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# DUAL MODE POTENTIAL IN URBAN AREAS

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16. Abstract

The purpose of this study was to determine the potential national applicability of an urbanwide Dual Mode system. The system, consisting of a mixed fleet of specially designed small personal vehicles and 12-passenger dial-a-ride minibuses operating on local streets and on a network of guideways, was examined in three hypothetical urbanized areas reflecting a broad spectrum of 1990 city types. After determining system cost and ridership in each scenario, Dual Mode's applicability as an urbanwide system was determined on the basis of three criteria: the abstract city's ability to pay for the system, the regional cost-benefit characteristics of Dual Mode, and the degree of need for additional high-capacity transportation facilities within the abstract city. The classification of the abstract cities as definite or doubtful candidates for Dual Mode was used to generate population-based applicability ranges, which in turn were used to identify the urbanized areas where Dual Mode appears to have definite or possible potential. It was found that 44 out of the nation's 372 urbanized areas, representing 68% of the projected 1990 urbanized area population, may be potential sites for urbanwide Dual Mode systems. The remainder of the urbanized areas should not, however, be excluded from consideration as possible sites for urbanwide Dual Mode systems. Detailed analyses of specific areas having a need for corridor or limited area circulation systems may lead to the identification of additional locales where Dual Mode could be applicable.

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# PREFACE

This study was undertaken to determine the national potential for urbanwide Dual Mode systems.

The study was performed by the Applications Division, Transportation Systems Center, under the sponsorship of the Office of the Assistant Secretary for Systems Development and Technology, U.S. Department of Transportation. The authors wish to acknowledge the assistance provided to them by Robert Krick of the Office of Systems Engineering, Katherine O'Leary of the Office of R&D Policy, and Calvin Perrine of the Applications Division.

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# 1. SUMMARY

## 1.1 STUDY OBJECTIVE

The specific objective of the Application Potential Study was to identify the national market for Dual Mode--that is, the number and types of urbanized areas for which Dual Mode might be an acceptable urbanwide transportation alternative. It was recognized that an individual city's ultimate decision on whether or not to build a Dual Mode system would require careful consideration of technological, economic, social, political, and geographic issues, many of which would be specific to the locale and/or unresolvable given the present stage of Dual Mode development. Accordingly, this analysis was never intended to provide a definitive evaluation of Dual Mode's suitability for a particular urbanized area. Rather, its objective was to define three categories of Dual Mode applicability (definite, possible, doubtful potential), and to identify the number of urbanized areas falling under these categories.

## 1.2 BACKROUND

The recently completed TSC report entitled Analysis of Dual Mode Systems in an Urban Area[1] showed that Dual Mode appears sufficiently attractive in a large urban area like Boston to warrant further technological development. The Office of the Assistant Secretary for Systems Development and Technology requested this study to determine the extent to which an urbanwide application of Dual Mode would appear appropriate in cities with different demographic, land use, transportation, and fiscal attributes.

## 1.3 STUDY APPROACH

The Dual Mode system analyzed in this study consisted of a mixed fleet of specially designed small personal vehicles and 12-passenger dial-a-ride minibuses operating on local streets and on a network of guideways extending throughout the city. This system was examined in a small sample of hypothetical urbanized areas which were developed to reflect a broad spectrum of city types. Numerous variables describing urban size and composition in 1990 were averaged for individual cities within several population-density clusters to form the data base for these representative abstract cities. Then, a Dual Mode network was designed for each abstract city on the basis of a level-of-service criterion (access time to the system). After determining system cost and ridership in each scenario, Dual Mode's applicability as an urbanwide system was determined by comparing net system cost to the city's fiscal capability, by determining the cost benefit performance ofthe system, and by considering the system's ability to satisfy the perceived transportation needs of each city.

## 1.4 RESULTS

Application of the ability-to-pay, cost-benefit, and needs criteria led to classification of the abstract cities as definite or doubtful candidates for urbanwide Dual Mode systems. These designations were then used to generate the following applicability ranges for Dual Mode, which were based only on 1990 population (since the results showed little sensitivity to density): definite potential for Dual Mode(over 2 million); possible potential (750,000 to 2 million); doubtful potential (under 750,000). The ranges for definite and possible potential were used to identify the urbanized areas where Dual Mode appears to have application potential. It was found that 44 out of the 372 urbanized areas, representing 68% of the projected 1990 urbanized area population, were in these categories.

It is quite possible that detailed analyses of the specific areas on an individual basis would lead to the discovery of some whose potential for Dual Mode as an urbanwide transportation form differed from their classification according to the above population boundaries. Moreover, if the constraint of urbanwide service were relaxed, the list of Dual Mode candidates would undoubtedly expand to include areas with a need for corridor or limited area circulation systems. Nevertheless, the results of this study are considered in the aggregate to be a fairly valid indicator of Dual Mode's potential applicability.

## 1.5 CONCLUSION

Based on the relatively large number and population of urbanized areas where Dual Mode appears to have definite or possible applicability as an urbanwide transportation form, it is considered that there is a strong justification for further research and development on this system.

# 2. INTRODUCTION

By 1990 there will be 372 urbanized areas* in the U.S., compared to only 259 in 1968 and 189 in 1960. These 372 areas are projected to have a 1990 population of 176,315,000, representing a 50% increase over the 1968 urbanized area population. Examining these trends on a less aggregate level, the typical urbanized area is expected to experience a 44% increase in population between 1968 and 1990 and an 86% increase in land area.

This rather spectacular rate of urban growth has significant implications with respect to transportation planning: larger population and land area mean more trips, longer trip lengths, the probability of greater congestion on existing traffic arteries, and, consequently, the requirement for additional and improved transportation facilities. Most if not all of the urbanized areas are already in the process of planning the transportation expansions and improvements which will be needed to satisfy 1990 travel demands. By and large these areas are proposing various mixtures of highway, bus, rapid transit, and commuter rail programs for their intra-urban needs--that is, they are considering only conventional transportation alternatives.

The Department of Transportation, in the interest of expanding the range of alternatives to include systems which might better serve urban mobility requirements, has been conducting numerous studies and demonstration projects to determine the technological and economic feasibility of innovative transportation concepts. One such study is the

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* Based on the Bureau of the Census definition, urbanized areas are "those urban places forecasted to have a population of 50,000 or more within the (1990) contiguous urban-in-fact boundary."[2]

recently completed TSC report entitled Analysis of Dual Mode Systems in an Urban Area,[1] which examined the benefits, impacts, and costs of various generic Dual Mode concepts in an urbanwide application. Since this analysis showed that Dual Mode systems appear sufficiently attractive in a large urban area like Boston to warrant further technological development, the Office of the Assistant Secretary for Systems Development and Technology initiated a TSC study to determine to what extent an urban-wide application of Dual Mode would seem appropriate in cities with different demographic, land use, transportation, and fiscal attributes. The specific objective of this Application Potential Study was to identify the national market for Dual Mode--that is, the number and types of cities for which Dual Mode might be an acceptable urbanwide transportation alternative.

# 3. STUDY APPROACH

## 3.1 INTRODUCTION

Figure 1 outlines the methodological approach used in this study. Since the intent of the analysis was to provide a general understanding of the potential market for Dual Mode rather than a detailed evaluation of its applicability in specific cities, a decision was made to examine Dual Mode in a small sample of hypothetical urbanized areas developed to reflect a broad spectrum of city types. Numerous variables describing urban size and composition in 1990 were averaged for individual cities within several population-density clusters to form the data base for these representative abstract cities. Then, based on knowledge about each abstract city's area, population density, and trip-making characteristics, a network was laid out, the vehicle fleet and terminals were sized, and system parameters such as cost, modal split, and revenue were calculated.

Dual Mode's financial applicability in each abstract city was determined by comparing net system cost to the city's fiscal resources (using the averaged data for the cities in the respective clusters) and by using comparable data for rapid transit systems proposed or under construction as a benchmark to determine whether or not each abstract city could afford an urbanwide Dual Mode system. Information on the cost-benefit performance of Dual Mode and data from the 1972 National Transportation Needs Study* on the dollar magnitude and modal breakdown of perceived urbanized area needs were then used to qualify the financially-based applicability findings.

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* The results of this study are contained in References 3,4, and 5, as well as unpublished computer printouts.

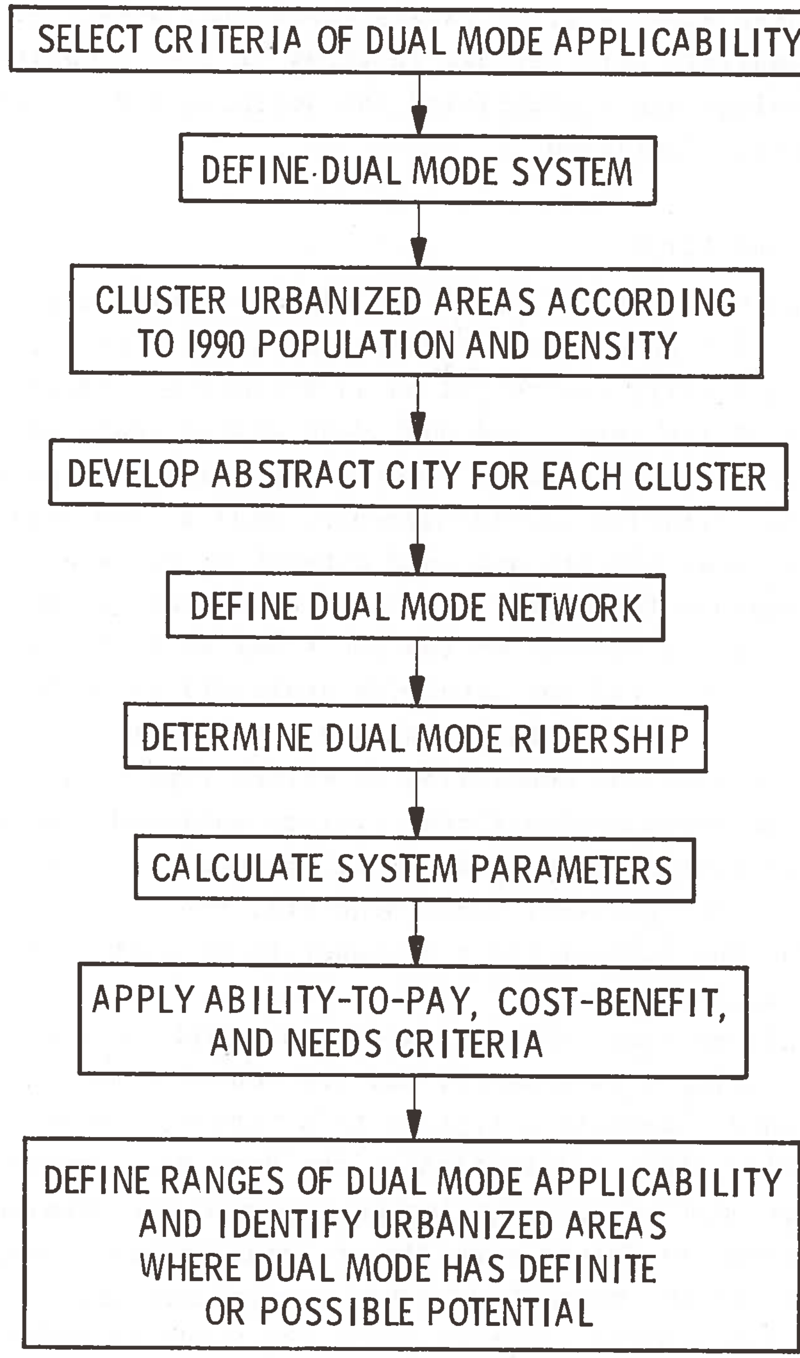



Figure 1. Methodology

On the basis of the ability-to-pay, cost-benefit, and needs criteria, three applicability ranges (definite, possible, doubtful potential) were defined in terms of 1990 population, and the urbanized areas comprising the definite and possible categories were identified.

3.2 SYSTEM DEFINITION

The Dual Mode concept refers to vehicles which are operated by manual control on existing streets during part of a trip and are automatically controlled on an exclusive guideway for another part of the trip. The Dual Mode system analyzed in this study consists of a mixed fleet of specially designed small personal vehicles and 12-passenger dial-a-ride minibuses operating on local streets and on a network of guideways extending throughout the city. This combination was selected on the basis of the results of the TSC study on Dual Mode[1] which showed that: (1) for urbanwide applications, a Dual Mode system consisting of both buses and small personal vehicles is more effective than one consisting of either type exclusively; and (2) of the three combinational systems analyzed, the new small vehicle system, made up of small personal vehicles and minibuses, has the greatest total benefits, the largest net benefits, and the highest ratio of benefits to costs, though at the highest capital cost.

The small personal vehicles are electrically powered, capable of seating 4 passengers, and are rented from the system. Figure 2 depicts a typical trip between a suburban origin and a downtown destination on the Dual Mode system. The small personal vehicle, having been previously obtained from the system, is driven manually on local streets from the user's origin to the nearest guideway entrance station. From there, the vehicle proceeds along the guideway under automatic control to the station nearest the user's destination. The

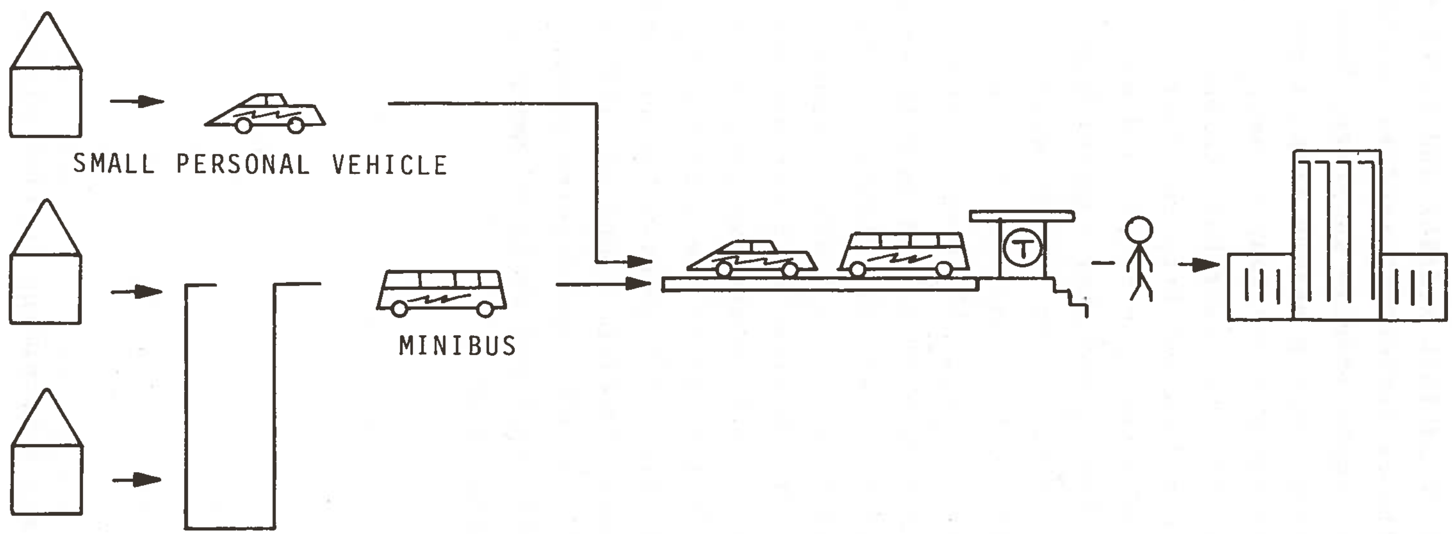



Figure 2. Typical Trip On Dual Mode

user leaves the vehicle at this station and walks to his destination; meanwhile, the vehicle is either allotted to another user in the area or is sent to a remote storage facility, from which it can be recalled when needed. For a return trip, a vehicle (not necessarily the same one previously used) is provided at whichever downtown station the user has chosen.

In the case of non-downtown trip destinations where street congestion is not such a severe problem (and where the guide-way network is less dense), the user regains manual control of the vehicle while exiting from the guideway and then drives it along local streets to his final destination.

The minibuses are electrically powered and system-owned, and they operate in a dial-a-ride fashion with unlimited transfers for off-guideway collection and distribution. The city is divided into numerous "tour areas," with a fleet of minibuses serving each area. After picking up a certain number of pass-engers within its tour area*, a minibus proceeds to the nearest guideway entrance. At this point the driver disembarks and the vehicle continues along the guideway under automatic control to the central business district, where it stops at the various downtown stations to discharge and receive passengers. The minibus, like the small personal vehicle, never leaves the guideway in the downtown area.

* The load factor varies according to time of day.

## 3.3 SCENARIO DEFINITION

It was recognized at the outset of this study that an individual city's ultimate decision on whether or not to build a Dual Mode system would require careful consideration of technological, economic, social, political, and geographic issues, many of which would be specific to the locale and/or unresolvable given the present stage of Dual Mode development. Accordingly, this analysis was never intended to provide a definitive evaluation of Dual Mode's suitability for a particular urbanized area. Rather, its objective was to define three categories of Dual Mode applicability (definite, possible, doubtful potential), and to identify the approximate number of urbanized areas falling under these categories.

In view of the above objective, a decision was made to examine Dual Mode in a small sample of hypothetical urbanized areas reflecting a broad spectrum of city types. Variables such as population, area, population density, highway mileage, and trip length were averaged for several groups of cities to form the data base for representative abstract cities. Then a Dual Mode network was designed for each abstract city on the basis of a level-of-service criterion (access time to the guideway for the small personal vehicle). In order to simplify the analysis of Dual Mode as an urbanwide system, it was assumed that Dual Mode would replace any existing transit or be built instead of proposed transit systems.

The process of scenario definition is described in detail below.

### 3.3.1 Clustering of Urbanized Areas

The first step in developing abstract cities was to classify the areas projected to have a 1990 population of 50,000 or more into relatively homogeneous groups on the basis of a selected set of measurable city characteristics. From among the numerous variables which have been used in previous cluster analyses--e.g., the 53 variables employed by General Motors Research Laboratories[6] --population and density were chosen because they seemed most likely to influence Dual Mode's suitability (through their effect on trip generation rates) and because 1990 projected values of these variables were readily available for all 372 urbanized areas from Needs Study data.[7]

Figure 3 shows the four clusters which were developed from a plot of each urbanized area's population vs. density. These clusters are hereinafter designated (from left to right) very low population, low population-low density, low population-high density, and high population. The New York, Los Angeles, and Chicago urbanized areas, with projected populations of 19 million, 13 million, and 9 million, respectively, were excluded from the high population cluster because they would have skewed the characteristics of that cluster's abstract city (indicated by an x ). Honolulu was excluded from the low population-high density cluster because of its unusually high density (in excess of 8,000 persons per square mile). Boston is identified in the figure since it served as an additional analytical scenario, representative of the very large urbanized areas in the high population cluster.

