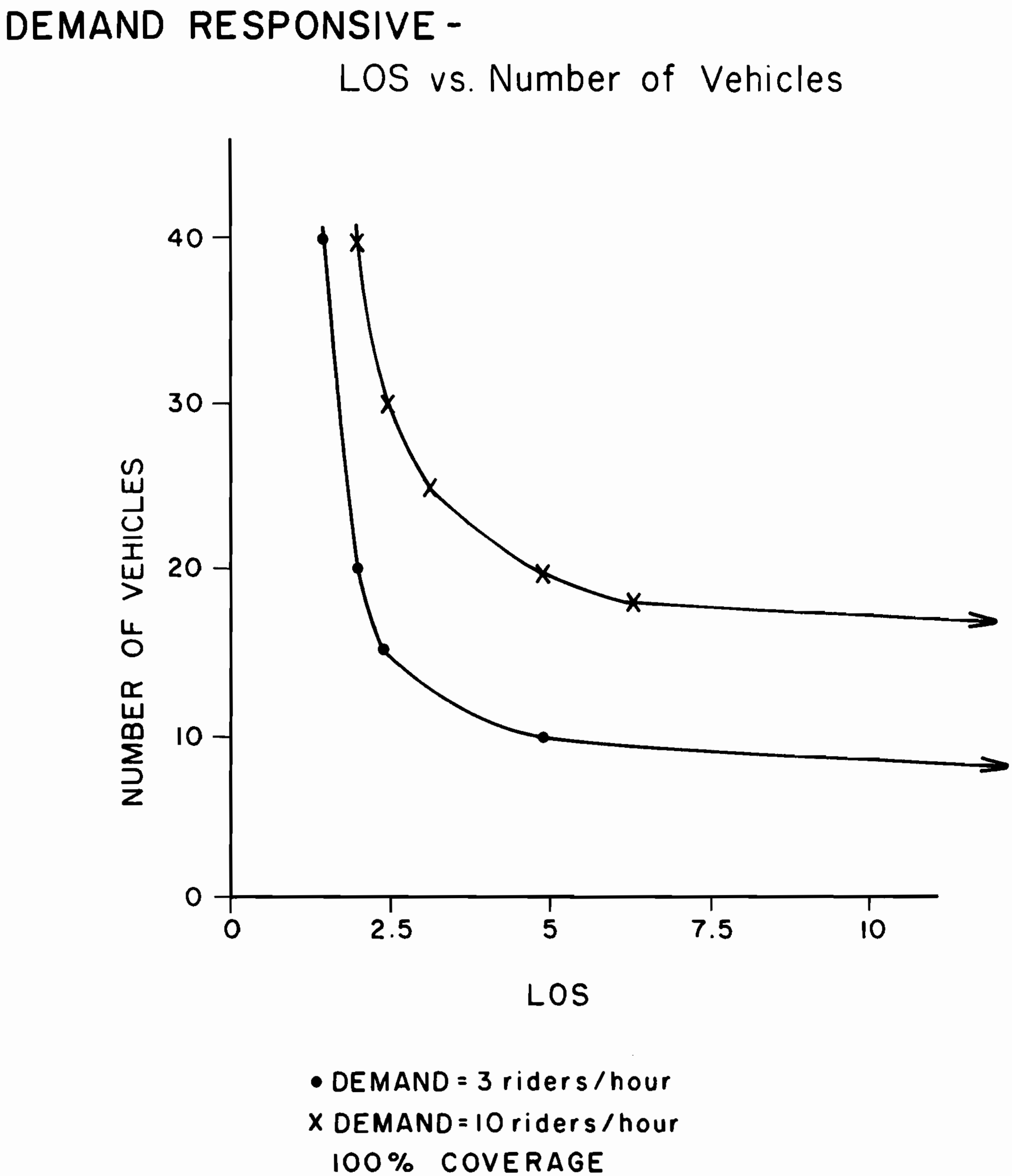


Fig. 5-8. Number of vehicles vs. LOS demand responsive example

hours operated. Revenue hours are those hours spent in service driving the routes. This cost component will include straight time wages, overtime and holiday premiums, and all operator benefits, such as vacation, medical, pension, social security, group insurance, and sick leave. These costs will also be dependent on the labor and union situation within the community. Table 5-6 presents the operators' wages and fringe benefits for the 19 transit operations in Texas.

Transportation Costs

Transportation costs are variable costs related to the consumption of fuel, oil, tires, and parts. Fuel and oil costs vary according to the operating characteristics of the vehicle used and the local costs for fuel and oil. In cases where service and maintenance are contractually provided they are included in the transportation costs. Table 5-7 lists the transportation costs for two buses in Midland's new demand responsive service.

Fixed Overhead Costs

Fixed overhead costs vary widely from one system to the next because they are a function of the maximum number of vehicles operated. Costs include salaries and benefits for management, maintenance personnel, route inspectors, dispatchers, and office personnel. Other related costs are office expenditures, storage, yard maintenance, marketing, legal audits, insurance, purchasing, licenses, and taxes. Many of these costs, such as legal, marketing, and audit costs, may be transferred to another city department. Table 5-8 gives selected wage rates for staff personnel.

Any type of operation will have certain basic staff requirements. A manager will be necessary to set policy and assure system operations and performance. The manager is responsible to city officials for the transit operation, personnel, bookkeeping, and purchasing. A senior level administrator with transit experience is desirable. The number of management personnel will be dependent on the size and complexity of the operation. For a small operation, proper management may involve only one-half of the hours necessary to adequately perform the job of a city engineer or manager. For large operations an additional assistant manager may be necessary to insure a smooth running operation. A part-time secretary will undoubtedly be required to handle correspondnece and other office duties. One or more

TABLE 5-6. AVERAGE OPERATOR COSTS, TEXAS TRANSIT SYSTEMS

City	Year	Starting Wage/Hr.	Top Wage/Hr.	Fringe Benefits
Abilene	1980	$ 4.14	$ 5.26	Social security, Texas retirement insurance
Amarillo	1980	4.50	5.75	Uniform allowance, sick leave, vacation time based on longevity
Austin	1980	5.93	6.52	Fringe benefits equal to approx. 37.6% of the wage
Beaumont	1980	4.26	5.00	Pension-5% deduction matched with 7½%, sick leave, life and hospital insurance
Brownsville	1980	3.08	3.08	Workman's compensation, life insurance, retirement, FICA
Corpus Christi	1980	3.96	5.11	Holidays, sick leave, vacation, insurance, TMRS, uniform
Dallas	1980	6.00	6.42	Bonus Pay
El Paso	1980	4.59	5.34	Fringe benefits equal to approx. 29% of the wage
Fort Worth	1980	5.86	6.15	Paid vacation, holidays, health and hospitalization insurance
Galveston	1980	4.58	4.58	Insurance
Houston	1980	6.93	8.15	Work and time incentives, longevity bonuses, medical insurance
Laredo	1980	4.19	4.24	Holidays, vacation time based on longevity, uniform, and disability
Lubbock	1980	4.16	4.94	Holidays
Port Arthur	1980	5.78	6.05	Fringe benefits equal to approx. 31.61% of the wage
Midland	1980	3.50	5.05	Fringe benefits equal to approx. 7% of annual wage
San Angelo	1980	3.62	3.87	Holidays, sick leave, vacation, insurance, TMRS, uniform
San Antonio	1980	5.29	6.37	Fringe benefits equal to approx. 58% of the wage, including uniform, sick leave, vacation and longevity pay, insurance
Waco	1980	4.60	5.16	Health insurance, pension, vacations, holidays, and uniform
Wichita Falls	1980	4.14	4.80	Health insurance, vacation, sick leave, and uniform

NOTE: Statistics and information compiled in cooperation with transit officials from the various transit departments and systems.

TABLE 5-7. TRANSPORTATION COST FOR TWO BUSES IN MIDTRANS DEMAND RESPONSIVE TRANSIT SERVICE, MIDLAND, TEXAS, JUNE, 1980

Item	Bus 1		Bus 2, with lift	
	Qnty.	Dollars	Qnty.	Dollars
Oil - quarts, cost	6	4.20	12	8.40
Fuel - gallons, cost	419.6	307.24	520.6	380.69
Labor - hours, cost	28	177.59	27	201.51
Parts				
No. 1 Direct	---	31.45	---	42.26
No. 2 Inventory	---	188.26	---	5.44
Filters	---	10.65	---	8.74
TOTAL OPERATING EXPENSE		$719.39		$647.04

Source: Operating Statistics, MIDTRANS, Midland, Texas, June 1980.

TABLE 5-8. LABOR COSTS FOR FIXED ROUTE AND DEMAND RESPONSIVE SYSTEM

Fixed Route - Austin, Texas

General Manager	NA
Manager	NA
Supervisors	14,448
Dispatchers	14,448
Mechanic I	13,632
Mechanic II	12,960
Mechanic III	12,480
Drivers	12,518
Servicemen	12,000
Secretary	12,564
Clerk	8,000
Cleaners	11,000

Demand Responsive - Midland, Texas

Director	34,416
Operations Supervisor	15,564
Maintenance Supervisor	13,416
Dispatchers	11,040
Drivers	10,504
Secretary	10,008
Custodian	7,488

Source: Personal interviews.

dispatchers are needed to keep the operation going by routing buses, handdling emergencies, and maintaining communications with the vehicle.

