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URBAN TRANSPORTATION ALTERNATIVES -- A MACRO ANALYSIS

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16. Abstract

The objective of this study was to evaluate the relative performance and effectiveness of seven transportation systems deployed on a regional basis: Highway (with limited bus), Comprehensive Bus, Exclusive Bus, Rapid Rail, Dial-A-Ride, Dual Mode, and PRT. The systems were analyzed in a hypothetical scenario reflecting the projected 1990 characteristics of the 30 largest U.S. urban areas (excluding the three biggest). A consistent basis for comparison was established by requiring approximately equivalent service and coverage for all systems. From the results of this analysis -- expressed in terms of service, cost and impact parameters -- the following conclusions were drawn. (1) Increased transit ridership is obtained when quality and level of service are increased, which, in turn, requires greater expenditures. (2) Each transportation system seems to have a given application for which it appears to be most suited; system effectiveness can be characterized by attributes such as trip length, service area trip density, system loading, and coverage. (3) Total urban transportation needs can best be filled by a combination of systems, each of which is utilized in the application for which it is most suited. (4) Further research and analysis effort should be devoted to obtaining increased understanding of the appropriate design and application of public transportation systems, expanding public transportation system options for service of short suburban trips, and establishing the relative effectiveness of various regional transportation system combinations.

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PREFACE

This study was performed in the spring of 1973 by the Applications Division, Transportation Systems Center, under the sponsorship and guidance of the Office of the Assistant Secretary for Systems Development and Technology, U.S. Department of Transportation. The authors gratefully acknowledge the aid, assistance and suggestions provided to them by the following persons: Katherine O'Leary of the Office of R&D Policy, Robert Krick of the Office of Systems Engineering, and Calvin Perrine of the Applications Division.

Since the completion of this study, understanding of the appropriate application of urban transportation systems has increased. It is hoped that informal dissemination of the views, methodology, and conclusions contained herein contributed to this gradual but noticeable change in perspective and was at least partially influential in the development of programs currently underway within the Department of Transportation.

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1. INTRODUCTION

In attempting to satisfy the present and future transportation requirements of urban areas, transportation planners have proposed a wide spectrum of alternatives, ranging from variants of existing transportation modes to new, as yet untested, forms. However, few transportation studies to date have dealt concurrently with the range of possibilities which will be available in the next decade or two. By and large, the majority of specific urban area studies have been confined to either conventional rail or bus systems, and evaluations of futuristic systems have rarely included comparisons with other systems.

Consequently, in an attempt to provide insight into the relative effectiveness of various forms of transportation, this study was initiated to evaluate the service, costs, and impacts of several transportation alternatives. The study objective was to obtain an increased understanding of systems applicability and utility, rather than to make definitive statements on the inherent worth of individual systems. Thus, the detailed numerical results are less important than their implications regarding specific areas of effective application for each system and appropriate systems combinations.

1.1 STUDY CONCLUSIONS

In summary, the conclusions reached in performing this study were the following:

- Increased transit ridership is obtained when quality and level of service are increased, which, in turn, requires greater expenditures. In other words, increased ridership for transit is attained through increased investment to improve service.
- Each transportation system seems to have a given application for which it appears to be most suited. System effectiveness can be characterized by attributes such as

trip length, service area trip density, system loading, and coverage.

- The study results and their implications tend to corroborate the contention that total urban transportation needs can best be filled by a combination of systems, each of which is utilized in the application for which it is most suited.
- Further research and analysis efforts should be devoted to: (1) obtaining increased understanding of the appropriate design and application of public transportation systems; (2) expanding public transportation options for service of short suburban trips; and (3) establishing the relative effectiveness of various regional transportation system combinations.

1.2 STUDY APPROACH

The study examined the following seven systems: Highway, Comprehensive Bus, Exclusive Bus, Rapid Rail, Dial-A-Ride, Dual Mode, and Personal Rapid Transit (PRT). In order to permit analysis of relatively "pure" or "clean" forms of the systems, transit service in each alternative was provided to the entire urban area, i.e., no attempt was made to select the most efficient service areas in the city for each particular system. Systems which were line-haul in nature were augmented with conventional bus feeder routes. In addition to equivalent coverage for all systems, approximately equivalent service was provided to establish a consistent basis for comparison of alternatives. The service criterion selected was an "access time" of 8.5 minutes between initiation of travel (or request for service) and motion of the first vehicle boarded. Design to this constraint allowed evaluation against a consistent service level; it did not necessarily permit the most effective service by each individual system in terms of frequencies and line spacings. Thus, it was possible to obtain a relative measure of system utility against fixed requirements, and thereby increase understanding of appropriate system application. It was not possible to determine that any system examined could not be a viable urban transportation mode.

The systems were deployed in a scenario designed by averaging the projected 1990 characteristics of the 30 largest U.S. urban areas (excluding New York, Chicago, and Los Angeles, whose inclusion in the sample would have biased the data excessively). The result was a circular urban area with a radius of 17 miles, a population of 2.3 million, and an average density of 2,500 persons per square mile. It had a one-mile radius Central Business District (CBD) and six major radial population corridors. Daily trips totaled five million. The characteristics of the seven urban transportation systems are described below and summarized in Table 1.

Highway: (Base Case)
: This system assumes a policy of continued emphasis on the use of the automobile, with limited bus service (not matching the service criteria) operating approximately as such systems do today. One hundred seventy-five miles of new freeway, beyond those existing in 1970, are constructed. No freeway is constructed in any of the other alternatives.

Comprehensive Bus:
: Compared to the Highway Base Case, increased density of bus routes is provided throughout the urban area, with no additional freeway constructed. All buses are local; no express service is provided. Standard 50-passenger buses are used.

Exclusive Bus:
: Standard 50-passenger buses operate on radial and circumferential exclusive roadways, with express service to the CBD provided from

TABLE 1. SUMMARY OF SYSTEM CHARACTERISTICS

System	Route Miles		Veh. Pass. Capacity	Suburban Collection and Distribution	Line Haul Travel	Downtown Collection and Distribution
	Freeway	Transit				
Highway Base Case	175	500 (ltd. bus)	50 (ltd. bus)	Fixed route, fixed schedule bus, which travels to destination or transfer pt.	Fixed route, fixed schedule local service	Fixed route, fixed schedule local service
Comprehensive Bus	0	1,100	50	Fixed route, fixed schedule bus, which travels to destination or transfer point*	Fixed route, fixed schedule local service on radial and circumferential streets*	Fixed route, fixed schedule local service*
Exclusive Bus	0	110 (busway) 750 (feeder bus)	50 (excl. bus) 25 (feeder bus)	Fixed route, fixed schedule feeder bus, which travels to exclusive busway station	Express and local service on radial busways; local service only on circumferential busways	Buses leave busway to provide fixed route, fixed schedule local service on downtown streets
Rapid Rail	0	110 (rail lines) 750 (fdr.bus)	80 (rail car) 25 (fdr.bus)	Fixed route, fixed schedule feeder bus which travels to rapid rail station	Local (all stops made) rapid rail service on radial and circumferential lines	Local rapid rail service on underground routes
Dial-A-Ride	0	-	12	Demand responsive bus service to destination or transfer point	Express and demand responsive service on radial and circumferential streets	Demand responsive service on downtown streets to destination
Dual Mode	0	150 (guideway)	4 (SPV) 12 (minibus)	SPV: drive to guideway entrance Minibus: demand responsive service to destination or onto guideway	SPV operates under automatic control on guideway (non-stop) Minibus operates under automatic control on guideway (non-stop, no driver)	On guideway directly to station near destination
PRT	0	825 (guideway)	4	PRT guideway station	Express (non-stop) PRT service on guideway	On guideway directly to station near destination

*More extensive coverage than limited bus system in Highway Base Case.

each station on the radials and local bus service on radials and circumferentials. Feeder service to Exclusive Bus stations is provided by 25-passenger buses operating at Comprehensive Bus route densities.