The planned approach was to study Dual Mode initially in the three clusters to the right of the 350,000 population boundary, and to examine the very low population cluster only if the results for these three were indeterminate. However, since a need never arose to analyze the 285-city cluster, no composite data was developed for it. Average population, land area, and density for the three clusters are presented below:

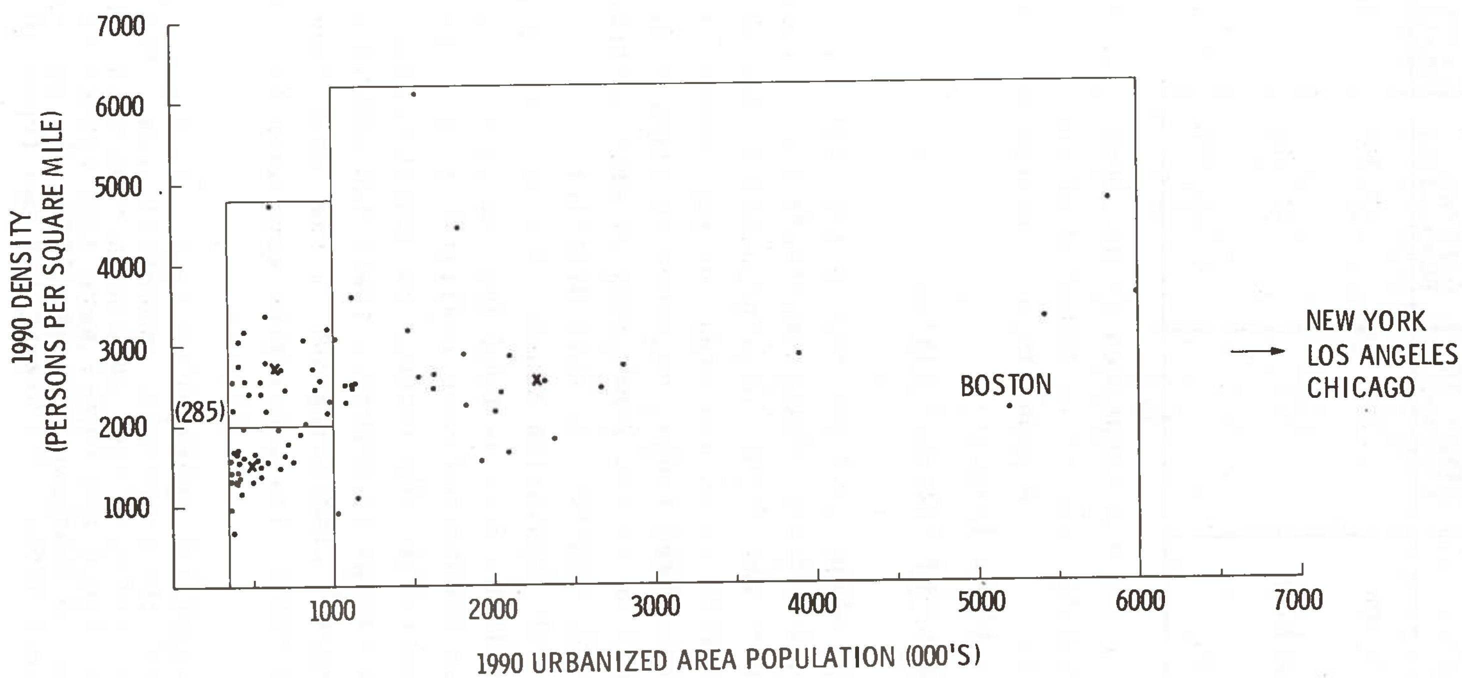



Figure 3. Urbanized Areas By Population And Density

| Cluster | No. of Urbanized Areas in Cluster | 1990 Average Population | 1990 Average Land Area | 1990 Average Density |
|---|---|---|---|---|
| Low population-low density | 23 | 502,000 | 346 | 1,450 |
| Low population-high density | 27 | 655,000 | 254 | 2,575 |
| High population | 31 | 2,260,000 | 907 | 2,500 |

Figure 4 lists the urbanized areas comprising each cluster. The high population cluster is composed of the 31 urbanized areas projected to have a 1990 population in excess of 1 million (excluding the three largest).

### 3.3.2 Development of Abstract Cities

A circular shape was selected as the most appropriate form for the abstract cities. Using available Census data for average SMSA* center city and fringe area populations and densities the total 1990 population and area for each abstract city were apportioned into three rings, as shown in Figures 5, 6, and 7. The dashed line in the inner ring of each abstract city circumscribes the central business district.

For the high population cluster's abstract city, uniform population densities were assumed for the central and middle rings. However, it was considered more realistic to hypothesize several population clusters in the large, low density outer ring to reflect the existence of suburban towns and communities. Six identical "fingers" comprising 30% of the outer ring land area and containing 60% of its population were used to create a

*Standard Metropolitan Statistical Area, usually having different boundaries from the comparable urbanized area. Throughout this analysis SMSA data were used in conjunction with urbanized area data; however, since the former were used either to develop trend lines relative to distance from the CBD or in per capita form, no inconsistency arose from mixing the two types of data.

| High Population Cluster | Low Population-High Density Cluster | Low Population-Low Density Cluster |
|---|---|---|
| Atlanta | Albuquerque | Akron |
| Baltimore | Allentown–Bethlehem–Easton | Albany-Schenectady-Troy |
| Boston-Providence | Baton Rouge | Austin |
| Buffalo-Niagara Falls | Birmingham | Beaumont-Port Arthur-Orange |
| Cincinnati-Hamilton | Davenport-Rock Island-Moline | Charlotte |
| Cleveland-Lorain-Elyria | Dayton | Columbia |
| Columbus | Flint | Des Moines |
| Dallas | Fresno | El Paso |
| Denver | Grand Rapids | Galveston-Texas City |
| Detroit | Hartford-New Britain | Greenville-Spartanburg |
| Fort Lauderdale | Las Vegas | Jackson |
| Fort Worth | Norfolk-Portsmouth | Jacksonville |
| Houston | Omaha | Little Rock-N. Little Rock |
| Indianapolis | Orlando | Mobile |
| Kansas City | Rochester | Nashville |
| Louisville | Sacramento | Newport News-Hampton |
| Memphis | St. Petersburg | Norman-Oklahoma City |
| Miami | Salt Lake City | Richmond |
| Milwaukee | Springfield-Chicopee-Holyoke | Rockford |
| Minneapolis-St. Paul | Syracuse | Scranton-Wilkes Barre |
| New Orleans | Toledo | Shreveport |
| Philadelphia Trenton | Wichita | South Bend |
| Phoenix | Wilmington | Tampa |
| Pittsburgh | | Tucson |
| Portland | | Tulsa |
| St. Louis | | W. Palm Beach |
| San Antonio | | Younstown-Warren |
| San Diego | | |
| San Francisco-Oakland-San Jose | | |
| Seattle-Tacoma | | |
| Washington | | |

Figure 4. Urbanized Areas Comprising Study Clusters

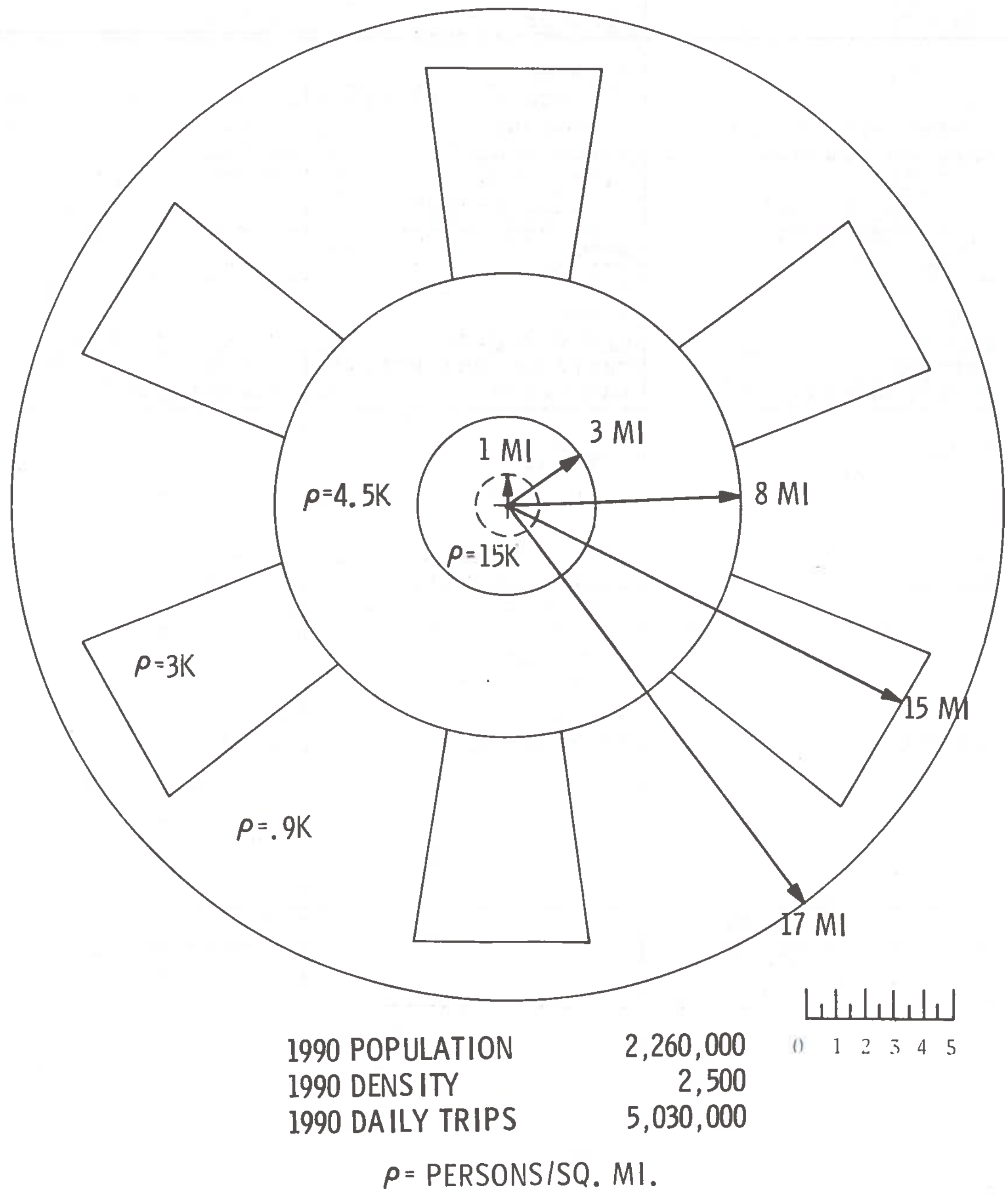
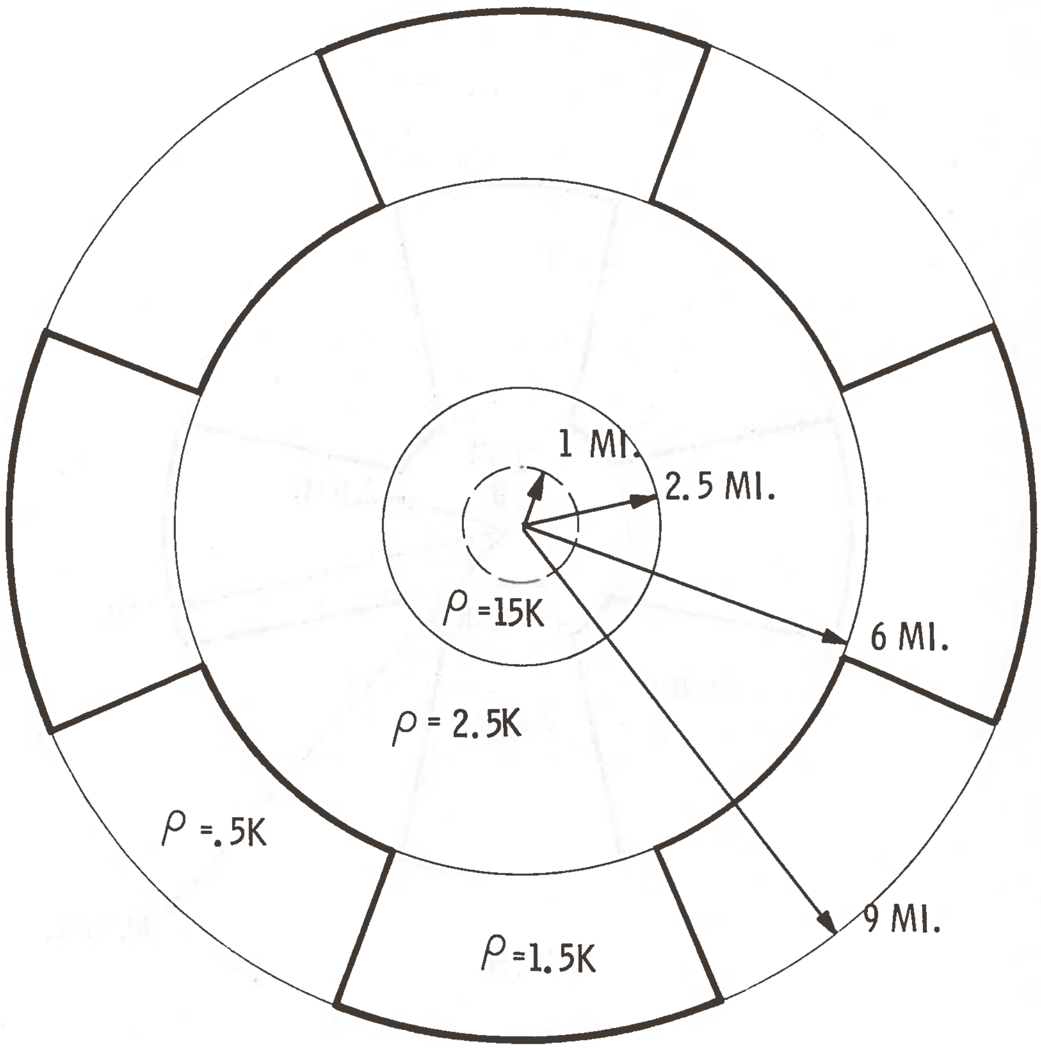


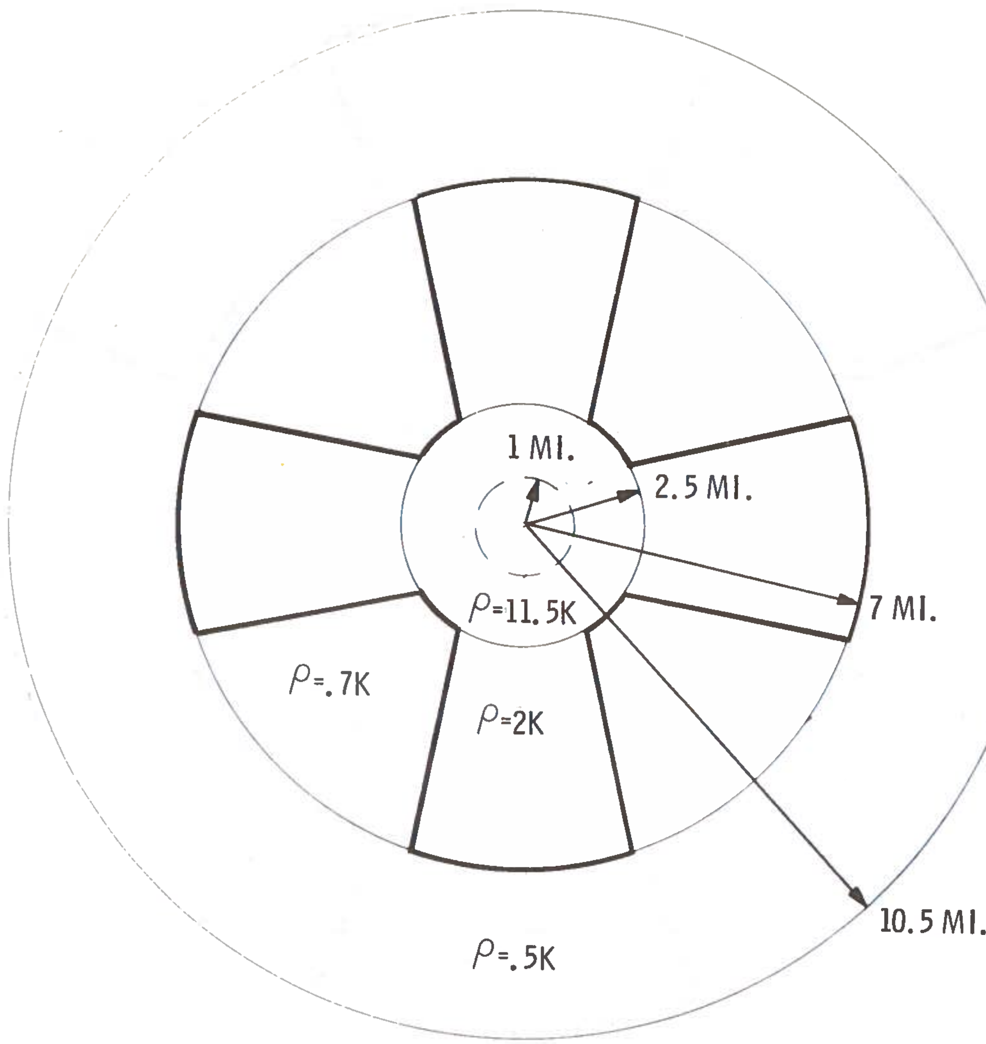

Figure 5. High Population Abstract City




| | |
|---|---|
| 1990 POPULATION | 655,000 |
| 1990 DENSITY (PERSONS/SQ. MI.) | 2,575 |
| 1990 DAILY TRIPS | 2,270,000 |

ρ = PERSONS/SQ. MI.

Figure 6. Low Population-High Density Abstract City




| | |
|---|---|
| 1990 POPULATION | 502,000 |
| 1990 DENSITY (PERSONS/SQ. MI.) | 1,450 |
| 1990 DAILY TRIPS | 2,012,000 |

$\rho$ = PERSONS/SQ. MI.

Figure 7. Low Population-Low Density Abstract City

number of travel corridors which appeared representative for this size city. The density of the fingers was thus twice that of the outer ring as a whole but only two-thirds the density of the middle ring.

For the low population-high density abstract city, uniform densities were assumed for the central and middle rings, but the outer ring was assumed to have only four fingers (reflecting the smaller dimensions of the city). These four fingers were allocated half of the outer ring land area and three-quarters of its population, yielding a finger density about 1.5 times that of the outer ring as a whole and nearly 60% of the middle ring value. Because of the low overall density of the low population-low density abstract city, the suburban clustering phenomenon was assumed to occur in the middle ring. The four fingers in that ring were again estimated to comprise half of the land area and three-quarters of the population, resulting in a finger density 4 times that of the middle ring as a whole and only 17% of the central ring density.

