1. Report No. UMTA/TX-88/2001-1F	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Planning Guidelines for Suburban Transit Services		5. Report Date August 1988
		6. Performing Organization Code Technical Report - 2001-1F
7. Author's) Earl J. Washington and Robert W. Stokes		8. Performing Organization Report No.
9. Performing Organization Name and Address Texas Transportation Institute The Texas A&M University System College Station, Texas 77843-3135		10. Work Unit No.
		11. Contract or Grant No. Study No. 2-10-88-2001
12. Sponsoring Agency Name and Address Texas State Department of Highways and Public Transportation, Transportation Planning Division P.O. Box 5051 Austin, Texas 78763		13. Type of Report and Period Covered Draft - September 1987 - August 1988
		14. Sponsoring Agency Code

15. Supplementary Notes

Technical assistance performed in cooperation with U.S. DOT, UMTA.
Technical Study Title: Public Transportation Services for Suburban Development Patterns

16. Abstract

Urban and suburban development patterns in Texas cities are characterized by a high degree of spatial dispersion. The relative locations of work and other activity centers and of residences result in travel patterns which are difficult to serve using conventional public transportation services. Innovative service concepts and approaches to route design and service planning are necessary to efficiently serve the large fraction of non-CBD oriented trips and still provide good service quality. The focal point of this study was to develop a set of general guidelines or procedures to assist transit service planners in planning, designing and implementing route and service changes to capture a larger share of the regional travel market. This report presents techniques which may be used to identify suburban travel patterns, alternative routing structures, and methods of evaluating the alternative service options.

17. Key Words Public transportation, suburban development, transit route planning, transit service planning, suburban travel pattern, transit performance.	18. Distribution Statement No restrictions. This document is available to the public thru The National Technical Information Service 5285 Port Royal Road Springfield, Virginia 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	105	

Form DOT F 1700.7 (8-69)

METRIC (SI*) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
LENGTH				
in	inches	2.54	millimetres	mm
ft	feet	0.3048	metres	m
yd	yards	0.914	metres	m
mi	miles	1.61	kilometres	km
AREA				
in²	square inches	645.2	millimetres squared	mm²
ft²	square feet	0.0929	metres squared	m²
yd²	square yards	0.836	metres squared	m²
mi²	square miles	2.59	kilometres squared	km²
ac	acres	0.395	hectares	ha
MASS (weight)				
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
VOLUME				
fl oz	fluid ounces	29.57	millilitres	mL
gal	gallons	3.785	litres	L
ft³	cubic feet	0.0328	metres cubed	m³
yd³	cubic yards	0.0765	metres cubed	m³

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

TEMPERATURE (exact)

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

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
LENGTH				
mm	millimetres	0.039	inches	in
m	metres	3.28	feet	ft
m	metres	1.09	yards	yd
km	kilometres	0.621	miles	mi
AREA				
mm²	millimetres squared	0.0016	square inches	in²
m²	metres squared	10.764	square feet	ft²
km²	kilometres squared	0.39	square miles	mi²
ha	hectores (10 000 m²)	2.53	acres	ac
MASS (weight)				
g	grams	0.0353	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams (1 000 kg)	1.103	short tons	T
VOLUME				
mL	millilitres	0.034	fluid ounces	fl oz
L	litres	0.264	gallons	gal
m³	metres cubed	35.315	cubic feet	ft³
m³	metres cubed	1.308	cubic yards	yd³

TEMPERATURE (exact)

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

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          °F      32        98.6              °F
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          °C                    37                °C
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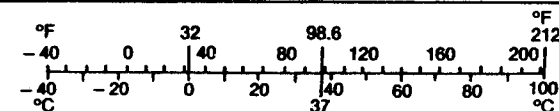
These factors conform to the requirement of FHWA Order 5190.1A.

* SI is the symbol for the International System of Measurements

PLANNING GUIDELINES FOR SUBURBAN TRANSIT SERVICES

by

Earl J. Washington
Assistant Research Planner
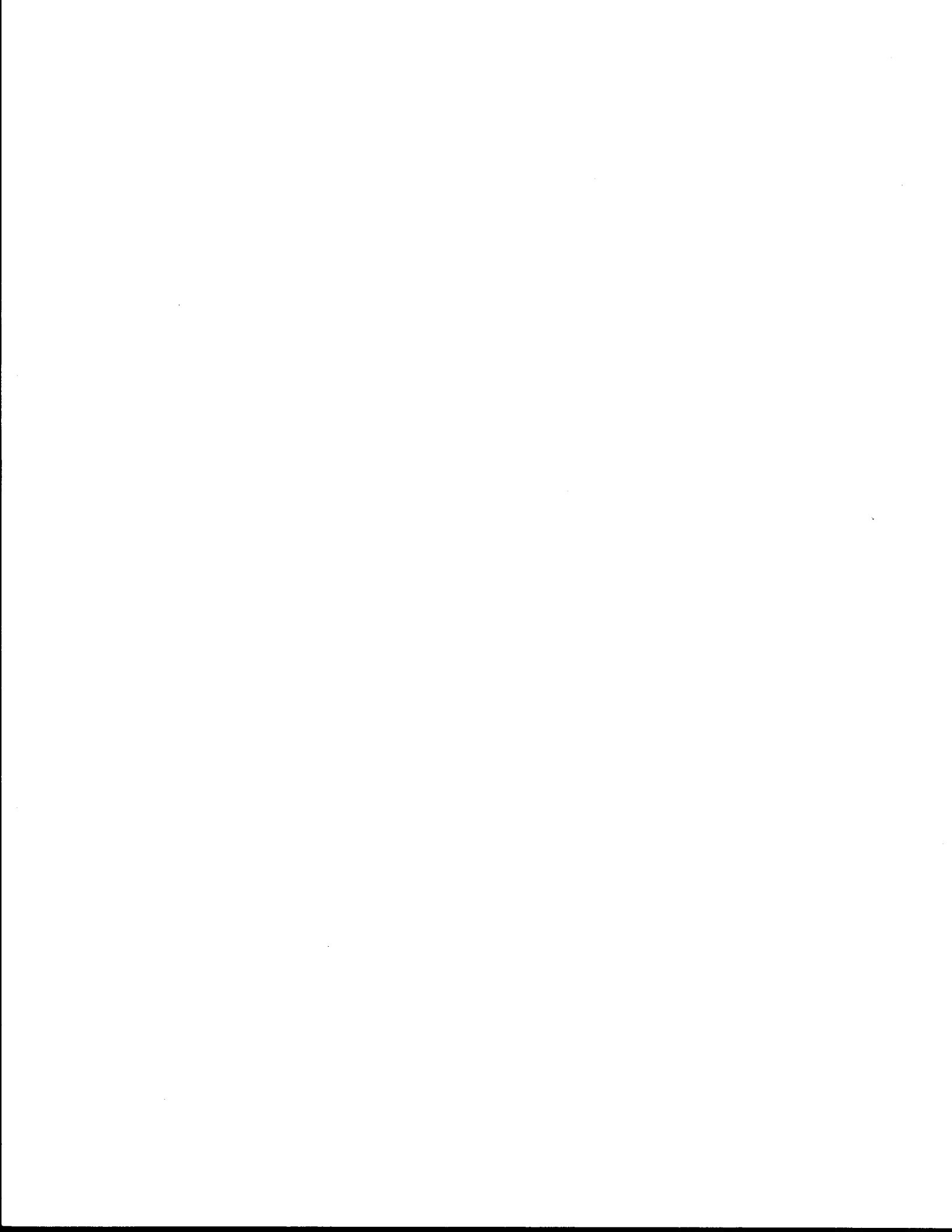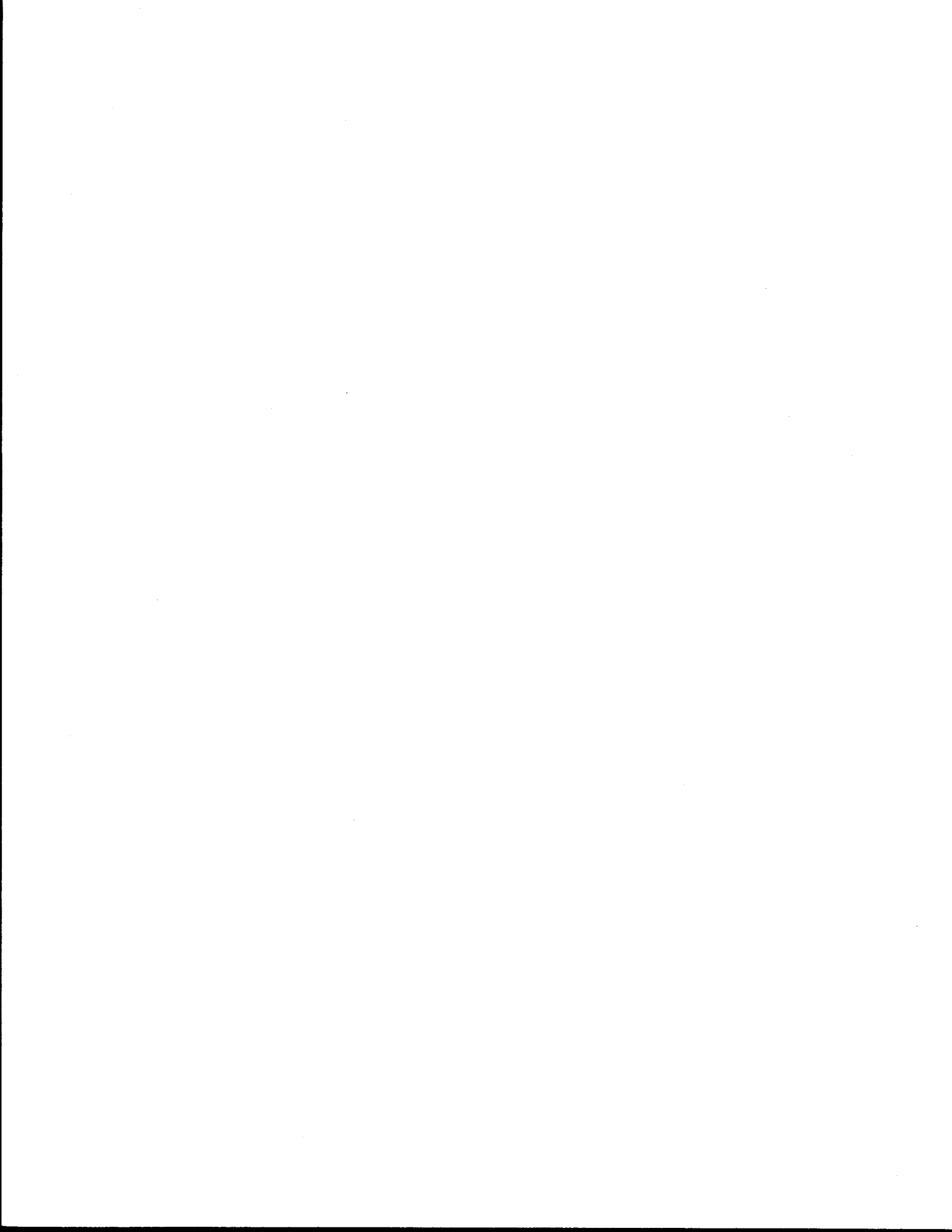
and

Robert W. Stokes
Associate Research Planner

ABSTRACT

Urban and suburban development patterns in Texas cities are characterized by a high degree of spatial dispersion. The relative locations of work and other activity centers and of residences result in travel patterns which are difficult to serve using conventional public transportation services. Innovative service concepts and approaches to route design and service planning are necessary to efficiently serve the large fraction of non-CBD oriented trips and still provide good service quality. The focal point of this study was to develop a set of general guidelines or procedures to assist transit service planners in planning, designing and implementing route and service changes to capture a larger share of the regional travel market. This report presents techniques which may be used to identify suburban travel patterns, alternative routing structures, and methods of evaluating the alternative service options.

IMPLEMENTATION STATEMENT

The taxpayers of Texas, local transit authorities, and the Texas State Department of Highways and Public Transportation (SDHPT) could benefit from the implementation of improved public transportation services in the suburban areas of major Texas cities. The potential increases in transit ridership which could result from improved services in suburban areas would benefit taxpayers and local transit authorities. The potential for increasing transit's share of the travel market could reduce vehicular traffic volumes on major thoroughfares, thus benefitting the motoring public and the SDHPT. Additionally, the results of this study should be helpful to transit service planners in planning, designing and implementing route and service changes to capture a larger share of the regional travel market.

DISCLAIMER

The contents of this report reflect the views of the authors who are responsible for the opinions, findings, and conclusions presented herein. The contents do not necessarily reflect the official views or policies of the Texas State Department of Highways and Public Transportation or the Urban Mass Transportation Administration. This report does not constitute a standard, specification, or regulation.
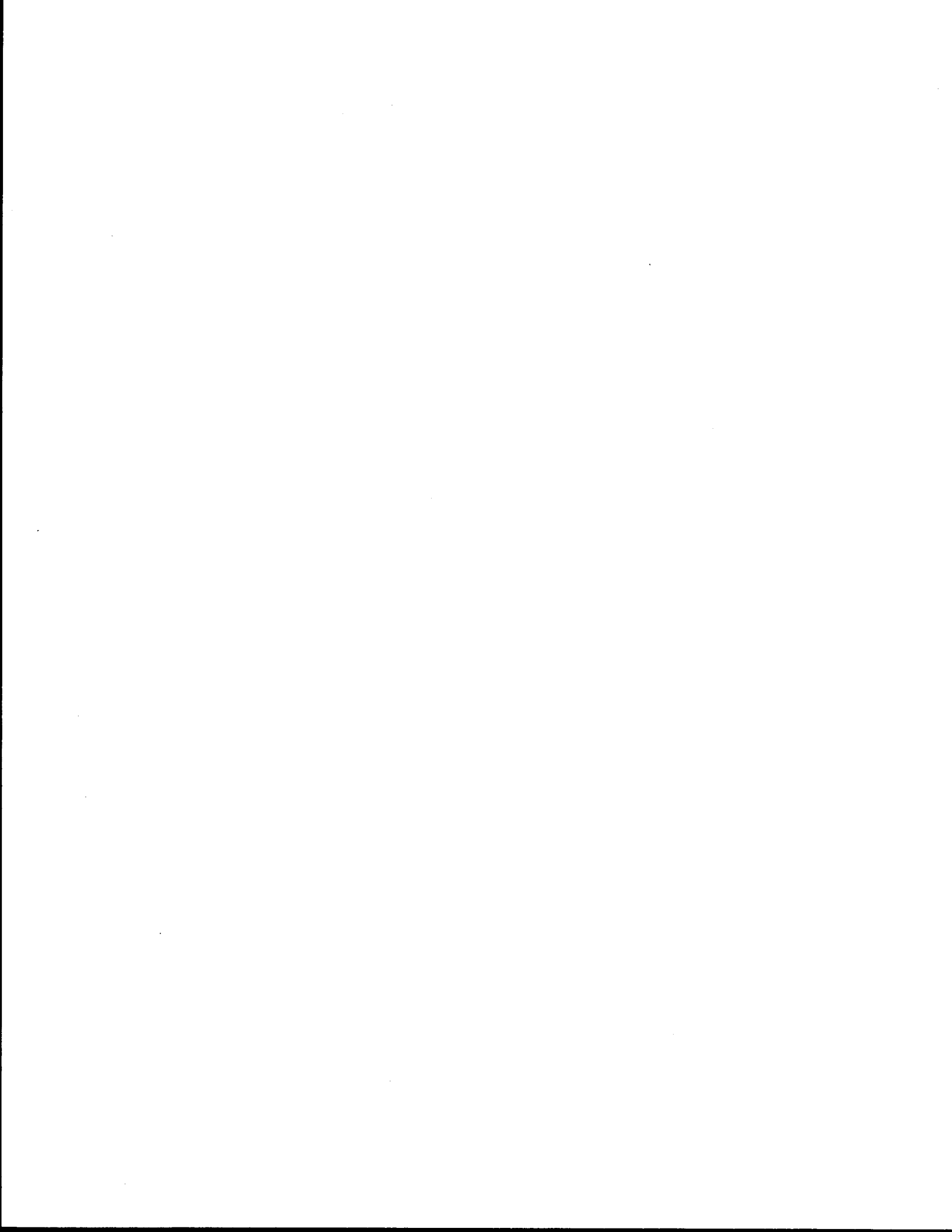
SUMMARY

Major activity centers located outside the traditional central business districts (CBDs) of our cities have become the principal areas of urban growth in recent years. This growth pattern has produced a polycentric urban form that is comprised of many concentrations of activities throughout the urban region. As a result, the CBD is no longer the single focus of activity in many of our larger urban areas. This evolving land use pattern has resulted in highly dispersed travel patterns, with the CBD being only one of several important destinations in the urban region.

This report provides general guidelines for use in the identification of suburban travel patterns, alternative routing structures, and methods of evaluation appropriate for suburban transit route structures.

Suburban travel patterns may be identified from a number of secondary sources. These sources include origin-destination surveys, Census Journey-To-Work data, on-board transit surveys, and other special studies (e.g., park-and-ride lot studies). These sources may be used to identify the following travel characteristics:

- Trip purpose
- Trip frequency
- Trip length
- Traveltime
- Time of day of trip
- Trip origin and destination
- Mode of travel
- Vehicle availability and occupancy

In addition to travel characteristics, these sources typically provide socioeconomic profiles of the respondents in terms of age, sex, occupation and level of education. Some special studies also contain information assessing the attitudes, impacts, or perceptions of the utility of a specific service.

Transit routing structures generally fall into one of four classifications: 1) radial; 2) ubiquitous; 3) grid; and 4) timed transfer systems (Figure S-1) (14).

The radial network configuration consists primarily of radial or diametrical routes, with the central business district or a major suburban activity center as its focal point. Since the area coverage and service intensity of the radial network are uneven, this type of network is best suited to radial street networks that converge on the CBD. Radial transit routing structures cannot efficiently serve suburb-to-suburb or other non-CBD travel demands (14).

The ubiquitous network represents a utopian approach for correcting the deficiency associated with the radial system. Unfortunately, this method appears to be unrealistic because it requires a quantity of service so high that even the most densely populated urban area could not generate enough ridership to support it (14).

Another approach to regional transit network design is the grid concept. Rather than focusing service on the CBD, the grid offers north/south, east/west service connections to most destinations of regional significance along major freeways or arterials. The grid network is characterized by two sets of parallel routes spaced at regular intervals, each operating along fairly straight paths. Routes are developed as elements of an interdependent, integrated system. A great deal of importance is placed upon the transfer in a grid system, because without it, a rider is severely limited in the number of destinations available to him. Yet with a single transfer, the rider can reach almost any major destination with little circuitous travel (14).