Rapid Rail: Electrically powered 80-seat rail cars, operated in trains, provide service on a track network identical to the layout of the Exclusive Bus roadways, and the same bus feeder service is provided to the rail stations as to the Exclusive Bus stations. All trains are local.

Dial-a-Ride: Twelve-passenger demand-responsive minibuses operate throughout the area. Short trips are accomplished on a single vehicle; longer trips require transfer to express minibuses.

Dual Mode: Small personal 4-passenger electrically powered vehicles are rented from the system operator by individuals. They are driven manually on streets to the guideway entrance, and operate automatically once on the exclusive guideway. Electrically powered dial-a-ride buses provide local service for short trips on streets throughout the area. Longer trips involve single-vehicle service using the guideway for some portion of the trip.

Personal Rapid Transit (PRT): An extensive guideway network is constructed through the urban area to provide station-to-station nonstop demand-responsive service by small personal 4-passenger captive vehicles. Access to stations is by walking.

In order to meet the service criterion of an 8.5-minute access time, extensive networks with more than 1,000 miles of Comprehensive Bus routes and 825 miles of PRT guideways are required. Dual Mode, making extensive use of highways for collection and distribution, requires just over 150 miles of guideway. Exclusive Bus and Rapid Rail need slightly more than 100 miles of exclusive rights-of-way, and also utilize 750 route miles of feeder service. The Highway Base Case has 500 route miles of limited bus service to complement the 175 miles of additional freeway constructed.

1.3 RESULTS OF THE ANALYSIS

The ridership estimation process yielded a 4 percent modal split for the limited bus system in the Highway Base Case. Exclusive Bus and Rapid Rail, with networks almost identical to each other and considerably better coverage than the limited bus in the Highway Base Case, achieve an 8% modal split. The Comprehensive Bus system attains a slightly higher modal split (9%) than the Exclusive Bus and Rapid Rail systems, primarily because it provides better local service and, in many cases, more direct service. Dial-a-Ride, a labor intensive system, and PRT, a capital intensive system, achieve modal splits of 13 and 14 percent, respectively, due to the relatively high level of service provided by each system. Dual Mode, with its mixture of dial-a-ride minibuses and small personal vehicles, captures 17 percent of all trips.

Capital costs ranged from a low of $70 million for the Comprehensive Bus alternative, where the purchase of vehicles accounted for 98 percent of the capital expenditure, to a high of $3.4 billion for the PRT alternative, where an extensive guideway network accounting for 75 percent of the capital cost was required for the system to meet the service criterion. System annual costs* increased generally with ridership, reaching a peak of over half a billion dollars for PRT. Operating costs ranged from 25 to 40 percent of system annual costs in the capital intensive PRT, Dual Mode and Rapid Rail systems, and from 75 to 95 percent of annual costs for the Dial-a-Ride, Comprehensive Bus, and Exclusive Bus systems with their large fleet of operator-driven vehicles. Only for the Dual Mode system did revenues exceed operating costs. Dial-a-Ride, as defined in this analysis, sustained an annual operating deficit (revenues minus operating costs) of almost $200 million per year, while the deficit for PRT was almost $74 million annually. Some form of capital subsidy would be required for all of the systems examined.

Construction of 175 miles of freeway displaced about 17,000 households within the region for the Highway Base Case. The PRT and Dual Mode systems required less than 40 percent of this number of displacements, and only a negligible number of families were moved due to the introduction of the other systems. The introduction of urbanwide transit systems with a high level of service, and often high line-haul speeds, did not, at the modal splits projected, result in any savings in energy consumption or pollution generation, compared to a policy of continued emphasis on use of the automobile.

Regional monetary benefits were measured relative to the Highway Base Case, and included benefits to all persons in the region, not just transit users. The total benefits were an aggregation of travel time savings, land value increases, tax revenues increases, and savings in household displacements. Based on an aggregation of the assumed dollar values assigned to quantitative impacts, all systems except Dial-a-Ride achieved regional benefits in excess of costs. Dual Mode and PRT resulted in the largest surplus of incremental benefits over incremental costs, but the benefits were obtained at the highest costs.

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*Consisting of annualized capital costs and annual operating costs.

1.4 IMPLICATIONS

Caution should be taken in the interpretation of these results, as they relate only to urbanwide service by simplistic forms of transportation systems. Thus, the significance of the numbers themselves is relatively limited. However, the insight obtained from the analysis suggested specific areas of effective application for each urban transportation system. These qualities of system effectiveness can be characterized by attributes such as trip length and service area trip density. Figure 1 arrays each of the system options examined in this study with respect to these factors. Trips are characterized as short (neighborhood, local) versus long (across the urban area). Service area trip density varies from low (fringes between suburban corridors) to high (central business district).

A highway system -- that is, the automobile -- provides fast, flexible, door-to-door, demand-actuated, attractive service for all trip lengths and for all but the high trip density areas where there is congestion. For those who for some reason cannot drive, a limited bus system can provide a minimal level of service. Thus the highway is a system with regional coverage and application in all but the densest areas.

A comprehensive bus network, with vehicles operating on existing streets with many stops, provides relatively slow service. Only in serving short to medium trip lengths is it able to maintain relatively acceptable trip times. Medium to high trip densities are required to provide adequate load factors. Comprehensive bus is most effective as a local service system.