3.3.3. Trip Generation and Distribution

The number of total daily trips was obtained by different methods for the high population abstract city compared to the two low population abstract cities, owing to the timing of data availability. For the former scenario, trip generation was assumed to be a function of residential density. Based on a study by Wilbur Smith and Associates[8] showing trip generation functions for several cities within the high population cluster, the following general relationship between daily trips per person and number of persons per residential acre was derived:

$$\text{Trips per person} = 2.2 - .006P$$

where P= persons per residential acre

Using 1963 Boston region residential acreage data as a guide, residential density estimates were made for the three rings of the high population abstract city. From these numbers total daily trips were calculated:

| | Total Daily Trips |
|---|---|
| Inner ring | 1,964,000 |
| Middle ring | 1,638,000 |
| Outer ring | 1,428,000 |
| TOTAL | 5,030,000 |

Data on peaking factors for 12 cities were gathered from the Wilbur Smith report.[8] An average of 19% was computed as the percentage of total trips occurring in a three-hour morning peak period.

Since the coefficients in the Wilbur Smith equation were based on cities within the high population cluster, it would have been inappropriate to use the equation to estimate the number of trips in the two low population abstract cities with generally lower densities (especially in view of the fact that trip generation rates are known to vary inversely with density). Accordingly, data which became available from the 1972 Needs Study[9] on total daily trips and evening peak trips for the individual urbanized areas comprising the two clusters were used. The total number of daily trips for each abstract city was apportioned among the three rings according to their relative populations, yielding the following trip data:

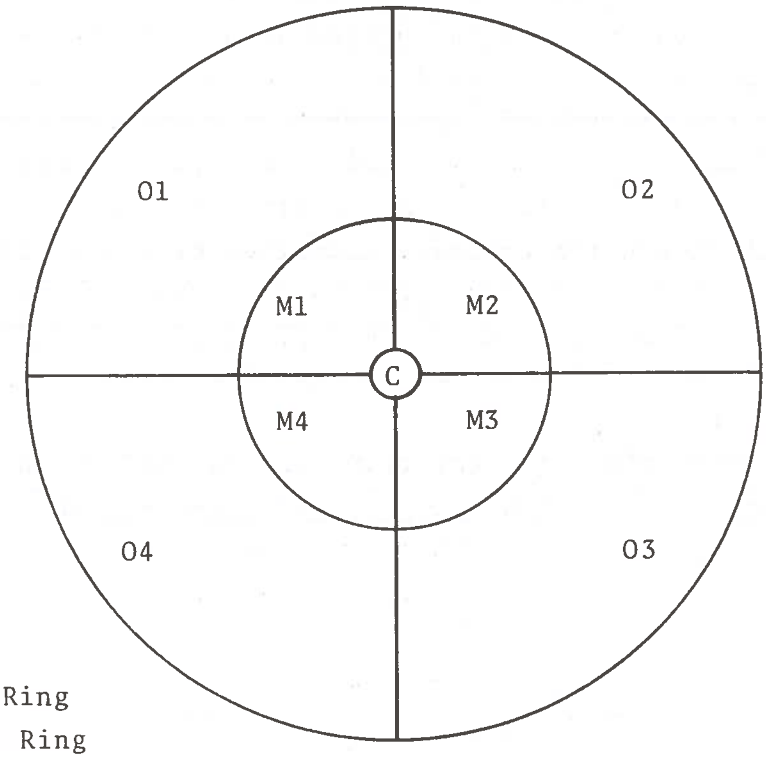
Total Daily Trips

| | Low Population-Low Density | Low Population-High Density |
|---|---|---|
| Inner ring | 16,000 | 25,000 |
| Middle ring | 1,348,000 | 1,482,000 |
| Outer ring | 648,000 | 763,000 |
| TOTAL | 2,012,000 | 2,270,000 |

Evening peak trip percentages were adjusted to obtain three-hour a.m. peak percentages of 19% and 18% for the low- and high-density abstract cities, respectively. It should be noted that the number of trips per person for the two low population abstract cities is considerably higher than that for the high population city (4 and 3.5 vs. 2.2), reflecting in part the varied characteristics of the cities and in part the different procedures and data sources used. The Needs Study trip data appear to be somewhat high compared to expected values. On the other hand, the number of trips per person resulting from the Wilbur Smith equation appears somewhat low (particularly in comparison to Needs Study trip data for the high population cluster cities). Adoption of a low trip generation rate for the larger cities and a high value for the smaller city did not affect the evaluation of Dual Mode applicability in each scenario, as is explained in Section 2 of the "Results" chapter.

The distribution of total trips was carried out by first dividing the city into nine zones (see Figure 8). The central business district (CBD) zone covered a circle of one mile radius. Four zones were created by dividing the middle ring (expanded to reach the CBD) into quadrants. Similarly, the outer ring was divided into four zones. Although 81 possible origin-destination pairs (9x9) were indicated, by symmetry these could be reduced to the 17 origin-destination pair categories listed in Figure 8. For example, the number of trips between any two adjacent outer ring zones was assumed to be the same as that for any other pair of adjacent outer ring zones.

The Boston region's 1963 Home Interview Survey trip data served as the basis for distributing trips within the high population abstract city. The region was partitioned into zones to resemble the abstract city. Trips for each origin-destination category were computed as percentages of total Boston region trips. These percentages were then scaled up or down appropriately to account for the fact that Boston, due to geographic constraints, is not a 360-degree city. The resulting trip distribution for the abstract city in the a.m. peak period is shown in Table 1. The estimation of new trips induced by the introduction of improved service was considered beyond the scope of analysis.




O = Outer Ring
M = Middle Ring
C = CBD

Origin-Destination Pair Cateogries

| O | D | O | D |
|---|---|---|---|
| O1 | O1 | M3 | O1 |
| O1 | O2 | M1 | M1 |
| O1 | O3 | M1 | M2 |
| O1 | M1 | M1 | M3 |
| O1 | M2 | M1 | C |
| O1 | M3 | C | O1 |
| O1 | C | C | M1 |
| M1 | O1 | C | C |
| M2 | O1 | | |

Figure 8. Abstract City Analysis Zones

TABLE 1. A.M. PEAK PERIOD TOTAL TRIP DISTRIBUTION FOR HIGH POPULATION ABSTRACT CITY (BY ORIGIN-DESTINATION PAIR CATEGORY)

| Category (O-D) | No.O-D Pairs | % of Total Trips |
|---|---|---|
| 01-01 | 4 | 33.8 |
| 01-02 | 8 | 5.0 |
| 01-03 | 4 | 0.3 |
| 01-M1 | 4 | 5.3 |
| 01-M2 | 8 | 3.7 |
| 01-M3 | 4 | 1.0 |
| 01-C | 4 | 5.7 |
| M1-01 | 4 | 3.3 |
| M2-01 | 8 | 2.2 |
| M3-01 | 4 | nil |
| M1-M1 | 4 | 15.7 |
| M1-M2 | 8 | 8.2 |
| M1-M3 | 4 | 1.3 |
| M1-C | 4 | 12.9 |
| C-01 | 4 | 0.2 |
| C-M1 | 4 | 0.9 |
| C-C | 1 | 0.5 |
| TOTAL | 81 | 100.0 |

Transit service in the outer ring was to be provided to the finger portion only (owing to an assumed minimum density criterion for Dual Mode service--about 1,000 persons per square mile--below which density it appears uneconomical to provide guideways and stations). Thus, outer ring trips had to be allocated between fingers and fringe. Sixty percent of those trips were allocated to the fingers and forty percent to the fringe.

For trips remaining wholly within the outer ring, the distribution among the six fingers was complicated by the fact that the original percentages were based on four quadrants. Noting the ratio of 1.5 fingers per quadrant and taking into account the finger/fringe population split and the distances between fingers, the following assumptions were made:

- Of trips remaining entirely within one outer ring quadrant (01-01), 60% have both ends in the fingers. Of this 60%, three-fourths are intra-finger trips and one-fourth are trips between adjacent fingers. The remaining 40% are outside the service area.

- Of trips between adjacent quadrants, 40% have both ends in the fingers. Of this 40%, two-thirds are trips between adjacent fingers and one-third are between alternate fingers. The remaining 60% are outside the service area.

- A minimal number of trips is assumed between opposite fingers.

The final trip distribution used in the analysis is shown in Table 2. Major trip flows are depicted in Figure 9.

Trip distributions for the low population high- and low-density abstract cities were derived from that of the high population city with suitable adjustments for the smaller cities' characteristics. In addition to the ring population distributions, the adjustments reflected a less core-oriented structure (relatively fewer trips to the CBD) and smaller sector sizes

TABLE 2. A.M. PEAK PERIOD TOTAL TRIP DISTRIBUTION FOR HIGH POPULATION ABSTRACT CITY (ADJUSTED FOR FINGERS AND FRINGE)

| Category (O-D) | No. O-D Pairs | % of Total Trips |
|---|---|---|
| Intra-finger | 6 | 15.2 |
| Adjacent finger | 12 | 6.4 |
| Alternate finger | 12 | 0.7 |
| 01-M1 | 4 | 3.2 |
| 01-M2 | 8 | 2.2 |
| 01-C | 4 | 3.4 |
| M1-01 | 4 | 1.5 |
| M2-01 | 8 | 1.3 |
| M1-M1 | 4 | 15.7 |
| M1-M2 | 8 | 8.2 |
| M1-M3 | 4 | 1.3 |
| M1-C | 4 | 12.9 |
| C-01 | 4 | 0.1 |
| C-M1 | 4 | 0.9 |
| C-C | 1 | 0.5 |
| Fringe Associated* | - | 26.5 |
| TOTAL | 87 | 100.0 |

* Percent of total trips outside Dual Mode service area.

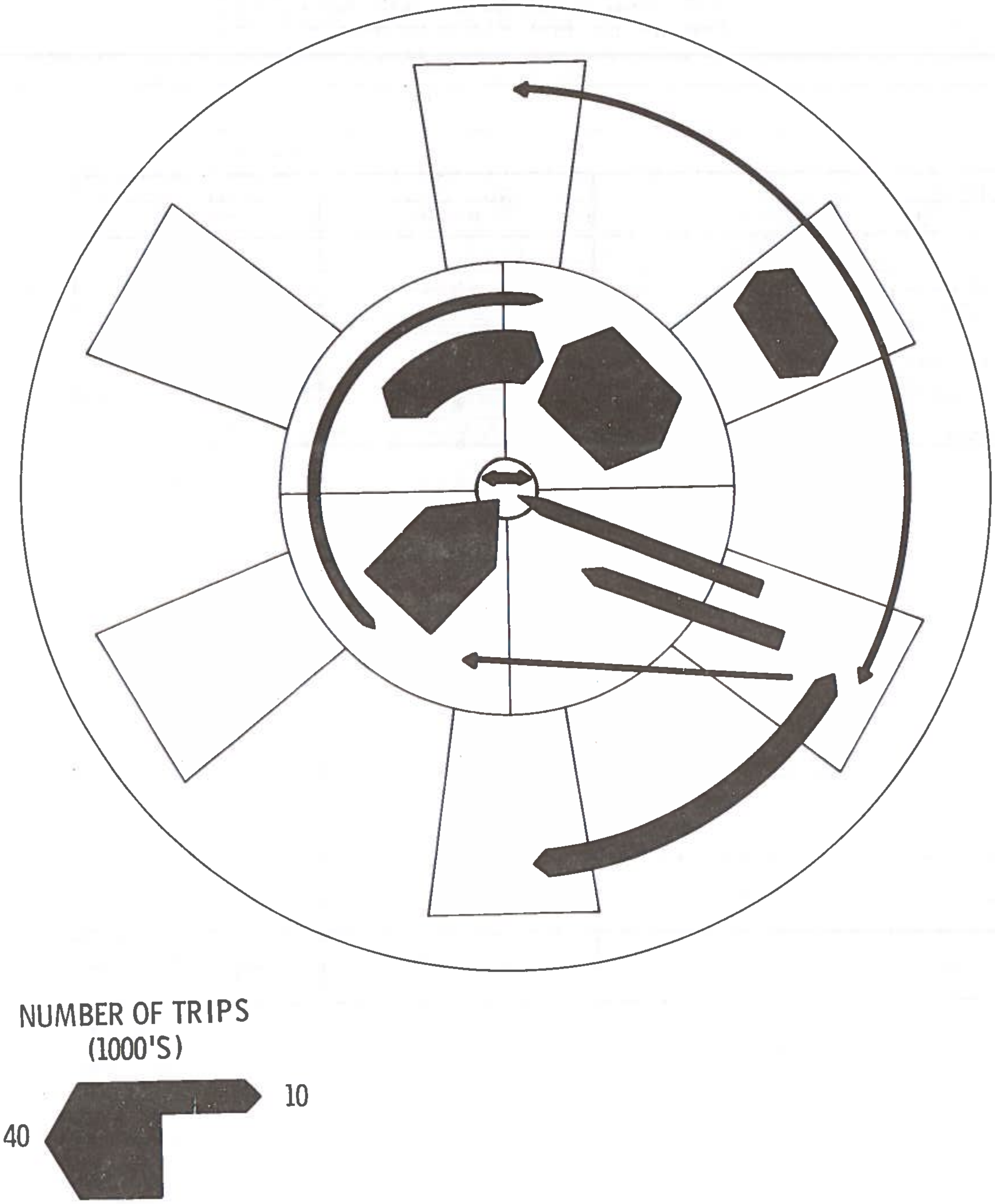



Figure 9. A.M. Peak Period Major Trip Flows By O-D Pair

(relatively more trips between than within sectors) in each of the smaller cities. Tables 3 and 4 show the peak total trip distributions for the low population high-and low-density cities, respectively. The last column of each table shows the percent of total trips occurring in the Dual Mode service area delineated by the finger boundaries. The Dual Mode service area was defined according to an assumed minimum density criterion (about 1,000 persons per square mile), below which density it appears to be uneconomical to provide Dual Mode guideway and stations. Persons living outside of the service area can use the Dual Mode system, but the modal split for fringe-associated trips is negligible. It can be seen that the percent of fringe-associated trips (outside the Dual Mode service area) is much higher for the low population-low density abstract city (Table 4) than for the other two abstract cities, reflecting the relatively large portion of the former city which does not meet the minimum density criterion.

### 3.3.4 Network Layout

The procedure for laying out the Dual Mode network in the three abstract cities was as follows. First, it was necessary to define a level-of-service criterion which could be held roughly constant across cities for network sizing purposes. The criterion chosen for areas outside the central business district (CBD) was time elapsed between leaving (arriving at) one's origin (destination) and starting (completing) the guideway line-haul portion of the trip in a small personal vehicle. The values selected were 8.5 minutes for the high population city and 6.5 minutes for the two low population cities (reflecting the latter cities' smaller land areas and hence shorter average trip lengths). These travel times were then used in conjunction with assumed driving speeds and ring population densities to calculate station spacing. Finally, guideways links were established between stations so as to provide maximum connectivity throughout the city with a minimum of guideway mileage. In

TABLE 3. A.M. PEAK PERIOD TOTAL TRIP DISTRIBUTION FOR LOW POPULATION-HIGH DENSITY ABSTRACT CITY

| Category (O-D) | No. of O-D Pairs | % of Total Trips | % of Total Trips* |
|---|---|---|---|
| 01-01 | 4 | 16.5 | 0.0 |
| 01-02 | 8 | 4.2 | 2.7 |
| 01-03 | 4 | 0.6 | 0.4 |
| 01-M1 | 4 | 5.5 | 4.4 |
| 01-M2 | 8 | 4.1 | 3.3 |
| 01-M3 | 4 | 1.0 | 0.8 |
| 01-C | 4 | 1.7 | 1.4 |
| M1-01 | 4 | 3.5 | 2.8 |
| M2-01 | 8 | 2.4 | 1.9 |
| M3-01 | 4 | nil | nil |
| M1-M1 | 4 | 26.3 | 18.4 |
| M1-M2 | 8 | 18.2 | 18.2 |
| M1-M3 | 4 | 3.3 | 3.3 |
| M1-C | 4 | 11.6 | 11.6 |
| C-01 | 4 | 0.1 | nil |
| C-M1 | 4 | 0.7 | 0.7 |
| C-C | 1 | 0.3 | 0.3 |
| TOTAL | 81 | 100.0 | 70.2 |
| Fringe-Associated** | | | 29.8 |

* Adjusted for fingers and fringe.

** Percent of total trips outside Dual Mode service area.

TABLE 4. A.M. PEAK PERIOD TOTAL TRIP DISTRIBUTION FOR LOW POPULATION-LOW DENSITY ABSTRACT CITY

| Category (O-D) | No. of O-D Pairs | % of Total Trips | % of Total Trips* |
|---|---|---|---|
| 01-01 | 4 | 15.6 | 0.0 |
| 01-02 | 8 | 4.1 | 0.0 |
| 01-03 | 4 | 0.6 | 0.0 |
| 01-M1 | 4 | 5.5 | 2.4 |
| 01-M2 | 8 | 4.4 | 1.9 |
| 01-M3 | 4 | 0.9 | 0.4 |
| 01-C | 4 | 1.1 | 0.7 |
| M1-01 | 4 | 3.7 | 1.6 |
| M2-01 | 8 | 2.5 | 1.1 |
| M3-01 | 4 | nil | nil |
| M1-M1 | 4 | 27.1 | 14.4 |
| M1-M2 | 8 | 20.9 | 15.9 |
| M1-M3 | 4 | 4.2 | 3.2 |
| M1-C | 4 | 8.6 | 7.5 |
| C-01 | 4 | 0.1 | nil |
| C-M1 | 4 | 0.5 | 0.4 |
| C-C | 1 | 0.2 | 0.2 |
| TOTAL | 81 | 100.0 | 49.6 |
| Fringe-Associated** | | | 50.4 |

* Adjusted for fingers and fringe.

** Percent of total trips outside Dual Mode service area.

the CBD, stations were spaced such that all points would be within walking distance.

Figures 10, 11, and 12 show the Dual Mode networks designed for each city. In the high population and low population-high density abstract cities, the very low density of the non-finger portions of the outer ring(900 and 500 persons per square mile, respectively) precluded any attempt to extend the Dual Mode guideway into those areas. In the case of the low population-low density abstract city, it was decided that the very low density of the middle ring fringe areas (700 persons per square mile) and the even lower density of the outer ring(500 persons per square mile) precluded extending the guideway into those areas.