Timed transfer systems (TTS) have been suggested as a method for transit to increase its share of the large and rapidly growing non-CBD travel market. The basic requirement of TTS is coordinated route planning and scheduling. With time transfers, the entire system, or its major portions, is laid out to allow vehicles to meet in timed sequence to allow convenient passenger
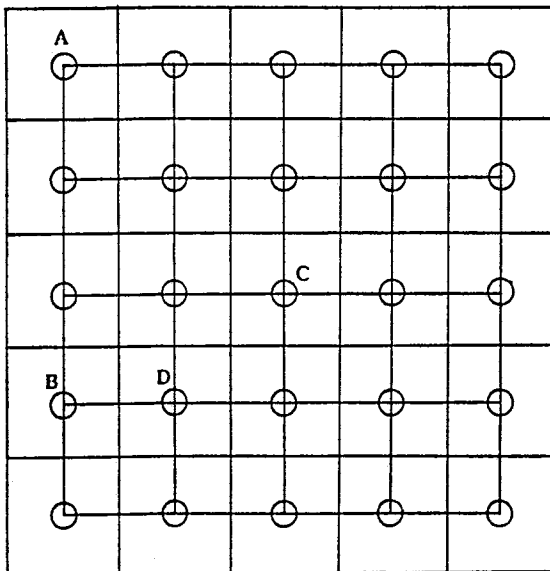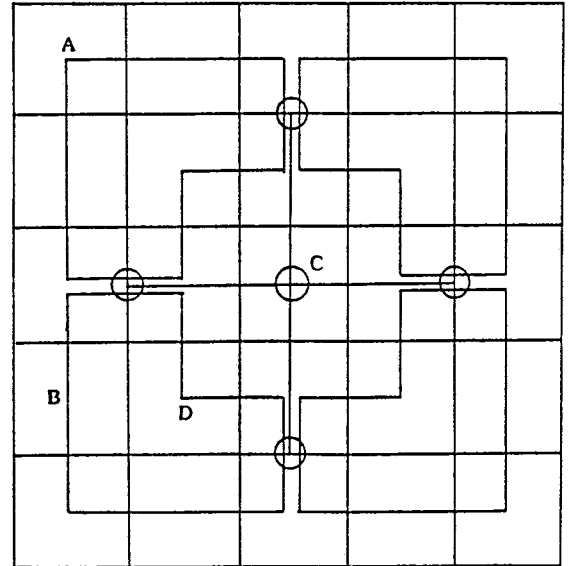
a) Radial
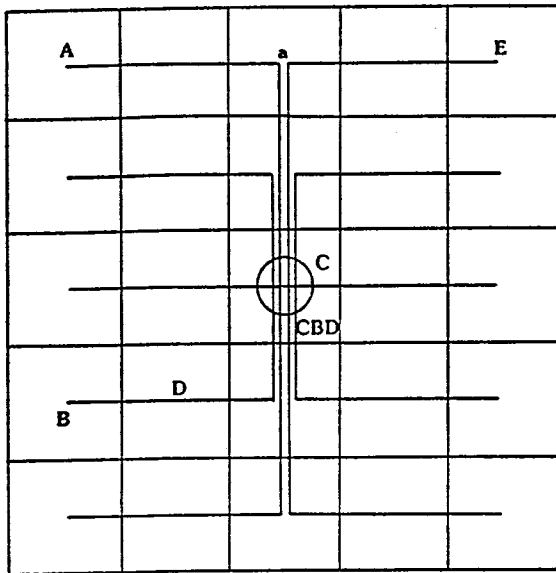
b) Ubiquitous
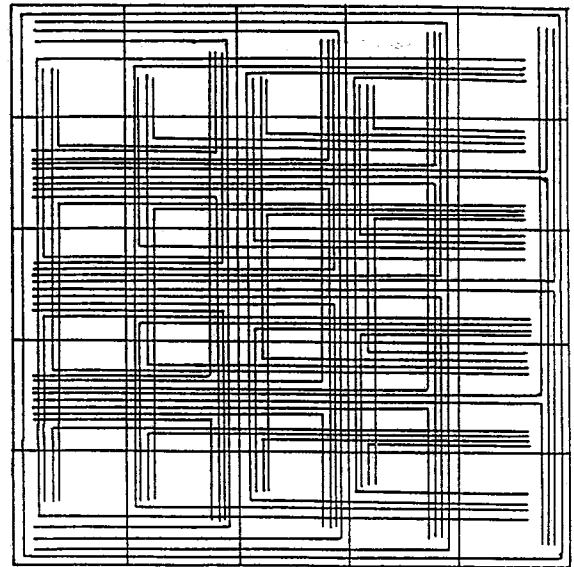
c) Grid

d) Timed Transfer

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

Figure S-1. Four Basic Transit Routing Structures

transfers. Most transfers occur without having to travel downtown and also occur at places designed for transfer activities (14).

Timed transfer systems may be classified into four types: 1) simple; 2) pulse scheduling; 3) lineup; and 4) neighborhood pulse. These classifications are variations determined by the number of converging routes, and schedule complexities. Simple timed transfers, where buses on two routes are guaranteed to meet regularly, illustrate the basic principles of timed transfers. They are most commonly used in the evening when both routes have low frequencies. This type is more likely to be found at outlying transfer points where few routes may meet (29).

Pulse scheduling is the type of TTS that has the most far reaching operational consequences. Important aspects of pulse scheduling include service frequency, routing, schedule adherence, spaces for buses to meet, and operator information policies.
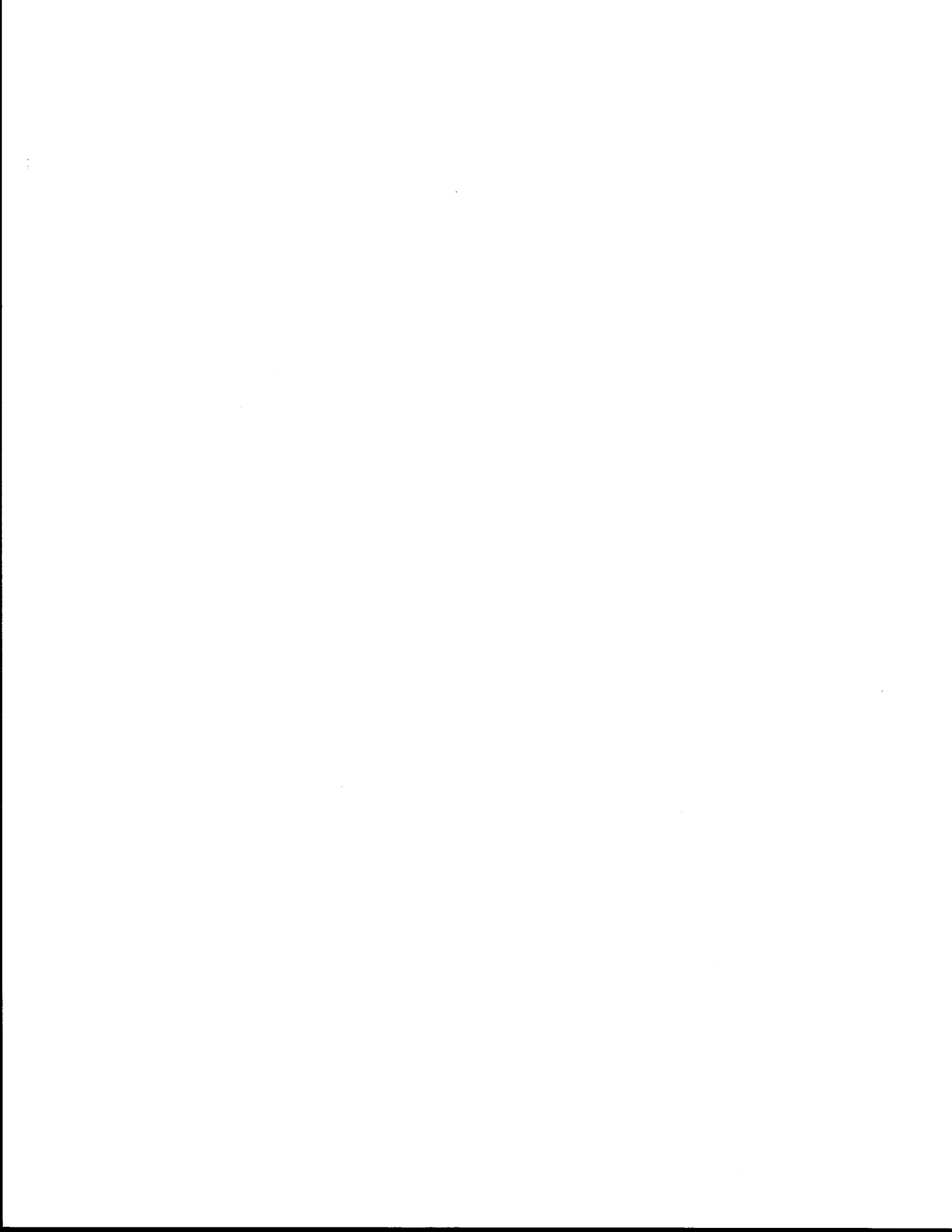
The other variants of timed transfers (lineups and neighborhood pulse) are basically pulse scheduling applied in different situations. A lineup is pulse scheduling used in the evening and in off-peak hours. A neighborhood pulse is pulse scheduling used on only a portion of the system.

Transit performance indicators have been suggested as potentially useful means of measuring and comparing the effectiveness and efficiency of transit operations. These indicators provide a means of evaluating the trade-offs between various goals in terms of services provided, the quality of those services and the cost of providing those services. Despite the fact that many transit systems have begun to conduct formal performance evaluations, no generally accepted set of evaluative criteria have been developed that can be applied to the different routing alignments typically examined in the provision of service to low density areas (27).

The effectiveness of transit performance indicators may be constrained by certain external factors. These factors can be grouped into five basic categories: 1) political constraints; 2) budgetary constraints; 3)

inadequate performance data; 4) data processing limitations; and 5) inadequacy of current indicators and performance standards (17).

This report describes several approaches that can be used to identify suburban travel characteristics, outlines alternate routing concepts that may be appropriate for suburban travel patterns, and discusses techniques that can be used to evaluate these service options.

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1. INTRODUCTION

1.1 BACKGROUND

Major activity centers located outside the traditional central business districts (CBDs) of our cities have become the principal areas of urban growth in recent years. This growth pattern has produced a polycentric urban form that is comprised of many concentrations of activities throughout the urban region. As a result, the CBD is no longer the single focus of activity in many of our larger urban areas. This evolving land use pattern has resulted in highly dispersed travel patterns, with the CBD being only one of several important destinations in the urban region.

Despite the continuing trend towards more dispersed development and travel patterns, most urban transit systems are still predominantly oriented to providing a high level of service to only the downtown areas of our cities. However, travel to the downtown typically accounts for only about 10-15 percent of an urban area's total work trips (Table 1). Consequently, the radial CBD orientation of most transit systems may be ignoring as much as 90 percent of the potential market. Clearly, important non-CBD destinations must be served if transit's share of the regional travel market is to increase significantly.

Table 1. Transit Shares of Commuting by Market, 1980

Live In	Work In		
	Central City	Suburbs	Outside Area
Central City	16.1%	5.6%	7.3%
Suburbs	8.0	1.6	7.6
Outside Area	2.5	0.9	0.7
All	13.0	2.1	0.7

Source: (1).

1

This situation has prompted transit planners and researchers to re-examine the overall design of many existing transit systems. A number of alternative routing and service schemes, such as grid routing, timed transfer service and subregional transit centers, have been suggested. However, due to the lack of financial resources, the lack of guidelines for identifying and evaluating service alternatives, and/or institutional resistance to new schemes, few alternative transit networks have been implemented in recent years.

This report provides general guidelines for use in the identification of suburban travel patterns, alternative routing structures, and methods of evaluation appropriate for suburban transit route structures.

1.2 STUDY OBJECTIVES

The objectives of this research are to develop guidelines for:

1) Estimating non-CBD oriented travel demands;

2) Identifying potential route design and service planning options to meet non-CBD oriented travel demands for a given land use configuration; and

3) Assessing the relative effectiveness of these service alternatives.

1.3 SCOPE

This report describes several procedures which can be used to identify suburban travel characteristics, outlines alternative routing alignments which may be appropriate for suburban travel patterns, and discusses evaluation techniques which measure the effectiveness and efficiency of these service alternatives. Additionally, the report presents a summary of general guidelines for planning suburban transit services.

1.4. PREVIOUS RESEARCH

1.4.1 Urban Commuting Patterns

The process of decentralization that has occurred in urban areas during the past 40 years is well documented. A 1978 report by Baerwald (2) identifies metropolitan freeway construction as a primary inducement to this pattern of out-migration. Spielberg (3) suggests that both jobs and households will increasingly be located in the suburbs, where the dominant transportation problems in the next two decades will be. Spielberg (3) also cites demographic shifts such as declining household size and moderate population growth to support his contention that travel by auto will increase faster than the population. Baerwald (4) classified the suburbanization trend into two forms, clusters and corridors. Clusters usually focus on a regional shopping center while corridors develop along freeways.

In a 1968 study, Ganz (5) reported that travel patterns were dominated by workers living and working in the central city, supplemented each day by a flow of workers living outside and commuting into the central city. In 1968, less than one-third of all workers lived and worked outside the central city. Ganz speculated that by 1985, these travel patterns would be reversed. One-half of all workers would live and work outside the central city, supplemented each day by a margin of workers living in the central city and working outside the central city. Workers living and working in the central city would make up only one-fifth of the workforce. Workers commuting into the central city would be equally matched by workers flowing out of the central city. The typical urban travel pattern would be from one outside central city origin to an outside central city destination, over a longer traveled route, without an increase in travel time. The line-haul trip to the central business district will represent an even smaller share of the travel market in the coming generations (5).

Westcott (6) examined employment and commuting patterns from a residential perspective with the use of a journey-to-work survey conducted by the Bureau of the Census. The author concluded that one third of all workers commute to jobs outside the geographic area in which they live.

3

Table 2 presents the trends in origin-destination (O-D) mixes of work trips within all U.S. urbanized areas, for 1975 and 1980. The results support the speculations of Ganz (5).

Table 2. Trends in Origin-Destination Mixes of Work Trips Within All U.S. Urbanized Areas, 1975 and 1980

Commute Pattern	1975		1980	
	Total Trips (in 1000s)	Percent	Total Trips (in 1000s)	Percent
Central City to Central City	16,528	33.4	20,879	33.0
Suburb to Central City	9,592	19.6	12,691	20.1
Suburb to Suburb	19,261	38.9	25,329	40.1
Central City to Suburb (reverse commute)	4,040	8.1	4,226	6.8
Total	49,421	100.0	63,125	100.0

Source: Reference (7).

Cervero (7) suggests the suburban office boom has contributed to the present travel patterns. Over 80 percent of all office floorspace in America's suburbs has been built since 1970. By comparison, only 36 percent of all downtown office buildings have gone up over the past 15 years. Nationwide, the share of total office space outside central cities jumped from 25 percent in 1970 to 57 percent in 1984. In some areas of the country, a tripling of current suburban office inventories has been projected by century's end. Houston's suburban office growth supports this contention. In 1970, only 39 percent of all office construction was outside of downtown Houston. By 1982, the share had catapulted to 87 percent.

Cervero (7) provides further evidence of demographic shifts as a factor in the pattern of changing travel characteristics. Table 3 shows that the preeminence in suburb-to-suburb commuting holds for all four regions of the country. Intersuburban travel is most prominent in the northeast, owing largely to the enormous amount of cross-town and interstate travel throughout

the greater New York metropolitan area. The south has the highest share of the traditional suburb-to-central city radial commuting, while the highest incidences of reverse commuting (central city to Suburbs) can be found in the Pacific states.

Table 3. 1980 Work Trip Patterns Within SMSAs for Different Regions of the U.S.

| Region of U.S. | Percentage of Total Work Trips within SMSA | | | |
	Central City to Central City	Central City to Suburb	Suburb to Central City	Suburb to Suburb
Northeast	32.2	4.7	15.3	47.8
North Central	30.7	7.0	20.3	49.0
South	36.1	6.1	23.7	40.1
West	32.4	9.3	19.9	38.4
Total U.S.	33.1	6.7	20.1	40.1

Source: (7).

Table 4 shows trends in suburban residences, employment locations and modal breakdowns for three large Texas cities from 1960 to 1980. Aggregate data indicates an increase in suburban residents of over 400 percent during this period. The corresponding increase in suburban residents who also work in the suburbs for the same period was slightly over 300 percent. In 1960 the private automobile was the dominant transportation mode (77%). Public transportation was utilized for roughly 2 percent of all trips. By 1980 the private auto utilization rate had risen to 93 percent, and public transportation use had shrunk to less than 1 percent.

Table 5 shows trends from 1970 through 1980 in metropolitan travel for 12 major Standard Metropolitan Statistical Areas (SMSAs), broken down by place of residence within each SMSA. The table reveals that the shares of trips destined to suburbs, reverse commutes and suburb-suburb journeys, rose in nearly all of the 12 SMSAs. Long haul trips from suburbia to places outside of SMSAs likewise jumped during the seventies in most places. Correspondingly, the role of inner-city trip making dropped sharply in almost all SMSAs. Only in the cases of Atlanta and Tampa did commuting shares within central cities rise (7).

Table 4. Trends in Suburban Residences Employment Locations and Modal Breakdowns for Large Texas Cities, 1960-1980

SMSA	1960				
	Suburban Residents	Suburban Residents/Workers	Transportation Mode		
			Private	Public	Other
Houston	105,047	52,269	131,927	3,994	15,789
San Antonio	48,925	33,608	31,518	563	42,910
Dallas/ Ft. Worth	151,955	87,805	192,242	4,992	36,260
Totals	305,927	173,682	355,687	9,549	94,959

SMSA	1980				
	Suburban Residents	Suburban Residents/Workers	Transportation Mode		
			Private	Public	Other
Houston	609,305	262,142	819,845	4,677	46,925
San Antonio	134,808	44,713	152,006	1,540	25,975
Dallas/ Ft. Worth	834,473	425,844	1,182,119	6,013	72,185
Totals	1,518,316	732,699	2,153,970	12,230	145,085

Source: (8).

In connection with the changing travel characteristics, modal commuting trends display the private automobile as the preferred mode of passenger travel in the nation's most rapidly growing metropolises, and by a wide margin (Table 6).