Since exclusive bus and rapid rail systems both use exclusive rights-of-way and relatively wide station spacing in order to increase trip speed, both require medium to long trip lengths to make this speed advantage apparent. At least a medium service area trip density is required to justify the cost of acquiring right of way and constructing exclusive guideways. At moderate trip densities, exclusive bus is more attractive, while increasing trip densities would tend to favor rapid rail. By their very

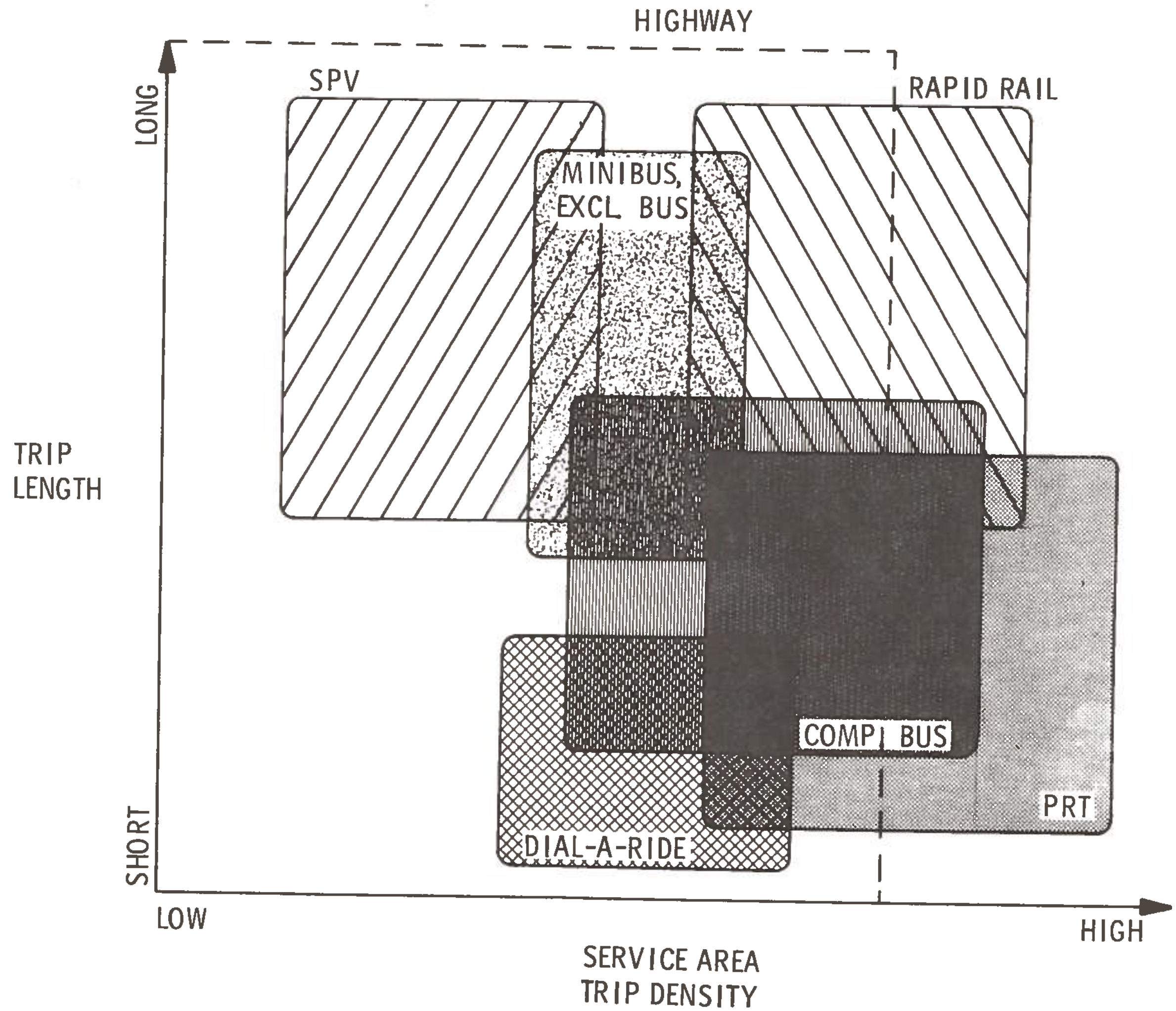

Figure 1. Effective System Performance

nature, both systems find their best application in corridors, although such corridors need not be radial, nor lead to the CBD.

Because dial-a-ride systems provide demand-responsive, door-to-door service, they are especially sensitive to commonality of origins and destinations for all passengers in one vehicle, and minimization of diversions to accept or discharge riders. The longer the potential trips and the more diverse the possible origins and destinations, the more difficult it becomes to achieve reasonable load factors at acceptable frequencies. Thus dial-a-ride appears to be most suited for the service of short trips in areas with medium trip densities. Smaller vehicles and/or altered operating strategies may make the system applicable to lower density areas as well.* With more concentrated demand, the larger buses and more structured service of a comprehensive bus system are more economical. Dial-a-ride is a local service system.

A dual mode system incorporates exclusive guideways similar to those in the exclusive bus and rapid rail systems, and is thus most effective for medium to long trips. Collection and distribution by the small personal vehicle is the same as the automobile, making it applicable in low to medium trip density areas. The minibus operates as a dial-a-ride collector/distributor, making it applicable in medium density areas, as described above. Since dual mode combines a highway collector/distributor with an automated exclusive guideway, and encompasses personal vehicles and buses, it includes many of the functions carried out by the other systems examined. Thus, dual mode is really the only regional system examined, having a broader range of effective application than any of the systems examined except the highway.

A PRT system provides personal demand-actuated origin to destination service (with short walks) on exclusive right-of-way. The high capital costs of an extensive automated guideway network are justified if they can be defrayed by heavy utilization of all

*Moreover, dial-a-ride may be the lowest cost option for providing public transportation for non-drivers in low density areas.

guideway segments. Thus PRT requires fairly high trip volumes with diverse origins and destinations, and medium to high service area trip densities. Because such trip densities are localized, PRT is most effective as a local system serving short to medium trip lengths. PRT stands out from all other systems in its ability to handle heavy traffic in highly congested urban cores.

It is apparent from the preceding discussion that total urban transportation needs can best be filled by a combination of systems, and that charts such as Figure 1 can aid in the selection of appropriate combinations.

2. BACKGROUND

There is increasing emphasis on evaluating urban transportation requirements from an integrated, regionwide standpoint rather than addressing specific localized needs outside of a regional context. This means that transportation analysis and implementation should be related to the total door-to-door trip, not just the discrete components of a trip (e.g., line-haul service). Collection/distribution systems which offer feeder service to line-haul systems, shelters to provide amenities for passengers at transfer points, and circulation systems for high density areas are some of the elements which must be combined into the region's transportation system in order to make it fully responsive to total travel needs.

In the past, the implementation of truly regional systems has been hampered by institutional barriers which have discouraged individual transportation systems from mutual cooperation. Instead of offering complementary service, system operators have competed for service, with the result that they have had to provide service unsuited to the design characteristics of their system and have therefore incurred operating losses. These problems have been aggravated by inflexible operating strategies which are unresponsive to changing residential and travel patterns. Degraded service has resulted in many cases.

Institutional barriers are gradually being removed through the formation of regional agencies to oversee and coordinate the needs of diverse political entities and through an active federal program of intermodal integration. Given the more favorable climate for regional planning, transportation planners recognize the need for understanding better the relative advantages and disadvantages of various options so that they can be utilized appropriately in composite regional systems.

The federal government is likewise aware of the need for an informed program of analysis and insight development in order to fulfill its responsibility of allocating R&D resources to assure the development of a range of effective systems for present and future needs. Accordingly, this study was undertaken to examine how transportation systems can be most effectively deployed as components of regionwide networks.