An additional part of the network design process was the determination of guideway alignment (at-grade, elevated, or tunneled) and locaton (on new vs. existing right-of-way). Since these cities were hypothetical rather than real urbanized areas, assumptions regarding the location and width of existing right-of-way guided the placement and alignment of the Dual Mode guideway. A decision was made to tunnel the Dual Mode network within the one-mile CBD so as to minimize displacement and/or disruptions of households and businesses. The following table presents information on Dual Mode guideway location and alignment in the three abstract cities:

| | Low Population-Low Density Abstract City | Low Population-High Density Abstract City | High Population Abstract City |
|---|---|---|---|
| Total Route Miles | 41.6 | 85.0 | 151.0 |
| Ring 1 | 23.6 | 21.0 | 19.5 |
| Ring 2 | 18.0 | 46.2 | 110.5 |
| Ring 3 | 0.0 | 17.8 | 21.0 |
| At-grade(new/existing ROW) | 24.6/6.0 | 50.0/12.8 | 57.8/41.4 |
| Elevated (existing ROW) | 6.0 | 13.2 | 41.3 |
| Tunneled (existing ROW) | 5.0 | 9.0 | 10.5 |

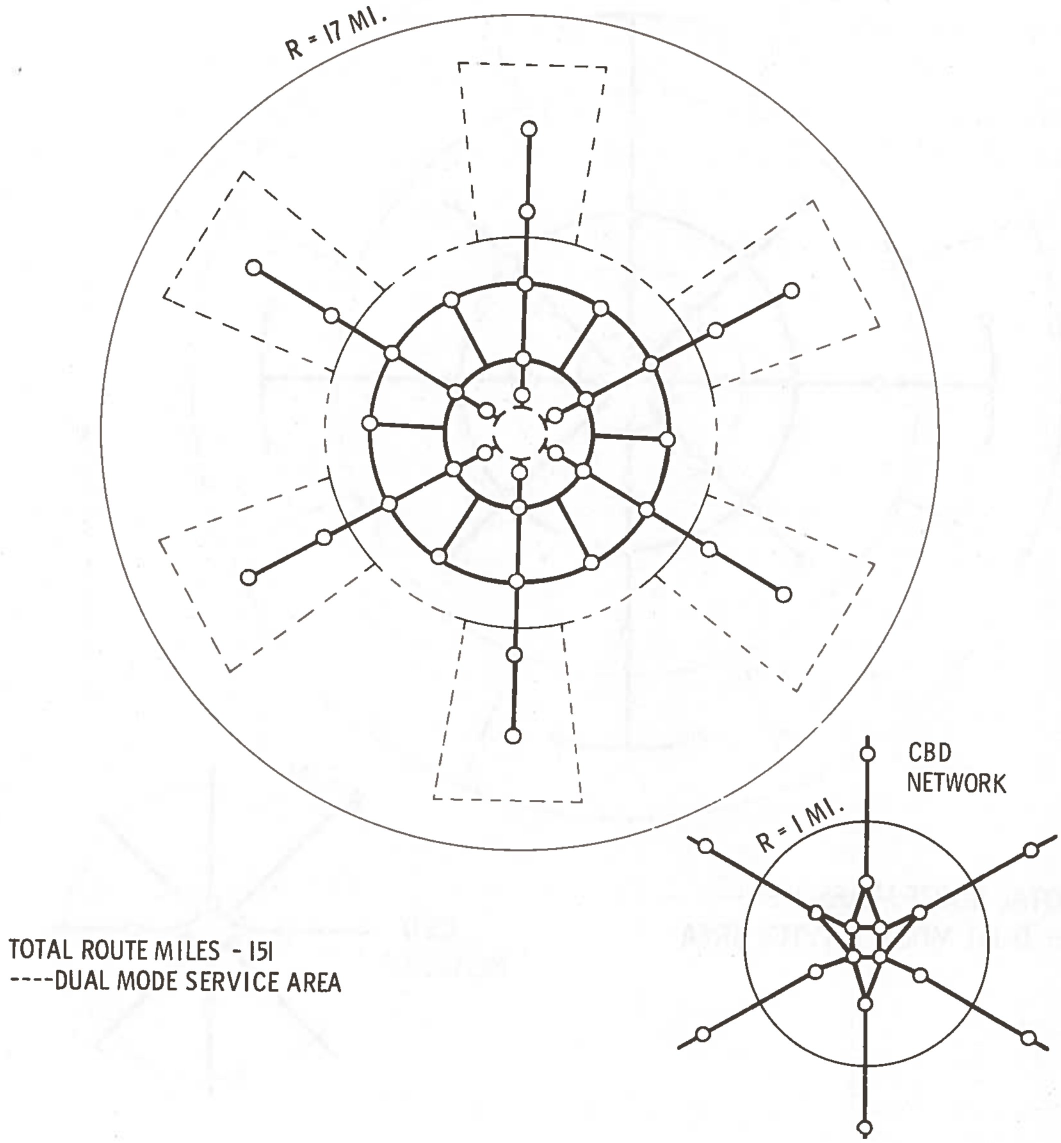



Figure 10. High Population Abstract City Dual Mode Network

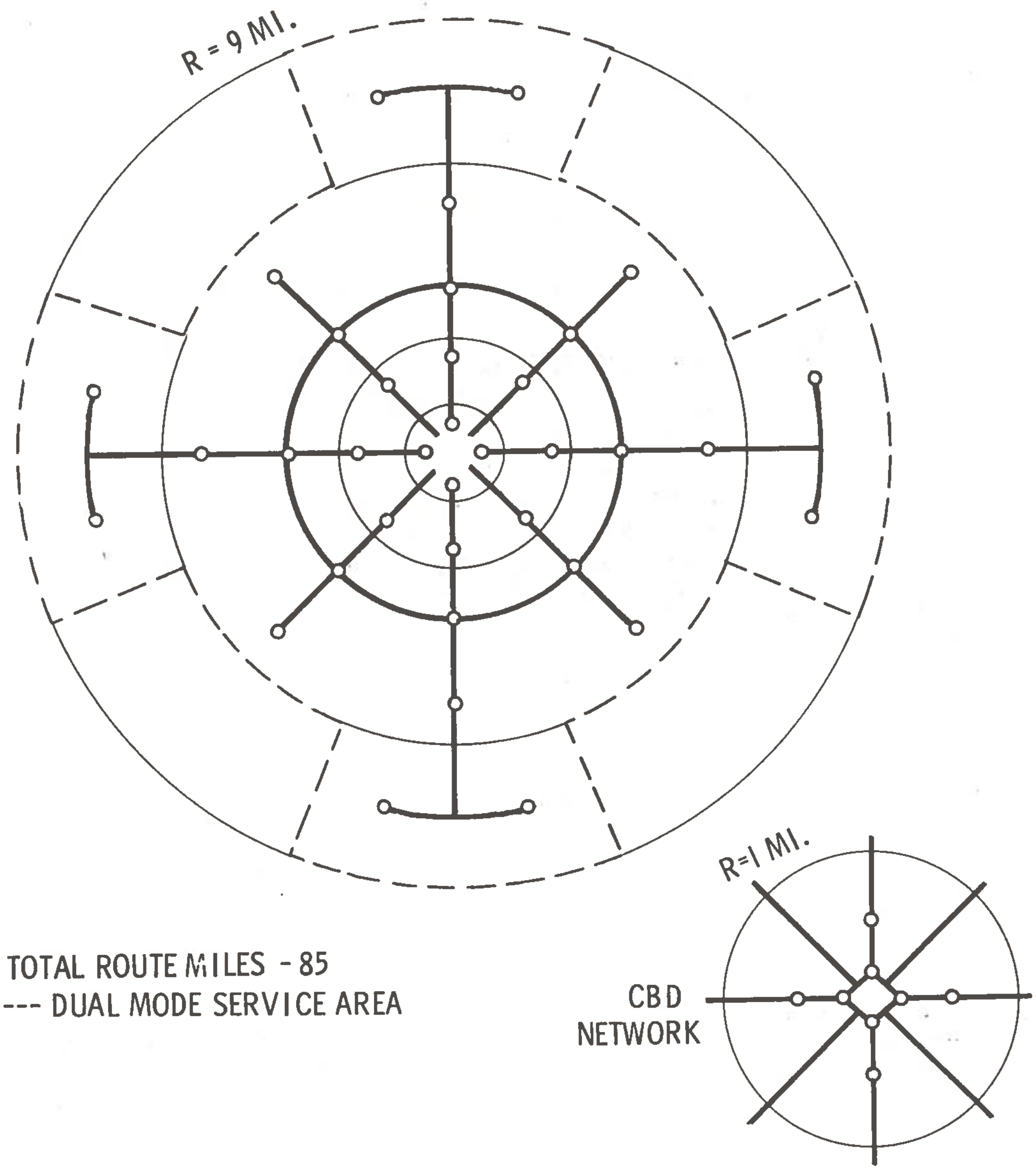



Figure 11. Low Population-High Density Abstract City Dual Mode Network

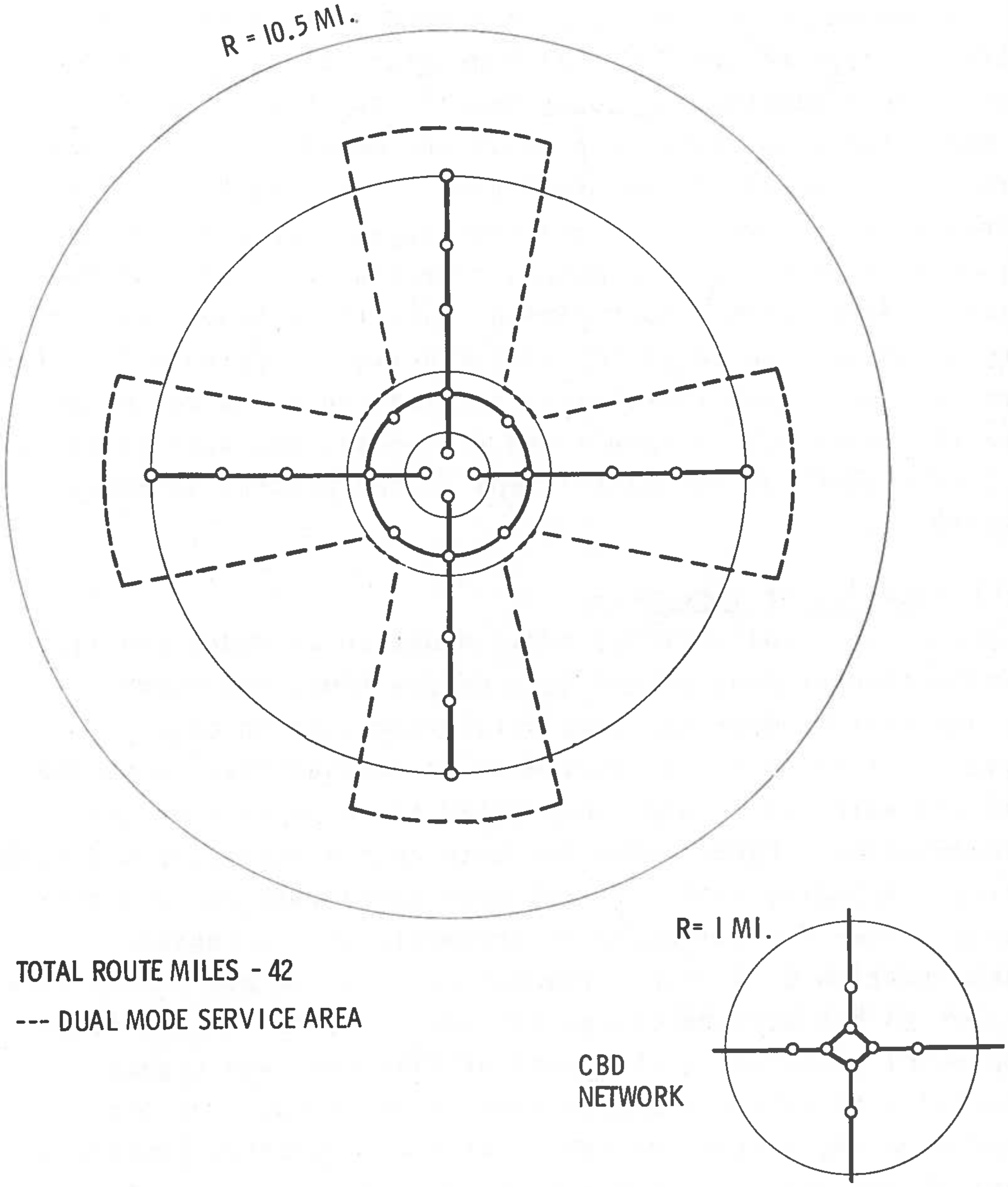



Figure 12. Low Population-Low Density Abstract City Dual Mode Network

## 3.4 RIDERSHIP DETERMINATION

### 3.4.1 Introduction

The demand estimation technique used in this study closely paralleled that of the TSC Dual Mode study except in level of detail. The N-Dimensional Logit Model* (calibrated in the Dual Mode study) was used to predict the modal split (percent of travel by transit) in the peak period for Dual Mode. Since no networks were coded, time and cost impedances used in the model were estimated from a mapped representation of Dual Mode in each abstract city. Peak period (a.m. three hour) transit ridership was scaled to yield daily ridership. Outputs from this process included such statistical information as person miles of travel, average trip speeds and distances, and average fares.

A flow chart of the basic steps in the process is shown in Figure 13.

### 3.4.2 Estimation of Impedances

Use of the N-Dimensional Logit Modal Split Model required the estimation of peak period trip excess time, non-excess time, and cost by mode for each origin-destination pair category. Excess time for Dual Mode is defined here to be the sum of all walk, wait, and other delay times between origin and destination. Excess time for auto is the unparking and parking time (including walk, if any) associated with an auto trip. Non-excess time for all modes is primarily the in-vehicle (moving) portion of a trip. Transit cost is the per person fare. Auto cost is the parking charge (if any). (Since it was found in the model calibration that auto driving cost was highly correlated with auto non-excess time, driving cost was not modeled as an explanatory variable; it was considered implicitly as part of the auto non-excess time variable, consequently avoiding the problem of estimating the perceived cost of operating a vehicle).

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* Descriptions of the theory and calibration of the Logit Model can be found in References 10 and 1, respectively.

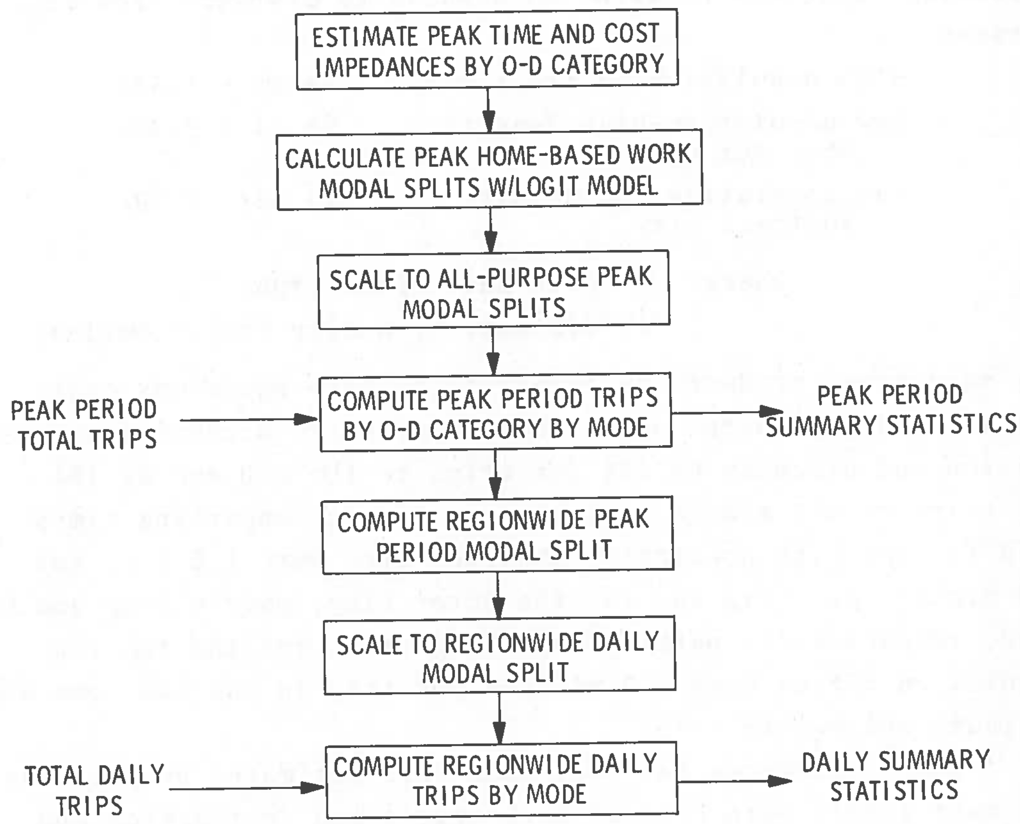


Figure 13. Demand Estimation Technique

For each origin-destination pair category analyzed impedances were estimated for an "average" trip, taking into account residential and employment density and approximate network layout to determine appropriate points of origination and destination. Distances were scaled from network maps.

Rather than performing a detailed network analysis (which would have exceeded the scope of this study), auto trip times (non-excess) were estimated according to the following equations relating auto speed to distance from city center:

| | |
|---|---|
| High population abstract city | $V = 15 + 1.35r$ |
| Low population-high density abstract city | $V = 14 + 2.22r$ |
| Low population-low density abstract city | $V = 15 + 2.00r$ |

where: $V$ = mean auto speed (mph)
$r$ = distance from city center (miles)

The auto times produced by integrating these equations over the assumed auto paths were then adjusted to account for congestion and circuity by 25% for trips to the CBD and by 10% for trips to the middle ring zones. Parking/unparking times used for the high population abstract city were 1.0,1.5, and 5.0 minutes per trip end for the outer ring, middle ring and CBD zone, respectively; parking/unparking times for the two low population cities were 3.0 minutes per trip in the CBD zone and 1 minute everywhere else.

Time impedances for Dual Mode were estimated by postulating the most likely path between each origin and destination and summing the various time components of the trip along that path. Table 5 describes the path for a typical Dual Mode minibus trip to the CBD.

Origin-destination out-of-pocket fares were based on two cents per airline mile multiplied by 1.4 to account for deviation from straight line routings. (The fare rate for modal split computation was consistent with that used in the TSC Dual Mode Study.)

TABLE 5. TYPICAL MINIBUS PERSON TRIP TO CBD DURING PEAK HOUR-HIGH POPULATION ABSTRACT CITY

| Time Component | Minutes | Miles |
|---|---|---|
| Wait for bus | 8.5 | - |
| Off-guideway to station | 13.7 | 3.7 |
| Station processing | 2.0 | - |
| On-guideway line haul | 3.5 | 3.0 |
| Station processing | 1.5 | - |
| Walk to station exit | 1.0 | - |
| Walk to destination | 4.1 | 0.2 |
| TOTAL | 34.3 | 6.9 |

Comparable auto door-to-door time - 21.6 minutes

TABLE 6. LOGIT MODEL COEFFICIENTS

| Mode | Excess Time(δ) | Non-Excess Time(β) | Cost(γ) | Constant(δ) |
|---|---|---|---|---|
| <u>Calibration</u> | | | | |
| Auto | -.258 | -.040 | -.026 | 0 |
| Local Bus | -.030 | -.027 | -.032 | -2.0 |
| <u>Application</u> | | | | |
| Auto | -.258 | -.040 | -.026 | 0 |
| Dual Mode | | | | |
| SPV | -.258 | -.040 | -.032 | +0.2 |
| Minibus | -.100 | -.027 | -.032 | -0.5 |

All impedances were calculated manually and tabulated for use in the Logit Modal equation.