If maintenance is performed internally, approximately one mechanic per ten vehicles will be needed to maintain the vehicles (Ref 76). In addition to the basic staff requirements, a special service staff is necessary to run a demand-responsive system. The inherent characteristics of a demand-responsive system necessitate the operation of an effective communications system for answering incoming telephone calls, routine vehicles, and communicating with the drivers. In terms of peak riders per shift, there should be a telephone answerer for every 30-40 riders, a scheduler for every 75 riders, and a dispatcher for every 75 riders (Ref 3). These requirements may be lessened through large-scale use of subscription service. This allows the schedulers to use the low-demand periods to work out schedules to be used at a later time.

Capital Costs

Capital costs are initial expenditures required to purchase assets needed to operate the system. Vehicles must be purchased before a transit system can operate. Other assets include buildings for operations, communication devices, auxiliary vehicles, maintenance equipment, and miscellaneous materials, such as fare collection systems.

Transit vehicle costs can be estimated by determining the service and operational requirements and then contacting several manufacturers for specific cost information. Federal and state finanacial support requires additional inspection procedures. Table 5-9 lists the purchase price for fixed route and demand responsive vehicles in selected Texas transit systems.

The costs of physical facilities vary directly with the type and requirements of the transit service. Small systems may be able to utilize existing public or private facilities. Large systems, however, may have to purchase new administrative and maintenance facilities. Table 5-10 lists average costs for building facilities. Maintenance and service equipment also need to be purchased. The equipment requirements will vary depending on whether the services rendered will be performed inhouse or contracted out. Table 5-11 lists essential maintenance equipment and average prices. Servicing equipment costs also vary according to operation size. For example, communication between the vehicles and dispatchers is desirable for large

TABLE 5-9. COST OF TRANSIT VEHICLES FOR SELECTED TRANSIT SYSTEMS IN TEXAS

FIXED ROUTE VEHICLES

City	Year	Model	Cost	Capacity	Wheelchair Lift
Abilene	1966	GM Diesel	$ 25,000	35	No
	1980	Undetermined	103,000*	28	Yes
Amarillo	1972	GMC	28,313	31	No
	1973	Twin Coach	30,970	33	No
	1977	AM General	65,464	45	No
	1978	Superior	22,450	28	No
Austin	1973	GMC	43,000	45	No
	1975	GMC		45	No
	1976	AM General		41	No
	1978	AM General	79,000	41	No
Beaumont	1975	AM General 9635A	60,000	43	No
Brownsville	1980	Trans. Mfg. T-30	70,000	32	No
	1980	Trans. Mfg. T-30	89,000	28	Yes
Corpus Christi	1979	GM RTS-II	102,943	37	No
	1980	Bluebird	70,814	31	No
Dallas	1964	GMC	31,261	51	No
	1965	GMC	30,591	51	No
	1966	GMC	31,635	51	No
	1972	GMC	42,414	51	No
	1975	GMC	53,186	51	No
	1975	Twin	53,727	21	No
	1975	Grumman Flxible	20,560	19	No
	1978	GMC	87,325	47	No
	1979	Superior	15,827	10	Yes
	1980	Grumman Flxible	107,500	48	No
El Paso	1978	GM RTS-II	94,200		No
Fort Worth	1973	Grumman Flxible	36,704	45	No
	1973	Grumman Flxible	38,733**	45	No
	1975	Grumman Flxible	51,117	51	No
	1978	GM RTS-II	94,200		No
	1980	GM RTS-II	138,227	51	No
Galveston	1975	GM 43-H	58,000	43	No
Houston	1975	GMC-5307A	58,540	51	NA
	1978	GM RTS-II	86,167	47	NA
	1979	Eagle	120,199	53	NA
	1979	GF-870	103,392	46	NA
Laredo	1980	Trnas. Mfg.	85,000	31	Yes
Lubbock	1980	GM RTS-II	126,606	37	No
	1980	GM RTS-II	145,000	37	Yes
Port Arthur	1979	Chance RT-50	79,000	25	No
San Antonio	1977	Trans Coach	38,000	20	No
	1978	GM RTS-II	85,000	47	No
	1979	Chance	41,000	20	No
	1980	GM RTS-II	112,000	38	No

Continued

TABLE 5-9. COST OF TRANSIT VEHICLES FOR SELECTED TRANSIT SYSTEMS IN TEXAS (continued)

City	Year	Model	Cost	Capacity	Wheelchair Lift
Waco	1979	Trans. Mfg.	71,000	31	No
	1979	Trans. Mfg.	79,000	29	Yes
Wichita Falls	1974	Ford Flxette	16,776	31	No
	1974	Twin Coach	32,533	31	No
	1975	Twin Coach	42,236	31	No
		DEMAND RESPONSIVE VEHICLES			
Austin		Chance Minibus	76,000	15	Yes
		Dodge Maxivan	11,000	4	Yes
Beaumont		Vans, converted	23,000		Yes
CARTS	1978	Collins	14,900	12	No
	1978	Collins	16,000	8	Yes
	1978	Wayne Transette	17,000	14	No
	1978	Wayne Transette	19,000	12	Yes
Fort Worth	1979	Dodge Van	17,281	12	Yes
Port Arthur	1979	Vans w/Braun Lifts	17,000		Yes
Midland	1980	Coach & Equip.	25,000	20	No
	1980	Coach & Equip.	28,000	12	Yes
San Antonio	1979	Dodge	9,000	8	Yes

*New bids on 1980 buses have not, at this time, been opened. This cost is an estimate. The model is undetermined for the above reason.

**Price differences on the 1973 Grumman models are due to variations in transmission size.

NOTE: Statistics and information compiled in cooperation with transit officials from the various transit departments and systems.

TABLE 5-10. TYPICAL COST OF PHYSICAL FACILITIES, 1977

I. Cost/Square Foot of Physical Facilities*

	1975	1977
Service	$75	$90++
Maintenance	$40	$48
Administrative+	$40	$48
Inspection & Storage	$30	$36
Parking		$ .28

II. Square Footage of Physical Facilities*

Required per Bus	Number of Square Feet
Stalls	100
Pit	60
Service, Fuel & Cleaning+	40
Stockroom+	20
Shoprooms	20
Administrative+	15
Parking+	560
Other - Restrooms, etc.+	35

III. Cost of Physical Facilities per Bus

	1975	1977
Maintenance Stalls	$4,000	$4,800
Inspection Pits	$1,800	$2,200
Service Lanes+	$3,000	$3,600
Stockrooms, Shoprooms, Other+	$2,200	$2,700
Administrative+	$ 600	$ 700
Parking**+		$ 157

*All Figures based on estimates in Bus Maintenance Facilities, U.S. DOT/UMTA, November, 1975. Adjusted to 1977 using 1975 as base year and 10 percent inflation.

**Parking cost based on two inches of base material and a total cost of $2.50 a square yard.

+Minimum facilities needed if maintenance contracted out.

++If minimum service is done certain equipment will not be necessary and cost could be as low as $50 a square foot.

TABLE 5-11. COST OF MAINTENANCE EQUIPMENT, 1975

Item	Minimum	High	Average Per Bus
Air Compressor*	$13,000	$52,000	$520
Brake Drum Lathe	4,000	8,000	80
Heavy-duty Press	2,000	4,000	40
Portable Lifts	4,000	16,000	140
Bus Washer	18,000	55,000	400
Interior Vacuum	15,000	30,000	220
Fuel Tanks*	3,000	5,000	45
Chain Hoist	3,000	9,000	60
Drill Press**	1,500	2,500	40
Metal Lath**	3,500	4,500	80
Arc Welder**	750	1,000	35
Wheel Dolly**	400	600	20
Miscellaneous Tools**	5,000	8,000	130

	1975	1977
Total Average per Bus	$ 1,810	$ 2,170
Total Average per Bus*		565

*Minimum equipment needed of systems leasing out maintenance.
**Estimations based on approximate value.

Source: Bus Maintenance Facilities, U.S. DOT/UMTH, November 1975.

operations. Mobile radios cost approximately $1500 per unit with an additional $5000 for the base radio. Citizen band radios, however, may be an alternative for smaller systems.

For comparative analyses, all costs associated with transit service should be presented in equivalent annual costs and all first, periodic, and depreciation costs should be considered.

Cost Model

There are three variables which primarily determine the total annual costs of a bus transit system. They are

1. the total number of buses,
2. the number of bus-hours operated, and
3. the number of bus-miles operated.

The inputs from the previous transit system models are curves relating number-of-buses to the level-of-service provided. Therefore, the number of buses has been previously assumed.

The number of bus hours operated per week will be dependent on the decision of the planner, transit manager, or other decision maker. A typical system operates 108 hours per week. Monday through Saturday, it may operate from 6:30 a.m. to 11:00 p.m. Some systems, having limited objectives, have reduced their operating hours to help implement those goals. The East Chicago Transit System does not begin operation until 10:00 a.m., to keep work trips from flooding the system (Ref 19).