2.1 SCOPE

Because of the time constraint imposed by the three month duration of this study, no new analytical methods or models were developed. Most of the techniques used were taken from a TSC study completed in 1972[1] of Dual Mode systems in an urban area. Most of the base data (e.g., unit costs, parameter values) were drawn from the above cited work.

This study examined the following seven systems:

- Highway (with limited bus)
- Comprehensive Bus
- Exclusive Bus (separate right-of-way)
- Rapid Rail
- Dial-A-Ride
- Dual Mode (bus and personal vehicle)
- PRT (Personal Rapid Transit)

The performance and effectiveness of these alternatives were measured based on their deployment as regionwide systems. While this strategy ignored the critical problem of optimizing each system for its specific application, it offered the advantage of a consistent analytic base for comparison. An appropriate sequel to this analysis would be to combine system alternatives into "hybrids" for regionwide service and evaluate the relative effectiveness of these new systems. While detailed evaluation of system combinations was considered to be beyond the scope of the analysis, several examples are included in this report for illustrative purposes.

2.2 APPROACH

The technique selected for the study was designed to produce sufficient numerical information to allow order of magnitude comparisons of the alternative systems, including ridership data, service costs and benefits, and regionwide impacts. It was considered important to provide a first-order estimate of patronage for each system to indicate relative level of demand expected for a given level of service.

The study approach is depicted in Figure 2. First, a scenario was developed to provide a consistent basis for evaluation of the alternative systems. A hypothetical city in the year 1990, a commonly used long-range transportation planning time frame, was synthesized from the characteristics of the set of the thirty largest urbanized areas.*

An access time criterion was chosen as the basis for determining roughly equivalent service levels and for sizing the alternative systems. Networks were then laid out to provide regionwide coverage at the service levels indicated.

Time and cost impedances to travel for each mode were determined and the ridership on the public (transit) mode in each system was then computed using a logit form modal split model.

System parameters, such as person-miles of travel, average trip speeds and distances, and average fares, were determined. The effect of each alternative on regionwide congestion, pollution output and energy consumption was calculated.

Capital and operating costs were computed for each alternative system. Using assumed dollar values of quantitative impacts, monetary benefits due to travel time savings, changes in land values, displacement savings, and tax revenue increases were calculated and aggregated for each alternative.

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*Excluding New York, Los Angeles, and Chicago.

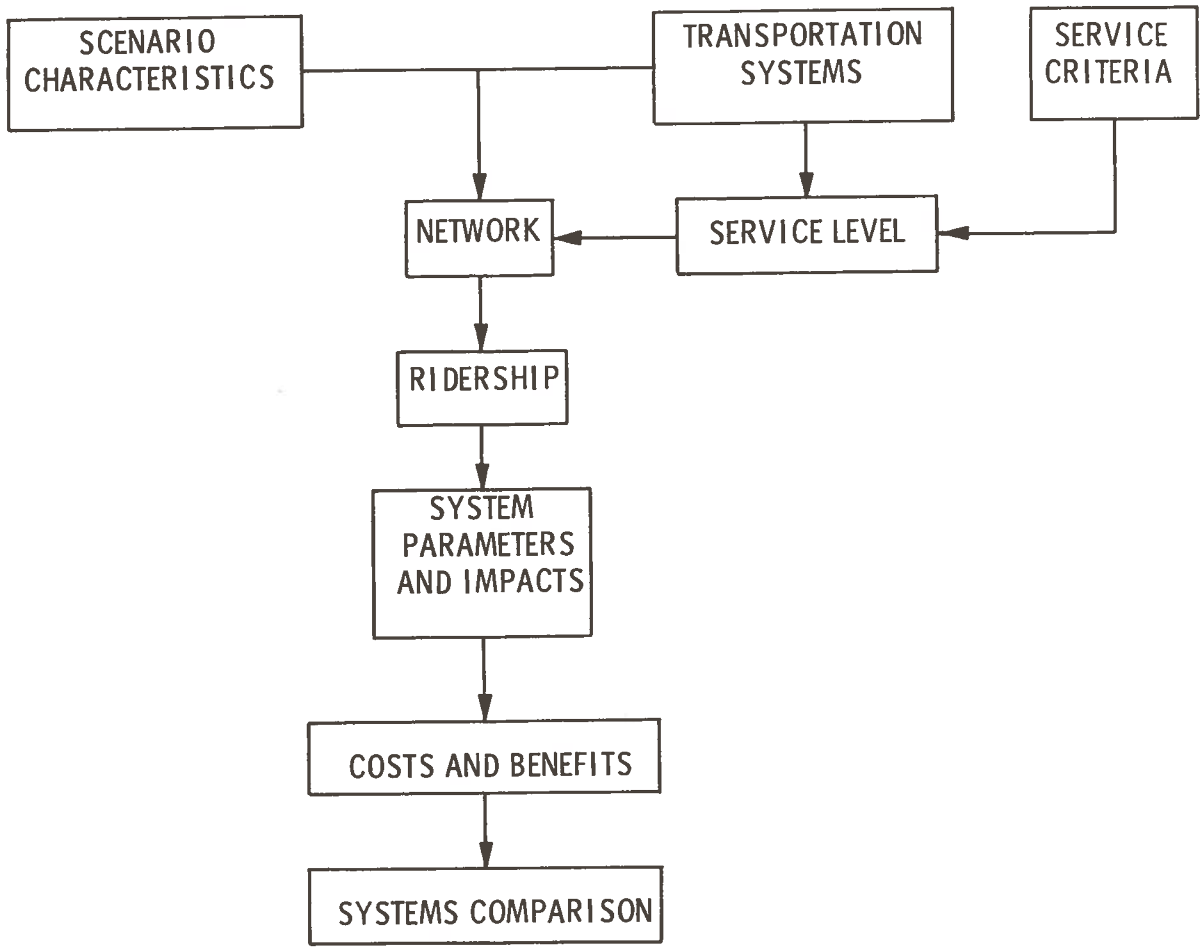

Figure 2. Study Approach

Finally, system parameters and indicators for the alternative systems were arrayed and compared with respect to costs and benefits. Conclusions regarding relative system effectiveness and applications were drawn, and several "hybrid" systems were synthesized.

Sections 3 through 8 describe in detail the study approach. Sections 9 through 11 contain the results and conclusions of the study.

Since the purpose of this study was to obtain first order insights in a short period of time, numerous short-cuts in technique and assumptions were required which, although inherently logical and consistent, could not always be validated. Therefore, caution should be taken in interpreting the results. They do not indicate the utility of any of the systems tested either in specific urban areas or in subregions of an urban area. They are meant only to provide a rough comparison of the systems' effectiveness in a scenario which, in order to maintain a consistent basis for evaluation, was somewhat constrained and artificial. Further, comparative numerical results which are close in magnitude should not be considered significant relative performance indicators.