### 3.4.3 N-Dimensional Logit Model Application

The N-Dimensional Logit Model, developed by Peat, Warwick, Mitchell and Co., was calibrated in the TSC Dual Mode study for home based work (HBW) trips in the peak period only. The results of that calibration were used directly in this study to produce peak and daily transit ridership to the peak HBW values.

In brief, the form of the Logit equation as used in the analysis was the following:

$$M_{t1} = \frac{\exp(T_1)}{\exp(T_1) + \exp(T_2) + \exp(A)} \qquad M_{t2} = \frac{\exp(T_2)}{\exp(T_1) + \exp(T_2) + \exp(A)}$$

where $M_{t1}, M_{t2}$ = transit modal split (fraction) for small personal vehicle (SPV), minibus

$T$ = transit impedance function

$T_1 = \alpha_{t1}X_{t1} + \beta_{t1}N_{t1} + \gamma_{t1}C_{t1} + \delta_{t1}$

$T_2 = \alpha_{t2}X_{t2} + \beta_{t2}N_{t2} + \gamma_{t2}C_{t2} + \delta_{t2}$

$A$ = auto impedance function

$= \alpha_a X_a + \beta_a N_a + \gamma_a C_a + \delta_{t2}$

$X_{t1}, X_{t2}, X_a$ = trip excess times for SPV, minibus, auto

$N_{t1}, N_{t2}, N_a$ = trip non-excess times for SPV, minibus, auto

$C_{t1}, C_{t2}, C_a$ = trip costs for SPV, minibus, auto

$\alpha, \beta, \gamma, \delta$ = impedance coefficents, constants

The calibrated coefficients for auto and local bus service are given in Table 6 along with those selected for use with Dual Mode. Since the selection of Dual Mode coefficients was based in part on the results of the calibration, the following points should be noted with regard to the calibrated values of the auto and bus coefficients:

- o Higher sensitivity to non-excess time for auto than for local bus riders--i.e., the normal auto user is more likely to be influenced in his choice of mode than the bus rider by line-haul travel time;

- Much higher sensitivity to excess time for auto than for local bus riders;
- Slightly lower sensitivity to cost for auto than for local bus riders.

Using the calibrated values as bounds, coefficients were selected primarily according to whether the vehicle type might be perceived by the patron to be "transit-like" or "auto-like". This criterion therefore reflected both the service characteristics of the sub-mode and the probable type of rider attracted to it (diverted from auto vs. existing transit). The constants, which mainly took into account unquantifiable variables such as reliability, comfort, image, etc., were selected on the same basis. (The calibrated constant for auto was by definition zero due to the calibration technique in which auto is considered the base mode.)

For example, the small personal vehicle, which closely resembles the auto, was deemed slightly more comfortable and reliable than the auto since automated travel on the guideway eliminates driving and reduces the possibility of unforeseen delays; hence, the slightly higher constant(+0.2) than auto.

3.4.4 <u>Trip Estimation</u>

Application of the Logit Model produced peak home-based work trip modal splits by origin-destination category. In order to calculate data on ridership, person-miles of travel and average trip speeds for peak and daily periods, it was neccessary to scale the peak home-based work modal splits to all-purpose peak and all-purpose daily values. The conversions were accomplished by using scale factors derived from Boston region base year data.

Peak period factors were based on the ratio of peak period all-purpose modal split to peak home-based work modal split (Boston data). This ratio was adjusted for each Dual Mode vehicle type to reflect the convenience of making a non-work trip (shopping, business, etc.) relative to a work trip. Daily scale factors were based on the ratio of daily all-purpose modal split to peak period all purpose modal split (Boston data). Individual adjustments were dependent on the overall level of service expected during the day (relative to peak), or, in the case of the Dual Mode small personal vehicle, the potential availibility of the vehicle. Dual Mode scale factors used are presented below:

Modal Split Scale Factors

| Dual Mode Vehicle | Peak Factor[1] | Daily Factor[2] |
|---|---|---|
| SPV | .90 | .75 |
| Minibus | .90 | .85 |

[1]Applied to peak period home-based work modal splits to yield peak period all-purpose modal splits.

[2]Applied to peak period all-purpose modal splits to yield daily all-purpose modal splits.

The peak factors were applied to Dual Mode peak period home-based work trip modal splits to yield peak period all-purpose trip modal splits by origin-destination pair category. These percentages were then multiplied by the peak period total trips in each O-D category, producing Dual Mode ridership by category in the peak period. Regionwide and CBD ridership were computed by appropriate summing. Person-miles of travel were calculated by category and summed to obtain peak period totals. Peak system loadings were approximated by assuming that 50 percent of peak period travel would occur in the peak hour.

Regionwide daily ridership was computed by applying the daily scale factors to the regionwide peak period all-purpose modal splits, and then multiplying the results by total daily trips. Daily person-miles traveled (as computed using origin-destination category distances) were normalized to ensure appropriate trip lengths for the size of the city.

## 3.5 FLEET SIZING

The size of the small personal vehicle (SPV) fleet was determined in a manner similar to that used in Reference 1. A vehicle was provided for each a.m. peak period SPV person-trip (divided by the SPV load factor), on the assumption that these vehicles would not be used for any other trips during the day, but would be parked instead. One vehicle was provided for every three off-peak person round-trips, to accommodate the home-based and business trips around town occurring throughout the day.

The size of the minibus fleet was determined by considering the off-guideway route structure and the access criterion (discussed in "Network Lay-Out" Section 3.3) The city was divided into collection/distribution areas of approximately 0.3 square miles each, and each of these was considered as a "route." A minibus was assumed to cover an off-guideway collection/distribution run of about 4 miles, enter the guideway, travel to the downtown area, and then come back out via the guideway to its collection/distribution route. The access criterion, as applied to the minibus, was the average time elapsing between placement of a call for service and the arrival of a minibus to pick up the passenger. The values used were 8.5 minutes during the peak period for the high population city and 6.5 minutes for the two low population cities, resulting in a bus headway of approximately 17 minutes in the large city and 13 minutes in the small ones. The combination of route length(which determines the amount of time a vehicle spends during the course of a round trip), route area (which determines the number of routes in the city) and headway (which determines the number of buses per route) fixed the fleet size. During the off-peak hours, the headways were doubled, and about half the minibus fleet was assumed to lie idle during these periods.

The vehicle fleets resulting from these considerations are as follows:

| Abstract City | Small Personal Vehicle Fleet | Minibus Fleet |
|---|---|---|
| High Population | 165,000 | 3,000 |
| Low Population-High Density | 79,000 | 1,400 |
| Low Population-Low Density | 50,000 | 900 |

## 3.6 SYSTEMS COSTS

Values for Dual Mode capital and operating costs were for the most part identical to those used in the TSC Dual Mode study, with certain modifications based on Reference 11. All costs were in 1970 dollars, and capital costs were annualized assuming a 10% interest rate and appropriate service lives for each system component.

Dual Mode capital costs were calculated on the basis of system components--i.e., guideway, intersections, terminals, acceleration-deceleration lanes, control center, maintenance facility, storage yard, vehicles. The cost of each component was arrived at by summing the cost of sub-elements such as land, structure, power distrubution, and command-and-control equipment. Operating costs were likewise calculated on a component basis.

Before discussing the individual component cost inputs, it is appropriate to present the land costs which were used in this study. The following table shows land cost by ring derived for the three abstract cities from 1967 Census of Governments data:

| Abstract City | Cost Per Acre | | |
|---|---|---|---|
| | Inner City | Middle Ring | Outer Ring |
| High Population | $98,000 | $81,000 | $49,500 |
| Low-Population-High Density | 60,000 | 48,000 | 32,500 |
| Low Population-Low Density | 46,000 | 35,500 | 25,000 |

Guideway capital and operating costs are given in the table below. The structual cost includes all supporting structure, tunnels, and running surface. Right-of-way costs are not shown explicitly; instead, the lane width per lane is provided, which was multiplied by system lane-miles in each ring and land cost per acre to obtain the total land cost attributable to guideways.

Capital Cost

| | |
|---|---|
| Structure ($/lane-mile)--at grade | $0.5 \times 10^6$ |
| elevated | $1.5 \times 10^6$ |
| tunneled | $5.0 \times 10^6$ |
| Land Width/Lane(ft.) | 12 |
| Command and Control($/lane-mile) | $0.25 \times 10^6$ |
| Power ($/lane-mile) | $0.4 \times 10^6$ |
| Operating Cost ($/lane-mile/year) | $0.02 \times 10^6$ |

Intersection costs consist of land, structure, and track costs over and above the cost of the intersecting guideway segments. The following table shows the acreage requirements, merge guideway mileage, and structual cost for the various types of intersections assumed in the three abstract city networks:

| Type of Intersection | Area (acres) | Merge Guideway (miles) | Structual Cost/Unit |
|---|---|---|---|
| At Grade | | | |
| 4-way-- 30mph | 7.0 | 1.30 | $1,400,000 |
| -- 60mph | 115.0 | 3.80 | 3,800,000 |
| 3-way-- 30mph | 3.5 | 0.66 | 1,100,000 |
| -- 60mph | 57.5 | 1.91 | 1,400,000 |
| Tunneled | | | |
| 4-way-- 30mph | 7.0* | 1.30 | 6,500,000 |
| 3-way-- 15mph | 0.25* | 0.30 | 2,000,000 |
| -- 30mph | 3.5* | 0.66 | 3,300,000 |

Dual Mode terminal capital costs were determined on the basis of passenger flow through the station during the design peak hour and construction type (at grade vs. tunneled). The average capital cost of stations (including acceleration-deceleration lanes) in the high population, low population-high density and low population-low density abstract cities was $2,475,000, $2,425,000 and $2,380,000, respectively. The average annual operating cost per station was $47,000 in all three scenarios.

The Dual Mode maintenance facility was assumed to require

* Land acquistion costs were not calculated for tunneled intersections.

5 acres of land in the high population city and 2 acres in the low population cities and to have corresponding structural costs of $5,000,000 and $2 000 000. The annual operating cost of the facility was $100,000 for all three cities. The command and control facility was assumed to have a capital cost of $12,000,000 (excluding the cost of 2 acres of land) and an annual operating cost of $800,000. Storage facility cost was based on the vehicle fleet size; the following table shows capital and operating costs in the three scenarios:

| Abstract City | Storage Facility Costs | |
|---|---|---|
| | Capital | Annual Operating |
| High Population | $\$130 \times 10^6$ | $\$1.8 \times 10^6$ |
| Low Population-High Density | $70 \times 10^6$ | $0.4 \times 10^6$ |
| Low Population-Low Density | $60 \times 10^6$ | $0.3 \times 10^6$ |

Data on the cost, passenger capacity, and lifetime of Dual Mode vehicles are given in the table below:

| | Small Personal Vehicle | Minibus |
|---|---|---|
| Capital Cost | $4,500 | $30,000 |
| Operating Cost ($/vehicle-miles-traveled) | | |
| On-guideway | .05 | .12 |
| Off-guideway | .05 | .72 |
| No. of Passengers | 4 | 12 |
| Lifetime (years) | 6 | 12 |

The $.60 difference in minibus operating cost for on-vs. off-guideway travel reflects the fact that a driver is not needed for the automated portion of a trip.

## 3.7 DETERMINATION OF DUAL MODE APPLICABILITY

The most crucial aspect of this study was the selection and use of a set of criteria of Dual Mode applicabilty, since this choice determined the methodological approach of the study and guided the interpretation of the findings. Three criteria were involved in the determination of Dual Mode applicability: the ability-to-pay criterion, which was used to determine whether or not each abstract city could afford a Dual Mode system; and the cost-benefit and needs criteria, which were employed to determine Dual Mode's applicability in those abstract cities which could afford it.

The ability-to-pay criterion involved the question of whether the degree of burden which an urbanwide Dual Mode system would impose on an area's financial resources seemed "reasonable" in light of the recent experience of cities building rapid transit systems. The "degree of burden" was expressed in terms of local annual capital cost plus operating deficit per capita as a percent of annual city revenue per capita. This percentage was calculated for Dual Mode systems in the abstract cities and for rapid transit systems proposed or under construction in various cities throughout the country.

The rationale behind choosing the ratio of annual system cost to annual city revenue as a measure of financial burden is as follows. There are numerous indicators of an area's fiscal capability or economic status--for example, annual revenue, annual expenditure, debt outstanding, debt issued during the year, per capita income, and annual retail sales. However, these measures are not equally appropriate for this analysis. Per capita income and annual retail sales deal with personal or business, as opposed to municipal, financial status. Although family or corporate conditions do sometimes influence people's receptivity toward large-scale programs (witness the Seattle voters' rejection of a rapid transit plan in 1968 and 1970, when the area was experiencing a serious economic recession), it would seem that measures of municipal wealth (which are to some degree influenced by personal or business income levels) are more meaningful determinants. Among the urban area indicators, annual revenue--consisting of receipts from property and sales taxes, utilites, liquor stores and other sources --

was selected as the most encompassing and appropriate.* Annual revenue was preferred over debt outstanding because it is more current. The total amount of long-term debt outstanding reflects bonds issued over a long period of time and tied primarily to projects carried out in the past, whereas annual revenue is applied soon after receipt to expenditures deemed worthy in the present. The annual revenue measure was chosen over annual debt issued because of its greater stability over time: since data from the 1967 Census of Governments[12] was to be used, it was desirable to have a measure which would be fairly representative of the 1965-70 period, rather than one which varies significantly from year to year in response to interest rate fluctuations. Having decided upon annual revenue as the indicator of a city's ability to pay for a system, it was neccessary to select an appropriate measure of Dual Mode cost with which it could be compared. The cost indicator had to be <u>annual</u> and had to reflect the <u>locally</u> perceived financial burden. Thus, local annual capital cost plus operating deficit was chosen--i.e., one-third of the annualized system cost** plus the difference (if any) between system operating cost and system revenue.***

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* Annual expenditure (for education, highways, welfare, interest on debt, etc.) is practically equal in value to annual revenue. However, it was preferable from a conceptual standpoint to relate Dual Mode costs to the revenue rather than expenditure side of the city balance sheet.

** Assuming one-third local, two-thirds Federal funding. Note: Subsequent to the completion of this analysis, there was a change in the Federal-local funding ratio to 80-20. Although no additional analysis was conducted using this ratio, it is possible that the effective decrease in the local financial burden would have resulted in a somewhat larger number of potential candidates for Dual Mode than that obtained.

***In the case of an operating profit, the local share of annual capital cost is computed by deducting the profit from total annual cost and dividing the remainder by three.

Before comparing system cost to city revenue for each abstract city, it was necessary to express these numbers in per capita terms so as to eliminate the incompatibility of geographic data base (SMSA for the revenue figures, vs. urbanized area for the system costs). The use of per capita data had the further advantage of putting the results for the three abstract cities of differing population on a comparable basis.

The system cost vs. city revenue comparison was performed by calculating local annual capital cost plus operating deficit per capita as a percentage of annual revenue per capita. The derivation of this percentage did not imply the adoption of a particular financing scheme for Dual Mode or rapid transit--e.g., it did not mean that the local annual capital cost plus operating deficit would be covered directly out of city revenue. Rather, this percentage was intended to represent the degree to which an urbanwide transportation system would strain an area's financial resources.

Dual Mode's applicability on the basis of ability to pay was determined as follows. The process of defining a Dual Mode system and examining it in the three abstract cities led to the calculation of system parameters such as cost, modal split, and revenue. The local annual capital cost plus operating deficit was divided by total population and then divided by annual city revenue per capita to obtain a percentage indicating degree of financial burden. In order to put into perspective the percentages obtained for the three abstract cities, comparable data were generated for cities which are currently building or planning rapid transit systems. This information provided an indication of what percentage range of system cost vs. city fiscal capability might be considered reasonable for high capital cost transportation systems. The real-city range was then used to classify each abstract city according to whether or not it could potentially afford an urban-wide Dual Mode system.

Although the inability to afford Dual Mode was a sufficient justification for excluding an abstract city (and the urbanized areas it represented) from the potential Dual Mode market, satisfaction of the ability-to-pay criterion was not sufficient in itself to justify including areas in the potential market. In particular, what was required for those abstract cities which could afford Dual Mode was some indication that: (1) these areas were in need of additional transportation facilities (viz., high capacity facilities) and (2) Dual Mode could provide monetary benefits in excess of its costs. If these two additional conditions were not satisfied, it would be necessary to rule out Dual Mode as a potential urbanwide transportation alternative. However, if these criteria were met, then Dual Mode could be judged an acceptable transportation alternative from a performance as well as financial standpoint. Thus, as a final step, information on the cost-benefit performance of Dual Mode and data from the 1972 National Transportation Needs Study on the dollar magnitude and modal breakdown of perceived urbanized area needs were used to qualify the financially based applicability findings.

On the basis of the ability-to-pay, cost-benefit, and needs criteria, three applicability ranges (definite, possible, doubtful potential) were defined in terms of 1990 population, and the urbanized areas comprising the definite and possible categories were identified.

# 4. RESULTS

## 4.1 SERVICE AND COSTS

Table 7 presents the salient results on service and costs for the Dual Mode systems in the three abstract cities. Modal split is somewhat higher in the high population and low population-high density city, reflecting the fact that the Dual Mode network was designed to serve only half of the population in the low density city, vs. 70 to 75% of the population in the other two cities (see "Trip Generation and Distribution" in section 3.3). System capital cost tends to be proportional to system extent, with the vehicle cost accounting for about one-third of the total. Although Dual Mode characteristics are basically similar in all three abstract cities (reflecting adherence to certain ground rules such as the access time criterion), the varying characteristics of the cities result in a wide discrepancy in the operating profit/loss picture: in the high population city, Dual Mode operates at a $13 million annual profit, whereas in the two smaller cities, it operates at a $12 million and $3 million deficit. The reason for this discrepancy is that the small personal vehicle fleet generates an operating profit roughly proportional to its size and annual usage (which in turn are directly related to city size). In the high population city, this SPV operating profit is more than sufficent to cover the minibus deficit and other system operating costs, whereas in the two smaller cities, the SPV profit is smaller than the sum of the minibus deficit (especially high in the high density city) and other operating expenses. It should be reiterated that these results (e.g., the minibus deficit) reflect the system in an urbanwide application and that consideration of Dual Mode in other applications (such as a corridor) might have different results.