The third measure of operation is the number of bus miles operated. This is closely related to the number of bus hours operated. The usual fixed route bus in a large community will oeprate at 10 to 15 mph (Ref 84). In smaller communities the higher value will be a better estimate. This value will be dependent on the number of stops and slow downs on the routes. These may be caused by passengers, traffic conditions, or traffic signals. Demand responsive systems usually operate about 5 mph faster than the fixed route system, or about 20 mph.

Of the three measures of operation used in this cost model two are policy related (number of buses and hours of operation) while the third is estimated using average values for vehicle speed of operation.

Curve Conversion

A curve conversion is required to understand the relationship between LOS, number of vehicles, and cost. This section provides a method for converting the N vs. LOS curves to annual cost vs. LOS curves. The annual cost is estimated by summing the cost types within each category and multiplying them by their respective measures of operation. Operator wages and benefits are measured by the number of hours of operation. Transportation costs are a function of the number of miles operated by the system.

$$\text{Annual System Cost} = \text{Annual FO} + (\text{Annual OW\&B} + \text{Annual TC} + \text{Annual CC}) \times \text{Number of Buses}$$

Each set of system parameters will produce a different equation.

Cost Model - Example, Texas

In two previous sections a community, Example, was used for illustration. From these studies, two sets of curves were created which relate number of buses to LOS. In order to place these divergent transit system types on common ground, the curves will be converted to annual system cost vs. LOS after an estimation of costs.

The assumptions made in the previous section which are needed in this model are

- system operated 108 hours per week,
- F.R. bus travels at an average speed of 15 mph, and
- D.R. van operates at an average speed of 20 mph.

The cost estimates are typical values taken from prior experiences and modofied to reflect present conditions. Operators' wages and benefits for both system types are estimated to be $4.50 per hour.

Transportation costs were set at 20¢ per mile for buses and 8.5¢ per mile for vans. Table 5-12 shows the component costs for each vehicle type.

Fixed overhead costs are costs related to permanent office personnel and equipment. It is assumed the maintenance and service functions have been contracted, which thereby reduces the overhead costs for the transit system. It is assumed that personnel requirements vary according to work loads or that larger properties require more management. Small systems with 15 or less buses require a staff similar to that shown in Table 5-13. The assistant managers could act as dispatchers. For larger systems, of 16 to 50

TABLE 5-12. EXAMPLES OF VEHICLE OPERATING COSTS

	GMC Coach $/Mile	Van $/Mile
Parts and Labor	.065	.005
Fuel	.08	.05
Oil	.005	.003
Tires	.014	.005
Service	.030	.020
	.194($/Mile)	.083($/Mile)

Source: Gordon Derr, Preliminary Evaluation of Public Transit Options for Small Communities. Masters Thesis, University of Texas at Austin, May 1978.

TABLE 5-13. TRANSIT SYSTEM MANAGEMENT PERSONNEL REQUIREMENTS

15 or less buses	16 to 50 buses
Manager	Manager
2 Asst. Managers	Asst. Manager
Secretary	2 Secretaries
	2 Dispatchers

Source: Gordon Derr, Preliminary Evaluation of Public Transit Options for Small Communities. Masters Thesis, University of Texas at Austin, May 1978.

buses, the staff, also shown in Table 5-13, would be increased according to typical requirements.

Demand responsive systems require additional personnel, particularly for their communication requirements. One call taker will be needed for every five buses and one scheduler for each 10 buses. Every 10 buses would require three staff personnel. In this sample procedure, their salaries are figured at \$800 each or \$24,000 or an additional \$2400 per bus per shift for calls and scheduling. Office supplies and utilities are assumed to be \$1400 + \$75 per office person.

Amortization of capital costs is considered at an annual vestcharge rate of 10 percent per year. For illustrative purposes, minibus costs are figured at \$23,000 each and vans, \$11,000 each. The administration building and bus parking cost about \$1000 per bus. In addition, \$2000 per year is needed for insurance and other expendable items, such as uniforms for drivers. Table 5-14 shows a summary of all of the cost items for each system type.

After the system has been described and the cost figures defined, the final step is to combine the level of service measure and the annual cost to form cost curves. Tables 5-15 thru 5-18 show the cost computations for the four service alternatives. The two fixed route sets, one and two, are shown in Tables 5-15 and 5-16, respectively. Table 5-17 shows the demand responsive option, using a demand density of 3 demands per square mile per hour. The D.R. system using 10 demands per square mile per hour is shown in Table 5-18. Figure 5-9 shows the final annual cost vs. level of service graphs.

An annual system cost and LOS can be obtained directly from Fig. 5-9. The figure can be varied in its application to reflect the decision making criteria of either cost or LOS. To illustrate the use of the curves, consider the set of LOS vs. cost curves shown in Fig. 5-10. As an initial consideration an annual cost of one million dollars is used to enter the curves. For that cost, four alternative are defined by the intersection of the constraint line (\$1 million) with each of the systems forms. The alternatives are:

TABLE 5-14. SUMMARY COST VALUES, EXAMPLE PROBLEM

	Fixed Route	Demand Responsive
Operators' Wages & Benefits (per bus hour)	$ 4.50	$ 4.50
Trnasportation Costs (per vehicle mile)	.20	.085
Fixed Overhead (size related)		
< 15 buses	42,000.	42,000. + 2,400.
≥ 15 buses	58,000.	58,000. + 2,400.
Office & Utilities	1,400. + 75. office person	1,400. + 75. office person
Capital Costs		
Per vehicle	23,000.	11,000.
Administration & Parking	1,000.	1,000.
Amortization Rate	10% (2,400.)	10% (2,400.)
Insurance & Miscellaneous	2,000.	2,000.
	4,400.	3,200.

TABLE 5-15. ANNUAL COST COMPUTATION, FIXED ROUTE BUS LAYOUT #1

F. R. Route Set #1 35% Coverage											
A	B	C	D	E	F		G	H	I	J	K*
Number of Buses	Hours of Operation	One Way and Back	Miles of Operation	TC	Size Category		F.O. Personnel	F.O. Supplies	CC	Total	LOS
N	Nx108x52	Bx4.50	Bx15 mph	D x $.2/mi	≤15	>15			Nx4400	C+E+G+H+I	
4	22,464	101,088	336,960	67,392	X		42,000	1700	17,600	230,000	5.44
8	44,908	202,176	673,920	134,784	X		42,000	2000	35,200	416,160	3.72
12	67,392	303,264	1,010,880	202,176	X		42,000	2300	52,800	602,540	3.15
16	89,856	404,352	1,347,840	269,568		X	58,000	2600	70,400	804,920	2.86
20	112,320	505,440	1,684,800	336,960		X	58,000	2900	88,000	991,300	2.69
24	134,784	606,528	2,021,760	404,352		X	58,000	3200	105,600	1,177,680	2.57
40	224,640	1,010,880	3,369,600	673,980		X	58,000	4400	176,000	1,923,260	2.34

*See Fig. 5-7 for LOS ratings.

TABLE 5-16. ANNUAL COST COMPUTATION, FIXED ROUTE BUS LAYOUT #2

F. R. Route Set #2 47% Coverage											
A	B	C	D	E	F		G	H	I	J	K*
Number of Buses	Hours of Operation	One Way and Back	Miles of Operation	TC	Size Category		F.O. Personnel	F.O. Supplies	CC	Total	LOS
N	Nx108x52	Bx4.50	Bx15 mph	D x $.2/mi	≤15	>15			Nx4400	C+E+G+ H+I	
4	22,464	101,088	336,960	67,392	X		42,000	1700	17,600	280,000	6.91
8	44,908	202,176	673,920	134,784	X		42,000	2000	35,200	416,160	4.46
12	67,392	303,264	1,010,880	202,176	X		42,000	2300	52,800	602,540	3.64
16	89,856	404,352	1,346,840	269,568		X	58,000	2600	70,400	804,920	3.23
20	112,230	505,440	1,684,800	336,960		X	58,000	2900	88,000	991,300	3.0
24	134,784	606,528	2,021,760	404,352		X	58,000	3200	105,000	1,177,680	2.82
40	224,640	1,010,880	3,369,600	674,980		X	58,000	4400	176,000	1,923,260	2.5

*See Fig. 5-7 for LOS ratings.