3. SCENARIO DEFINITION

3.1 PLASTICTOWN DEVELOPMENT

A hypothetical 1990 city, dubbed Plastictown, was used as the basis for analyses of the alternative modes. This city was developed from composite characteristics of the 30 largest urbanized areas (excluding New York, Chicago, and Los Angeles)* selected according to projected 1990 urbanized area population. Table 2 shows the 30 cities and their 1990 populations and land areas. Populations and areas were averaged to yield the population, land area, and density of the abstract city: 2.26 million persons, 907 square miles, and 2,500 persons per square mile. Populations and densities of the 30 urbanized are shown in Figure 3.

A circularly shaped region was selected as the most appropriate for the study. Using available Census data on average SMSA center city and fringe area populations and densities, the city was divided into three rings as shown in Figure 4. 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 "fingers" comprising 30% of the outer ring land area and containing 60% of the outer ring population were used, in effect, to create six travel corridors, a number which appeared representative for this size city. The density of the "fingers" was thus twice that of the outer ring as a whole but still only 2/3 the density of the middle ring. It was decided that the very low density of the remaining portion of the outer ring precluded any attempt to provide transit service to that area, making it the only part of the abstract city not to be served.

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*These cities would have dominated the synthesis and skewed the abstract city characteristics.

TABLE 2. LARGEST URBANIZED AREAS IN 1990

Urbanized Area	1990 Population (1000's)	1990 Area (sq. miles)
New York*	19165	4294
Los Angeles*	13383	2679
Chicago*	8157	2365
Philadelphia	5944	1663
San Francisco	5817	1229
Detroit	5420	1642
Boston	5147	2401
Washington	3921	1387
Cleveland	2806	1029
St. Louis	2662	1094
Houston	2371	1311
Minneapolis/St. Paul	2320	906
Baltimore	2101	737
Pittsburgh	2091	1244
San Diego	2050	852
Atlanta	2017	929
Dallas	1926	1237
Seattle	1830	823
Miami	1816	634
Milwaukee	1790	404
Cincinnati	1631	624
Kansas City	1623	669
Phoenix	1538	593
New Orleans	1524	250
Denver	1467	461
San Antonio	1154	1047
Columbus	1136	454
Indianapolis	1123	457
Buffalo	1123	312
Portland	1070	428
Memphis	1031	471
Fort Worth	1030	1142
Louisville	1000	449
30-City Average	2260	907

Density = 2500 persons per square mile

*Excluded from averages.
Source: U.S. D.O.T. Needs Study.[2]

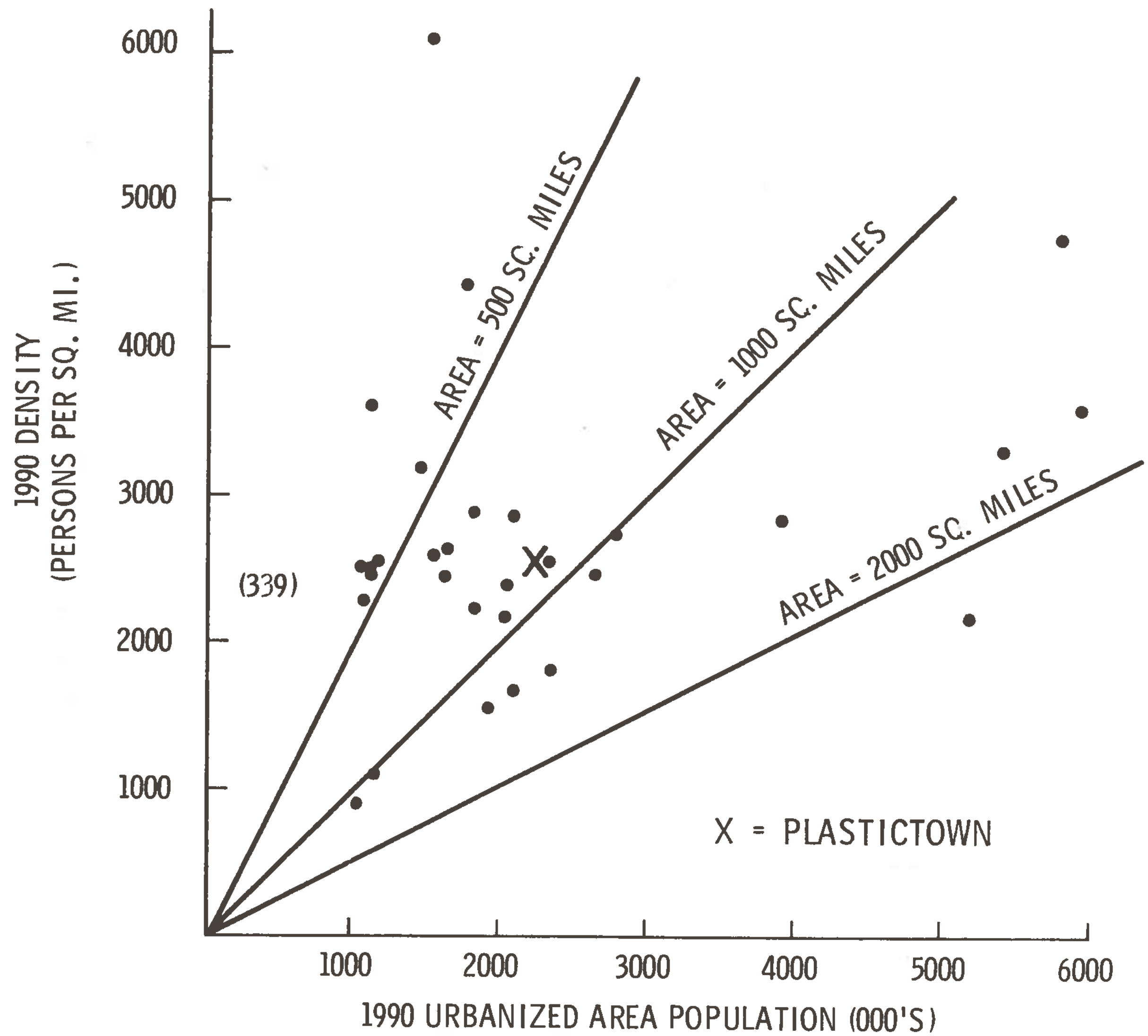
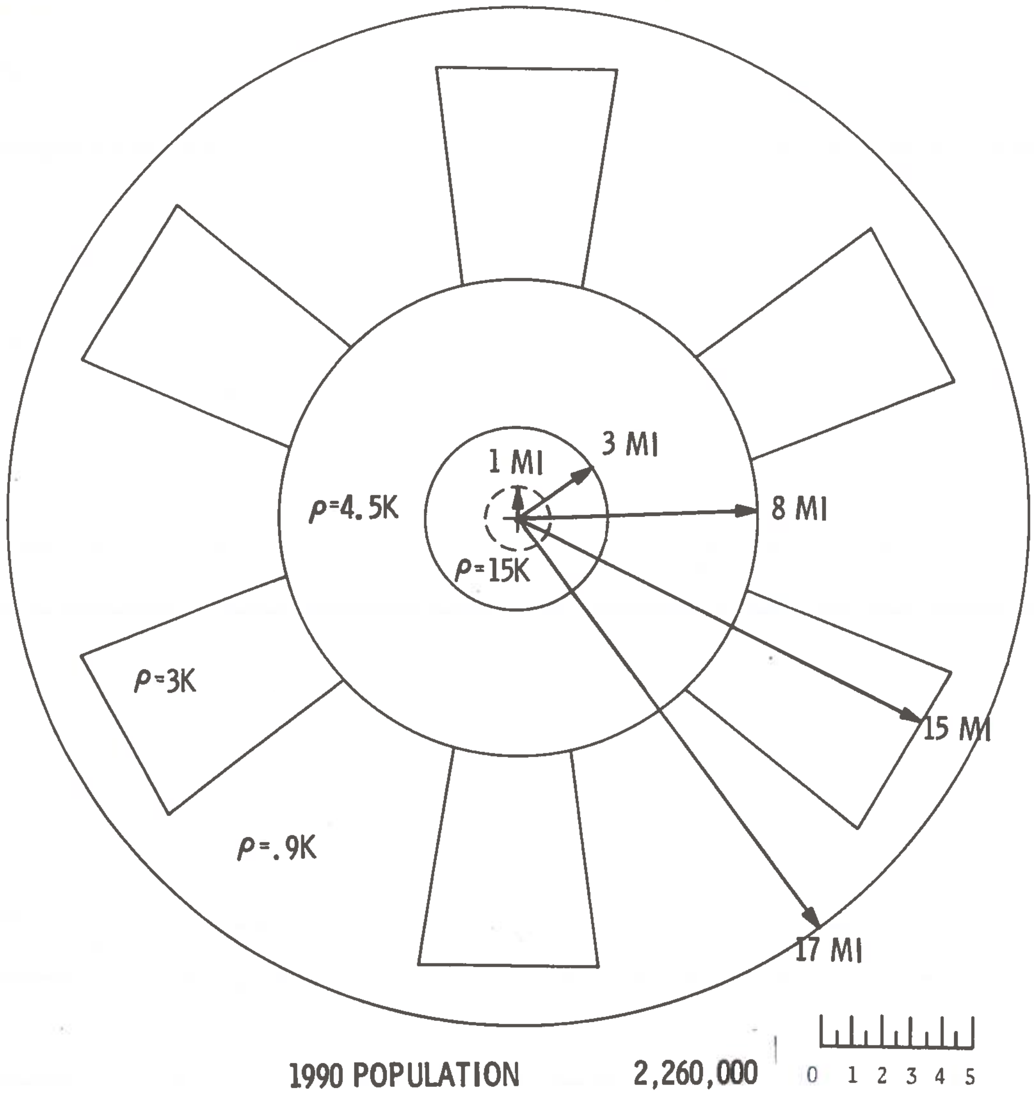