System annual capital plus operating cost, like system capital cost, is proportional to system route mileage. However, this cost on a per passenger trip basis is practically the same in all three cities, owing to the fact that ridership increases with system extent. Because of the operating profit

TABLE 7. DUAL MODE SERVICE, COSTS, AND REVENUES

| | High Population Abstract City | Low Population-High Density Abstract City | Low Population-Low Density Abstract City |
|---|---|---|---|
| SERVICE: | | | |
| System Route Miles | 151 | 85 | 42 |
| Daily Modal Split (%) | 17 | 20 | 13 |
| Peak CBD Modal Split (%) | 61 | 57 | 49 |
| COSTS AND REVENUES: | | | |
| System Capital Cost ($ X $10^6$) | 2,400 | 1,200 | 700 |
| System Vehicle Capital Cost ($ x $10^6$) | 800 | 400 | 250 |
| System Annual Operating Profit ($ x $10^6$) | +13 | -12 | -3 |
| System Annual Capital Plus Operating Cost ($ x $10^6$) | 470 | 240 | 140 |
| System Cost Per Passenger Trip ($) | 1.80 | 1.75 | 1.85 |
| Local Annual Capital Cost Plus Operating Deficit ($ x $10^6$) | 110 | 70 | 40 |

in the high population city, the local annual capital cost plus operating deficit shows a less than proportional increase with system extent.

The above statistics show that Dual Mode costs vary with system and city size and that the profit/loss situation is subject to certain economies of scale in large vs. small cities, but do not in themselves answer the question of whether Dual Mode is applicable in the scenarios studied. It is therefore necessary to apply the ability-to-pay, cost-benefit and needs criteria.

## 4.2 DUAL MODE APPLICABILITY

Figure 14 shows local annual capital cost plus operating deficit (from Table 7) on a per capita basis for the three abstract cities plus Boston.* It can be seen that the annual per capita cost of Dual Mode is nearly $30 higher in the low population-high density abstract city than in the low population-low density city.

This is because the relatively high density of the former city results in a relatively large service area,where Dual Mode guideways must be provided in accordance with the specified access time criterion. The costs of the extensive network (which is twice as long as that in the low density city) must be defrayed over a population which is only 30% greater, resulting in a comparatively high annual cost per person in the high density city. Another item to note with regard to Figure 14 is that the Boston data point is not exactly comparable to the other three, in that the network was not laid out to conform to an access time criterion. Nevertheless, even allowing for the fact that the Boston point might be slightly higher if the criterion were applied, a definite trend is apparent from this figure: the annual cost per capita declines as city size increases, particularly in the under-two million population range.

Figure 15 presents the reverse side of the coin: city revenue per capita by SMSA population size group. The trend

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* The Boston point is based on data from the report Analysis of Dual Mode Systems in an Urban Area[1].

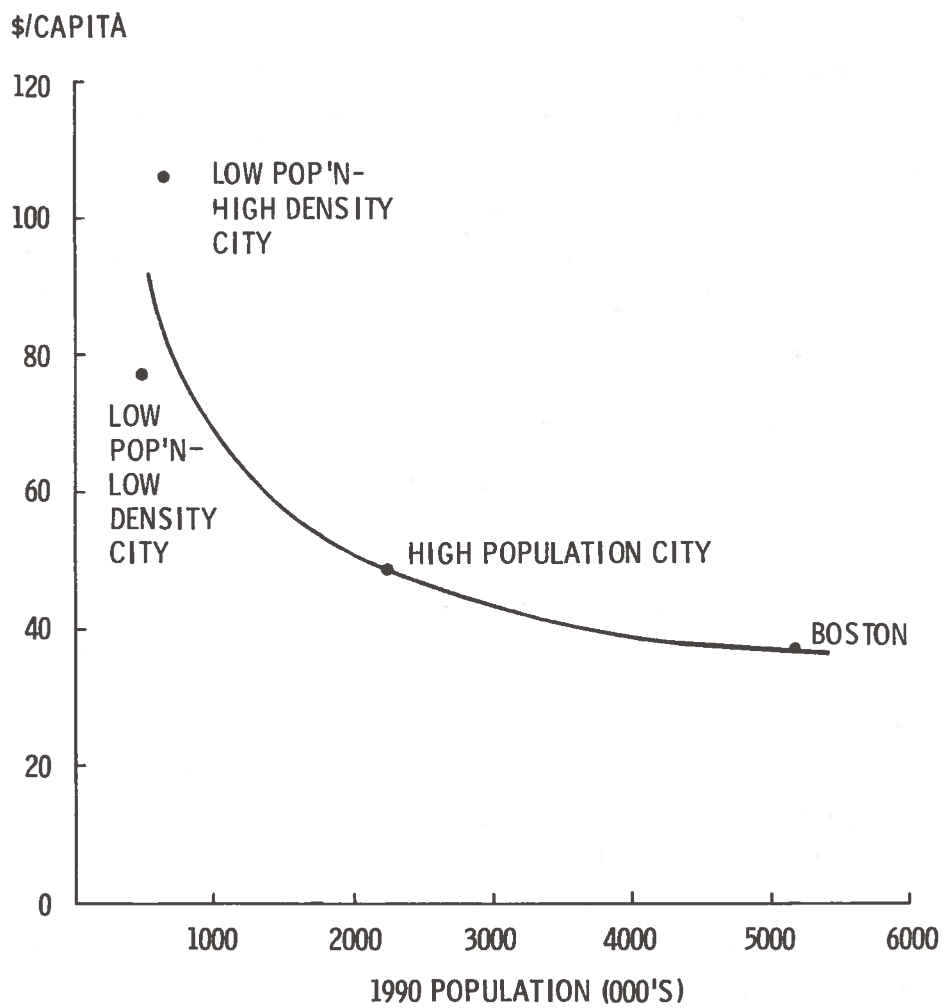


Figure 14. Local Annual Capital Cost Plus
Operating Deficit Per Capita

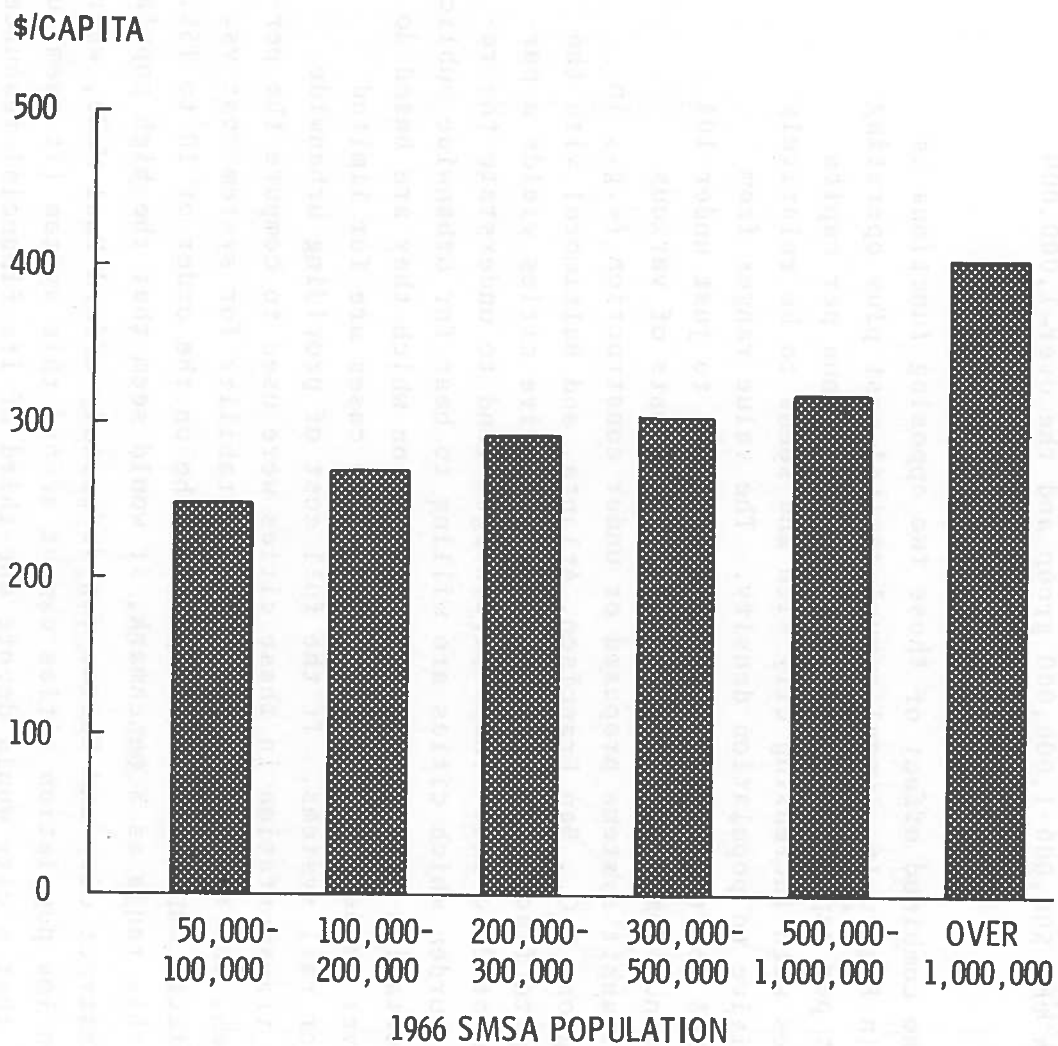


Figure 15. Revenue Per Capita By
SMSA Population Size Group

which can be observed in this figure is that the ability to pay for goods and services increases with city size. For instance, revenue per capita for SMSA's with over one million inhabitants is about 60% greater than that for the smallest SMSA's. The sharpest increase in revenue per capita occurs between the 500,000-1,000,000 group and the over-1,000,000 group.

The combined effect of these two opposing functions is shown in Figure 16. Local annual capital cost plus operating deficit per capita as a percent of city revenue per capita declines with increasing city size and seems to be relatively insensitive to population density. The value ranges from about 30% for the two low population cities to just under 10% in Boston. Comparison of the per capita costs of various rapid transit systems proposed or under construction (e.g., in Washington, D.C., San Francisco, Atlanta, and Baltimore) with the per capita fiscal resources of the respective cities yields a percentage of 2 to 11%. These percentages tend to understate the relative burden which cities are willing to bear for urbanwide public transportation systems, since the costs on which they are based do not cover feeder bus systems and in some cases are for limited corridor rail systems. If the full cost of providing urbanwide public transportation in these cities were used to compute the percentages, the resultant range of acceptability for system cost vs. city fiscal capability would probably be on the order of 10 to 15%. Using this range as a benchmark, it would seem that the high population abstract city and Boston can definitely afford Dual Mode, whereas the two low population cities cannot afford this system (it seems unlikely that a city would devote one-third of its financial resources

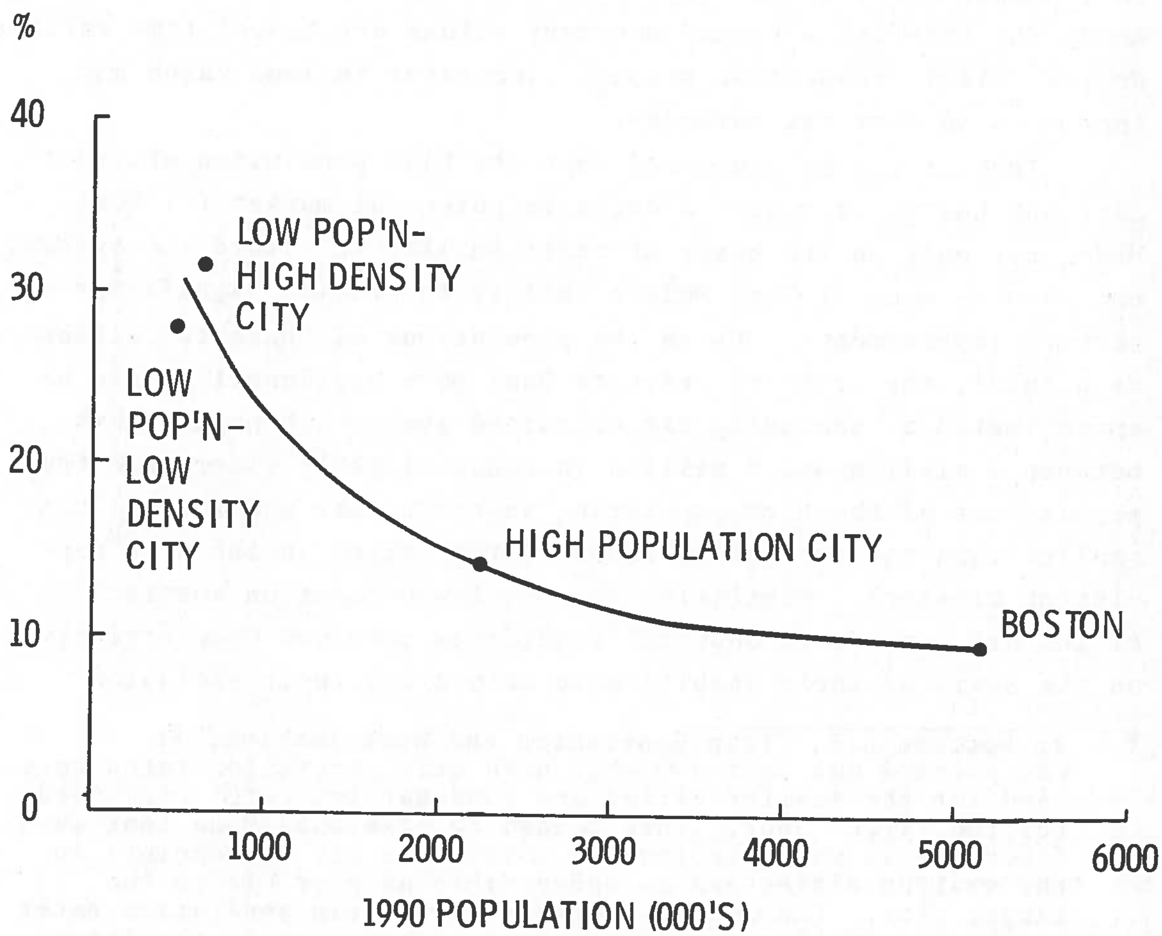


Figure 16. Local Annual Capital Cost Plus Operating Deficit Per Capita As A Percent Of City Revenue Per Capita

to transportation).*

Having determined that the high population abstract city and Boston can afford an urbanwide Dual Mode system, it is appropriate to consider the suitability of such a system in these scenarios from the standpoint of costs and benefits. When Dual Mode is compared to the highway plus local bus case in the high population abstract city and compared to a proposed 1990 highway plus transit plan in Boston, it has large incremental dollar benefits relative to the base case, which are more than double the incremental costs.** Among the benefits assigned monetary values are travel time savings, driver relief, relocation savings, increases in land value and increases in city tax revenues.

Thus it can be concluded that the high population abstract city and Boston represent a definite potential market for Dual Mode, not only on the basis of their ability to afford the system, but also because of Dual Mode's ability to provide significant service improvements. Using the populations of these two cities as a guide, the range of definite Dual Mode applicability can be approximated as including the urbanized areas with populations between 2 million and 6 million (a range slightly wider than the populations of the high population abstract city and Boston, but smaller than the population range of the cities in the high population cluster). Similarly, the two low population abstract cities are considered doubtful candidates for Dual Mode strictly on the basis of their inability to afford it; their exclusion

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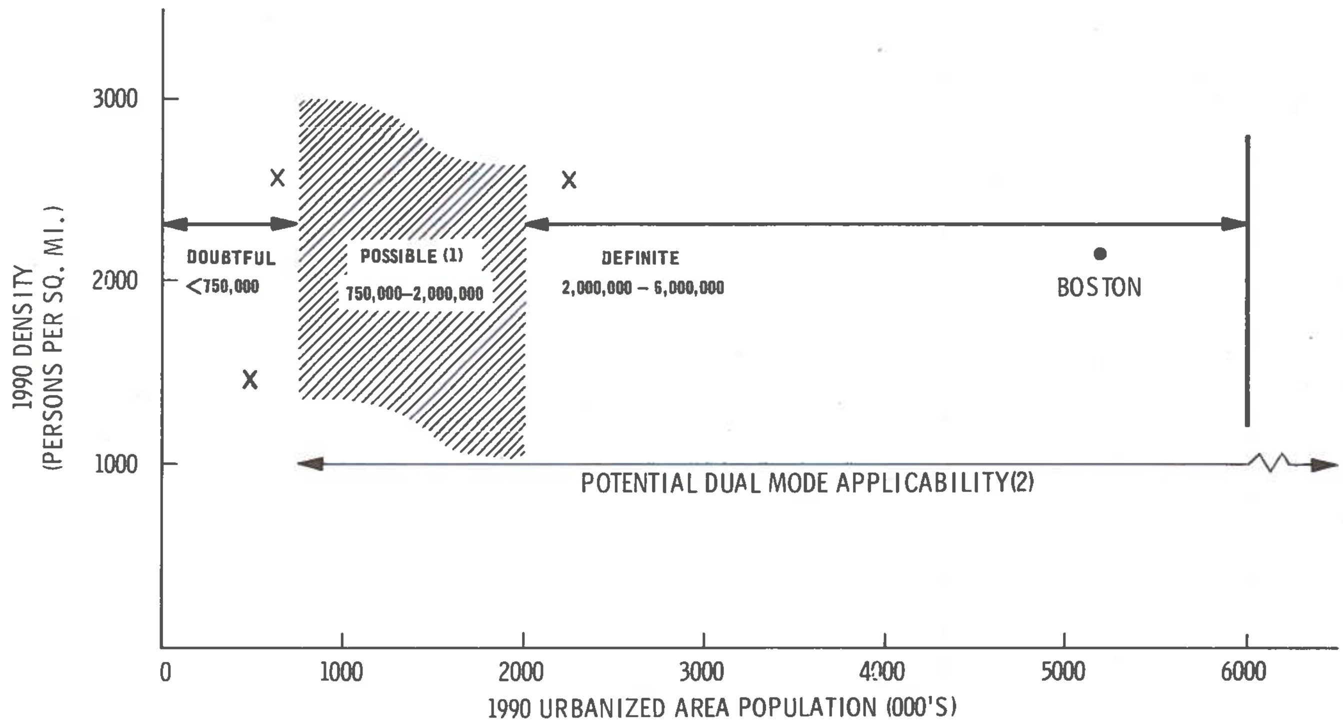
* In Section 3.3, "Trip Generation and Distribution," it was pointed out that somewhat high trip generation rates were used for the smaller cities and somewhat low rates were used for the larger ones. This tended to make Dual Mode look as favorable as possible(from an ability-to-pay standpoint) in the smaller cities and as unfavorable as possible in the larger city. The use of somewhat lower trip generation rates in the two smaller cities and/or a higher rate in the large city would have widened the gap in their respective ability-to-pay percentages, since the local annual capital cost plus operating deficit would have increased in the former cities and decreased in the latter.