1.4.2 Estimating Transit Demand

The use of census data in travel demand estimation has been the subject of a number of research efforts. One facet, housing for example, can be selected and modeled to estimate the impacts on transit patronage. Lutin and Markowicz (9) developed a computer graphic package as part of an interactive computer model designed to assess the impact of housing policies on transit ridership in urban transit corridors. The authors utilized a mode-split model that uses U.S. Bureau of Census data to predict ridership for the transit line, based on discrete combinations of mode and access mode including walk-and-ride, park-and-ride, kiss-and-ride, and feeder bus. The program permits the analyst to input alternative residential patterns, with

Table 5. Changes in Commuting Patterns Within and Between Central City and Other Locations, 1970-80

SMSA	Percent of Central City Residents Commuting						Percent of Residents Living Outside of Central City Commuting					
	Inside Central City		to Outside of Central City		to Outside of SMSA		to Central City[a]		Outside Central City[a]		to Outside of SMSA	
	1970	1980	1970	1980	1970	1980	1970	1980	1970	1980	1970	1980
Atlanta	69.2	73.3	18.4	14.6	12.4	12.1	36.2	26.9	62.7	68.3	1.1	4.8
Dallas	81.2	74.9	11.1	18.7	7.7	6.4	41.7	30.9	54.7	60.1	3.6	9.0
Denver	78.3	75.5	14.9	16.4	6.8	8.1	41.2	38.6	58.7	61.0	0.1	0.4
Houston	78.4	77.5	7.4	8.2	14.2	14.3	40.4	43.8	59.5	54.0	0.1	2.2
Los Angeles	63.5	63.8	22.9	24.2	13.6	12.0	16.3	19.4	76.0	79.8	7.7	0.8
Orange County	44.5	40.9	29.0	34.8	26.5	24.3	19.9	19.2	65.0	69.3	15.1	11.5
Phoenix	78.6	74.5	13.0	14.9	8.4	10.6	26.8	26.4	73.2	72.9	.0	0.7
San Diego	78.2	73.1	14.0	12.7	7.8	14.2	29.5	30.2	70.4	69.4	0.1	0.4
San Francisco	75.6	73.4	11.1	13.2	13.3	13.4	25.8	28.7	67.6	66.0	6.6	5.3
San Jose	46.5	42.6	36.2	41.5	17.3	15.9	15.7	8.2	84.2	91.5	0.1	8.5
Seattle	80.8	77.4	12.6	15.3	6.6	7.3	41.4	36.1	58.2	60.8	0.4	3.1
Tampa	73.3	75.2	16.3	18.9	10.4	5.9	32.3	29.6	67.4	66.9	0.3	3.5
12 SMSA Average[b]	70.7	68.5	17.2	19.5	12.1	12.0	30.4	27.3	66.4	68.5	3.2	4.2
U.S.[c]	80.7	71.8	15.2	14.5	4.1	13.7	32.8	28.0	59.4	55.8	7.8	16.2

[a]Outside of the central city but within the SMSA.
[b]Nonweighted average of the 12 SMSAs.
[c]All U.S. SMSA

Source: Reference (7).

Table 6. Modal Breakdowns of Commuter Trips, 1970-80

SMSA	Private Vehicle			Public Transporation[a]			Other[b]		
	1970	1980	Change in %	1970	1980	Change in %	1970	1980	Change in %
Atlanta	84.6	88.3	+3.7	9.4	7.6	-1.8	6.0	4.1	-1.9
Dallas	88.0	91.8	+3.8	5.2	3.4	-1.8	6.8	4.8	-2.0
Denver	85.2	85.5	+0.3	4.4	6.1	+1.7	10.4	8.4	-2.0
Houston	86.9	91.9	+5.0	5.4	3.0	-2.4	7.7	5.1	-2.4
Los Angeles	85.9	85.5	-0.4	5.5	7.0	+1.5	8.6	7.5	-1.1
Orange County	92.5	90.9	-1.6	0.3	2.1	+1.8	7.2	7.0	-0.2
Phoenix	88.9	89.1	+0.2	1.2	2.0	+0.8	9.9	8.9	-1.0
San Diego	75.8	81.2	+5.4	4.2	3.3	-0.9	20.0	15.5	-4.5
San Francisco	73.5	73.7	+0.2	15.2	16.4	+1.2	11.3	9.9	-1.4
San Jose	88.7	89.0	-0.3	2.3	3.1	+0.8	9.0	7.9	-1.1
Seattle	83.5	82.1	-1.4	7.1	9.6	+2.5	9.4	8.3	-1.1
Tampa	87.6	90.4	+2.8	3.1	1.8	-1.3	9.3	7.8	-1.5
12 SMSA	—	—	—	—	—	—	—	—	—
Average[c]	84.8	86.2	+1.4	5.5	5.8	+0.3	9.7	7.9	-1.8
U.S.[d]	77.7	84.1	+6.4	8.9	6.4	-2.5	9.4	7.9	-1.2

[a]Includes bus, rail transit, railroads, and taxicab modes.
[b]Includes bicycle, walk, and other modes as residents who work at home.
[c]Nonweighted average of the 12 SMSAs.
[d]All U.S. SMSA

Source: Reference (7).

respect to location and density, in the transit corridor and to evaluate the effects on transit ridership by comparing alternative housing policies.

Hunt et al. (10) suggest the use of a geodemographic model that uses a combination of geographic, demographic, and transit service data to estimate bus ridership for a given suburban area. The following four data sets are integrated into a working system that can be used to evaluate existing routes, explore the need for new route locations or frequency changes, and target potential markets.

● A digitized, computer-readable map of the boundaries of census tracts using a latitude and longitude coordinate system.
● Census statistics that provide detailed descriptions of the households and residents in each tract.
● Census statistics that describe the workers in each tract.

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● A computerized map of each bus route that provides regular service in the region of interest (these service lines are digitized in the same coordinate system as the census tract maps).

Notess (11) proposed the use of friction factors as used in the gravity model for trip distribution as a basis for deriving a measure of access to jobs and willingness to travel. Levinson (12) recommended forecasting future transit ridership based on: corridor population and employment growth; changes in service levels resulting from the various options; and effects of changes in gasoline price, parking cost, and increased traffic congestion.

Current route level demand estimation techniques range from simple judgmental techniques which rely on estimates of experienced individuals to methods based on time series data which utilize statistical analysis. Techniques between these extremes include the noncommittal survey which is applied through home interviews or on-board surveys and direct demand based on cross-sectional data. Attempts to identify or develop simple, reliable procedures that permit transit agencies to forecast the incremental ridership changes resulting from various bus service changes in a variety of operating environments (e.g., those of differing density, system size, employment concentrations, and service patterns) are forthcoming. The state-of-the-art in demand estimation is a major problem area in suburban transit planning. Table 7 presents a summary of existing route level demand estimation techniques. Many of these approaches are utilized in the analysis of the introduction of new routes, route alignment, and route extensions or cutbacks. Despite the availability of these known techniques, the state-of-the-art is not very advanced. It appears there is a wide disparity between methods appearing in the literature and procedures employed in the industry. Some agencies use variations of these techniques which lack the sensitivity and reliability to predict route level ridership impacts resulting from service changes. As a consequence, there is a need to review and document techniques or develop new techniques.

Table 7. Summary of Route-Level Demand Estimation Techniques

Method Type of Analysis	Model Form	Forecast Variable	Model Inputs	Type of Analysis	Application
Judgmental Technique	No specific form exhibited.	Ridership at system level. Ridership at route level. Ridership by time of day. Ridership along short segments of route.	Dependent on application.	Introduction of new routes. Changes in service hours. Route extension or cutbacks. Realignment of routes. Headway changes.	Estimates of experienced individuals. Delphi approach.
Noncommittal Survey Techniques	Extrapolation of survey responses from potential users of service area. (1) multiply the average trips per household by the number of households. (2) Adjust for bias in the responses (5-50%) based on the planners judgement.	Ridership by route level. Ridership by time of day. Ridership by special market segments. Ridership along specific portions of route.	Survey Responses (1) user or non-user (2) location (3) travel patterns (4) trip purpose (5) auto availability	Alternative fare Service frequency. Hours of operation. Routings.	Home interview mail-out/mailback. On-board surveys.

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Table 7. Summary of Route-Level Demand Estimation Techniques (Cont.)

Method Type of Analysis	Model Form	Forecast Variable	Model Inputs	Type of Analysis	Application
Direct Demand Based on Cross-Sectional Data					
(1) Similar Routes	Mathmatical equation.	Daily ridership estimations at the route level. Ridership by time of day.	Route type (express or local). Population density of area. Income level of area residents. Total area employment. Directness of Route. Route Frequency.	Introduction of new route. Route extension. Expansion of service hours for a route. Route realignment.	3 Step Process (1) Characteristics of proposed route compared to other routes in system. (2) Ridership and level of service of the similar route used to estimate ridership or trip rate. (3) Analyst used his own judgement to adjust results differences between the two routes.
(2) Simple Rules of Thumb	Forecast variable is directly proportional to the single model input.	Average daily ridership on a single route.	Number of dwelling units within 1/4 mile of route. Number of bus miles operated. Number of parking spaces in the fringe area park-and-ride lot.	Development of the rule. It's use for prediction.	Mathematical equation.

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Table 7. Summary of Route-Level Demand Estimation Techniques (Cont.)

Method Type of Analysis	Model Form	Forecast Variable	Model Inputs	Type of Analysis	Application
(3) Multiple Factor Trip Rate Models	Mathematical equation.	Ridership per day on a single route.	Description of service area. Quality of service provided.	Introduction of new route. Determine impact of changes in level of service.	Manual procedure (1) Derive base trip generation figure. (2) Multiply curves, nomographs and factors to develop final patronage prediction.
(4) Aggregate Route Regression Models	Statistical Technique.	Average daily ridership. Estimate route ridership by direction. Estimate route ridership between zones.	Ridership counts from a number of different routes in a system combined with information on service levels and socio-economic attributes of the route corridor.	Calculator Calibrations.	Computer Scientific Calculator.
Methods Based on Time Series Data					
(1) Elasticity Methods	Statistical Technique.	Change in the average daily route ridership by specific segments of route, for certain times of day, by direction and market segment.	Calibration (1) Identification of ridership levels before service change. (2) Identification of ridership levels after service change. (3) Value of factor measuring type of service change.	Adjustment of fare or service frequency on an existing route.	Choice of value for the elasticity of (1) Weighted average of measures used in prior studies (2) Average elasticity measures using before and after data for routes of a given property.

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Table 7. Summary of Route-Level Demand Estimation Techniques (Cont.)

Method Type of Analysis	Model Form	Forecast Variable	Model Inputs	Type of Analysis	Application
(2) Trend Analysis	Statistical Technique.	Anticipated ridership at a specified time in the future.	Ridership level for a number of past periods.	To identify those routes which are losing or gaining ridership in a stable pattern.	Calibrate model using existing data and then insert the number of the desired time period to be forcast into the equation. Calculator with statistical capabilities.

Source: Reference (13).

1.4.3 Suburban Transit Routing Structures

Past studies investigating route design and service planning options fall under one of five classifications: (1) radial systems; (2) ubiquitous systems; (3) grid systems; (4) timed transfer systems; and (5) other approaches.

Radial networks consist primarily of diametrical routes, which focus on the central city (CBD), or on a suburban major activity center. The routes may take the form of spokes, or pitch forks. However, the configuration is usually determined by the roadway network upon which it is superimposed. A basic flaw of this type of network is that it does not easily accommodate most travel destined to places other than the Central Business District (14).

The ubiquitous routing method represents a direct means of correcting the inherent deficiencies found in the radial network configuration. The Ubiquitous system attempts to connect each pair of O-Ds with it's own route, thus eliminating the need for transferring between routes. However, due to the high quantity of service requirements, this approach appears to be idealistic. This approach typically requires a very densely populated area to generate sufficient ridership for economic feasibility (14).

Grid networks consist of lines laid out in a rectangular pattern with many transfer possibilities at intersecting points. It is very straight forward and contains two sets of routes. The first includes parallel routes running in a north-south direction. These routes do not join or cross each other. The second set includes parallel routes running in a east-west direction. These do not join or cross each other; but they cross every north-south route and vice versa. A traveler can get from any location to any other without backhauling by transferring no more than once. Grid networks are well suited to evenly populated areas with grid street patterns, which require rather uniform quality of transit service (14).

Another multidestinational routing method is the timed transfer system. In this system the routes are laid out to create a manageable number of strategic locations where several routes intersect and where it is possible

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to schedule connections between all transit vehicles going in both directions on those routes. Its advantage over other multidestinational approaches is that it relies on scheduled connections between routes and does not require the grid systems frequent service on most routes for most of the day.

Recent experiences in Edmonton, Alberta; Vancouver, British Colombia; Portland, Oregon; and Denver, Colorado, all primarily western cities, provide useful precedents for designing multidestinational networks. Many areas have realized from 50 percent to 200 percent increases in ridership over the past five to ten years, a period of stagnant or declining ridership in most other parts of the United States and Canada, after converting to timed-transfer operations. Specific examples are described in the following paragraphs (14).

Edmonton, Alberta, began converting its radial bus system to a time transfer network in the early 1960's. Throughout the next decade this process accelerated. The previously declining patronage stabilized and, more recently, has grown faster than population and faster than patronage for systems in other Canadian cities. Transit in Edmonton now carries about 13 percent of all trips in the city. Edmonton's roadway layout is characterized by substantial discontinuties caused by river valleys, ravines, railway yards, an airport, university lands and industrial tracts (14).

Vancouver, British Columbia, has most recently begun implementing timed transfer services as part of a massive program to expand transit to low density suburban areas. The timed transfer approach is integrated with planning for the staged implementation of light rail transit and with land use planning. Transfer points are implemented in existing or proposed suburban activity centers. Patronage response has been heavy, with per capita rides on transit as high as fifty to sixty (equivalent to about a 5 percent modal split) in low density suburban areas that had no transit service before 1973 (14).

Historically multidestination route alignments have found limited application in North America. However, Toronto has utilized a grid transit orientation since the 1920's. Transit there now carries over 20 percent of

these trips in metropolitan Toronto. Over 70 percent of these trips do not cross downtown cordons, indicating success in attracting nondowntown travel (14).

Another approach which is closely associated with timed transfer systems is the transit center-based transit system. Schneider et al. identify the following advantages of the center based network (15); 1) Broader penetration of the regional travel market; 2) Increased system efficiency through good fleet optimization possibilities; 3) Good user comprehension of network; and 4) Good system integration through several locations in the region.

Schneider et al., also note the following disadvantages of the transit center-based system: 1) Opposition from CBD interest; 2) Extensive capital requirements; 3) Public opposition; 4) Opposition from shopping center owners/managers, and 5) Schedule design complexities.

Schneider et al. (16) identified the following ten-step process that could be used to design a transit-center-based transit system.

1. Select the number of and locations for the transit centers upon which the system will be based. Use well-known major activity centers whenever possible.

2. Define a primary service area around each transit center identified above.

3. Divide the metropolitan area into subregions using the primary service area boundaries defined above as the basis for this subregionalization.

4. Identify other major activity and employment centers located in each subregion and classify them as to their regional or subregional importance.

5. Analyze the travel patterns within each subregion by trip type and time, using the best available origin-destination data.

6. Analyze the travel patterns between stations, by trip type and time, using the best available origin-destination data.

7. Determine which travel patterns, in space and time, are appropriate markets for transit service.

8. Design alternative route/schedule plans for those local, radial and circumferential services judged to be high potential markets.

9. Evaluate the alternatives and select the plan that best meets the objectives of the various interest groups in the region.

10. Devise an implementation plan that is phased and prioritized.

1.4.4 Evaluation of Suburban Transit Routing Structures

Bus service evaluation methods may be classified on the basis of performance criteria and service standards. These criteria may be categorized into three basic classifications to reflect different evaluative focal points. Each of these classifications and the performance criteria that they contain are described below (17).

Route Design Criteria

1. Bus Stop Spacing	4. Route Length
2. Route Coverage	5. Route Duplication
3. Route Deviation	6. Route Structure

Each of these six performance criteria relates to the basic structure and design of a transit system's route network. Factors such as the location of transit services, the structure and configuration of transit routes, and patron accessibility to transit services are measured by these criteria.

Service Quality Criteria

1. Vehicle Loads
2. Vehicle Headways
3. Schedule Adherence
4. Passenger Safety
5. Bus Shelter Placement

6. Passenger Transfers
7. Missed Trips
8. Span of Service
9. Public Complaints

Each of these nine performance criteria are used to monitor or evaluate the amount and level of service that is provided by a transit agency. These criteria address such issues as passenger convenience, service reliability, passenger comfort and safety, and patron satisfaction with public transit.

Economic and Productivity Criteria

1. Passengers per Vehicle Hour
2. Cost Recovery
3. Passengers per Vehicle Mile
4. Passengers per Trip
5. Cost per Passenger

Each of these five performance criteria are used to monitor or evaluate the financial and ridership performance of individual transit lines or services.

Additionally, a second classification scheme may be used to categorize the practices of an agency based on the manner in which each performance criteria is monitored or evaluated. The following four categories are used in this classification (17):

1) **Formal Service Standard** - An official policy objective(s) that is used to evaluate a particular performance criterion by establishing specific benchmarks that identify acceptable and unacceptable performance levels, as well as the range of remedies that are required to address unsatisfactory performance. The formality of the standard is a reflection of its status within an agency as official policy and the existence of a formalized

performance evaluation and review process for the criterion. Due to the standard's official status, a major effort is normally made to adhere to its requirements under most situations and conditions.

2) **Informal Service Standard** - A specific performance objective(s) that is used to evaluate a performance criterion. The performance objective(s) has no official or policy status within an agency and is used as an internal guideline only. The standard's informal nature may result in less than universal application under various situations or conditions at the discretion of the department or manager responsible for the evaluation activity.

3) **Proposed Service Standard** - This is the situation in which a transit system is either in the process of developing a service standard to evaluate a performance criterion or it is currently involved in securing approval for recently developed standards or the implementation of standards that have recently been approved. Most agencies with "proposed" standards envision that the standards will receive formal status in the near future.

4) **Criterion Monitoring** - This is the situation in which a transit system does not currently possess (or is in the process of developing) a service standard to evaluate a performance criterion. However, despite the lack of a standard, the agency does track or monitor the performance criterion by collecting/analyzing pertinent data and calculating various indicators and statistics on a more or less regular basis. Transit systems that monitor performance criteria frequently use such general terms as "minimize" or "maximize" which indicate a desire to improve some aspect of performance, but fail to set acceptable performance levels that are quantifiable or measurable (17).

Kyte, Stanley and Gleason (18) focused on service impacts and service reliability in their evaluation of a time transfer system implemented in the suburban Westside of Portland Oregon. The evaluation technique was designed to determine (a) how well the service had met project objectives and (b) the operational efficiency and effectiveness of the current service design. Specifically, the study examined three areas of performance: 1) ridership

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(growth and travel patterns); 2) performance (system and route level); and 3) schedule reliability.

Janarthanan and Schneider ([19]) outlined the elements of a multicriteria evaluation of alternative transit system design. This approach consists of a multicriteria methodology and concordance analysis. An example of this approach involves the use of a weighted linear equation in which system objectives and criteria are evaluated for different alignments. In another study ([20]), cost (determined from vehicle miles traveled), coverage area, passenger travel time, and competitiveness with the walk mode are the performance measures used to evaluate each routing pattern.

1.4.5 Summary

This section of the report identified the urban commuting patterns which have contributed to suburban mobility problems, techniques commonly employed in the estimation of transit demand, routing structures which may appropriately serve this need, and methods of evaluating these suburban transit routing structures.

A review of the related literature indicates the current dispersed travel patterns may have been induced by one or more of the following factors:

- Metropolitan freeway construction ([2]);
- The suburban office boom ([7]); and,
- Demographic shifts.