Figure 3. Top 30 Urbanized Areas



1990 POPULATION	2,260,000
1990 DENSITY	2,500
1990 DAILY TRIPS	5,030,000

ρ= PERSONS/SQ. MI.

Figure 4. Plastictown

3.2 TRIP GENERATION AND DISTRIBUTION

Prior to determining the proportions of trips made on each alternative mode, total daily trips taken in Plastictown were estimated and distributed among selected origin-destination pairs. Major trip flows resulting from the procedure described below are depicted in Figure 5.

A study done by Wilbur Smith and Associates[3] showed trip generation rates for several cities as a function of residential density. From this data a rough 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 area data as a guide, residential density estimates were made for the three rings of the abstract city. From these numbers total daily trips were calculated:

Inner ring	1,964,000 Trips
Middle ring	1,638,000
Outer ring	1,428,000
Total	5,030,000

The percentage of total trips occurring in a three-hour morning peak period was estimated to be 19% of the total daily trips based on Wilbur Smith data for 12 cities.

The distribution of total trips was carried out by first dividing the city into nine zones (see Figure 6). 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 (9 x 9) were indicated, by symmetry these could be reduced to the 17 origin-destination pair categories listed in Figure 6.

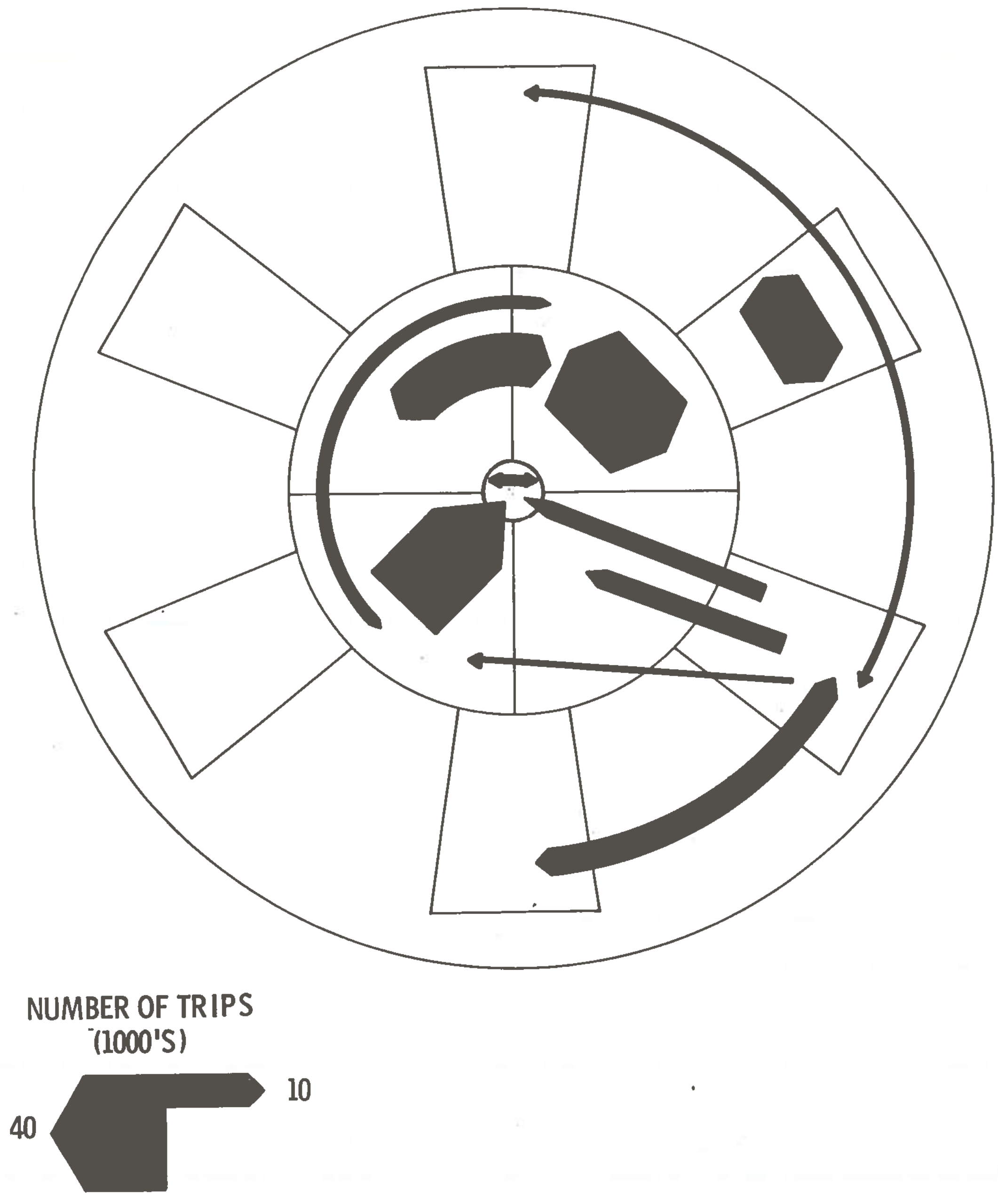
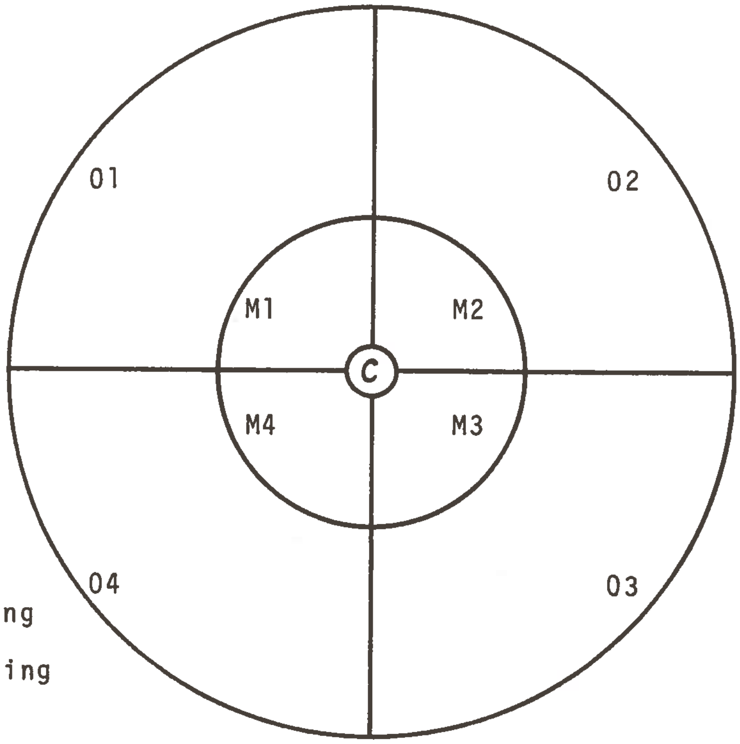