TABLE 5-17. ANNUAL COST COMPUTATIONS, DEMAND DENSITY EQUALS 3 DEMANDS PER SQUARE MILE PER HOUR

D. R. Demand Density = 3 persons/mi^2											
A	B	C	D	E	F		G	H	I	J	K*
Number of Buses	Hours of Operation	One Way and Back	Miles of Operation	TC	Size Category		F.O. Personnel	F.O. Supplies	CC	Total	LOS
N	Nx108x52	Bx4.50	Bx15 mph	D x .085	≤ 15	>15			Nx4400	C+E+G+ H+I	
10	56,160	252,720	1,123,200	95,472	X8		66,000	2000	32,000	448,192	4.79
15	84,240	379,080	1,684,800	143,208	X9		78,000	2075	48,000	650,363	2.36
20	112,320	505,440	2,246,400	190,944		X11	106,000	2225	64,000	868,609	2.0
40	224,640	1,010,880	4,492,800	381,888		X17	154,000	2675	128,000	1,677,443	1.45

*See Fig. 5-8 for LOS ratings

TABLE 5-18. ANNUAL COST COMPUTATIONS, DEMAND DENSITY EQUALS 10 DEMANDS PER SQUARE MILE PER HOUR

D. R. Demand Density = 10 persons/mi^2											
A	B	C	D	E	F		G	H	I	J	K*
Number of Buses	Hours of Operation	One Way and Back	Miles of Operation	TC	Size Category		F.O. Personnel	F.O. Supplies	CC	Total	LOS
N	Nx108x52	Bx4.50	Bx20mph	Dx.085	≤ 15	> 15			Nx3200	C+E+G+ H+I	
18	101,088	454,896	2,021,760	171,849		X11	101,200	2225	57,600	787,770	6.22
20	112,320	505,440	2,246,400	190,944		X	106,000	2225	64,000	868,609	4.81
25	140,400	631,800	2,808,000	238,680		X13	118,000	2375	80,000	1,070,855	3.14
30	168,480	758,160	3,369,600	286,416		X15	130,000	2525	96,000	1,273,101	2.46
40	224,480	1,010,860	4,492,800	381,886		X	154,000	2675	128,000	1,677,443	1.91

*See Fig. 5-8 for LOS ratings

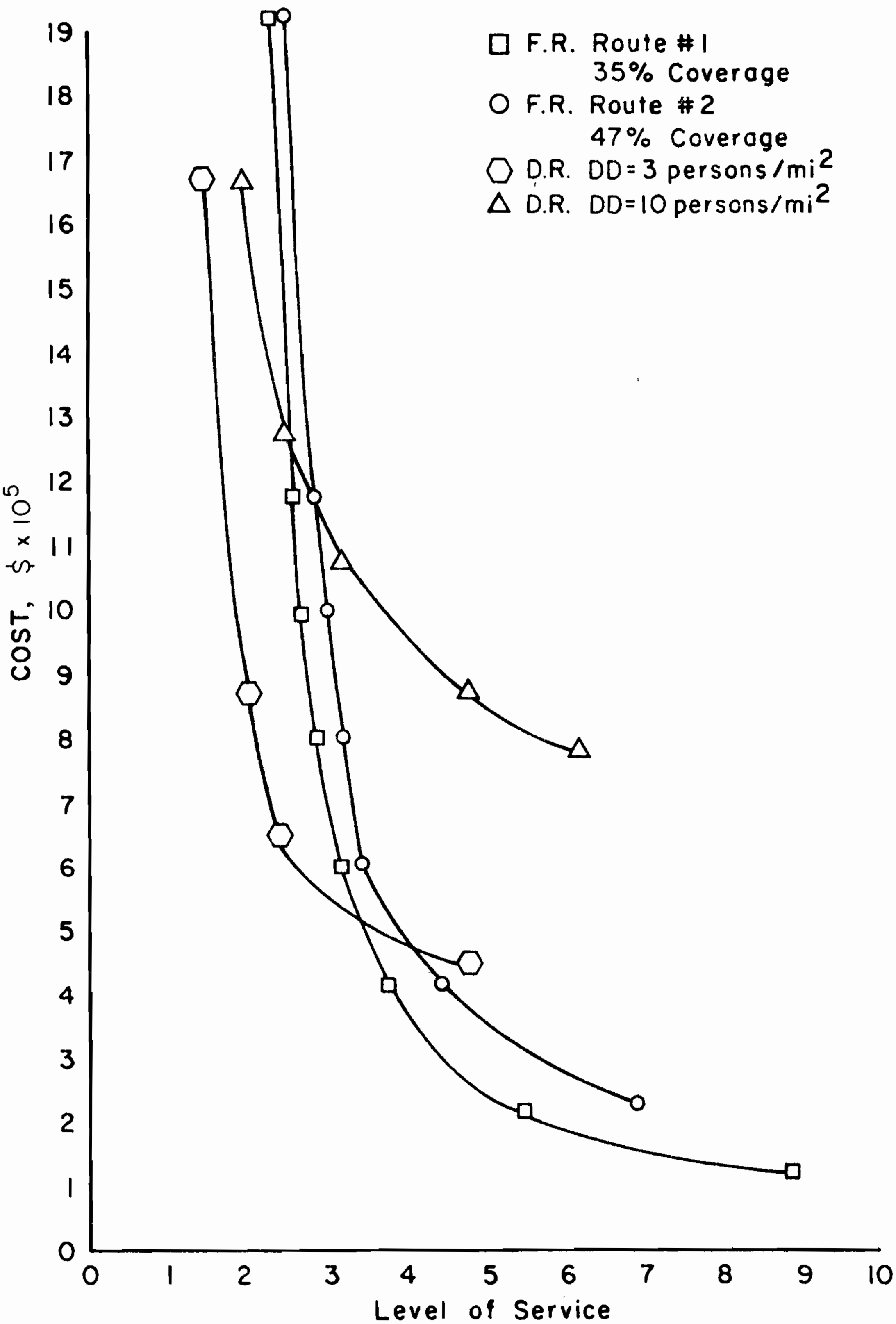


Fig. 5-9. Annual cost vs. level-of-service

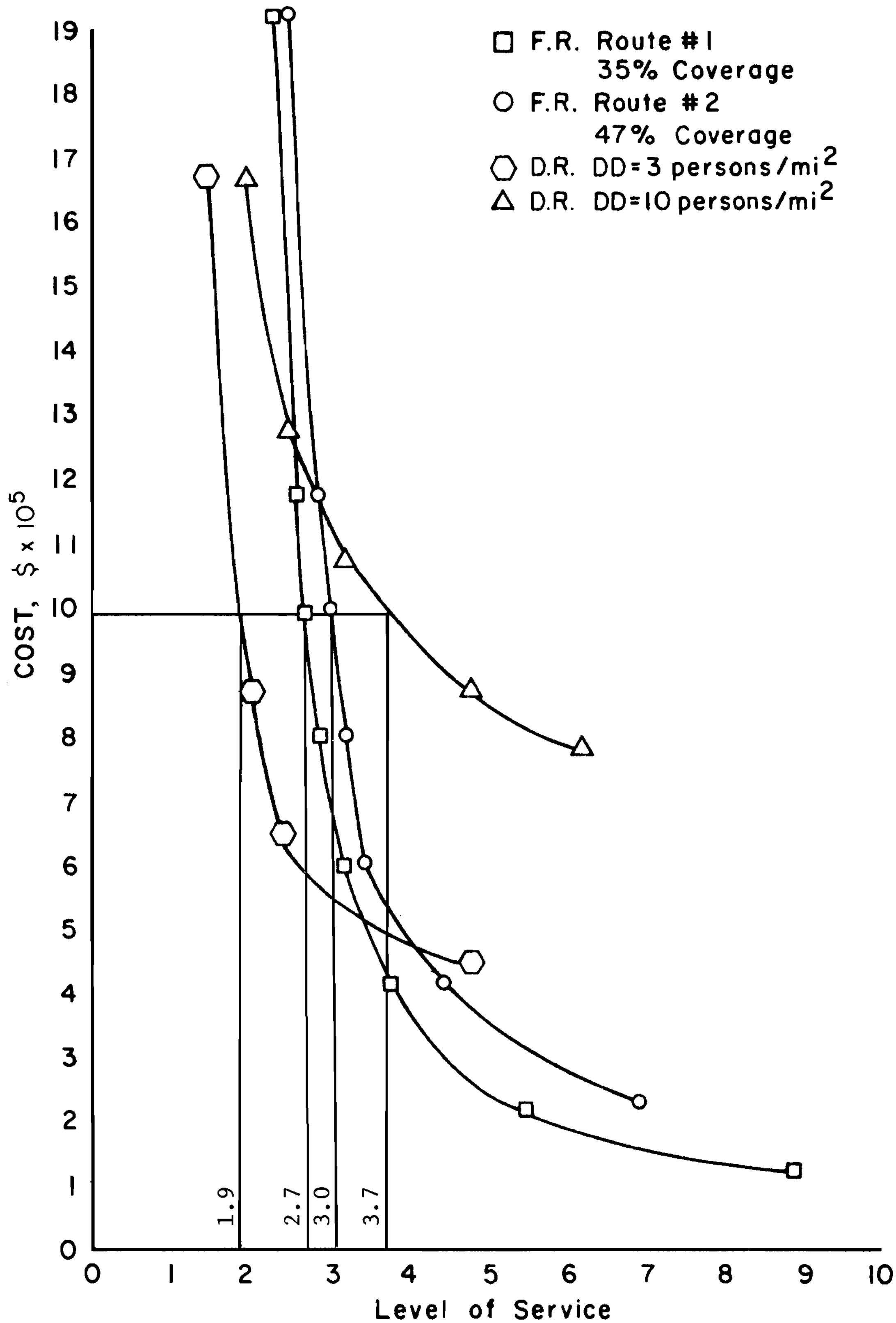


Fig. 5-10. Alternative choice using cost criteria

System	LOS
F.R., 35% cover	2.7
F.R., 47% cover	3.0
D.R., DD = 3/sq mi	1.9
D.R., DD = 10/sq mi	3.7

If the LOS was the initial criterion then the horizontal axis is entered with a predetermined value. Figure 5-11 shows an LOS criterion of 3 and the resultant annual costs.