Recent studies estimate that current commuting patterns consist of one-third of all workers commuting to jobs outside the geographic area in which they live ([6]).

The estimation of transit demand generally involves the use of census and demographic data. Specific examples include:

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- One facet, housing for example, can be selected and modeled to estimate the impacts on transit patronage (9);

- Geographic, demographic and transit service data may be modeled to estimate bus ridership for a given suburban area (10);

- Future transit ridership may be forecast based on corridor population, employment growth, changes in service levels resulting from various options, and the effects of changes in gasoline price, parking cost, and increased traffic congestion (12).

Table 7 (p. 10) presented a summary of existing route level demand estimation techniques. Many of these approaches are utilized in the analysis of the introduction of new routes, route re-alignment, and route extensions or cutbacks. Despite the availability of these known techniques, the state-of-the-art is not very advanced. It appears there is a wide disparity between the methods appearing in the literature and procedures employed in the industry. Some agencies use variations of these techniques which lack the sensitivity and reliability to predict route level ridership impacts resulting from service changes. As a result, there is a need to review and document existing techniques or develop new techniques.

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ubiquitous system attempts to connect each pair of O-Ds with it's own route, thus eliminating the need for transferring between routes. However, due to the high quantity of service requirements, this approach appears to be idealistic. This approach would require a very densely populated area to generate sufficient ridership for economic feasibility (14).

Grid networks consist of lines laid out in a rectangular pattern with many transfer possibilities at intersecting points. It is very straight-forward and contains two sets of routes. The first includes parallel routes running in a north-south direction. These routes do not join or cross each other. The second set includes parallel routes running in a east-west direction. These do not join or cross each other; but they cross every north-south route and vice versa. A traveler can get from any location to any other without backhauling by transferring no more than once. Grid networks are well suited to evenly populated areas with grid street patterns, which require rather uniform quality of transit service (14).

Another multidestinational routing method is the timed transfer system. In this system the routes are laid out to create a manageable number of strategic locations where several routes intersect and where it is possible to schedule connections between all transit vehicles going in both directions on those routes. Its advantage over other multidestinational approaches is that it relies on scheduled connections between routes and does not require the grid systems frequent service on most routes for most of the day (14).

Bus service evaluations may be classified on the basis of performance criteria and service standards. These criteria may be categorized into three basic classifications, route design criteria, service quality criteria, and economic and productivity criteria (17).

Additionally, a second classification scheme may be used to categorize the practices of an agency based on the manner in which each criteria is monitored or evaluated. These categories are (1) formal service standards, (2) informal service standards, (3) proposed service standards, and (4) criterion monitoring (17).

2. IDENTIFYING SUBURBAN TRAVEL PATTERNS

2.1 GENERAL

As indicated in the previous section, recent changes in urban travel patterns will require substantial innovation and broad expansion in our urban transportation systems. These transportation needs will arise in response to growth and changes in the structure of employment and its intra-metropolitan area location, as well as the relative shift of metropolitan area population to the outside central city portions of metropolitan areas (5). Travel patterns in these suburban areas are generally scattered. Except for some concentration to the central business district (CBD), to the airport, or to large shopping centers and industrial parks, travelers do not concentrate in corridors where they could be served by conventional public transportation services. Automobile dependency and freeway construction has caused accessibility to become distributed more evenly throughout the region.

Suburban travel patterns may be identified from a number of secondary sources. These sources include origin-destination surveys, census journey-to-work data, on-board transit surveys and, other special studies (e.g., park-and-ride lot studies). These sources may be used to identify the following travel characteristics:

- Trip Purpose
- Trip Frequency
- Trip Length
- Traveltime
- Time of day of trip
- Trip origin and destination
- Mode of travel
- Vehicle availability and occupancy

In addition to travel characteristics, these sources typically provide socioeconomic profiles of the respondents in terms of age, sex, occupation and level of education. Some special studies also contain information

assessing the attitudes, impacts, or perceptions of the utility of a specific
service.

2.2 SECONDARY SOURCES

2.2.1 Origin-Destination Surveys

Origin-destination (O-D) surveys represent one approach used to identify
the travel patterns of a given area. The primary function of an O-D survey
is to obtain information on existing travel patterns so that efficient
transportation of people and goods can be planned and provided.   The
information obtained from an O-D survey typically includes (21):

- Where people begin and end their trips
- How they travel (mode)
- When they travel (time of day)
- Why they travel (trip purpose)
- Where they park
- Trip frequency
- Vehicle occupancy

This data is needed to aid in the planning of major street systems, freeway
location and design, major bridge locations, public transit improvements, and
terminal facilities.

Table 8 presents an aggregate summary of the results of several recent
O-D surveys conducted in Houston, Texas. The data represent A.M. peak period
travel (6:00 - 9:00 A.M.) between major geographic sectors (Figure 1) in the
Houston metropolitan area.   It should be noted that the data have been
aggregated from a number of individual freeway surveys. As a result, the
data show a preponderance (62%) of travel to the central city. The data,
therefore, are not representative of total urban travel patterns.
Nevertheless, the data illustrates several useful trends. For example, the
diagonal of the trip table shows that approximately 10% of the urban area's
trips are of an intrazonal nature. These intrazonal trips are generally
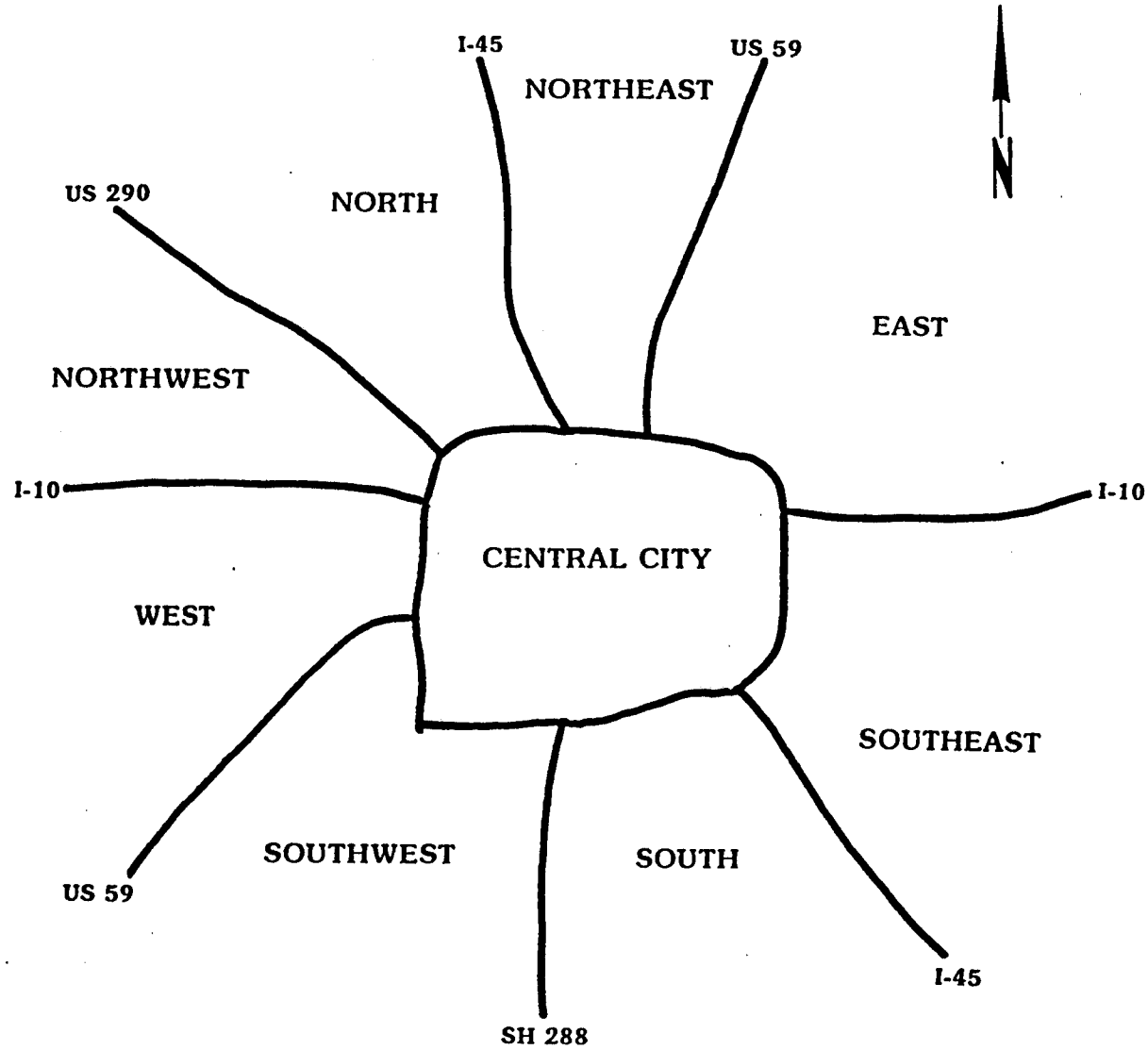
Figure 1. Houston O-D Sectors

Table 8. Distribution of Houston A.M. Peak Period Origins/Destinations

O_AREA   D_AREA

FREQUENCY PERCENT	EAST	WEST	NORTH	SOUTH	C-CITY	N/EAST	N/WEST	S/EAST	S/WEST	N-HUSTON	TOTAL
EAST	6 0.02	7 0.02	21 0.06	1 0.00	56 0.15	3 0.01	11 0.03	4 0.01	7 0.02	0 0.00	116 0.30
WEST	41 0.11	567 1.49	144 0.38	55 0.14	3005 7.87	23 0.06	1278 3.35	64 0.17	467 1.22	33 0.09	5677 14.87
NORTH	280 0.73	771 2.02	2615 6.85	42 0.11	4035 10.57	334 0.87	749 1.96	294 0.77	202 0.53	138 0.36	9460 24.78
SOUTH	1 0.00	7 0.02	8 0.02	11 0.03	256 0.67	0 0.00	9 0.02	4 0.01	16 0.04	0 0.00	312 0.82
C-CITY	57 0.15	25 0.07	158 0.41	87 0.23	1571 4.12	32 0.08	60 0.16	89 0.23	50 0.13	11 0.03	2140 5.61
N/EAST	35 0.09	100 0.26	328 0.86	6 0.02	582 1.52	54 0.14	84 0.22	35 0.09	31 0.08	9 0.02	1264 3.31
N/WEST	115 0.30	306 0.80	607 1.59	86 0.23	5316 13.92	84 0.22	632 1.66	158 0.41	348 0.91	54 0.14	7706 20.19
S/EAST	3 0.01	4 0.01	21 0.06	2 0.01	34 0.09	0 0.00	5 0.01	11 0.03	1 0.00	1 0.00	82 0.21
S/WEST	102 0.27	113 0.30	276 0.72	179 0.47	8498 22.26	54 0.14	618 1.62	126 0.33	827 2.17	15 0.04	10808 28.31
N-HUSTON	13 0.03	42 0.11	123 0.32	5 0.01	299 0.78	20 0.05	50 0.13	30 0.08	16 0.04	13 0.03	611 1.60
TOTAL	653 1.71	1942 5.09	4301 11.27	474 1.24	23652 61.96	604 1.58	3496 9.16	815 2.13	1965 5.15	274 0.72	38176 100.00

Source: (22, 23).

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second only to the central city in terms of their contribution to the area's total travel.

Data comparable to that presented in Table 8 should be available for most major Texas cities. These data, along with other secondary data sources, should be sufficient to identify general urban travel pattern. Of course, "site-specific" studies may be needed to more precisely identify local travel patterns.

2.2.2 Census Journey-to-Work Data

Census journey-to-work (JTW) data is another source used to identify urban travel patterns and characteristics. This is a special tabulation of 1980 census data tailored to geographic areas that are used in transportation planning. Local transportation planning organizations submit specifications to the census bureau for the geographic detail required for their area (e.g., traffic zones or census tracts), and the bureau then produces a standard set of tabulations for those planning areas.

The JTW files contain the following information:

Demographic Characteristics

1) Age
2) Sex
3) Type of Household (i.e. Married Couple, Female-Headed, etc.)
4) Position within Household (i.e. spouse, child, other nonrelative, etc.)

Economic Characteristics

5) Family Income
6) Poverty Status
7) Occupation (white-collar, blue-collar, service, farm, other)
8) Number of hours worked last week
9) Number of weeks worked last year

Housing Unit or Household Characteristics

10) Number of automobiles in the household
11) Number of persons in the household
12) Number of housing units in the structure
13) Number of workers in the household

Geographic Distinctions

14) Census geographic Regions and Divisions
15) Place of Residence (central city or suburbs)
16) Place of Work (central business district, remainder of central city, outside a central city)

Travel Characteristics

17) Mode of travel
18) Travel time
19) Origins and destinations (census tract to census tract)
20) Vehicle occupancy

Tables 5 and 6 (p.7-8) presented aggregate summaries of JTW urban travel patterns.

The journey to work is one of the principal considerations in the design of highway and transit systems. The peak period traffic that occurs during the journey to work generally determines the capacity needed for the urban transportation system. This source examines travel characteristics similar to those described in the previous section.

There are certain inherent advantages and disadvantages associated with JTW data as compared to other secondary sources of information discussed in this section. These are outlined below:

Advantages

- The data will probably be available for virtually any urban area considering transportation improvements.

- The data is basically an expanded 12.5% sample. This is likely a much larger sample than any recent O-D survey for a major urban area.

Disadvantages

- The current journey to work data is 1980 data and is already eight years old. The new 1990 data will probably not be available until 1992 or 1993. This may diminish the usefulness of the data in areas experiencing cyclical economic swings in either direction.

- No accurate methods exist to account for any transportation system network changes in the travel patterns reflected in the journey to work trip table.

- There is a basic definitional difference between journey to work trips and the home based work trips used in the traditional travel demand modelling process. The census basically asked if you went to work in the last seven days and, if so, where and by what mode of travel. There are no adjustments made for part-time workers or weekend workers or absenteeism. The trips in the JTW work trip table are only the home to work trip and do not include the work to home trips.

2.2.3 On-Board Transit Surveys

The use of on-board surveys is a common approach employed in the identification of travel patterns in urban areas. In this approach users of a specific service or facility are surveyed while in the act of patronage. The survey should focus on the following issues:

● Travel patterns and trip characteristics such as trip purpose, frequency, origin, destination, and auto availability;

● Attitudinal information assessing the effectiveness and utility of a service or facility in achieving its objective; and

● Socio-economic profiles of the patrons (age, gender, occupation and level of education).

Table 9 shows data from a recent Houston METRO on-board survey and illustrates the type of information available from these surveys. The information in Table 9 indicates that as much as 20% of the workers in Houston's major activity centers (Figure 2) have non-radial travel directions.

Table 9. Trip Direction for Transit Riders Destined for Houston's Major Activity Centers by Percent of Workers Surveyed by Area

Direction	CBD	Post Oak	Greenway	Energy Corridor (I-10W)
Radial Inbound	43.9%	39.7%	41.5%	71.9%
Radial Outbound	42.4%	41.0%	43.7%	25.4%
Crosstown Eastbound	0.3%	3.7%	7.2%	0.0%
Crosstown Westbound	0.4%	1.3%	7.6%	0.0%
Crosstown Northbound	8.1%	5.5%	0.0%	2.7%
Crosstown Southbound	4.9%	8.8%	0.0%	0.0%
Total	100.0%	100.0%	100.0%	100.0%

Source: (24).

The on-board survey has advantages and disadvantages when compared to other sources. The advantages are presented below (25):

● There is considerable cost savings in the administration of this form of survey. It does not require postage as a mailout would, and requires less manpower than an origin-destination survey.
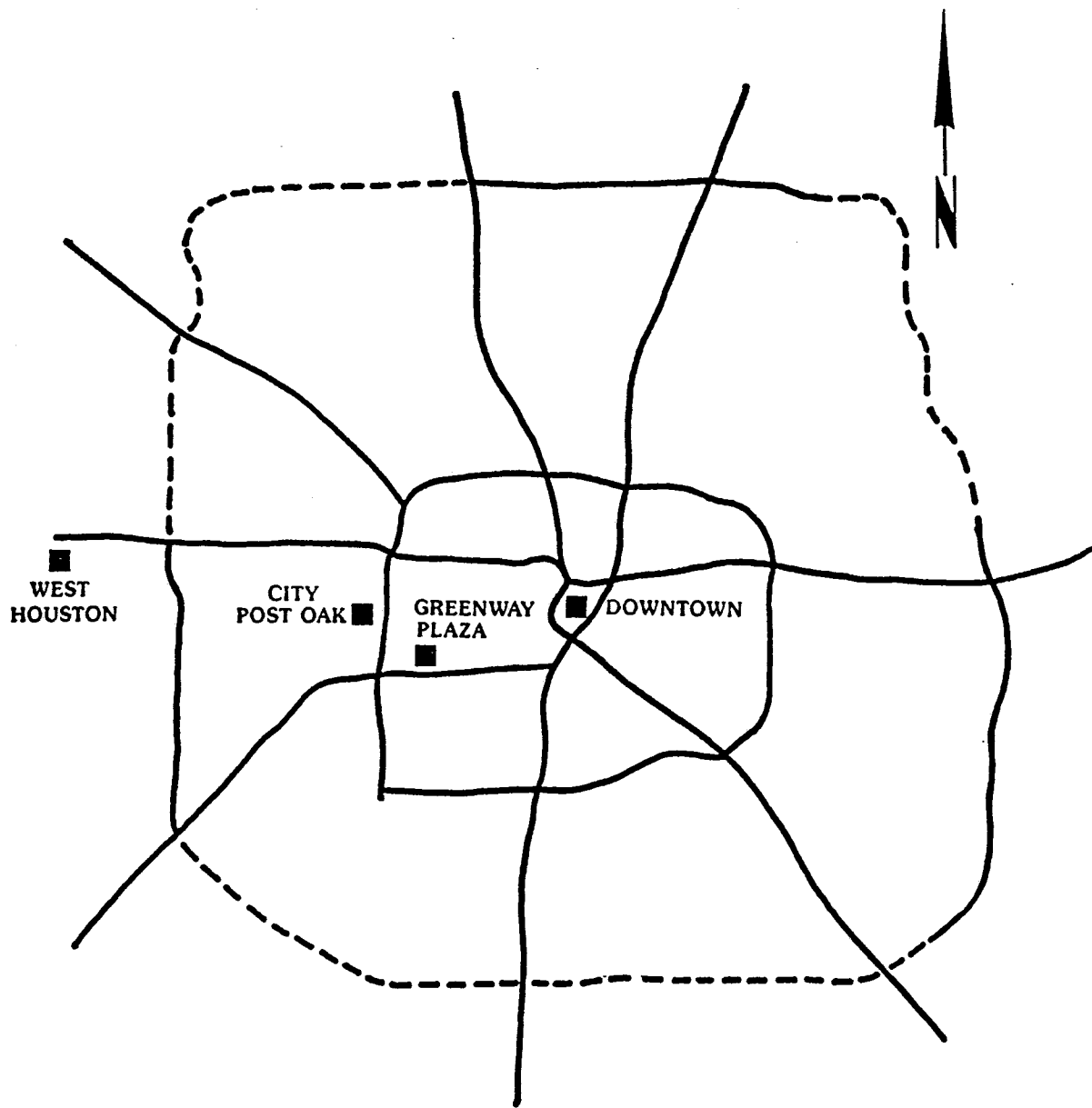
Figure 2. Houston's Regional Activity Centers

Source: (24).