Figure 5. A.M. Peak Period Major Trip Flows by O-D Pair



O = Outer Ring

M = Middle Ring

C = CBD

Pair Category (O-D)	No. O-D Pairs	% of Total Trips
O1-O1	4	33.8
O1-O2	8	5.0
O1-O3	4	0.3
O1-M1	4	5.3
O1-M2	8	3.7
O1-M3	4	1.0
O1-C	4	5.7
M1-O1	4	3.3
M2-O1	8	2.2
M3-O1	4	nil
M1-M1	4	15.7
M1-M2	8	8.2
M1-M3	4	1.3
M1-C	4	12.9
C-O1	4	0.2
C-M1	4	0.9
C-C	1	0.5
TOTAL	81	100.0

Figure 6. A.M. Peak Period Total Trip Destination

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 Plastictown. 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 Figure 6. This distribution remained constant for each baseline studied. The estimation of new trips induced by the introduction of improved service was considered beyond the scope of the analysis.

3.3 OUTER RING TRIP ALLOCATION

In order to allocate outer ring trips between fingers and fringe, a simple proportion between population and trip generation was used for trips having one end (only) in the outer ring. 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 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 (O1-O1), 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 3.

TABLE 3. A.M. PEAK PERIOD TOTAL TRIP DISTRIBUTION (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
O1-M1	4	3.2
O1-M2	8	2.2
O1-C	4	3.4
M1-O1	4	1.5
M2-O1	8	1.3
M1-M1	4	15.7
M1-M2	8	8.2
M1-M3	4	1.3
M1-C	4	12.9
C-O1	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 service area.

4. SYSTEM DESCRIPTIONS

4.1 INTRODUCTION

The seven systems selected for evaluation represent a broad range of alternatives with respect to the quality of service provided (convenience, comfort, etc.), probable level of funding required, and extent of implementation to date. Although many other systems could have been examined, it was felt that this group was representative of the alternatives being considered by today's planners.

The first system discussed below, the Highway Base Case, will most often be used as a basis for comparison of the other alternative systems.

4.2 HIGHWAY BASE CASE

The Highway system represents the results of the city's continued policy of emphasis on automobile and bus systems through 1990. In addition to the basic network of 175 miles of freeway and 1300 miles of surface arterials existing in 1970, another 175 miles of freeway were assumed to have been built by the year 1990. The resulting freeway network is shown in Figure 7. It should be noted that only in this system was any freeway construction assumed beyond that existing in 1970. In all the other systems, the 1970 freeway and surface arterial networks represent the limit of development of highway facilities.

The bus system provides limited service throughout most of the urban area, with frequencies and coverage typical of today's situations. Buses are diesel-powered.

4.3 COMPREHENSIVE BUS

In this system, public transportation is provided by a very extensive bus network extending throughout the heavily populated area of the city. A segment of this network is shown in Figure 8. To provide a maximum of connectivity, both radial and circumferential