** More detailed information on the costs and benefits of Dual Mode in Boston and in the high population abstract city can be found in References 1 and 13, respectively.

from the potential market on this account would seem to render unnecessary any consideration of potential benefits of a Dual Mode system. Using the population of the larger of these two abstract cities as a guide to estimating the upper bound of inability to afford Dual Mode, the range of doubtful Dual Mode applicability can be approximated as including the urbanized areas with populations under 750,000 (a value slightly higher than that for the low population-high density abstract city). Regarding the urbanized areas with populations between 750,000 and 2 million, no definite conclusions can be drawn as to Dual Mode's suitability from an ability-to-pay or cost-benefit standpoint, since none of the abstract cities analyzed fall within this population range. However, based on the finding that urbanized areas with over 2 million persons have definite potential for Dual Mode, and those with under 750,000 have doubtful potential, the areas within the 750,000 to 2 million range are considered to constitute a possible category of Dual Mode applicability. New York, Los Angeles and Chicago are likewise assumed to be in the possible category, since their rather unique transportation problems and solutions cannot be understood through the generalized approach used in this study (and, moreover, these cities were omitted from the high population cluster in developing that cluster's abstract city).

Figure 17 shows the applicability ranges based on the ability-to-pay and cost-benefit criteria. The boundaries shown in this figure can be used to identify, on the basis of 1990 population, those urbanized areas where Dual Mode appears to have definite or possible potential as an urbanwide system. Figure 18 presents a list of these areas; the "doubtful" category is not shown, since there are over 300 urbanized areas in this group. Figure 19 shows the location throughout the U.S. of the 13 definite candidates and 31 possible candidates for Dual Mode. It can be seen that most of these candidate areas are in the eastern half of the country. Moreover, as might be expected, the places where Dual Mode has definite applicability tend to be the larger, older cities, located primarily in the Northeast.




(1) NEW YORK, LOS ANGELES AND CHICAGO ARE ASSUMED TO BE IN "POSSIBLE" CATEGORY

(2) THE DETERMINATION OF DUAL MODE APPLICABILITY FOR SPECIFIC AREAS WOULD REQUIRE A TRANSPORTATION PLANNING ANALYSIS TO QUANTIFY THE COSTS, BENEFITS, AND IMPACTS OF THE PROPOSED SYSTEM

Figure 17. Dual Mode Applicability

| DEFINITE POTENTIAL | POSSIBLE POTENTIAL |
|---|---|
| Atlanta | Birmingham |
| Baltimore | Buffalo |
| Boston-Providence | Chicago |
| Cleveland | Cincinnati |
| Detroit | Columbus |
| Houston | Dallas |
| Minneapolis-St. Paul | Dayton |
| Philadelphia | Denver |
| Pittsburgh | Ft. Lauderdale |
| St. Louis | Ft. Worth |
| San Diego | Hartford |
| San Francisco | Indianapolis |
| Washington, D.C. | Jacksonville |
| | Kansas City |
| | Los Angeles |
| | Louisville |
| | Memphis |
| | Miami |
| | Milwaukee |
| | New Orleans |
| | New York |
| | Norfolk |
| | Oklahoma City |
| | Orlando |
| | Phoenix |
| | Portland |
| | Rochester |
| | Sacramento |
| | St. Petersburg |
| | San Antonio |
| | Seattle-Tacoma |

Figure 18. Urbanized Areas With Potential Dual Mode Applicability* (List)

* The applicability of Dual Mode for specific urbanized areas was not evaluated, but would have to be determined on the basis of individual transportation planning analyses.


Figure 19. Urbanized Areas With Potential Dual Mode Applicability (Map)

At this juncture it is important to point out that the determination of population ranges of applicability and the identification of urbanized areas within these ranges do not imply a steadfast population rule of thumb regarding Dual Mode potential. For these results are based on an analysis of hypothetical cities having the average characteristics of 25 to 30 urbanized areas within their respective clusters. It is quite possible that detailed analyses of specific urbanized areas on an individual basis would lead to the discovery of some whose potential for Dual Mode as an urbanwide transportaion form differed from their classification according to the population buoundaries shown in Figure 17. Moreover, if the analysis were to consider Dual Mode in other than an urbanwide context, the list of Dual Mode candidates would undoubtedly expand to include areas with a need for corridor or limited area circulation systems. Nevertheless, the results of this study, particulary the numerical findings to be presented below, are considered in the aggregate to be a fairly valid indicator of Dual Mode's potential applicability.

The final criterion to be applied involves the degree of need for additional transportation facilities. The most comprehensive and up-to-date source of information on transportation needs over the next two decades is the 1972 National Transportation Needs Study, sponsored by the Department of Transportation in cooperation with State and local governments and private industry. The published and unpublished data from this study consist of 20-year needs estimates as well as alternative capital improvement programs submitted by the States and urbanized areas. The needs estimates represent each area's projection of "the amount and cost of (publicly or privately sponsored) transportation facilities and equipment required to carry a forecasted amount of travel at a specified level of service,"[14] with no budgetary or legislative constraints. The three capital improvement programs, on the other hand, are based on specified Federal funding levels, Federal-State matching ratios, and eligible program areas and apply only to publicly sponsored facilities. The following discussion is limited to needs estimates, which are felt to reflect more accurately the actual magnitude of urban transportation requirements, as well as the preferred allocation of funds among modal programs. As a reference point, total dollar needs for individual urbanized areas during the 1970-90 period are about twice the total dollar allocations for 1974-90 under capital improvement alternative II, which assumes a high level of Federal fund availability and the continuation of existing legislative constraints.

Table 8 shows total and per capita dollar needs for 1970 to 1990 by modal program and urbanized area size group, as well as a percentage breakdown of needs by program for each size group. Figure 20 shows per capita needs broken into highway, transit, and other categories. The dollar needs represent the total capital cost (in 1969 dollars) of replacements and additions required to satisfy desired service levels as of January 1, 1970 (backlog needs) plus those required to meet specified service levels as of 1980 and 1990. A number of observations can be made from this table and figure. First of all, it is clear that all urbanized areas size groups (though not necessarily all the areas within each group) project a large need for improvement and/or expansion of facilities in all modal categories. The annual needs estimate for all urbanized areas is $16,554.7 million, or $93 per capita. Second, both total and per capita needs show a direct correlation with city size: for instance, per capita needs for urbanized areas with over 2 million inhabitants are 50% higher than per capita needs for the smallest areas (with 50,000 to 100,000 population). A third observation is that this increase in needs with city size does not occur uniformly across modal programs, but rather is most noticeable in the transit sector. There is a 50-fold difference in per capita rapid rail needs of the smallest vs. largest areas, and a 500-fold difference in the respective total rail needs. Airports show the next highest percentage difference, followed by bus systems, highways, and other intercity programs. The

TABLE 8. 1970-1990 DOLLAR NEEDS BY URBANIZED AREA POPULATION SIZE GROUP AND BY MODAL PROGRAM

| Urbanized Area Population Size Group | Highway | Highway Related | Public Transportation | | Airports | Other Intercity | Total |
|---|---|---|---|---|---|---|---|
| | | | Bus | Rapid Rail | | | |
| 50,000-100,000 | | | | | | | |
| $ Millions | 12,962.82 | 606.04 | 406.61 | 112.57 | 650.83 | 268.45 | 15,010.02 |
| $ Per Capita | 1209 | 56 | 38 | 10 | 61 | 25 | 1400 |
| % of Total | 86.4 | 4.0 | 2.7 | 0.7 | 4.3 | 1.8 | 100.0 |
| 100,000-250,000 | | | | | | | |
| $ Millions | 21,754.12 | 1,088.66 | 561.07 | 146.03 | 1,921.96 | 396.29 | 25,868.72 |
| $ Per Capita | 1351 | 68 | 35 | 9 | 119 | 25 | 1606 |
| % of Total | 84.1 | 4.2 | 2.2 | 0.6 | 7.4 | 1.5 | 100.0 |
| 250,000-500,000 | | | | | | | |
| $ Millions | 21,898.72 | 1,378.78 | 843.98 | 190.15 | 1,611.03 | 1,083.50 | 27,014.87 |
| $ Per Capita | 1298 | 82 | 50 | 11 | 95 | 64 | 1601 |
| % of Total | 81.1 | 5.1 | 3.1 | 0.7 | 6.0 | 4.0 | 100.0 |
| 500,000-1,000,000 | | | | | | | |
| $ Millions | 22,880.08 | 1,014.68 | 1,143.54 | 854.46 | 2,079.96 | 266.20 | 28,838.75 |
| $ Per Capita | 1139 | 51 | 73 | 56 | 104 | 13 | 1436 |
| % of Total | 79.3 | 3.5 | 4.0 | 3.0 | 7.2 | 0.9 | 100.0 |
| 1,000,000-2,000,000 | | | | | | | |
| $ Millions | 32,507.64 | 1,782.42 | 2,437.14 | 2,956.64 | 5,265.16 | 1,270.83 | 46,220.85 |
| $ Per Capita | 1225 | 67 | 92 | 111 | 198 | 48 | 1741 |
| % of Total | 70.3 | 3.9 | 5.3 | 6.4 | 11.4 | 2.7 | 100.0 |
| Over 2,000,000 | | | | | | | |
| $ Millions | 117,820.58 | 3,574.73 | 6,813.47 | 45,249.08 | 12,607.97 | 2,065.79 | 188,131.62 |
| $ Per Capita | 1347 | 41 | 78 | 517 | 144 | 24 | 2151 |
| % of Total | 62.6 | 1.9 | 3.6 | 24.1 | 6.7 | 1.1 | 100.0 |
| Total | | | | | | | |
| $ Millions | 229,832.54 | 9,445.32 | 12,205.82 | 49,508.94 | 24,136.92 | 5,351.06 | 331,093.42 |
| $ Per Capita | 1294 | 53 | 70 | 281 | 136 | 30 | 1864 |
| % of Total | 69.4 | 2.9 | 3.7 | 15.0 | 7.3 | 1.6 | 100.0 |

SOURCE: U.S. Dept. of Transportation, 1972 National Transportation Study: Data Tabulations, National Aggregates by Population Size Groups and Geographic Areas, Office of the Assistant Secretary for Policy and International Affairs, September 1972. (Reference 5.)

Per capita figures were derived from total dollar amounts.

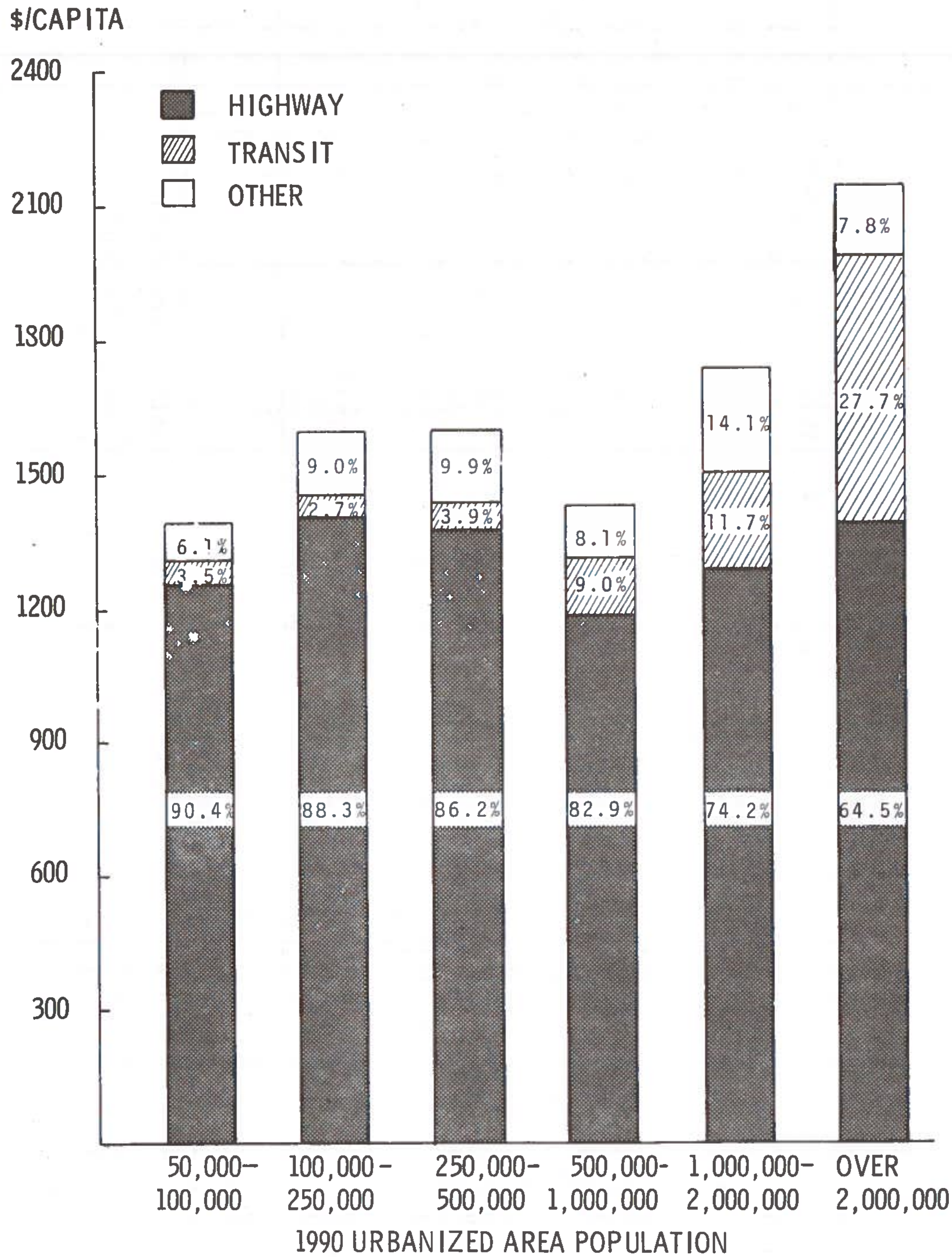



Figure 20. 1970-90 Dollar Needs Per Capita By Urbanized Area Population Size Group

effect of this phemomenon is that highway needs account for about 90% of total needs in the 50,000 to 100,000 population size group, compared to only 65% in the over-2 million group; transit needs, on the other hand, represent only 3% of total needs in the smallest areas,vs. 28% in the largest areas, with the increase occuring primarily in the rapid transit sector.

Based on the preceding findings, it can be concluded that the larger urbanized areas perceive a significant need (in relative and absolute terms) for high capacity, high capital cost systems. Figure 21 ties this conclusion more closely to the applicability results presented above by showing average dollar needs per capita for the urbanized areas within the three categories of Dual Mode potential. Comparing the definite and doubtful categories, there is almost a twofold difference in total per capita needs and more than a 5-to-1 ratio in the percentage of dollar needs allocated to transit. Still another observation is that both the definite and possible categories have a higher propensity for transit than urbanized areas on the average, whereas the doubtful category is far below the national average in this respect.

Figure 22 indicates the types of transit systems in which the 44 urbanized areas comprising the definite and possible categories would like to invest. All of the areas indicate a need to replace and/or expand their bus fleets, 31 would like to expand or install rapid transit, and 30 show a need for new or improved exclusive busways. There is an overwhelming preference for rapid transit, a high cost alternative, in the definite category, whereas in the possible category several urbanized areas favor the exclusive busway as a lower cost means of expanding capacity. For the definite category, the average number of track miles of rapid transit added is 210, and the average number of additional route miles of exclusive busway is 52.* Corresponding figures for the possible category are 86 track

* These averages include only the areas building the particular type of facility and are not necessarily averages for all the urbanized areas in each category of Dual Mode applicability.

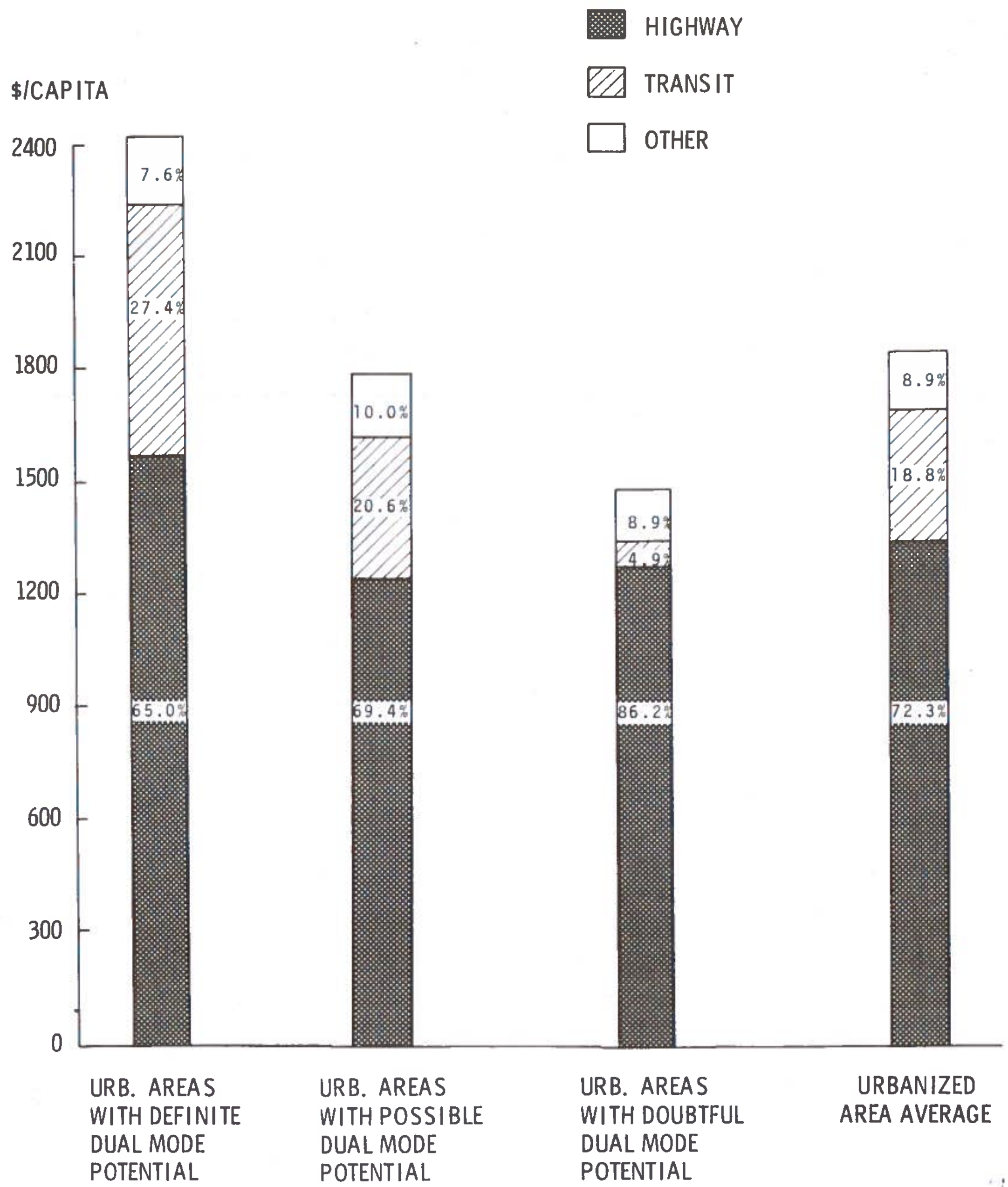



Figure 21. 1970-90 Dollar Needs Per Capita

Urbanized Areas in Which Dual Mode Appears to Have Definite Potential

| Rapid Transit & Exclusive Busway | Rapid Transit Only | Exclusive Busway Only |
|---|---|---|
| Atlanta | Baltimore | |
| Boston-Providence | Cleveland | |
| Detroit | Philadelphia | |
| Houston | St. Louis | |
| Minneapolis-St. Paul | San Diego | |
| Pittsburgh | | |
| San Francisco | | |
| Washington, D.C. | | |

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Urbanized Areas in Which Dual Mode May Be Applicable

| Rapid Transit & Exclusive Busway | Rapid Transit Only | Exclusive Busway Only |
|---|---|---|
| Chicago | Buffalo | Cincinnati |
| Columbus | Dayton | Indianapolis |
| Dallas | Kansas City | Louisville |
| Ft. Worth | Miami | Milwaukee |
| Hartford | | Phoenix |
| Jacksonville | **No Need for Rapid Transit or Exclusive Busway** | Sacremento |
| Los Angeles | | San Antonio |
| Memphis | | Seattle-Tacoma |
| New Orleans | | |
| New York | Birmingham | |
| Norfolk | Denver | |
| Orlando | Ft. Lauderdale | |
| Portland | Oklahoma City | |
| St. Petersburg | Rochester** | |

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| Type of Transit Need | No. of Areas |
|---|---|
| Rapid Transit & Excl. Busway | 22 |
| Rapid Transit Only | 9 |
| Exclusive Busway Only | 8 |
| None of Above | 5 |
| TOTAL | 44 |

*SOURCE: 1972 National Transportation Needs Study(unpublished data)

**Detailed breakdown of needs not available

Figure 22. Urbanized Areas Indicating Need To Upgrade, Expand, And/Or Install Conventional Transit Systems Between 1970 And 1990*

miles and 37 route miles. Thus, the lower absolute and relative amount of dollar needs devoted to transit for the possible category reflects the higher propensity for exclusive busways as opposed to rapid transit and the smaller quantities desired of both types of transit facilities.