● The on-board survey response rate is generally higher (from 96% to 100%) than for a mailout survey which is usually about 45-50%. It also reduces the time frame between the distribution phase and analysis phase of the study.

● Since the surveyor is available for questions, it reduces the possibility of a respondent misinterpreting the survey instructions or questions.

The major disadvantage associated with the on-board survey is the task of coordination. The distribution and administration phases must be completed in a concise time period to avoid duplication of respondents.

2.3 SPECIAL STUDIES

2.3.1 Telephone Surveys

Telephone surveys represent another approach used in the identification of travel patterns. It is similar to the on-board survey in structure, form and content, however, it is often directed at individuals that are non-users of a specific service or facility. As such, most questions are heavily weighted toward attitudinal issues relating to the respondents knowledge of the availability of the service, reasons for not utilizing the service and factors that would encourage use of a specific service. The advantages and disadvantages of the home telephone survey are summarized below (25):

Advantages

1. The surveyor is able to control the sample size by repeating calls until the desired number of respondents are located.

2. There is usually a high response rate and questions are less likely to be misunderstood by the respondents because the surveyor is available for clarification.

3. The turn around time is much faster.

Disadvantages

1. The cost may be a factor, particularly when toll calls are required.

2. The process may be labor intensive due to time restraints placed on the surveyors.

Table 10 presents an example from other special studies which may be used to identify travel patterns and trip characteristics of suburban areas. This survey was used in the assessment of the trip characteristics of transit users of the North Freeway (I-45N) Transitway in Houston, Texas.

Table 10. Trip Characteristics of Transit Users, North Freeway Transitway, Houston, Texas

Trip Characteristic	Total Sample 1985	1986	Park-and-Ride Routes 1985	1986	Express Routes 1985	1986
Trip Purpose						
	----	(n=1256)	----	(n=1152)	----	(n=104)
Work	----	99%		99%		97%
School	----	1%	----	1%	----	3%
Trip Frequency (days/week)						
	----	(n=1251)	----	(n=1147)	----	(n=104)
0-1	----	1%	----	1%	----	2%
2	----	0%	----	0%	----	1%
3	----	1%	----	1%	----	1%
4	----	3%	----	3%	----	4%
5 or more	----	95%	----	95%	----	92%
Trip Destination						
	----	(n=1252)	----	(n=1149)	----	(n=103)
Downtown	----	94%	----	95%	----	91%
Galleria	----	1%	----	1%	----	1%
Texas Med. Cntr.	----	1%	----	1%	----	1%
Greenway Plaza	----	2%	----	2%	----	----
Other	----	2%	----	1%	----	7%

n = Sample Size
Source: (26).

2.3.2 Mailout Survey

In those instances when the information needed is minimal but the geographic area to be sampled is extensive, a mailed questionnaire would be the most effective. Mailing list may be obtained from various civic and social organizations or purchased from advertising concerns. However, the response rate for mailed questionnaires is highly variable, ranging from 10 to 70 percent of the survey sample. Several steps may be used to increase the response rate and also ascertain effects of bias due to non- response:

1. Enclose a cover letter which legitimates the survey, assures anonymity of responses, urges a prompt reply, and thanks the respondent for his or her cooperation.

2. Include with the mailing a self-addressed, stamped envelope for return of the questionnaire.

3. Send a follow-up mailing to those persons who do not initially respond.

4. Make certain the questionnaire is easy to complete and not ambiguous. Most questions should be of the multiple-choice type, requiring a check for the appropriate answer.

5. Use available socio-demographic data to compare respondents with non-respondents in order to ascertain possible bias in the data.

6. If funding is sufficient, follow up with a personal interview on a subsample consisting of non-respondents. This will increase the representativeness of the sample and also make available information regarding the possible bias created by non-response.

2.4 SUMMARY

Four procedures are described in this report for identifying travel patterns. The following general procedures can be used to identify suburban travel patterns.

Origin-destination surveys provide information on existing travel patterns so that efficient transportation of people and goods can be planned and provided. This information usually includes data on: 1) where people begin and end their trips; 2) mode of travel; 3) when they travel; 4) why they travel; and 5) where they park if they are vehicle drivers.

Journey to work census data is a special tabulation of 1980 census data tailored to geographic areas that are used in transportation planning. Local transportation planning organizations submit specifications to the census bureau for the geographic detail required by their area, usually traffic zones or census tracts, and the bureau then produces a standard set of tabulations for those areas. The advantages of this approach of identifying travel characteristics are: 1) the data is probably available for most areas considering transportation improvements; and 2) the data is basically a 12.5% sample which is probably much larger than any recent O-D survey for a major urban area. The disadvantages associated with this approach are: 1) the current JTW is 1980 data and already eight years old and the new data will probably not be available until 1992 or 1993; 2) no accurate methods exist to account for any transportation system network changes in the travel patterns reflected in the JTW work trip table; and 3) there is a basic definitional difference between JTW trips and the home based work trips used in the traditional travel demand modelling process.

On-board transit surveys examine the travel characteristics, socio-economic profiles, and attitudinal perceptions of patrons utilizing a specific service or facility. The advantages of this approach are it generally is cost-effective, produces a higher response rate, and reduces the possibility of a respondent misinterpreting instructions or questions. The primary disadvantage of the on-board survey approach is the task of coordination.

Special studies conducted by various planning agencies often take the form of 1) home telephone surveys and 2) mailout surveys. These approaches may be applied when surveying non-users of a specific service or facility, or when the information needed is minimal but the geographic area to be sampled is extensive. The procedures for coordinating and administrating these surveys is very similar to other approaches used in the identification of travel patterns.

3. IDENTIFYING ALTERNATIVE ROUTING STRUCTURES

3.1 GENERAL

Transit route structures historically have focused on central business districts of our cities. Travel to the CBD generally constitutes a small and declining percentage of the total trips. In order to serve the majority of trips, new route structures oriented to larger and increasing segments of regional travel should be developed (28).

In addition to planning individual routes, an operator must analyze the total network and ensure that it provides satisfactory service for the entire city. The design of a transit network, or route alignment should be based on the following considerations:

Area Coverage. This determines the extent or dispersion of a network in the area it services, it defines the area served by the transit system.

Number of Trips Served. Travel desire lines may be determined from various origin-destination studies; transit lines should follow these desire lines to the extent possible.

Directness of Travel. Tranfers should be kept to a minimum. However, in those instances when transfers are required measures should be taken to minimize the inconvenience to patrons.

Cost. The cost of various system configurations should be analyzed along with the other characteristics, particularly the service quality.

Topography. The existing street system represents constraints on the type of transit networks that are feasible.

This section reviews the following commonly used routing alignments: 1) radial; 2) ubiquitous; 3) grid; and 4) timed transfer system (28).

3.2 RADIAL NETWORK

A radial network configuration consists predominantly of radial or diametrical routes, with the central business district or a major suburban activity center as its focal point (Figure 3). It tends to follow the heaviest desire lines "radiating" from the focal point in several directions and splitting into many branches with lower service intensity toward lower density suburban areas. Route duplication in the central area provides adequate capacity for handling the concentrated travel volumes on these network sections (14).
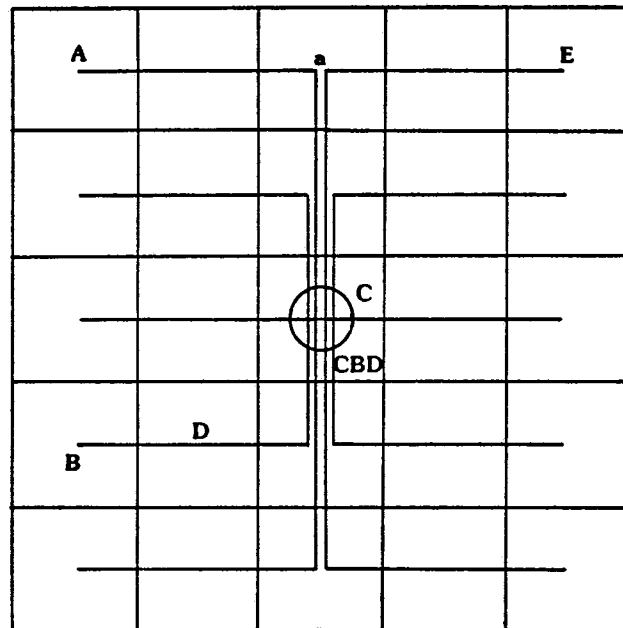

Figure 3. Radial System

In planning and scheduling branch lines, regularity of service on the joint sections must be carefully analyzed to prevent pairing of vehicles, this occurs when one delayed, overloaded vehicle is followed by a lightly loaded vehicle. This problem may be particularly acute during the peak hours. A radial network has a lower connectivity than other network forms. Usually circumferential routes must be provided to allow more direct travel for non-radial trips. Since the area coverage and service intensity of the radial network are uneven, decreasing from the center outward, this type of

network is best suited to concentrated cities with radial street networks
(14). The primary flaw with the radial system, regardless of the
configuration of the roadway network upon which it is superimposed, is that
it does not easily accommodate most travel destined to places other than the
central business district. Despite the inherent deficiency of the radial
network it is the alignment most commonly used in North American cities.

3.3 MULTIDESTINATION NETWORKS

3.3.1 Ubiquitous Network

The ubiquitous network represents a straight-forward method for
correcting the deficiency associated with the radial system without requiring
passenger transfer between routes (Figure 4). Unfortunately, this method
appears to be unrealistic because it requires a quantity of service so high
that even the most densely populated urban area could not generate enough
ridership to support it. Another shortcoming of this approach is that the
passenger load characteristics are not compatible with fixed route scheduled
transit on most of the routes. In practice, the only routes which would
attract enough patronage to justify them would be those serving the CBD.
Economics would then transfer a ubiquitous system into a radial system (14).
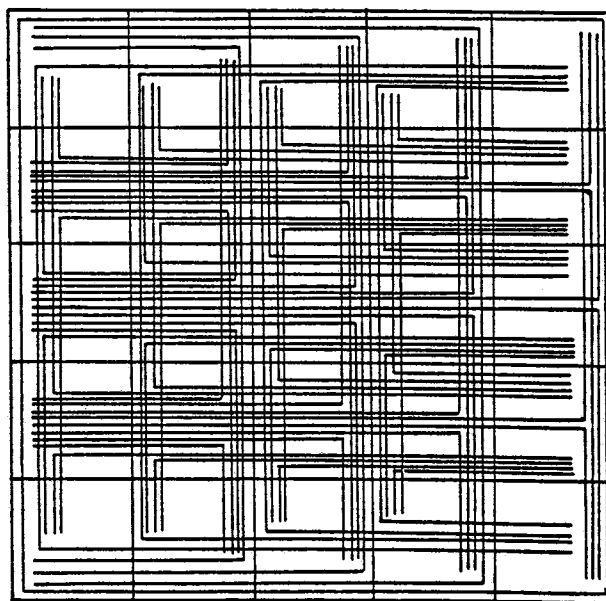

Figure 4. Ubiquitous System

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3.3.2 Grid Network

The grid network is a very direct approach to service provision. It consists of two sets of routes. The first set includes parallel routes running in a north-south orientation. These routes do not join or cross each other. The second set consists of parallel east-west routes. These do not join or cross each other; but they cross every north-south route and vice versa (Figure 5). A traveller can get from any location to any other without backhauling by transferring no more than once. The grid system offers the connectivity of the ubiquitous system, although a transfer is involved for most trips (14).
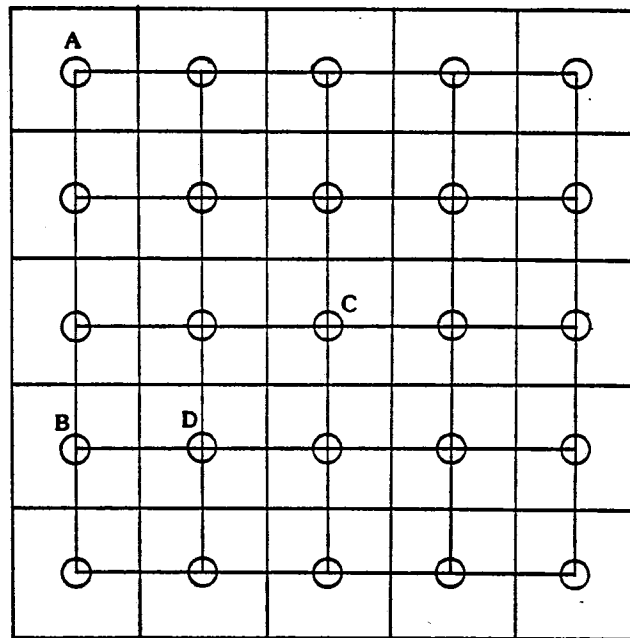
Figure 5. Grid System

For the transfer system to work, most routes in a grid system must have frequent service for most of the day. The reason is that a necessary prerequisite for a tolerable transfer is a short wait between vehicles for the transferring passengers. The short waiting time can be achieved through scheduled connections or through frequent service. The former solution cannot be employed on a grid system because of the large number of route intersections. Therefore, the grid network must rely on frequent service.

It appears that the maximum headway on a grid system should be about ten minutes. With less frequent service, uncertainty about transfer time becomes too much of a burden for transfer passengers. They would not likely use the system, leaving on board only those patrons who could begin and end their trips on the same route. That number would be a very small percentage of the total potential number of trips (14). Grid networks are well suited to evenly populated areas with grid street patterns, which require rather uniform quality of transit service.

3.3.3 Timed Transfer Systems

Another multidestination routing method is the timed transfer system (TTS). This network form has, by definition, focal points and fixed route links among them (Figure 6). Distances among the focal points are rather uniform, except if operating speeds vary; in that case link lengths tend to increase with speeds. The basic requirement of a TTS is coordinated route planning and scheduling. With timed transfers, the entire system, or its major portions, is laid out to allow vehicles to meet in timed sequence to allow convenient passenger transfer movement. Most transfers occur without having to travel downtown and also occur at places designed for transfer activities (14).
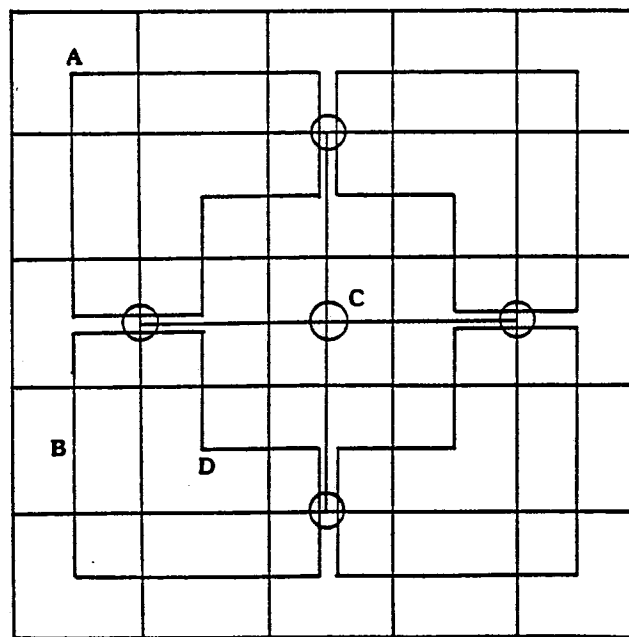
Figure 6. Timed Transfer System

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Its advantage over the grid system is that it relies on scheduled connections between routes and does not require the grid system's frequent service on most routes for most of the day. The routes would be laid out to create a manageable number of strategic locations where several routes intersect and where it is possible to schedule connections between all transit vehicles going in both directions on those routes. Typical headways for this type operation range from thirty minutes to one hour. These points are called timed transfer centers (14).

A timed transfer center often consists of an off-street platform around which eight to twelve buses can park. Generally, such a center is used on a half-hour cycle. For 15 to 20 minutes, the platform is deserted; then passengers begin to appear. Finally, buses appear from all directions and surround the platform which then fills with transferring passengers. In a few minutes, the buses are gone, and all is quiet. The cycle is repeated every thirty minutes (14).

Timed transfer systems may be classified into four types: 1) simple, 2) pulse scheduling, 3) lineup, and 4) neighborhood pulse. These classifications are variations determined by the number of converging routes, and schedule complexities. For example, the simplest form of timed transfers involves only two routes. At the other end of the complexity scale is the extensive use of timed transfers (pulse scheduling) where vehicles on all or most routes are scheduled to meet at the major transfer point nearly simultaneously, hold until all the vehicles have come in, and then leave together. The two other types of timed transfer fall between these two extremes (29).

Simple timed transfers, where buses on two routes are guaranteed to meet regularly, illustrate the basic principles of timed transfers. Simple timed transfers are used by many transit properties, from the smallest to the largest. They are most commonly used in the evening when both routes have low frequencies. This type, almost by definition, is more likely to be found at outlying transfer points where few routes may meet.

The primary concern in the implementation of simple timed transfers, is schedule coordination to ensure that buses arrive at the transfer point at the same time. There are differences in the way operators handle the unavoidable problems of schedule unreliability. Some operators have the buses lay over for 2-5 minutes at the transfer point, assuming that such a layover provides enough of a cushion to ensure that the buses will meet. Other operators use "dynamic control" to hold the first bus until the second bus arrives, if the second bus has transferring passengers. The problem with "static control," where each bus is simply scheduled to hold until the other arrives, is that if one bus breaks down or is extremely late, the schedule of the second bus is needlessly disrupted (29).

Pulse scheduling, or extensive timed transfers, is the type of timed transfer that has the most far-reaching operational consequences. The transit properties that currently use this option are extremely diverse, serving a wide variety of communities all over the United States, including college towns, industrial cities, and bedroom suburbs.

Important aspects of pulse scheduling include service frequency, routing, schedule adherence, space for buses to meet, and operator information policies. Since all buses are meeting, it is possible to speak of a "pulse frequency" of which all route frequencies are a multiple. the most common pulse frequency is 30 minutes. Other pulse frequencies such as 35 and 45 minutes are also used. These frequencies typically do not change between the peak and off-peak periods.

The need for all or most routes to have the same headway, in turn, constrains the routing of buses. When implementing pulse scheduling, many properties find their natural routes are too long and that pulse limits their route miles. A typical remedy is to cut short the ends of the routes. Additionally, routing can be used to achieve headways that do not divide evenly into route run times. Conversely, some agencies have routes that are too short. The operators response to this problem is typically to increase layovers to equalize running times or to extend the routes by loops or other means, thus adding area coverage. In practice, the choice of a pulse frequency can never be made independently of routing decisions. A major

influence in the balance between frequency and routing is the size and shape of the relevant transit district.