The four alternatives defined are:

System	Cost, $
F.R., 35% cover	670,000
F.R., 45% cover	1,000,000
D.R., DD = 3/sq mi	550,000
D.R., DD = 10/sq mi	1,120,000

The relationships shown on the figure suggest the degree of substitutability of annual cost and LOS. By moving along the curve for a given system the sensitivity becomes apparent. The optimum point is a function of the desires as expressed through the community's goals and objectives or the decision makers. For example, the lower portion of the curve, where the slope is small, indicated that for each dollar invested there is a greater change in the LOS. The upper part of the curve, where the slope is large, indicates that for each invested dollar a smaller LOS change is anticipated. There is a point on each curve where the tradeoff between LOS and cost are "equal," or a point at which the effective change in cost or LOS is neutralized. This suggests a beginning point for investigating alternative systems. Using Fig. 5-12 and the procedure of selecting the "neutral" point on each curve, four alternatives are defined:

System	Cost, $	LOS
F.R., 35% cover	370,000	4.0
F.R., 57% cover	550,000	4.1
D.R., DD = 3	650,000	3.0
D.R., DD = 10	1,100,000	3.1

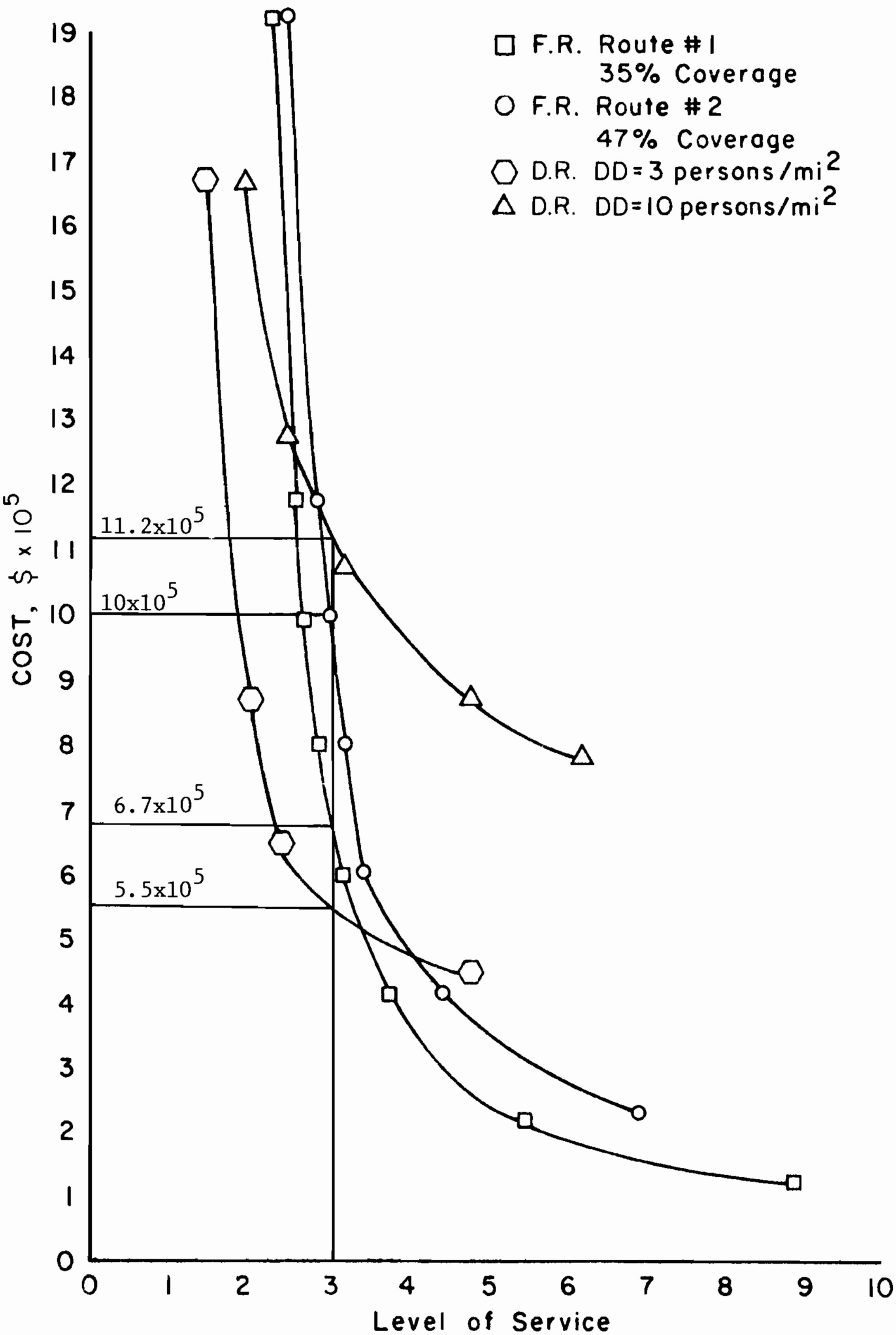


Fig. 5-11. Alternative choice using level-of-service criteria

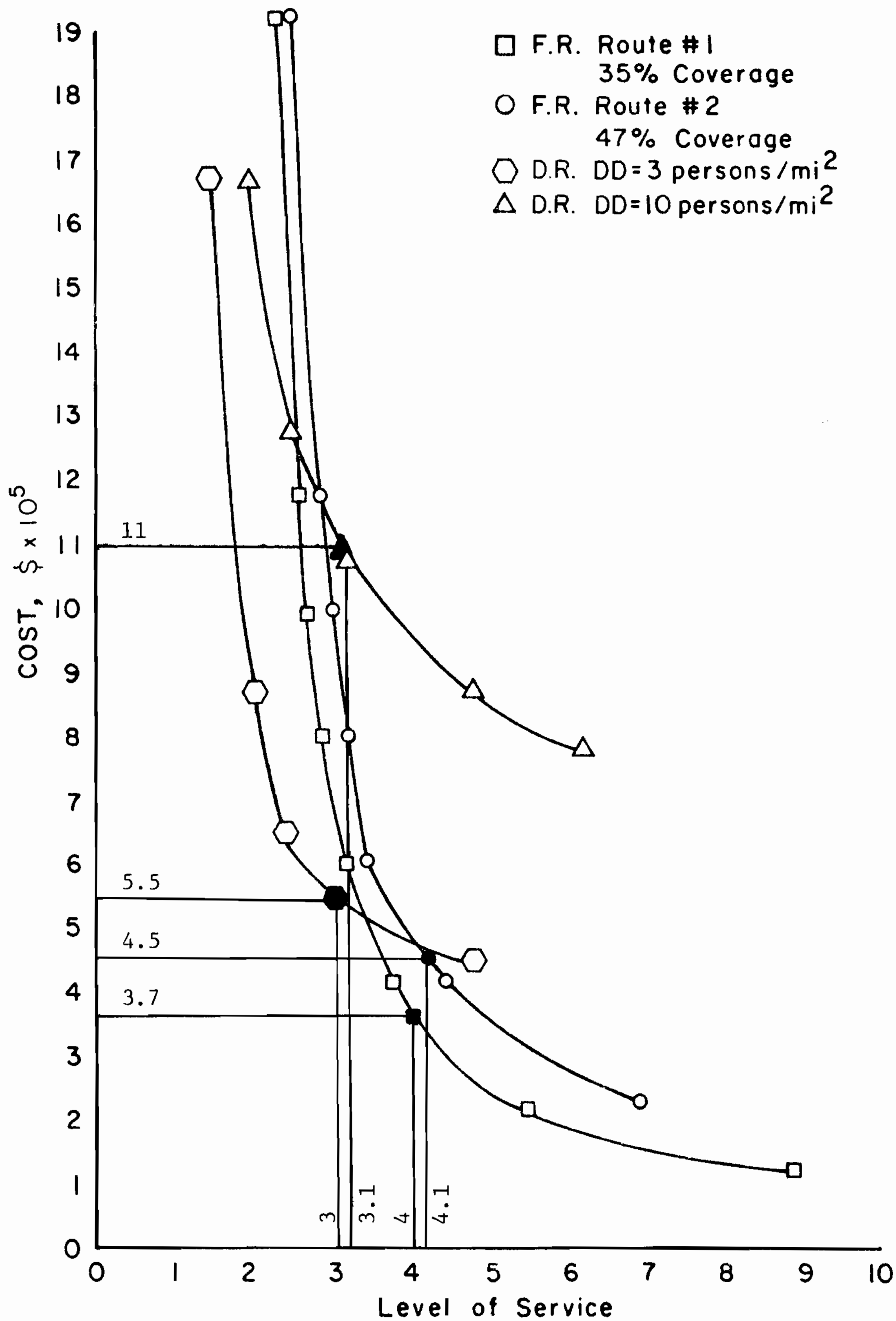


Fig. 5-12. Level-of-service using "optimizing" criteria

SUMMARY

This chapter presents an expedient methodology for assessing public transit options for small communities. The initial step involved the selection of appropriate transit service descriptors for all possible options. The temporal and spatial variations in transit supply and demand necessitated at least two descriptors for bus transit service. Two appropriate measures were coverage and level-of-service. Coverage measures the spatial supply of transit. The level-of-service measure, the relationship between travel times by transit and auto, describes the supply of service variations with time. After the selection of descriptors, a model for a demand responsive system was applied. A comparable model for fixed route service was developed by considering each trip component. The output of these models was the relationship between the number of buses supplying service and the resultant service. The number of buses, however, was not deemed a suitable measure for an evaluation process. Therefore, a cost model was developed to convert the number of buses and system characteristics to annual system cost. Cost estimates of bus system components were provided as a background for the cost model. The possible alternatives are represented by curves on an annual system cost vs. level-of-service graph. The points on those curves may be converted to descriptions of alternative systems by reversing the cost model procedure.