The relation between the capital cost of satisfying perceived transportation needs and the capital cost of an urbanwide Dual Mode system can be seen in the following table, which shows the stated transit and highway needs per capita and Dual Mode capital cost per capita as a per cent of total dollar transportation needs:

| | Dual Mode Potential | |
|---|---|---|
| | Definite | Possible |
| Transit Needs Per Capita as a Percent of Total Transportation Needs | 27% | 21% |
| Highway Needs Per Capita as a Percent of Total Transportation Needs | 65% | 69% |
| Dual Mode Capital Cost Per Capita as a Percent of Total Transportation Needs | 43% | 70% |

It is apparent that even among the urbanized areas with definite potential for Dual Mode, the per capita cost of this system exceeds the per capita amount allocated to transit needs. However, Dual Mode costs are far below the combined amount allocated to highway and transit. Since an urbanwide Dual Mode system combines transit-type and highway-type service characteristics, it is likely that urbanized areas choosing this option would do so as a substitute for all planned ("needed") transit construction and much if not all of their planned highway construction. Thus the capital investment per capita for Dual Mode would be considerably lower than that required for comparable service and capacity in the form of highway and transit facilities.

In addition to examining whether the results on Dual Mode applicability conform to urbanized area needs as reported in the 1972 National Transportation Needs Study, it is appropriate to consider the current plans for rapid transit throughout the country. The Appendix to this study contains a brief survey of existing and proposed rapid transit systems including PRT) and reflects the most recent information available to TSC as of June, 1974. The list of cities definitely planning to build rapid transit is somewhat less extensive than that shown in Figure 22, undoubtedly reflecting the longer term orientation and/or overstated nature of the needs estimates. However, neither list is intended to modify the results on Dual Mode's potential, since in the first place, the TSC Dual Mode study showed that Dual Mode could operate in combination with an existing rapid transit system, and more important, this analysis is meant to provide a general understanding of the potential market for Dual Mode rather than detailed evaluation of Dual Mode's applicability in specific cities. The table below summarizes the results of this study:

| Dual Mode Potential | Number of Urbanized Areas | Percent of Urbanized Area Population |
|---|---|---|
| Definite | 13 | 25% |
| Possible | 31 | 43 |
| Doubtful | 328 | 32 |
| Total | 372 | 100 |

It can be seen that Dual Mode appears to have definite or possible potential in the 44 largest urbanized areas throughout the country. Though accounting for only 12% of the total number of urbanized areas, this potential market for Dual Mode compromises nearly 70% of the projected 1990 urbanized area population of 176 million.

# 5. CONCLUSIONS

This study has determined that 44 urbanized areas accounting for 68% of the 1990 urbanized area population are potential candidates for urbanwide Dual Mode systems. These numbers in themselves would appear to justify further research and development (funded by Federal and other sources) on Dual Mode. However, if the various constraints and assumptions used in ths analysis were relaxed or changed, the potential market for Dual Mode would expand considerably. For example, if the constraint of urbanwide service with a specified access time were relaxed, the list of Dual Mode candidates would expand to include areas with a need and ability to pay for corridor or limited area circulation systems. A different definition of the size, composition, and operation of the Dual Mode vehicle fleet (e.g., a substantially reduced minibus tour area) would likewise enlarge the Dual Mode market. Perhaps the most far-reaching change in assumptions would be a statutory revision permitting a higher Federal contribution to transit project costs. If, for instance, the Federal government's share increased to 90%, even the smaller urbanized areas with relatively limited fiscal capabilities could consider Dual Mode as an alternative transportation system. Since the potential market for Dual Mode is even larger than that specifically identified in this study (i.e., in excess of 68% of the urbanized area population), it is considered that there is a strong case for continuing to explore the various technological, economic, and social issues related to Dual Mode.

# APPENDIX

## SURVEY OF EXISTING AND PROPOSED RAPID TRANSIT SYSTEMS

A large number of cities are making plans to build rapid transit systems, actually building them, or improving existing ones. New York, Chicago, Boston, Philadelphia, and Cleveland all have rapid transit systems and are planning improvements. San Francisco, Washington, D.C., Pittsburgh, Atlanta, and Baltimore are currently constructing new systems, while the cities of Detroit, Miami, Buffalo, and Honolulu are arranging financing for their proposed systems. Cincinnati, Los Angeles, and Minneapolis-St. Paul have completed planning studies. The cities that are considering some form of rapid transit but have not completed planning studies include Kansas City, St. Louis, Houston, and Rochester. Among those developing plans for Personal Rapid Transit (PRT) systems alone or in conjunction with rapid rail and/or bus are Minneapolis-St. Paul, Rochester, Denver, Seattle, and Las Vagas.

This appendix will discuss these cities' rapid transit plans, listing such data as the stage of transit development and the size and cost of the system. The contents of this report reflect the most recent information available to TSC as of June 1974 from regional planning agencies, transit systems, the Urban Mass Transportation Administration (UMTA), and secondary sources.

The first group of cities, those with existing systems, have found that their systems are overcrowded and/or not extensive enough to service the needs of particular segments of their population. Moreover, most of them have experienced a gradual decline in transit ridership related either to the above conditions or to a gradual deterioration in the facilities. Therefore, all of these cities are planning expansions and/or improvements for their transit systems.

New York City contains the country's most extensive rapid rail system, consisting of 237 route miles and operating at a cost of about $450 million per year. The Metropolitan Transit Authority is planning 14 extensions or new lines for the rapid transit system.

The main project, a new 4.5-mile subway on Second Avenue, is under construction and will have a capital cost of $415 million.

Chicago's rapid transit system, the second largest in the United States, consists of 102 route miles and operates at an annual cost of around $55 million. The city is in the process of implementing a $140 million improvement program funded by UMTA. Future plans include $750 million for improvements to the downtown subways, and a $100 million airport extension.

Boston has a 65-mile rapid transit system which is controlled and operated by the Massachusetts Bay Transportation Authority (MBTA). The system presently operates at an annual cost of about $42 million. An extensive program has been initiated for the MBTA which will include new lines, extensions and relocations of the existing lines, new cars and maintenance ships, and modernization. The MBTA has also received a $19.5 million advance land acquistion loan from UMTA to aid in the purchase of 145 miles of Penn Central right-of-way.

The Philadelphia area has two rapid transit systems. The system operated by the Southeastern Pennsylvania Transportation Authority (SEPTA) consists of 47 route miles and annually operates at a cost of around $21 million. The 14.5-mile Philadelphia Lindenwold Speedline, constructed at a capital cost of $94 million, began operation in 1969 and has an annual operating cost of about $4 million. This line connects with the Philadelphia Transit System, linking the Philadelphia central business district with the city of Camden and the southwestern suburban areas of Camden County. The Lindenwold line represents the first phase of a proposed 70-mile regional improvement program which is expected to be completed by 1985. SEPTA is currently in the process of implementing a $1.37 billion, six-year capital improvement program, as funds permit. The program involves new cars, track renewal, station improvements, and parking lot improvements. Future plans for the Lindenwold Line include new cars, a new station, and several extensions.

There are two independent rapid rail systems in Cleveland. One, operated by the Cleveland Transit System(CTS), is 23 miles long, including a 4-mile airport extension, and operates at an an annual cost of about $4.5 million. The other system, the Shaker Heights Rapid Transit System, is 13 miles long and has an annual operating cost of about $2 million. The CTS is presently conducting a Five County Transit Study to identify its needs and expansion. The Shaker Heights Rapid Transit System has a municipal subsidy pending for improvements, extensions and parking lot expansion.

In 1962, a decision was reached in San Francisco to build the Bay Area Rapid Transit System (BART) linking the existing transit lines to a regional rail network. The entire 75-mile system,* most of which is now operating, has a total capital cost of $1.6 billion. Planned improvements include the extension of BART to the San Francisco International Airport and a rapid transit line to San Jose. BART has requested an UMTA grant for 36 buses to extend the outer service area.

A $2.98 billion rapid transit system is currently under construction in the Washington, D.C. area. Scheduled for completion in 1979, the system will be the third largest in the country, having 98 route miles. Initial subway service is scheduled for June 1975.

Construction is underway for a $290 million transit project devised by the Early Action Program for the Pittsburgh area. The project calls for the construction of a 10.5-mile rubber-tired, small vehicle electric rapid transit system and two exclusive busways, as well as improvement of the existing trolley system.

In 1965 the Metropolitan Atlanta Rapid Transit Authority was created to search for solutions to Atlanta's transportation problems. The Transit Authority proposed plans for a 50-mile rapid rail system plus an extended, improved bus system. Right of way acquisition and relocation for the $1.72 billion system is underway. The MARTA is also continuing surface system improvements and transit design work.

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*Including the 3.5 mile San Francisco Municipal Railway

The Mass Transit Administration of Baltimore has begun construction of Phase 1 of a 28-mile transit system. The total system should cost approximately $660 million, and revenue operations are scheduled to begin in 1981.

Buffalo is presently arranging financing for a one-corridor rapid rail system. Plans made by the Niagara Falls Transportation Authority call for the first stage to be the development of 11 miles of a proposed 12.5-mile system. Phase 1 is estimated to cost $260 million and is expected to be completed by 1981.

Miami has proposed an $805 million transit system. The plans are for a 54-mile rubber-tired, small vehicle electric rapid transit system connecting downtown Miami, the International Airport and the Miami Beach area. Voters have approved a $130 million bond issue for the local share, and UMTA has granted $1.6 million for an engineering study. Construction is expected to take place between 1975 and 1980.

Honolulu has approved plans for a rubber-tire on fixed guideway system. The one-corridor, 22-mile system will be supported by an extensive feeder bus network and is expected to have a capital cost of $700 million. Revenue service is scheduled to begin in 1980.

A six-corridor transit study has been completed in the city of Detroit by the Southeast Michigan Transportation Authority (SEMTA). The proposed system consists of 81 miles of rapid rail and 12 miles of PRT. The half-cent share of gas tax revenues will provide $10 million for capital cost, $10 million for operating subsidies, and $2 million for demonstrations.

A regional transportation study has developed a recommended regional rapid transit plan for Cincinnati. The proposed five-line system includes approximately 57 route miles and has a total capital cost of approximately $460 million.

Los Angeles is considering plans for an eight-corridor system consisting of 116 miles of double track and costing about $6.6 billion. The rapid transit system will be supplemented by a two-corridor, 24-mile exclusive busway network and a extensive feeder bus network. A public referendum is scheduled for November 1974 on two sales tax increases to finance construction and operation of the proposed system.

The Metropolitan Transit Commission has devised plans for a transit improvement program for the Minneapolis-St. Paul region. The plans call for a "family of vehicles" system consisting of several types of transit, including rapid transit, PRT and express bus. The Commission has broken the development of the comprehensive system into six major task periods. One task period, involving the design, construction, and initial operation of the 37-mile first stage of the fixed guideway system, is expected to take place between 1974 and 1981 at a cost of about $750 million.

A mass transit study, supported by UMTA planning funds, is currently underway in Kansas City. In this study two alternatives are being considered, a six-mile exclusive busway network with feeder service and a 79-mile, six-corridor rapid rail system with feeder service.

The East-West Gateway Coordinating Council is presently in the engineering phase of a program to plan a rapid rail system for the St. Louis region. Preliminary plans call for 86 miles of rapid rail and 14 miles of commuter rail with a possible 17-mile extension to the airport on the Illinois side of the Mississippi. System cost is estimated to be a little over $2 billion (not including the 17-mile link). Construction is expected to begin in 1978 and should be completed by 1986.

Local funding for a $1.45 billion rapid transit program for Houston was defeated in the fall of 1973. Consequently, the city of Houston is undertaking a new analysis of alternatives. Currently under consideration is a twin mode transit system, fixed guideways (probably rail) and busways, that will cost $1.45 billion.

A 19-mile rapid rail system with a PRT feeder network has been proposed for Rochester. The rapid rail network will make extensive use of existing right-of-way and is estimated to cost $120 million.

Denver's Regional Transportation District has recently adopted a $1.56 billion transit system plan with completion anticipated in 1983. One of the main components of the plan is a 100-mile PRT system connecting Denver, Boulder and Greeley. Plans also call for local, express and regional bus service.

Other cities considering PRT systems as a solution to their transportation problems are Seattle (for the downtown and university area)* and Las Vegas (eight-mile system along the strip).

Figure A-1 summarizes the status of the systems described above.

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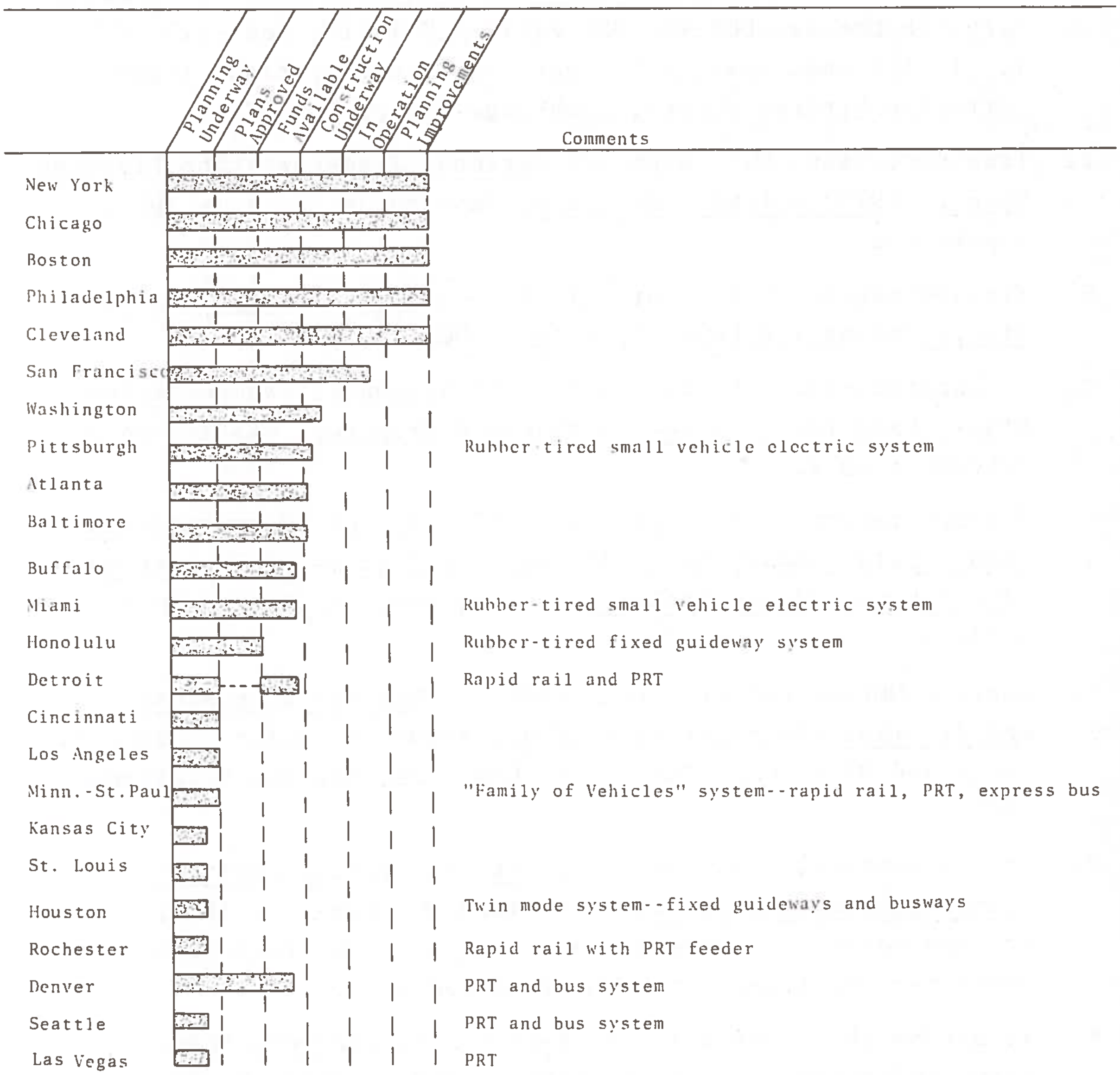
*Plans also call for an extensive regional bus system.




Based on information available to TSC as of June 1974.

Figure A-1. Status of Rapid Transit Systems

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