Ensuring schedule adherence is a major problem for pulse properties. The reasons for schedule unreliability tend to be the same as those on nonpulse properties: traffic congestion, breakdowns of new buses and interference from trains. Since the essence of timed transfers is to ensure that transferring passengers make connections, maintaining schedule adherence is more important on pulse properties.

The other variants of timed transfers 1) lineups and 2) neighborhood pulse are basically pulse scheduling applied in different situations. A lineup is pulse scheduling used in the evening and in off-peak hours. A neighborhood pulse is pulse scheduling used on only a portion of the system. Most of the operator actions associated with these variants are similar to those for pulse scheduling. The major differences that do exist are discussed in the following paragraphs (29).

Lineups are used by many nonpulse transit properties in the evening or on weekends. The populations served by this type of TTS range from 100,000 to in excess of 2,000,000. Most properties use a headway of 1 hour for their lineups, which is the same headway often used in the evening by pulse properties. Most lineups have 5-10 layovers, which may be the product of routing adjustments. For example, one property may reduce the coverage of an outlying suburb, while another adds a night loop to some routes.

The difference between neighborhood pulse and fullscale pulse systems is the size of the system in which the pulsing routes are found. With neighborhood pulse, a set of local routes pulse together to facilitate travel within a neighborhood. Because this may occur in areas outside of the congested CBD, neighborhood pulse can be found in very large cities or on any property that has non-CBD subcenters that are logical transfer points. The actions required to do this are quite similar to the actions associated with pulse scheduling (29).

3.4 NETWORK DESIGN COMPARISONS

3.4.1 Passenger Appeal

The relative passenger appeal of the radial, grid, and timed transfer systems can be tested by considering user disutility in the context of the models presented in Figures 3, 5 and 6. User disutility is the total cost to the user for traveling. It includes out-of-pocket money cost and time spent in travel. Empirical studies have shown time to be the more important variable. Travelers will choose one mode over another largely on the basis of the difference in time required to travel between two points. Planners can predict the probability of a traveller choosing one mode over another. This probability is called modal split and is usually expressed as a percentage (14).

Thompson applied a logit model to San Diego, California data to evaluate the different route configurations in terms of passenger appeal and daily operating cost. The logit model shows that network design is one of the basic determinants of user disutility characteristics. This model was applied to the hypothetical travel situations typical to the network configurations presented in Figures 3, 5 and 6. It was used to predict transit modal splits for the radial, grid, and timed transfer systems between the following points shown in those figures: Case 1 represents travel on a radial alignment destined to the CBD (Figure 3). Case 2 represents non CBD travel on a grid alignment (Figure 5). Case 3 represents non CBD travel on a TTS alignment (Figure 6).

The model uses household income, out of pocket cost, line-haul transit travel and auto times, and terminal and access transit times. It yields the transit modal split for trips between home and work. This result can be factored to yield the modal split for all trips (14).

The following assumptions are used:

1.   Auto travel time is based on 25 mile-per-hour speeds (the typical urban automobile speed)

2. Transit travel times are based on 12 mile-per-hour speeds (the typical bus system operating speed)

3. Walking time to and from transit is five minutes

4. Total auto terminal time is three minutes

5. Out-of-pocket costs for auto and transit are equal

6. Income level is $10,000

7. Base headways are fifteen minutes for the radial, ten minutes for the grid, and thirty minutes for the timed transfer systems

8. The first wait for buses is eight minutes for radial, five minutes for grid, and ten minutes for timed transfer

9. Transfer times are eight minutes for radial, five minutes for grid, and three minutes for timed transfer.

This model, combined with the preceeding assumptions for travel between the points described earlier, results in modal splits as shown in Table 11. It is seen that as would be expected the radial system gives high CBD mode splits. Other systems give high non-CBD mode splits. The radial system yields a marginally higher modal split (18 percent) to the CBD, but that the grid and to a lesser extent, the timed transfer system yield significantly higher modal splits for the other two cases (14).

In view of the above, network design and its effect on connectivity can be seen to influence a transit system's ability to attract patronage for a given urban area. Multidestination systems appear to have the ability to attract three to four times more passengers overall than radial systems in similar urban areas (14).

Table 11. Transit Network Design Modal Split Comparisons

	Line Haul Distance in Miles			Transfers			Line Haul Time (minutes)			First Wait & Access Time (minutes)			Work Trip Transit Modal Split (percentage)		
Case[a]	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Type of Network Design															
Auto	4	3	4	-	-	-	10	7	10	3	3	3	-	-	-
Radial	4	6	5	0	1	1	20	38	33	13	13	13	18	8	10
Grid	4	3	4	1	0	1	25	15	25	10	10	10	16	19	18
Timed Transfer	4	4	4	1	1	1	23	23	23	15	15	15	16	15	16

[a]Case 1 represents travel on radial alignment destined to the CBD (Figure 3).
Case 2 represents non-CBD travel on grid alignment (Figure 5).
Case 3 represents non-CBD travel on TTS alignment (Figure 6).

Source: Reference (14).

3.4.2 Daily Cost

Thompson (14) used California data to compare the daily operating cost of each type of network design. Typical operating cost based on desired headways can be computed for each routing method.

Operating costs are a direct function of the number of trips operated over the length of each system for any unit of time, if the following assumptions are met.

1. Every route in each model operates with the same technology (buses are assumed here).

2. Every route in each model operates at the same speed.

The number of trips is, in turn, determined by:

1. The desired minimum number of minutes between vehicles passing a given point.

2. Where the "policy headway" does not provide sufficient capacity to carry everybody wanting to ride, the additional trips required to accommodate these people.

The relative cost for each network can be computed by multiplying the number of daily trips for a given policy headway by the number of route miles for each network. The computation results in daily vehicle miles, which can be multiplied by a typical unit cost per vehicle mile ($1.50 assumed here).

The route miles for each of the models are required first. They can be directly measured from Figures 3-6. Alternatively, they can be computed for a model of any number of O-D's to a side with the following formulas (14):

For radial system $RM = 3/2N^2 - N - 1/2$ . . . . (1)

For ubiquitous system $RM = 3N^3 - 6N^2 - 2N + 5$ . . . . (2)

For grid and timed transfer systems $RM = 2N^2 - 2N$ . . . . (3)

Where RM = route miles, and N is the number of O-D's on one side.

Daily trips for a given policy headway are computed by multiplying the number of operating hours per day, assumed to be 18 here. For example, a policy headway of 10 minutes results in six trips per hour, or 6 X 18 = 108 trips per day (14).

Table 12 summarizes the operating cost required for the four different transit network designs and expanded versions of them. The expanded model area, more typical of medium-sized urban regions, covers an area of 10 miles by 10 miles with route spacing every half mile, connecting subareas each a half mile square. The generalized route mile formulas (1), (2) and (3) (shown above) were used to generate the route miles for the expanded example. Typical headways for radial, grid, and timed transfer systems are 10 minutes, 15 minutes, and 30 minutes, respectively (14).

As shown in Table 12, the expanded model daily operating costs for these three systems are $62,640 for radial, $119,980 for grid, and $39,960 for timed transfer, based on typical policy headways. Based on policy headways

alone, one of the multidestination systems would actually cost less to operate than a downtown radial system (14). However, policy headways alone do not give an accurate cost picture. Some parts of some routes would likely become overloaded during peak periods for each system. The grid and timed transfer system would, most likely have to operate more frequently than specified by policy headways on lines serving the CBD. The requirement would also be prevalent during rush hours with the radial system, but to a lesser extent because of the extensive route duplication in the downtown area. Passenger overloads would probably increase the daily operating cost for grid and timed transfer networks in comparison to that of the radial system (14).

An important consideration, though, is that the grid and timed transfer system would operate bus trips in addition to those specified by policy head-

Table 12. Transit Network Design Daily Cost Comparisons

Type of Network Design	Route Miles		Daily Network Operation Costs[a]					
			Vehicle Headways for Model Examples[b]			Vehicle Headways for Expanded Examples[c]		
	Model Examples[b]	Expanded Examples[c]	10 min.	15 min.	30 min.	10 min.	15 min.	30 min.
Radial	32	290[d]	10,364	6,912	3,456	93,960	62,640	31,320
Ubiquitous	220	10,783[d]	71,280	47,520	23,760	3,493,692	2,329,128	1,164,564
Grid	40	370[d]	12,960	8,640	4,320	119,880	79,920	39,960
Timed Transfer	38	370[e]	12,312	8,208	4,104	119,880	79,920	39,960

[a]All-bus systems assumed; daily operating costs are daily vehicle miles times $1.50 per vehicle mile.
[b]Five-mile by five-mile area with one-mile route spacing.
[c]Ten-mile by ten-mile area with half-mile route spacing.
[d]Calculated from formulas 1-3 (p. 48).
[e]Assumed same as grid (see text).

Source: Reference (14).

ways only as required by passenger demand. Every additional bus would carry a full load, so that added revenues would tend to match added cost. In contrast, the extensive route duplication of the radial system would probably result in many more buses than required by policy headways operating into the CBD area many times of the day. Additionally, a radial system serving just one major and specialized destination would probably be characterized by less off-peak revenue and much less patronage and revenue on the outer parts of the lines. The net result would probably be higher operating cost for a

grid or timed transfer system than for a radial system of similar route coverage, but much higher revenues as well, with cost for added services more closely matched to added revenues. There seems little reason to believe that deficits for multidestination systems would exceed those for radial systems (14).

3.5 SUMMARY

In summary, routing structures generally fall into one of four classifications: 1) radial; 2) ubiquitous; 3) grid; and, 4) timed transfer systems (28).

The radial network configuration consists primarily of radial or diametrical routes, with the central business district or a major suburban activity center as its focal point. Since the area coverage and service intensity of the radial network are uneven, decreasing from the center outward, this type of network is best suited to concentrated cities with radial street networks (14).

The ubiquitous network represents a utopian approach for correcting the deficiency associated with the radial system. Unfortunately, this method appears to be unrealistic because it requires a quantity of service so high that even the most densely populated urban area could not generate enough ridership to support it (14).

Another approach to regional transit network design is the grid concept. Rather than focusing service on the CBD, the grid offers north/south, east/west service connections to most regional destinations of regional significance along major freeways or arterials. The grid network is characterized by two sets of parallel routes spaced at regular intervals, each operating along fairly straight paths. Routes are developed as elements of an interdependent, integrated system. A great deal of importance is placed upon the transfer in a grid system, because without it, a rider is severely limited in the number of destinations available to him. Yet, with a single transfer, the rider can reach almost any major destination with little circuitous travel.

Timed transfer systems have been suggested as a method for transit to increase its share of the large and rapidly growing non-CBD destined travel market during both peak and off-peak periods. The basic requirement of a TTS is coordinated route planning and scheduling. With time transfers, the entire system, or its major portions, is laid out to allow vehicles to meet in time sequence to allow convenient passenger transfer movement. Most transfers occur without having to travel downtown and also occur at places designed for transfer activities (14).

Timed transfer systems may be classified into four types: 1) simple, 2) pulse scheduling, 3) lineup and 4) neighborhood pulse. These classifications are variations determined by the number of converging routes, and schedule complexities. Simple timed transfers, where buses on two routes are guaranteed to meet regularly, illustrate the basic principles of timed transfers. They are most commonly used in the evening when both routes have low frequencies. This type is more likely to be found at outlying transfer points where few routes may meet.

Pulse scheduling is the type of TTS that has the most far reaching operational consequences. Important aspects of pulse scheduling includes service frequency, routing, schedule adherence, spaces for buses to meet, and operator information policies.

The other variants of timed transfers 1) lineups and 2) neighborhood pulse are basically pulse scheduling applied in different situations. A lineup is pulse scheduling used in the evening and in off-peak hours. A neighborhood pulse is pulse scheduling used on only a portion of the system. Most of the operator actions associated with these variants are similar to those for pulse scheduling (29). Table 13 summarizes the characteristics of the different network types.

Studies show that timed transfer systems do not work well everywhere. Residential densities of anywhere between 3,000 and 6,000 persons per square mile seem best suited for operationalizing these networks. In suburban areas with densities far below the 3,000 persons per square mile minimum threshold, more flexible modes of mass transportation are needed, either as feeders

Table 13. Summary of Characteristics of Different Network Types

Network/ Type Characteristic	Grid	Radial/ Circumferential	Ubiquitous	TTS
Area coverage	Very Good	Good in central area, decreasing outward	Ubiquitous but unstable	Variable
Directness of travel	Poor	Good for radial, poor for many others	Usually good	Variable
Transfers: convenience and delay	For most trips one	For most trips none	Poor	Excellent
Service quality	Uniform	Excellent for radials, lower for other directions	Personalized-varies	Very good
Network clarity and image	Excellent	Very good	Very pooor	Very good

Source: (30).

into timed transfer centers or also as direct connectors into outlying workplaces themselves (7).

Thompson applied a logit model to San Diego, California data to evaluate the different route configurations in terms of passenger appeal and daily operating cost. The logit model shows that network design is one of the basic determinants of user disutility characteristics. The results of this analysis indicate that network design and its effect on connectivity can be seen to influence a transit systems ability to attract patronage for a given urban area. Multidestination systems appear to have the ability to attract three to four times more passengers overall than radial systems in similar urban areas (14).

Thompson also used California data to compare the daily operating cost of each type of network design. Typical operating cost based on desired headways can be computed for each routing method. The relative cost for each network can be computed by multiplying the number of daily trips for a given

policy headways by the number of route miles for each network. The computation results in daily vehicle miles, which can be multiplied by a typical unit cost per vehicle mile (see Table 12). Based on the results of Table 12 there seems to be little reason that deficits for multidestination systems would exceed those for radial systems (14).

4. <u>EVALUATING ALTERNATIVE SERVICE OPTIONS</u>

4.1 GENERAL

In recent years the U.S. transit industry has experienced increasing fiscal pressures that have been caused by dramatic rises in transit operating costs, decreased federal assistance, and the reluctance of communities to increase local tax bills to support public transit services. In response to these fiscal pressures that have constrained transit systems' abilities to maintain or improve existing service levels, many agencies have begun to carefully re-examine the manner in which their limited resources are allocated by developing more rational approaches to improve system efficiency and effectiveness.

Transit performance indicators have been suggested as potentially useful means of measuring and comparing the effectiveness and efficiency of transit operations. These indicators provide a means of evaluating the trade-offs between various goals in terms of services provided, the quality of those services and the cost of providing those services. Despite the fact that many transit systems have begun to conduct formal performance evaluations, no generally accepted set of evaluative criteria have been developed that can be applied to the different routing alignments typically examined in the provision of service to low density areas.

The effectiveness of transit performance indicators may be constrained by certain external factors. These factors can be grouped into five basic categories: 1) political constraints; 2) budgetary constraints; 3) inadequate performance data; 4) data processing limitations; and 5) inadequacy of current indicators and performance standards. Each of these factors are discussed in the following paragraphs (<u>17</u>).

Constraints created by the political environment are the most common problem in evaluating bus service. Political constraints are defined as influence that is exerted on service decisions by various interest groups and other government entities such as municipal governments. The transit systems are sometimes frustrated because these constraints make it difficult to

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routinely eliminate or reduce unproductive services. On the other hand, some transit systems are sometimes forced to implement new services that are unproductive because of political considerations.

Budgetary and financial constraints also present significant problems for transit systems evaluation processes. The problems assumed two general forms. First, capacity constraints created by limitations to the number of vehicles that a system can afford to operate restrict service expansion that might be justified by the results of performance evaluations. Second, there are also limitations on the resources that are available to expand or improve the quality of bus service evaluation efforts. The personnel that are required for most data collection and analysis activities are viewed as support personnel which are often given a lower budgetary priority than "line" personnel such as bus operators and mechanics. Other service evaluation and monitoring resources and inputs such as data processing systems and funds to conduct special studies and research are often viewed in a similar light (17).

Inaccurate or insufficient performance data and inadequate data processing capabilities are a major source of problems facing transit's evaluations. A typical complaint is the lack of sufficient, high quality data. Transit systems that are concerned about their data processing capabilities are generally desirous of developing more automated techniques that do not rely on labor intensive processes or are capable of providing more readily useable data for analysis.

Dissatisfaction with existing performance indicators or service standards is a relatively insignificant problem among transit systems. This occurs when managers feel that the performance indicators currently employed do not provide enough information or that their standards are out-dated and in need of revision (17).

This section presents recommended criteria for evaluating alternative routing structures.

4.2 POTENTIAL USES OF TRANSIT PERFORMANCE MEASURES

The potential uses of transit performance evaluation criteria are many. These uses generally fall into one of two classifications: 1) funding and 2) planning, management and policy functions.

From a funding perspective transit performance evaluations can provide a means by which transit is able to justify its financial needs when competing against other public services for scarce resources. However, the use of performance evaluations as a policy tool in allocating funding resources across transit systems has limited appeal. It therefore appears that the most beneficial applications of transit performance measurement lie in the areas of planning, management and policy (27). Consistent, current and comprehensive information concerning the performance of urban public transportation systems can be an important policy tool. Information from performance data monitoring can be helpful in assessing the effectiveness of alternative program and policy options.

The information provided by performance measurement can facilitate the assessment of service effectiveness and management in finding ways to reduce costs and help community leaders and other local decision-makers determine the level and types of transit services their community can afford. In addition, such information can provide management with the knowledge of which services or service aspects are performing better than others (27).

Also, performance measurement can be helpful to management in the area of allocating resources within the transit system. If a transit manager is to realize optimal improvement from the resources available, then the allocation of those resources must be made to those services which are most efficient and effective in achieving the stated objectives. In other words, a priority of funding within a transit system can be established in order that the public will receive the maximum benefits.

Planning on a continuing basis is essential to the success of a transit system. However, in the planning process very often certain goals and objectives for the provision of transit service may be conflicting. As such,

there is a need to evaluate the extent to which a particular transit improvement relates to each of the goals and objectives set forth in the areawide transportation plan. One way this can be accomplished is by a trade-off analysis that uses relevant transit performance measures related to the specific goals and objectives under consideration (27).

Improving urban public transportation services has been a nationwide concern in recent years. The increasing reliance on local, state and federal funding sources to provide the financial support necessary to implement various transit improvements has led to the need for evaluating these potential improvements in terms of their effect on transit efficiency and effectiveness measures. When collected over a period of time, performance measurements would enable evaluation of particular investment programs and policies in terms of changes in system performance. Furthermore, the information provided by various performance measures can be useful for the planning of new or additional service, as well as for influencing decisions to modify or continue existing service (27).

4.3 CONCEPTS OF EFFICIENCY AND EFFECTIVENESS

It is generally agreed that public transit should perform both efficiently and effectively. Therefore, measures of transit performance are usually classified as either efficiency indicators or effectiveness indicators (27). Briefly stated, efficiency indicators are most commonly used to evaluate the process by which transit services are produced; that is, the relationship of inputs to outputs, or the concept of "doing things right." Measures of effectiveness are concerned with the extent to which the service provided--in terms of quantity, location and character--corresponds to the goals ad objectives established for it and the needs of the community. Effectiveness, then, is the comparison of produced output to intended output, or the concept of "doing the right things" (27).