CHAPTER 6. SUMMARY AND CONCLUSIONS

Recent years have clearly demonstrated a renewed public and governmental interest in lower cost transit alternatives. The public perspective focuses mainly upon energy efficiency, environmental protection, and the concern for the transportation needs of the mobility disadvantaged. This perspective also emphasizes the efficient integration of land use with transit systems through short range, low capital intensive investments. This interest is not limited to large metropolitan areas that are traditionally viewed as being compatible with transit systems, notably the more sophisticated rail transit systems. Medium size cities and smaller cities, defined in this report as those falling within the 10,000 to 20,000 population range, have also indicated interest in transit alternatives. The willingness to implement transit and paratransit modes is also a local policy response to federal financing formulas that provide matching funds for capital and operating costs of a local transit system. Also funds for various technical studies can be obtained to facilitate community programs through an enhanced, balanced transportation system.

The alternative transit options that are typically emphasized in small to medium size cities differ in many respects from those options associated with larger cities. The emphasis has shifted from high to lower capital intensive projects. As a result, high densities and heavily travelled corridors are no longer a functional prerequisite for transit implementation. The federal government has also contributed to this shift by making funds available for lower cost transportation systems. Additionally, the time element of planning and implementation can be shortened, thereby allowing for a more reasonable evaluation of costs and benefits.

In Texas, the spatial pattern of cities has been influenced by transportation systems. As a result, they are typically characterized by lower population densities, excellent highway systems, and a low per capita transit usage. The physical characteristics of Texas cities, therefore, are more closely related to the transit characteristics of bus and paratransit facilities.

A statistical determination of the applicability of each of these modes to communities with less than 200,000, based on structural, social, and economic characteristics, forms the core of the research findings. Various transit options were presented, including conventional fixed route buses, jitneys, demand responsive buses, subscription buses, pooling operations, taxis, other ride sharing operations, and bicycles. The transit options were then correlated with the statistical findings to provide a preliminary evaluation guide to interested communities.

The correlation was determined by the following procedure:

1. Through a review of the relevant literature, involving urban and transit classification systems, the characteristics of cities and their inhabitants related to public transportation were identified. The major characteristics were structural, related to the city, and socioeconomic, related to individuals, in nature.

2. A regression analysis was then performed on 40 city characteristics to replicate the studies in the literature review. The percent of work trips by transit was the dependent variable. A preliminary computer analysis highlighted 25 of the 40 variables as being significant. These variables were then selected for further study. Since the objective of multiple regression analysis was to find the best set of variables to form an estimating equation, four final equations were selected. The equations reflected four cases including all 27 Texas urban areas, non-Valley areas, only areas with transit, and small areas.

3. The statistical technique of factor analysis was then utilized to identify clusters of interrelated variables which are independent of each other. Through this process, the Texas cities were classified into separate categories, according to the clusters of interrelated variables. Six factors, defined and labeled by the principal loadings of the variables, were identified.

    - Factor 1 - the principal loadings represent seven social and economic variables. Income and minority variables dominate the pattern.
    - Factor 2 - the principal loadings represent a later stage in the life-cycle pattern.
    - Factor 3 - the principal loadings represent apartment living and the employment of residents in government and educational services.
    - Factor 4 - the principal loadings represent the size and age of the city.
    - Factor 5 - the principal loadings represent recent growth experience of the city.
    - Factor 6 - the principal loadings represent high population density and white collar employment.

4. Based upon these factor dimensions, six classes of cities were identified. The classification, drawn from transportation-related characteristics is a means of providing a preliminary recommendation of appropriate transit and paratransit options.
5. An overview of the lower cost transit alternatives to fixed guideway systems was then presented to familiarize city and planning personnel with management techniques, primary users, service patterns, costs, and previous experience. The transit alternatives were fixed route systems, demand responsive service, and selected paratransit options. In the first category, conventional fixed route bus systems and jitneys were discussed. Demand responsive systems, taxis, and shared taxis were reviewed as potential options. Finally vanpools, carpools, subscription buses, and bicycles were included in the paratransit discussion.
6. The transit alterantives were then correlated with each of the city classes that were identified through factor analysis. Transit alternatives and classes were compared for cities with less than 50,000 population and for cities with populations between 50,000 and 200,000. These population divisions allowed for a more detailed understanding of the relation between population, transit characteristics and transit options. Tables 4-1 and 4-2 encapsulate the correlation process.
7. A cost and level-of-service guide for fixed and demand responsive systems was subsequently included to familiarize policymakers with important planning considerations.

It should be noted that this report is a guideline for screening and assessing appropriate transit options for smaller cities. Hopefully it will function to focus attention away from impractical transit options and toward a package of more appropriate programs. The appropriate package must then be specifically studied for feasibility and planning considerations. However, the following general conclusions can be advanced.

1. Extensive fixed guideway systems are inappropriate for Texas cities with less than 200,000, primarily because of the capability of mobility satisfaction by other options.
2. Lower cost transit options——fixed route, demand responsive, and paratransit——are appropriate for smaller communities, both in terms of cost and ability to meet a range of transportation services.
3. The structural and socioeconomic characteristics of a city have a definite effect on the demand for transit options.
4. Cost and level-of-service requirements vary according to the transit service provided and the extent of service coverage.

In summary, results and guidelines suggested in this report may provide assistance through an appreciation of varying size cities in Texas, their unique characteristics, public transportation needs and options, and the range of elements pertinent to evaluation and decision making.

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APPENDIX A

APPENDIX A

Appendix A contains 14 tables that relate statistical parameters, variables, techniques, and results for the statistical procedures of regression and factor analysis. The transit/city classification system, derived from these integrated procedures, provides preliminary transit option selection assistance.

TABLE A-1. PARAMETERS FOR ESTIMATING POTENTIAL TRANSIT USAGE

AGE OF AREA

Census year in which city first reached 50,000 inhabitants
Percent houses built 1939 or earlier
Distance from CBD (concentric zone theory)

POPULATION

Total population
Logarithm of population
Population over 5 years of age
Percent of population increase
Growth ratio
Migration rate

POPULATION DENSITY

Persons per square mile
- work density
- residential density

Logarithm of density

HOUSING

Percent of units owner occupied
Percent of families in owned single dwelling unit
Percent of families renting apartments in buildings having 5 or more dwelling units
Size of lot of single family home
Percent in one unit structures
Percent of housing units deteriorated and delapidated

AUTOMOBILES

Percent of units with (one or more/two or more) autos
Percent of units with no automobile
Number of car per thousand population

INCOME

Median family income
Mean individual income of worker
Median gross rent
Median value of each dwelling unit
Economic factor (population, dwelling units, number of workers, autos owned)

RACE OR MINORITIES

Percent of population non-white
Percent of population Negro

(continued)

TABLE A-1. PARAMETERS FOR ESTIMATING POTENTIAL TRANSIT USAGE (continued)

EMPLOYMENT

Percent of labor force in manufacturing
Percent of labor force in white collar (or high status) occupations
Percent of labor force unemployed

EDUCATION

Median school years completed

AGE OF INDIVIDUAL

Percent of workers between 16 and 44
Age of head of household

SEX

Percent of total labor force female
Females/males
Percent divorced females and males
Percent married women, husband present in the labor force

TABLE A-2. TRANSIT WORK TRIPS IN TEXAS URBANIZED AREAS, 1970

Urbanized Area	Population	All Work Trips	Transit Work Trips	Percent Transit
Abilene	90,571	36,727	455	1.24
Amarillo	127,010	52,004	658	1.27
Austin	264,499	108,697	3,966	3.65
Beaumont	116,350	44,056	1,675	3.80
Brownsville	52,627	14,571	839	5.76
Bryan-College Station	51,395	19,767	76	.38
Corpus Christi	212,820	78,518	2,204	2.81
Dallas	1,338,684	568,027	39,936	7.03
El Paso	337,471	115,616	10,191	8.81
Fort Worth	676,944	276,765	7,736	2.80
Galveston	61,809	23,864	2,449	10.26
Harlingen-San Benito	50,469	15,088	86	.57
Houston	1,677,863	679,493	40,314	5.93
Laredo	70,197	19,953	1,647	8.25
Lubbock	150,135	58,432	478	.82
McAllen-Pharr-Edinburg	91,141	27,239	228	.84
Midland	60,371	24,189	---	---
Odessa	81,645	31,596	11	.03
Port Arthur	116,474	39,925	614	1.54
San Angelo	63,884	25,880	289	1.12
San Antonio	772,513	286,420	18,006	6.29
Sherman-Denison	55,343	22,268	30	.13
Texarkana*	58,570	22,641	469	2.07
Texas City-La Marque	84,054	32,501	164	.50
Tyler	59,781	24,658	200	.81
Waco	118,843	45,094	1,126	2.50
Wichita Falls	97,564	41,208	809	1.96

*Includes Arkansas portion

Source: U.S. Bureau of the Census, 1970 Census of Population, Final Reports PC(1) - 45, Texas (Washington: Government Printing Office, 1971-72).