Table 14 presents a listing of potentially useful indicators of efficiency and effectivnesss which have been proposed by various professionals in the transportation industry.

Table 14. Potential Transit Performance Indicators

Effectiveness Measures

    Accessibility and Reliability

        ● Percent of population within 1/4 mile of a route
        ● Percent of transit dependent within 1/4 mile of a route
        ● Revenue passengers/service area population
        ● Percent of employment served by transit
        ● Percent of population more than 1 hour from key destinations
        ● Time required to travel between major origin and destination points
        ● Headways
        ● Number of buses taking x minutes longer than schedule
        ● Percent of buses 1 minute early to 4 minutes late
        ● Percent missed trips
        ● Average waiting time of passengers
        ● Excess waiting time of passengers
        ● Seat hours/capita

    Utilization of Service

        ● Revenue passengers/service area population
        ● Revenue passengers/vehicle mile
        ● Revenue passengers/vehicle hour
        ● Total passengers/vehicle
        ● Total passengers/vehicle mile
        ● Total passengers/vehicle hour
        ● Passenger miles/vehicle mile
        ● Revenue passengers/capacity hour
        ● Revenue passengers/capacity mile
        ● Revenue passenger miles/capacity hour
        ● Revenue passenger miles/capacity mile
        ● Average length of passenger journey
        ● Number of annual passengers/annual seat miles

    Convenience

        ● Hours of service
        ● Bus travel time/auto travel time
        ● Transfer opportunities/route mile
        ● Number of transfers/number of passengers
        ● Average operating speed
        ● Bus stop spacing
        ● Vehicle step height
        ● Information services

    Comfort

        ● Maximum number of passengers/total available seats (averaged over each route at
          maximum load point)
        ● Peak hour floor area/passenger (averaged over each route at the maximum load point)
        ● Ventilation

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Table 14. Potential Transit Performance Indicators (Cont.)

- Vehicle jerk
- Average bus age
- Vehicle cleanliness

Labor/Usage Relationship

- Passengers/employee hour
- Passenger miles/employee hour

Safety

- Number of accidents/vehicle mile
- Number of crimes/vehicle mile
- Vehicle miles/number of road calls

Efficiency Measures

Costs, Revenues, Deficit

- Operating cost/total passengers
- Operating cost/revenue passengers
- Operating cost/passenger mile
- Operating cost/vehicle mile
- Operating cost/vehicle hour
- Operating cost/capacity mile
- Operating cost/capacity hour
- Operating cost/operating revenue
- Maintenance cost/vehicle mile
- Maintenance cost/vehicle hour
- User cost/trip
- Revenue/vehicle hour
- Total revenue/operating costs
- Operating revenue/vehicle mile
- Operating revenue/passenger mile
- Operating revenue/passenger
- Operating revenue/$ of direct cost for providing service
- Operating revenue/vehicle
- Net deficit/total operating cost
- Net deficit/hours of service
- Net deficit/total revenue passengers
- Net deficit/total passenger revenues
- Net deficit/passenger mile
- Net deficit/vehicle mile

Vehicle Utilization

- Revenue vehicle miles/revenue vehicle hours
- Peak vehicles required/off-peak vehicles required
- Spare vehicles/required fleet size
- Revenue vehicle hours/total vehicle hours
- Daily vehicle miles/scheduled number of vehicles

Table 14. Potential Transit Performance Indicators (Cont.)

- Vehicle seat capacity/total transit seats
- Percent lost mileage
- Annual vehicle hours of service/revenue vehicle
- Annual vehicle miles of service/vehicle
- Revenue vehicle hours/vehicle
- Revenue vehicle miles/vehicle

Labor Productivity

- Revenue vehicle hours/employees
- Revenue vehicle miles/employees
- Total vehicle miles/employee
- Total vehicle hours/total employee hours
- Capacity hours of revenue service/employee hour
- Capacity miles of revenue service/employee hour
- Total vehicle miles/bus operators
- Annual vehicle hours/annual employee hours
- Passengers/employee hour
- Passengers/employee
- Operators/vehicle
- Operator pay hours/vehicle hour
- Annual vehicle miles/operator
- Annual vehicle hours/operator
- Annual passengers/operator
- Absenteeism (operators and maintenance)
- Total labor input/vehicle miles operated
- Total labor input/passenger mile
- Total labor input/passenger

Maintenance

- Average fleet age
- Vehicles/mechanic
- Annual vehicle hours/mechanic
- annual vehicle miles/mechanic
- Vehicle miles/quart of oil consumed
- Vehicle miles/gallon of fuel consumed
- Vehicle miles/maintenance related road call
- Facility age

Source: Reference: (27).

While the listing in Table 14 is extensive, it is by no means complete. There are considerable differences of opinion within the transit industry and among the governmental agencies as to which criteria provide the best measurement of transit performance (27). There is also some disagreement concerning whether or not the use of ratios is valid in measuring and evaluating system performance; it is argued that ratios are not really

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measures of efficiency and effectiveness at all, unless the objective is to optimize the ratio itself. It should also be noted that although the indicators in Table 14 have been classified as either measures of efficiency or effectiveness, it is entirely possible for the same indicator to measure either efficiency or effectiveness, depending on the objective being sought. Consider the following example (27).

System A carried 1,500 passengers at a cost of $20,000 and System B carried 1,000 passengers at a cost of $10,000. If the goal is to carry the maximum number of riders, then System A is the most effective. However, if the goal is to carry each rider as inexpensively as possible, then System B is the most efficient. In other words, if the goal is to maximize ridership, then operating expense per passenger represents an effectiveness measure of "doing the right things." If, on the other hand, the goal is transporting each rider as economically as possible, then operating expense per passenger becomes an efficiency measure of "doing things right."

Although there may be a fine line between efficiency and effectiveness in some cases, it is generally agreed that effectiveness measures are usually "cost-free," and usually do not include ratios involving the use of resources. Indicators of effectiveness should measure the degrees to which the goals of the system are accomplished, whereas efficiency measures should involve input/output relationships in attaining the goals (27).

4.4 SELECTING THE APPROPRIATE PERFORMANCE INDICATORS

The selection of how many and which measures to use as performance indicators is highly dependent on the individual system involved. Each performance indicator, by virtue of component data elements, focuses on different aspects of transit performance (27). It remains, then, to consider how the choices regarding performance measurement vary according to their intended uses. External uses such as annual reports can probably be accommodated by fewer measures of a more aggregate nature than the evaluative, planning and decision-making uses which are internal to the system. With regard to internal uses, there is a need for further differentiation in number, type and level of detail of performance measures

on the basis of functional application and organizational characteristics. For example, monitoring the performance of an operations department would require a distinctly different set of measures than would monitoring the performance of an individual transit route or a particular type of service (such as park-and-ride). The former application is likely to be oriented toward efficiency measures which relate output to input (e.g., the cost of performing specific maintenance or scheduling function, etc.), while the latter application would concentrate more on effectiveness measures which describe the quality of output (e.g., schedule adherence) and the degree to which output is consumed (e.g., passengers per vehicle hour) (27).

Upon determining the intended uses of the performance evaluation, several criteria should be applied in the selection of specific indicators. In general, performance indicators chosen should be:

- Related to a stated system objective;
- Easily understandable and defineable;
- Measurable from available data; and
- Acceptable to the parties involved.

Finally, each indicator chosen should be analyzed in terms of inherent weaknesses, biases and drawbacks (27).

An important consideration in the selection of transit performance measures (and in the overall design of the performance monitoring program) is the level of financial resources and staff expertise available for data collection and data processing. Complying with the recent UMTA reporting requirements has undoubtedly resulted in significant changes in accounting procedures and expansion of the data collection, processing and reporting efforts by many transit systems in the state. While UMTA is underwriting a significant portion of the costs of complying with these requirements, nevertheless, there may be a shortage of funds, expertise and staff enthusiasm to design and implement a transit performance measurement system which will involve a substantially expanded data base with detailed levels of stratification (27). For example, at one point in time, the San Mateo County Transit District in California was collecting data for use in 141 different

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performance indicators. All of the indicators were felt to have stated something interesting about the system's performance and all possibly would serve some useful purpose someday. However, data collection and analysis is costly, and a significant portion of it can be meaningless and wasteful (27).

4.5 RECOMMENDED PERFORMANCE INDICATORS

In terms of recommendations, the literature suggests that when monitoring the performance of an individual transit route, emphasis should be placed on effectiveness measures which describe the quality of output (e.g., schedule adherence) and the degree to which output is consumed (e.g., passengers per vehicle hour (27). As shown in Table 14 several performance indicators exist that meet this requirement.

The Tri-Met System of Portland, Oregon, which operates a pulse scheduled system initiated a comprehensive evaluation of its suburban westside service that was designed to address a number of important concerns. The evaluation focused on two general areas: service impacts and service reliability. Three areas of performance were examined: 1) Ridership, growth and travel patterns 2) Performance, system and route level, and 3) Schedule reliability. Specific performance indicators utilized by Tri-met were:

- The ratio of revenue service hours to total platform hours as a measure of schedule efficiency,
- Riders per vehicle hour and operating cost per hour as a measure of economic efficiency, and
- Boarding riders per service hour and system cost per hour as a measure of the performance of individual routes (18).

The Metropolitan Transit Authority of Harris County (METRO) operates a conventional radial system and suggests utilization of the following performance indicators for all local routes:

- subsidy per passenger trip,
- revenue to cost,

- passenger trips per revenue mile, and
- passenger trips per revenue hour.

New or improved transit lines which have been in service for less than one year are evaluated primarily on ridership productivity, but all performance indicators are monitored to assess the lines overall performance.

5. PLANNING GUIDELINES FOR IMPLEMENTING SUBURBAN TRANSIT SERVICES

5.1 GENERAL

Suburban transit services should ideally be designed in accordance with demographic trends and the configuration of the existing street and highway system. Demographics generally identify travel patterns through analyses of population shifts, housing, shopping and employment opportunities. An equally important consideration is the efficient design of the transit network, individual routes and facilities which contribute to an economical operation. This section of the report contains a set of basic guidelines which may be used for implementing suburban transit services.

5.2 IDENTIFYING SUBURBAN TRAVEL PATTERNS

Prior to the implementation of suburban transit services, the issue of current travel patterns should be analyzed. Suburban travel patterns may be identified from a number of secondary sources. These sources include origin-destination surveys, census journey-to-work data, on-board transit surveys, and other special studies (e.g., park-and-ride lot studies). These sources are typically used in the identification of travel characteristics (e.g., trip purpose, frequency and length), socio-economic profiles and attitudinal perceptions regarding a specific service. Many organizations routinely collect and maintain such data for most urban areas. Examples include public transportation properties, metropolitan planning organizations, councils of government, state highway departments, city and county transportation departments, local engineering and planning consultants, and transportation management associations.

As might be expected, each source of information consists of certain advantages and disadvantages. These are summarized in Table 15.

Table 15. Advantages and Disadvantages of Approaches to Identifying Suburban Travel Patterns

Source	Advantages	Disadvantages
Origin-Destination	1. The process is relatively inexpensive and usually provides good population coverage. 2. This approach generally results in a high response rate.	1. Collection of the data may be labor-intensive and hazardous. 2. Possible bias may occur due to better response by some drivers.
Census Journey-To-Work	1. The data will probably be available for virtually any urban area considering transportation improvements. 2. The data is basically an expanded 12.5% sample. This is likely a much larger sample than any recent O-D survey for a major urban area.	1. The data is collected from the decennial census, thus, age may diminish the usefulness of the data in areas experiencing cyclical economic swings in either direction. 2. No accurate methods exist to account for any transportation system network changes in the travel patterns reflected in the journey to work trip table.
On-Board Transit Surveys	1. There is considerable cost savings in the administration of this form of survey. It does not require postage as a mailout would, and less manpower requirements than an O-D survey. 2. The on-board survey response rate is generally higher (from 96-100%) than for a mailout survey which is usually about 45-50%. It also reduces the time frame between the distribution and analysis phase of the study. 3. Since the surveyor is available for questions, it reduces the possibility of a respondent misinterpreting the instructions.	1. The major disadvantage of the on-board survey is the task of coordination. The distribution and administration phases must be completed in a concise time period to avoid duplication of respondents.

Table 15. Advantages and Disadvantages of Approaches to Identifying Suburban Travel Patterns
(Cont.)

Source	Advantages	Disadvantages
Special Studies (1) Telephone Surveys	1. The surveyor is able to control the sample size by repeating calls until the desired number of respondents are located. 2. There is usually a high response rate and questions are less likely to be misunderstood by respondents because the surveyor is available for clarification 3. The turnaround time is much faster.	1. Cost may be a factor, particularly when toll calls are required. 2. The process may be labor intensive due to time restraints placed on the surveyors.
(2) Mailout Survey	1. May be used to sample extensive area.	1. May incur a low response rate.

Source: (21, 25).

5.3 IDENTIFYING ALTERNATIVE ROUTING STRUCTURES

Once the existing travel patterns have been identified and analyzed, the next step is to identify an appropriate routing structure. This should ideally be based on the relationship between route structure, development patterns and travel patterns. The selection and design of a transit network, or route alignment should also be based on area coverage, number of trips served, directness of travel, cost and topography. The relevant aspects of each element are summarized below.

Area coverage expresses the extent or spread of a network in the area it serves; it is defined as the area served by the transit system. The area within a 5-minute walking distance (about 1/4 mile) from all transit stations is considered as the primary served area. Points between 5- and 10-minute walking distance represent the secondary served area. But for outlying stations where many passengers use automobiles for access to transit, the served area is much greater and its approximate boundaries can be found only through surveys of passenger origins.

Most of the potential passengers within a five-minute walk of a transit stop can be expected to use the available service provided it is of satisfactory quality. Beyond the five-minute radius, the percentage choosing transit drops off rather rapidly, due to unwillingness of people to walk so far.

In determining how far out the transit service should extend, ideally the entire urbanized area should be served. A publicly owned transit agency should attempt to extend its network to cover as extensive an area as is economically reasonable and socially desirable, so that it provides a public service to the entire community. Private companies, on the other hand, often find it unprofitable to service the lower density outlying regions and can only be expected to provide transit service in areas for which external financial assistance is available (28).

Number of trips served should be maximized by proper network design. Travel desire lines may be determined from various origin-destination studies; transit lines should be made to follow these desire lines to the greatest possible extent (28).

Directness of travel should also be provided as much as possible. This is defined as the ratio of the actual physical travel distance between two points via the transit system to the straight line distance between these two points. It is desirable to minimize this ratio; however, route layouts are often constrained by street patterns and topography. Directness of routes for the entire system can best be minimized by connecting large traffic generators and placing routes along the most concentrated travel desire lines, while serving populated areas between them as much as possible (28).

While directness of route is a desirable goal, it often conflicts with area coverage which should be maximized. Area coverage can often be increased by the use of more circuitous routes. Where demand for transit is high, it is feasible to have direct routes that provide good area coverage; however, in areas of low demand, service would be too infrequent if only direct routes were used. When circuitous routes are necessary, it is

desirable that their greatest circuity occur on outlying sections of the route so that the least number of riders are delayed (28).

Transfers of passengers among lines should be minimized by designing long routes along the heaviest concentrations of desire lines.

Cost of various system configurations must be weighed against the other characteristics of each, particularly the service quality.

Topography and existing street network always represent constraints on the type of transit networks that are feasible.

Optimum density of the network should be determined through a trade-off analysis between density of lines and frequency of service.

As mentioned previously, route alignments generally fall under one of four categories: 1) radial; 2) ubiquitous; 3) grid and 4) timed transfer systems (27). This section summarizes the attributes of each.

A radial network configuration consists predominantly of radial or diametrical routes, with the central business district or a major suburban activity center as its focal point (Figure 3). It tends to follow the heaviest desire lines "radiating" from the focal point in several directions and splitting into many branches with lower service intensity toward lower density suburban areas. Route duplication in the central area provides adequate capacity for handling the concentrated travel volumes on these network sections (14). A radial network has a lower connectivity than other network forms. Usually circumferential routes must be provided to allow more direct travel for non-radial trips. Since the area coverage and service intensity of the radial network are uneven, decreasing from the center outward, this type of network is best suited to concentrated cities with radial street networks.

The ubiquitous network represents a straight-forward method for correcting the deficiency associated with the radial system without requiring passenger transfer between routes (Figure 4). Unfortunately, this method

appears to be unrealistic, because it requires a quantity of service so high that even the most densely populated urban area could not generate enough ridership to support it. Another shortcoming of this approach is that the passenger load characteristics are not compatible with fixed route scheduled transit on most of the routes. In practice, the only routes which would attract enough patronage to justify them would be those serving the CBD. Economics would then transfer a ubiquitous system into a radial system (14).

Grid systems typically produce a few routes used very intensively. This characteristic may not be intuitively obvious because the grid system is oriented to dispersed trips. The grid system offers the connectivity of the ubiquitous system, although a transfer is involved for most trips. For the transfer system to work, most routes in a grid system must have frequent service for most of the day. Grid networks are well-suited to evenly populated areas with grid street patterns, which require rather uniform quality of transit service.

Another multidestination routing method is the timed transfer system (TTS). This network form has, by definition, focal points and fixed route links among them (Figure 6). Distances among the focal points are rather uniform, except if operating speeds vary; in that case link lengths tend to increase with speeds.

The basic requirements of TTS is coordinated route planning and scheduling. With timed transfers, the entire system, or its major portions, is laid out to allow vehicles to meet in timed sequence to allow convenient passenger transfer movement. Most transfers occur without having to travel downtown and also occur at places designed for transfer activities (14).

Its advantage over the grid system is that it relies on scheduled connections between routes and does not require the grid system's frequent service on most routes for most of the day. The routes would be laid out to create a manageable number of strategic locations where several routes intersect and where it is possible to schedule connections between all transit vehicles going in both directions on those routes. Typical headways

for this type operation range from 30 minutes to one hour. These points are called timed transfer centers (14).

From a regional context, no single local routing pattern could be recommended that would effectively serve different areas. Instead, it is suggested that a combination of alignments be considered. For example, a radial network of routes should be designed to connect the outlying transit nodes with the regions CBD. Circumferential routes should be laid out to connect the various outlying transit centers in the region and the grid concept may be utilized in the CBD where grid street patterns exist. The decision as to which route pattern to use in a given situation should be based on explicit objectives which acknowledge financial constraints and the service needs of the area.

5.4 ROUTE PLANNING GUIDELINES

This section examines aspects of route planning guidelines. The basic elements and concepts of route planning are defined and illustrated. A method for planning an individual transit route is presented with a step by step description, and numerical examples. It should be noted, that the lack of reliable route-level demand estimation procedures poses a real problem in the development of this section. Despite the availability of the route level demand estimation procedures shown in Table 7 (p.10), the state-of-the-art is not very advanced. It appears there is a wide disparity between methods appearing in the literature and procedures employed in the industry. Some agencies use variations of these techniques which lack the sensitivity and reliability to predict route level ridership impacts resulting from service changes. As a consequence, there is a need to review and document existing procedures or develop new procedures.