TABLE A-3. CORRELATION OF INDEPENDENT VARIABLES WITH TRANSIT USE

Independent Variable	Correlation Coefficient
OWNER	-.671
NOCAR	.626
POP1920	.585
SINGLE	-.563
CCDENS	.507
FOREIGN	.459
POP	.421
UNEMPLOY	.413
SPANISH	.360
EDUC5YRS	.263
POPCHA	.238
INCOM	.229
HHSIZE	.229
GOVT	.223
MILITARY	.215
YOUNG	.202
WHITECOL	.165
FEMALE	.164
EDUC	-.159
FEMWORK	-.148
MEDAGE	-.129
NEWHOUSE	.121
BLACK	.114
DISABLED	-.114
ELDERLY	-.018

TABLE A-4. VARIABLES IN REGRESSION EQUATION FOR ALL AREAS

Variable	Regression Coefficient	F Level	Significance Level
OWNER	.4336	87.60	0.1 percent
FOREIGN	.1151	1.40	
POP1920	.0247*	40.20	0.1 percent
FEMWORK	.1120	3.62	10.0 percent
EDUC5YRS	.1910	13.97	1.0 percent
UNEMPLOY	1.2145	17.16	0.1 percent
SINGLE	.1030	6.35	5.0 percent
YOUNG	.3605	15.27	1.0 percent
MEDAGE	.6001	22.33	0.1 percent
DISABLED	.2509	4.00	10.0 percent
MILITARY	.4014	3.81	10.0 percent
NEWHOUSE	.0497	1.77	

*When measured in thousands of persons

TABLE A-5. VARIABLES IN REGRESSION EQUATION EXCLUDING LOWER VALLEY AREAS

Variable	Regression Coefficient	F Level	Significance Level
POP1920	.0213*	87.00	0.1 percent
YOUNG	.4771	37.74	0.1 percent
DISABLED	-.4805	21.08	0.1 percent
ELDERLY	.6445	48.12	0.1 percent
UNEMPLOY	1.3233	53.55	0.1 percent
BLACK	.0449	10.59	1.0 percent
OWNER	-.2770	119.84	0.1 percent
INCOM	-.2040	15.39	1.0 percent
FOREIGN	.1215	3.44	10.0 percent

*When measured in thousands of persons

TABLE A-6. VARIABLES IN REGRESSION EQUATION FOR AREAS WITH TRANSIT SERVICE

Variable	Regression Coefficient	F Level	Significance Level
POP1920	.0355*	54.73	0.1 percent
OWNER	-.6090	64.95	0.1 percent
FOREIGN	.7613	53.10	0.1 percent
MEDAGE	.6986	46.04	0.1 percent
YOUNG	.3489	20.17	1.0 percent
WHITECOL	-.2096	20.76	1.0 percent
UNEMPLOY	-2.1039	14.79	1.0 percent
SINGLE	.2464	15.48	1.0 percent
NOCAR	-.0609	1.75	
POP	-.0018*	6.32	5.0 percent
NEWHOUSE	.0728	5.38	10.0 percent

*When measured in thousands of persons

TABLE A-7. VARIABLES IN REGRESSION EQUATION FOR SMALLER AREAS

Variable	Regression Coefficient	F Level	Significance Level
NOCAR	.2358	7.52	5.0 percent
OWNER	-.4312	29.31	0.1 percent
EDUC	-.1523	10.62	5.0 percent
FEMALE	-.2430	8.22	5.0 percent
NEWHOUSE	-.0536	1.62	
SINGLE	.1405	7.27	5.0 percent
CCDENS	-.0006	6.86	5.0 percent
UNEMPLOY	1.0150	7.20	5.0 percent
EDUC5YRS	-.1950	11.85	1.0 percent
DISABLED	-.2825	4.93	10.0 percent
BLACK	-.0441	1.32	

TABLE A-8. DESCRIPTION OF FACATOR ANALYSIS

Factor analysis is not a unitary concept, and it encompasses a large variety of procedures. For explanatory purposes, a non-technical description of the major steps will be presented. While oversimplified and incomplete, the description will provide a basic idea of what actually occurs in the factor analytic procedure.

1. Product-moment correlation coefficients are computed between each pair of variables across the units of analysis (cities). The result is a correlation matrix of all the variables, which is then used as the basic input to the factor analysis.

2. Initial factors are extracted. In this phase, the initial data-reduction possibilities of the technique are explored by constructing factors on the basis of the interrelationships in the data. Initial factors are usually extracted so that one factor is independent from the other; hence, the factors are orthogonal.

3. The extracted factors are rotated by a chosen rotational technique (in this instance, varimax rotation) in order to achieve simpler and more meaningful factor patterns. The varimax rotational technique attempts to have each variable load at the maximum loading (1.0) on only one factor.

4. An array of factor loadings for each variable on each factor is generated, thereby enabling the researcher to see the strength of the relationship between each original variable and each factor. Ultimately only the variables most highly correlated with each factor may be used to define the factor.

5. Factor scores are calculated for each unit of analysis (cities). These scores are developed by combining each variable value weighted according to the strength of its impact on each factor. All factor scores are normalized. That is, on each factor, the scores have a mean of zero and a standard deviation of one.

TABLE A-9. GROUP 1: LOW SOCIOECONOMIC STATUS CITIES

City No.	City	Score
2	Alice	1.075
12	Beeville	.930
16	Brownsville	2.798
28	Del Rio	1.494
32	Eagle Pass	4.065
33	Edinburg	2.414
48	Harlingen	1.664
61	Lamesa	.377
63	Laredo	2.823
69	McAllen	2.017
75	Mission	2.568
86	Pecos	.614
87	Pharr	3.196
91	Port Lavaca	.507
94	Robstown	1.877
95	Rosenberg	.099
98	San Benito	2.865
100	Seguin	.727
112	Uvalde	1.282
114	Victoria	.201
118	Weslaco	2.826

TABLE A-10. GROUP 2: ELDERLY/DISADVANTAGED CITIES

City No.	City	Score
17	Brownwood	1.698
20	Cleburne	1.123
22	Conroe	.651
25	Corsicana	1.853
29	Denison	.751
35	Ennis	1.047
40	Gainesville	1.226
45	Greenville	.903
49	Henderson	1.470
56	Kerrville	2.946
66	Longview	.212
68	Lufkin	.374
70	McKinney	1.275
71	Marshall	1.326
78	New Braunfels	.545
82	Palestine	1.226
84	Paris	1.332
88	Plainview	.118
101	Sherman	.932
104	Sulphur Springs	1.464
105	Sweetwater	.818
106	Temple	1.011
107	Terrell	2.032
108	Texarkana	1.425
110	Tyler	.707
113	Vernon	1.708
115	Waco	1.167
116	Waxahachie	1.118
117	Weatherford	1.064

TABLE A-11. GROUP 3: COLLEGE/GOVERNMENT TOWNS

City No.	City	Score
1	Abilene	.256
3	Alvin	.256
6	Austin	1.715
8	Bay City	.420
14	Big Spring	.593
18	Bryan	.551
21	College Station	5.436
23	Copperas Cove	1.744
30	Denton	2.395
39	Freeport	.381
53	Huntsville	3.821
57	Killeen	2.853
58	Kingsville	1.815
67	Lubbock	.763
74	Mineral Wells	.779
76	Nacogdoches	2.370
99	San Marcos	2.322
121	Wichita Falls	.765

TABLE A-12. GROUP 4: LARGE, OLD CITIES

City No.	City	Score
4	Amarillo	.419
10	Beaumont	.682
15	Borger	-.142
26	Dallas	5.152
34	El Paso	2.228
38	Fort Worth	2.579
41	Galena Park	-.305
42	Galveston	1.179
52	Houston	6.332
60	La Marque	-.341
81	Orange	.438
90	Port Arthur	.071
97	San Antonio	4.140
109	Texas City	-.111
120	White Settlement	-.092

TABLE A-13. GROUP 5: RECENT GROWTH CITIES

City No.	City	Score
5	Arlington	1.424
7	Balch Springs	.847
11	Bedford	2.043
19	Carrollton	2.240
27	Deer Park	1.298
31	Duncanville	2.648
36	Euless	2.040
37	Farmers Branch	2.100
43	Garland	1.972
44	Grand Prairie	.799
50	Hereford	.543
54	Hurst	2.046
55	Irving	1.871
62	Lancaster	.440
64	League City	1.270
72	Mesquite	1.872
79	North Richland Hills	1.297
85	Pasadena	.387
89	Plano	2.663
93	Richardson	2.280
103	South Houston	.071

TABLE A-14. GROUP 6: DENSE, WHITE CITIES

City No.	City	Score
9	Baytown	.223
13	Bellaire	2.475
24	Corpus Christi	.765
46	Groves	.755
47	Haltom City	-.138
51	Highland Park	3.260
59	Lake Jackson	.281
65	Levelland	-.066
73	Midland	.407
77	Nederland	.715
80	Odessa	.658
83	Pampa	.352
92	Port Neches	-.180
96	San Angelo	.389
102	Snyder	-.103
111	University Park	3.919
119	West University Place	4.081

APPENDIX B

APPENDIX B

GUIDELINES FOR ROUTE LAYOUT DESIGN AND DEVELOPMENT OF LOS RELATIONSHIPS

Data Collection and Analysis

The first step in a route layout procedure is to gather the following information:

1. Map of the community——the base map should have an approximate 1" = 1000' scale and show the existing street system.
2. Socioeconomic data for the community——to be used for identifying higher density dwelling unit areas, lower income areas, and other areas characteristic of higher transit ridership. This information may be available from census data or from a local source.
3. List of major trip generators——lists of large employers and large commercial areas should be available from a local organization. Any activities that attract people, such as military bases, colleges, and recreational areas, should be listed.
4. Information on average trip length——average trip length data may not be available, and an estimate will be required.

After the above information is gathered, a base map overlay should be drawn showing areas of higher concentrations of transit trip ends.

Alternative Route Layouts

The second step is to lay out approximate routes which represent various levels of coverage for the system. The minimum set should link the major trip generators, such as the central business districts, regional centers, and major employers. The maximum set should provide for the maximum coverage, with transit routes spaced approximately one-half mile apart throughout the community. An intermediate set may reflect a compromise route structure providing service to all the areas served by the minimum set plus service to the next order of community activities but less than the maximum set of routes. The following are desirable route characteristics offered by the National Committee on Urban Transportation (Ref 46):

1. Routes should be direct with respect to origins and destinations of passengers, connecting principal residential areas with the community's major commercial and industrial centers.
2. Cross travel and interchange to and from secondary centers, such as schools, and so on, should be made reasonably easy, with a minimum of transferring, consistent with economy.
3. Routes should be free of duplication, except where they must converge.
4. Feeder routes connecting with arterial routes, or extensions of regular routes, should be utilized (where justified) in sparsely populated areas.
5. A route should draw from not less than one-quarter mile on both sides thereof; this distance should be in excess of one-quarter mile in thinly populated or restricted areas.
6. Availability and accessibility to patrons are the marks of well-planned transit routes. Subdivision design should make provision for continuous transit routes readily accessible to pedestrians. Streets adequate for transit vehicle movements, with areas properly located for stops and interchanges between routes, should be developed.
7. Each route should include a minimum number of turning movements and have adequate provision for turn-around at both ends and for layover at one or both ends where necessary.
8. Routes should possess reasonable long-term flexibility (not necessarily day-to-day flexibility) so that they may meet changing conditions.

Estimation of Route Coverage

The third step is to estimate the coverage of each route. The coverage will be composed of two measures: the percentage of dwelling units and the percentage of all other activities served by the system. These two measures will be multiplied together to form a composite measure.

1. The simplest way to measure dwelling units is to assume a uniform density of dwelling units over the entire community. The density of Texas cities is generally low. The higher-density Texas cities are those found within major metropolitan areas, such as the suburbs of Dallas and Fort Worth. Most of the "newer" cities are lower in density and have large single-family residential areas. A mean density of 2,000 persons per square mile is typical for that group; however, estimates of density should be made in each case.
2. The percentage of other activities may be facilitated by categorizing them, estimating each category separately, and then aggregating for an overall estimate.
3. The estimates of the total coverage is the product of the two measures.

The final output of this step is an estimate of the coverage of each set of alternative route layouts.

Development Relationship Between LOS and Number of Transit Vehicles

The fourth step is to relate the number of vehicles (e.g., 8 buses) operating in a system to the LOS it provides. For each route set outlined in step two the following procedure should be followed:

1. Meausre the round-trip lengths of each of the proposed routes in the set. Using the estimated bus speed, determine the length of time, to the next highest five-minute interval, required to make a round-trip. The summation of the route times provides an estimate of the total time required to serve routes.

2. Select the number of buses required in the iterative process, implicit in this procedure. Begin with "N", number of vehicles, equal to the total route time in hours, or with at least one bus on each route, then increase "N" in increments which are multiples of N_R, number of routes.

3. Compute headway, H:

$$H = \frac{\text{total route time}}{N} .$$

4. Compute $TT_{Transit}$ = travel time by transit.

$$TT_{Transit} = 2 \text{ min} + 1/2H + \frac{\text{average trip length}}{\text{average vehicle speed}}$$

$$+ E(1 - \frac{1}{N_R})\ 1/2H + 2 \text{ mi} .$$

5. Compute TT_{Auto} = travel time by car.

6. Compute LOS

$$LOS = \frac{TT_{Transit}}{TT_{Auto}} .$$

7. As the LOS is computed for each value of N, plot it on an N vs. LOS graph. Sufficient iterations to produce a relationship between N and LOS are required.

APPENDIX C

APPENDIX C

There are several models available which relate the number of buses used in the system to LOS based on several transit characteristics. The following is a brief description and critique of several LOS models.

Arrillager and Mochaloin use a graph (Fig. C-1) which relates peak hour density to fleet size per square mile for a given LOS. This graph assumes a travel time by bus of 60 minutes. This includes a one-half hour wait and one-half hour ride time, and is based on a long 2.5-hour AM and PM peak (Ref 3).

Although this procedure is readily useable, its simplistic approach causes problems as far as suitability and flexibility. The travel time by bus is so large as to produce large losses. Input of demand density will produce the needed fleet size. This model is extremely inflexible as it contains no provisions for variation of parameters. In addition, it does not include the service area size as a parameter, which would seem to be highly correlated to travel time.

Kirby, et al (Ref 38), present a simple predictive model of many-to-many service based on simulation work done at MIT's Urban System Laboratory (Ref 19). The model is a simple equation:

$$LOS = 1 + \frac{A}{N} (0.68 + 0.072D) \quad 2$$

where

N = number of vehicles in service,

A = service area (in square miles),

D = demand density (requests per hour per square mile),

LOS = level-of-service ratio.

The range of values over which the model was calibrated is not documented although there is comparison of results of predictions versus values for existing systems. The model is suitable for the output desired, number-of-buses vs. LOS. This model seems to be fairly flexible, but its usefulness is limited by its lack of range limits.

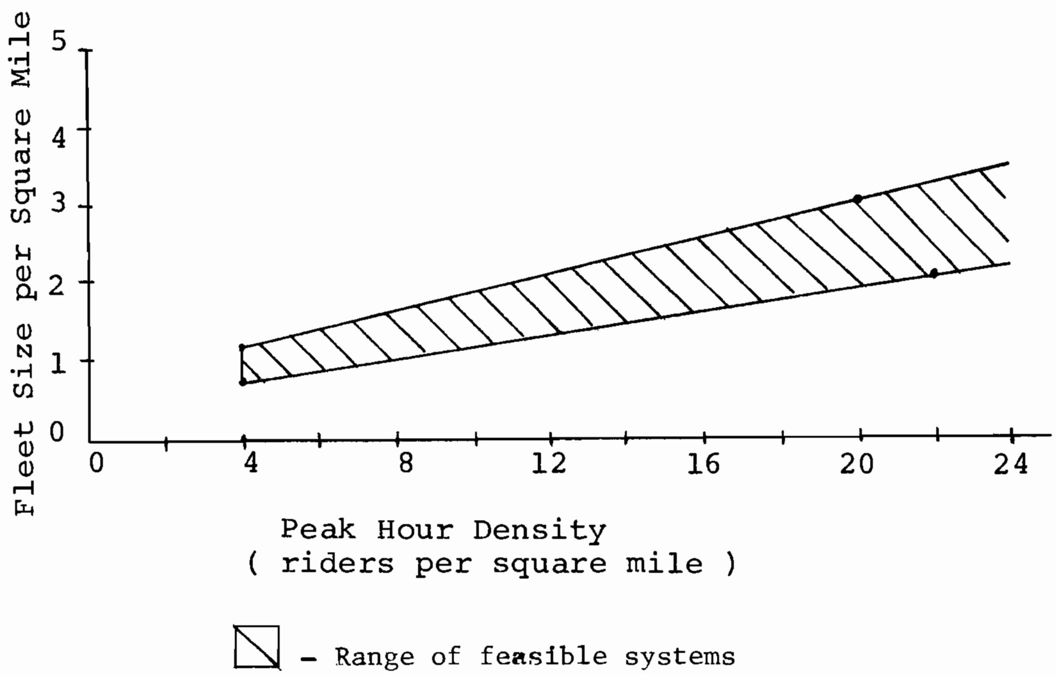

Fig. C-1. Range of feasible demand responsive systems (Ref 3)

Shilling and Fielding (Ref 59) take their model from the same source as Kirby. Their view is that absolute time is a more important variable than LOS and they have revised the equation.

$$T = 2.2 \sqrt{A} \left\{ 1 + \left[\frac{A(0.82 + 0.087D)}{N} \right]^2 \right\}$$

where

T = travel time by bus (wait _ ride)

A = service area size (in square miles)

D = demand density (trips per square mile per hour)

N = number of vehicles in service

(2.2 $\sqrt{A}$ represents the automobile or direct, travel time required to make a trip of average length in A at a speed of 15 mph)

As this model was developed from the same work as the previous model, the discussion holds true with one additional comment. In smaller communities average trip length varies proportionally with the size of the community and the socioeconomic level of the people. The inclusion of the average trip length as a constant reduces the flexibility of the model.