Noteworthy developments in this area are the mode split percentages identified by Thompson (14). These percentages were developed to show ridership comparisons between different transit network designs. As shown in Table 16, there is considerable variance in the forecast ridership of the different route orientations.

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Recent experiences in Portland suggest that modal splits roughly 50-200 percent above those developed by Thompson are possible through the use of a multi-destinational network (14).

Table 16. Transit Network Design Ridership Comparisons

Case	Alignment	Work Trip Transit Modal Split
1	Radial	.18
	Grid	.16
	Timed-Transfer	.16
2	Radial	.08
	Grid	.19
	Timed-Transfer	.15
3	Radial	.10
	Grid	.18
	Timed-Transfer	.16

Source: (14).

Assumptions: Case 1 represents movement from outlying area to the CBD.
Case 2 represents crosstown movement bypassing the CBD.
Case 3 represents crosstown movement to the fringe of the CBD.

5.4.1 Definition of Basic Elements

The definitions provided in this section will be of assistance in understanding the process of planning and scheduling a route. According to Vuchic et al., (28) the following operating elements merit consideration in route planning decisions.

Headway (h) is the time interval in minutes between two successive departures of transit vehicles on a line. Transit users are interested in having service with short headways to minimize waiting time. However, since for any given volume of passengers per hour it is cheaper to operate a smaller number of large vehicles than a greater number of small vehicles, the operator is interested in operating with larger vehicles at longer headways. Consequently, headways are usually determined as a compromise between passenger convenience and operating cost.

The point along a transit line at which minimum possible headways between successive vehicles are the longest determines the minimum headway for the whole line (h_{min}). The minimum headway should be determined for stops with heavy passenger boarding/alighting; the longest of these headways is critical and therefore represents the minimum possible headway on the line (28).

Frequency of Service (f) is the number of transit trips passing a point on the line during one hour (or any given period of time). Thus, short headways mean high frequency, long headways represent low frequency. The two are related by the formula:

$$f = 60/h$$

where f is in vehicles per hour and h is in minutes.

The maximum frequency of vehicle arrivals (f_{max}) is determined by the minimum headway as:

$$f_{max} = 60/h_{min}$$

Vehicle Capacity (C_v) is the total number of passenger spaces on the vehicle. It is calculated by adding the number of seats plus the standing capacity. This definition applies to interurban rapid transit, local bus and trolley lines. For suburban railroads and for bus and trolley lines with medium or long average trip lengths, seating capacity alone is commonly used as C_v (28).

Passenger Volume (p) is the number of passengers traveling on a line past a fixed point during one hour, or during some other specified period of time. Passenger volume varies along the line with time of the day, day of the week, and season of the year (28).

Maximum Load Section (MLS) is the line section between two stations on which the maximum passenger load occurs.

Design Hour Volume (DHV) is the highest passenger volume for all sections along the line. This volume is the basic factor in determining the line capacity which should be offered (28).

Line Capacity Offered (C) is the total number of passenger spaces offered at a fixed point of a transit line during one hour. Line capacity is basic to transit system planning and design. Each facility must provide the capacity equal to or greater than DHV. The line capacity is derived from the product of frequency and vehicle capacity:

$$C = f \times C_v$$

Capacity is expressed in persons/hour (28).

The Maximum Line Capacity (C_{max}) is the maximum of passengers per hour a line can carry with minimum operationally feasible headways. C_{max} is given as the product of maximum frequency and vehicle capacity:

$$C_{max} = f_{max} \times C_v = 60/h_{min} \times C_v$$

Operating Time (T_0) is the scheduled time interval between departure of a vehicle from one terminal (end-of-line stop or station) and its arrival at another terminal on a route; usually expressed in minutes (28).

Operating Speed (V_0) is the average speed of a transit vehicle, including stopping time at stations or stops and expected delays for traffic reasons (as on surface lines, such as bus and trolley). It is computed as the one-way line length (L) in miles divided by the operating time in minutes:

$$V_0 = 60L/To$$

Speed computed by this equation is in (miles per hour).

Terminal Time (t_t) is the time a vehicle spends at a terminal or end-of-line stop in excess of the interval required for the boarding and

alighting of passengers. Its purpose is to allow time for vehicle turning or change of driver's cabin, rest of the driver (or crew), and adjustment in schedule (e.g., to maintain uniform headway, or to recover delays incurred in travel).

The crew rest and the delay recovery usually govern the terminal time for bus and trolley lines. The minimum rest time is often determined by labor union contract. Since the rest and delay recovery times depend on durations of operating time, terminal time for surface systems is often expressed through a ratio (y) of terminal and operating times: $y = t_t/T_o$. The value may range between 0.12 and 0.18, depending on labor work rules, traffic conditions, variation in passenger volume and other local factors.

On lines during time periods for which traffic congestion is serious, travel time varies considerably. For such cases, long terminal times should be allowed so that departure time for the return trip can be kept and schedules maintained despite moderate delays. For rapid transit or other systems with high schedule reliability, the terminal time is independent of operating time and length, and it can be much shorter than for lines running in mixed traffic. A common value for terminal time for rapid transit is 5 to 8 minutes (28).

Cycle Time (T) is the total round trip time for a vehicle, i.e., the time interval between two consecutive times the same vehicle passes a fixed point traveling in the same direction. This time can be expressed as:

$$T = 2(T_o + t_t),$$

if the line has equal T_o for each direction and equal t_t for each terminal. All these time intervals are usually expressed in minutes.

Commercial Speed (V_c) is the average speed of a transit vehicle for a complete round trip:

$$V_c = 120L/T,$$

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V_c being in mph., T in minutes and L in miles. Commercial speed is the most important type of speed for the operator since it directly determines (along with headway) the required fleet size and cost of operation.

Fleet Size (N_f) is the total number of vehicles which a transit agency owns. The fleet size consists of the vehicles required for regular peak hour service on all lines (N), vehicles in reserve (N), plus vehicles which are in maintenance and repair (N_m):

$$N_f = N + N_r + N_m.$$

Load Factor (a) is the ratio of the number of passengers in a vehicle to the vehicle capacity. A higher value means that a vehicle is crowded and that it is more likely that some vehicles will not have sufficient capacity to collect all waiting passengers (28).

5.4.2 Criteria for Determining the Basic Operating Elements

Prior to scheduling operations for an individual line, certain operational issues with regard to the basic elements of service must be resolved. Specifically, decisions must be made on the headways which will be used during different hours, spacing of stops along lines, load factors, fleet size and vehicle capacity (28).

Two basic requirements determine headways: (1) adequate capacity must be provided to meet passenger demand; (2) service must have a certain minimum frequency.

The first requirement is the basis for scheduling on heavily traveled lines or during peak hours. In such cases, the operator must provide adequate capacity which results in shorter headways than the second requirement would give (28).

The frequency of service which will provide needed capacity to meet the demand is obtained by dividing passenger volume on the maximum load section

(P) by the average number of passengers assigned to each vehicle through selection of the value for load factor (d). Thus, the required frequency is:

$$f = P/a \times c_v$$

The headway is computed as:

$$h = 60/f = 60 - x \ a \ x \ c_v/p \ (\underline{28}).$$

Since all schedules with headways greater than 6 minutes should be such that passengers can easily memorize them, the departure times should repeat themselves every hour. Therefore, the headways must be numbers divisible as whole numbers into 60; i.e., they should have the following values:7.5, 10, 12, 15, 20, and 30. When headways longer than 30 minutes are appropriate, values of 40, 45, and 60 minutes should be used.

For off-peak hours, weekends, or lightly traveled lines, the minimum frequency requirement usually governs. That is, headway should not be greater than the one which is determined by the service policy and revenue, i.e., the operator's policy with respect to the minimum service frequency. This is the so-called policy headway (hp), which should also be one of the above numbers. This headway should never be longer than one hour and desirably not longer than 30 minutes (28).

For a given passenger volume on a line, service can be provided by a small number of large capacity vehicles or a greater number of smaller capacity vehicles. The second combination results in a higher frequency of service, but requires higher investment and operating cost than the first combination.

The procedure to be followed in scheduling a transit line is presented in the following sequence of steps. Sample data are given to demonstrate the computations (28).

Step 1: Collection of required data. The basic data which are necessary to schedule a line must be obtained. Defined earlier in this section, those data are:

One-way line length: $L = 10$ minutes

Operating time: $T_o = 45$ minutes for peak period

$T_o = 40$ minutes for off-peak period

Maximum load: $P = 375$ persons per hour for peak period

Vehicle capacity: $C_v = 45$ seats $+ 25$ standees $= 70$

Step 2: Determination of Some Operating Factors. Based on the definitions and description of terms in Section 5.4.1, determine or compute:

Operating speed: $V_o = 60L/T_o$

$= 13.3$ mph for peak period

$= 15.0$ mph for off-peak period

Policy headway: $H_p = 15$ minutes

Load factor $a = 0.7$

Minimum terminal time: $t_t = 6$ minutes

(The initially assumed values for the load factor and the terminal time t_t are often adjusted later in the calculation procedure).

Step 3: Determination of headway. First, calculate headway h:

$h = 60/ a \times C_v/P = 60/0.7 \times 70/375 = 7.84$ minutes

The value of h computed in this way must be rounded down to the nearest practical value for headway. If the obtained value is longer than 6 minutes, only the following numbers should be used: 7.5, 10, 12, 15, 20, 30, 40, 45 and 60; thus vehicle departure times repeat themselves every hour except for headways of 40 and 45 minutes.

Second, the headway computed above must be compared with h_p; the smaller of the two is adopted. Since in this case the computed value for headway is $h = 7.84$ and that is shorter than $h_p = 15$, the value of 7.5 minutes is

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adopted as the headway during the peak period and 15 minutes during the off-peak period.

Step 4: Computation of Cycle Time. Cycle time is computed as follows:

$T = 2(To + tt)$
$= 2(45 + 6) = 102$ minutes for peak period
$= 2(40 + 6) = 92$ minutes for off-peak period

Step 5: Determination of Fleet Size and Adjustments of Previously Determined Factors.

The required fleet size (N) is obtained from the following equation:

$N = T/h$

Since N must be an integer, the computed value is rounded up to the next whole number.

$N = 102/7.5 = 13.6 = 14$ vehicles for peak period
$= 92/15 = 6.3 = 7$ vehicles for off-peak period

A new cycle time T' is then computed for each period using the calculated fleet size values:

$T' = N \times h$
$= (14)x(7.5) = 105$ minutes for peak period
$= (7)x(15) = 105$ minutes for off-peak period

Cycle times for the two cases are usually not equal, as happened in this case.

A new terminal time tt is then computed using:

$tt' = (T'-2 \, To)/2$
$= (105 - 2(45))/2 = 7.5$ minutes for peak period

= (105-2(40))/2 = 12.5 minutes for off-peak period

If the difference between peak and off-peak values is small, adopt the computed fleet size N, T' as cycle time and tt' as terminal time.

Finally, we can compute the commercial speed Vc:

Vc = 120L/T
    = 120 (10)/105 = 11.4 mph for peak period
    = 120 (10)/105 = 11.4 mph for off-peak period

A summary of the scheduling results is shown in Table 17.

Table 17. Summary of Scheduling Results

Item	Peak Period	Off-Peak Period
Headway (h)	7.5 minutes	15 minutes
Cycle Time (T)	105 minutes	105 minutes
Terminal Time (tt)	7.5 minutes	12.5 minutes
Fleet Size (N)	14 vehicles	7 vehicles
Commercial Speed (Vc)	11.4 mph	11.4 mph

Source: (28).

5.5 MONITORING AND EVALUATING SERVICES

After the travel patterns and route structure have been identified and the route has been implemented, the final step is to develop a system for monitoring/evaluating the service. The literature has suggested emphasis should be placed on effectiveness measures which describe the quality of output (e.g., schedule adherence) and the degree to which output is consumed (e.g., passengers per vehicle hour).

In accordance with this theory, Table 14 (p. 59) presents several potential useful effectiveness measures. These measures fall under the broad categories of (1) accessibility and reliability, (2) utilization of service, (3) convenience, (4) comfort, (5) labor/usage relationship and (6) safety.

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The selection of how many and which measures to use is highly dependent on the individual system involved. An important consideration in this determination is the level of financial and human resources available for data collection and data processing. It is recommended that only a few indicators be selected from each of the broad categories described above. In general those selected should be based on the following considerations:

- Related to a stated system objective
- Easily understandable and definable
- Measurable from available data; and
- Acceptable to the parties involved.

5.6 SUMMARY

This section of the study presented a specific set of planning guidelines for implementing suburban transit services. This process consists of four general steps:

Step 1: Identification of Suburban Travel Patterns. This process may be attained by any of several secondary sources. These sources include origin-destination surveys, census journey-to-work data, on-board transit surveys and other special studies. These sources typically identify travel characteristics, socio-economic profiles and attitudinal perceptions of users and non-users of a specific service.

Step 2: Identification of Alternative Routing Structures. This should be based on the relationship between development patterns and travel patterns. Additional considerations include area coverage, number of trips served, directness of travel, cost and topography. A radial network configuration consists predominately of radial or diametrical routes, with the CBD or a major suburban activity center as its focal point. A radial network has a lower connectivity than other network forms. Grid systems typically produce a few routes used very intensively. The grid system offers the connectivity of the ubiquitous system, although a transfer is involved for most trips. The timed transfer system has, by definition, focal points and fixed route links among them. It's advantage over the grid system is

that it relies on scheduled connections between routes and does not require the grid systems frequent service on most routes. The decision as to which route alignment to use in a given situation should be based on explicit objectives which acknowledge financial constraints and the service needs of the area.

Step 3: Route Planning Guidelines. Based on the travel patterns identified in Step 1 and the network configuration selected in Step 2, this step identifies and defines the basic elements of the route planning process. Decisions should be made regarding the following basic operating elements:

1) Headways	9) Operating time
2) Frequency of service	10) Operating speed
3) Vehicle capacity	11) Terminal time
4) Passenger volume	12) Cycle time
5) Maximum load section	13) Commercial speed
6) Design hour volume	14) Fleet size
7) Line capacity	15) Load factor
8) Maximum line capacity	

The interaction of these elements are illustrated in section 5.4.2. One problem of note which hinders the development of this section is the lack of reliable route level demand estimation procedures. It appears there is a wide disparity between methods appearing in the literature and procedures employed in the industry. Some agencies use variations of these techniques which lack the sensitivity and reliability to predict route level ridership impacts resulting from service changes. As a consequence, there is a need to review and document existing procedures or develop new procedures.

Step 4: Monitoring and evaluating services. The final step in planning guidelines for implementing suburban transit service is to develop a system which may be used to monitor and evaluate the services. Emphasis should be placed on effectiveness measures which describe the quality of output (e.g., schedule adherence) and the degree to which output is consumed (e.g., passengers per vehicle hour).

The selection of how many and which measures to use is highly dependent on the individual system involved. An important consideration in this determination is the level of financial and human relations available for data collection and data processing. In general those selected should be based on the following considerations:

- Related to a stated system objective;
- Easily understandable and definable;
- Measurable from available data; and
- Acceptable to the parties involved.
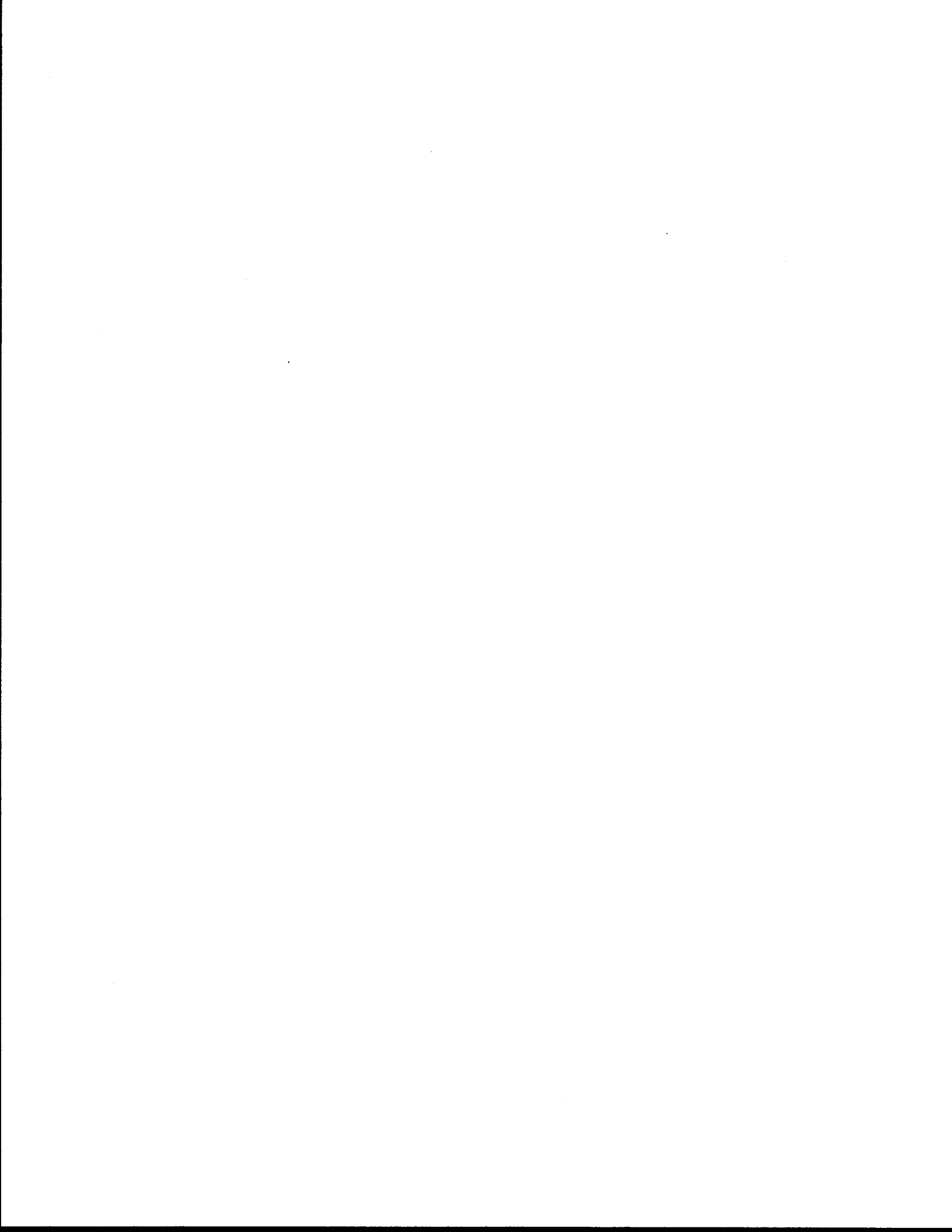
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