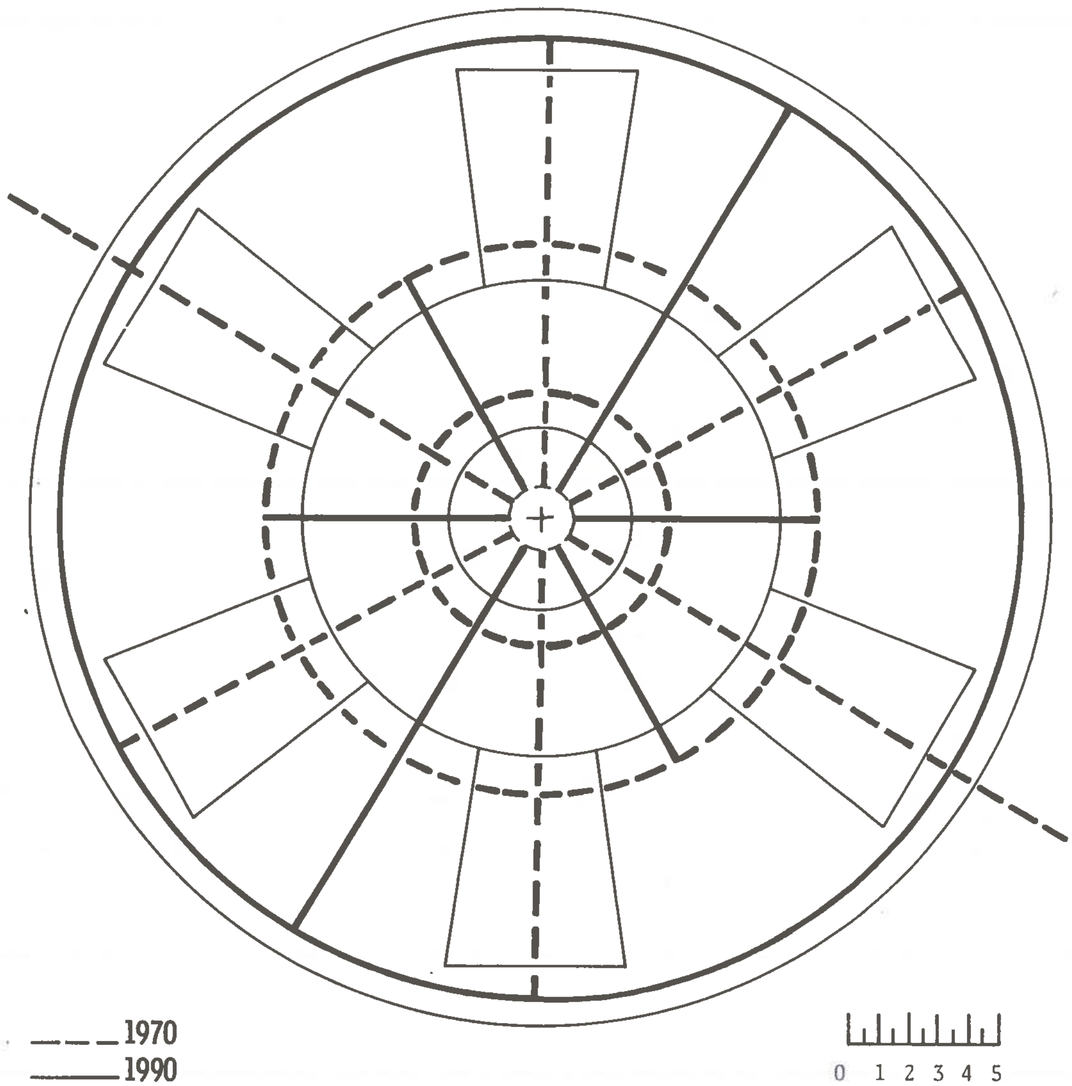


Figure 7. Freeway Network

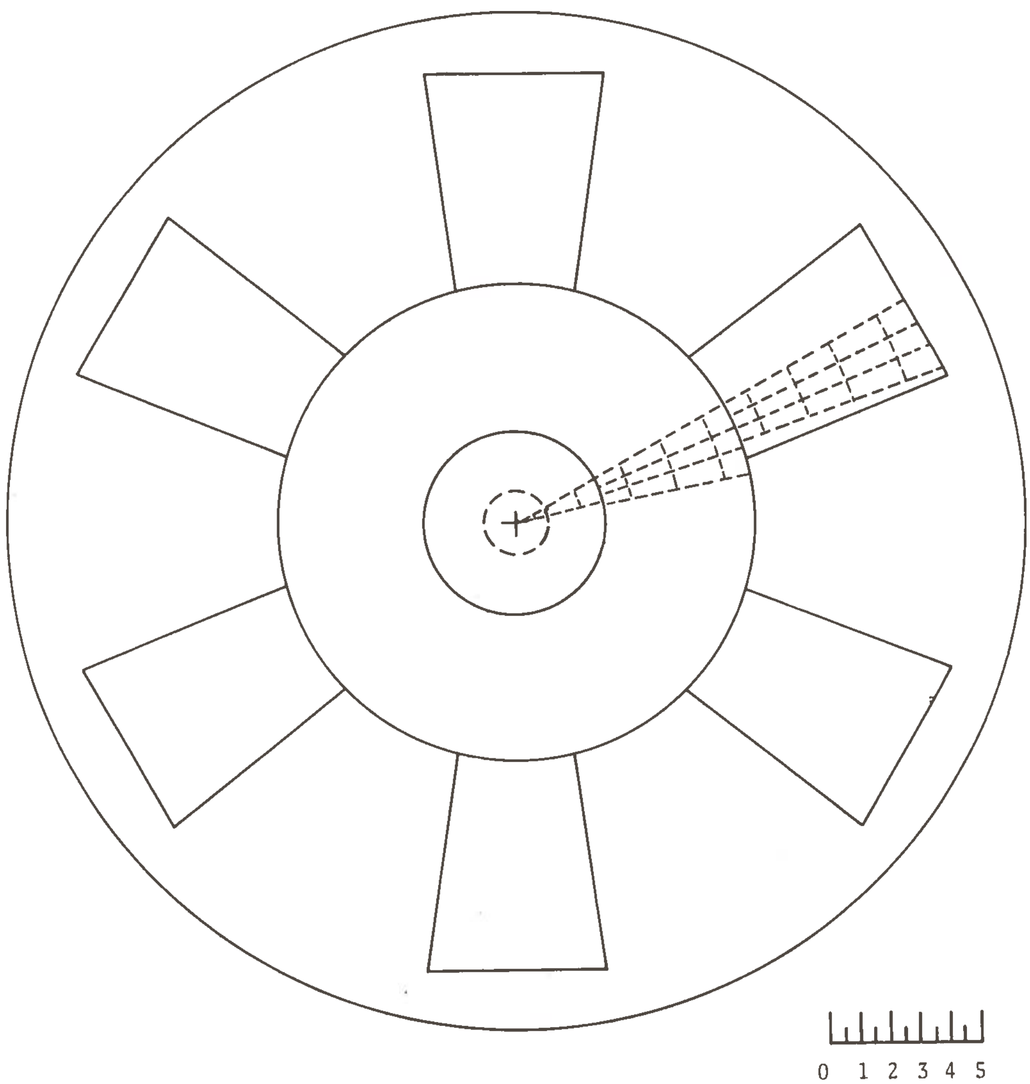


Figure 8. Comprehensive Bus Network

routes exist. Buses on radial routes travel to and from the urban core. It is possible to go from any point in the city to any other (within the coverage area) by transferring between routes. The buses, diesel-powered, all operate on fixed routes and schedules, and no express service exists.

4.4 EXCLUSIVE BUS

Buses operating on exclusive busways provide radial and circumferential service for the city. Off the busway local buses serve to collect and distribute the passengers. There are stations along the busway for passengers transferring between the local and exclusive lane buses. All of the circumferential buses and some of the radial buses stop at all the stations along the way. The remainder of the buses on the radial busways are expresses, traveling from only one station to the downtown area. By an appropriate combination of transfers between express and/or local buses, it is possible to travel between any two areas of the city (within the area of coverage).

A sample trip from an urban neighborhood to the downtown area is depicted in Figure 9, and the exclusive busway network and a sample of the local routes are shown in Figure 10. Each busway station is served by a number of local routes. Many trips are possible using the local system alone (either on a single local bus or by transferring from one local to another at a busway station or at other convenient points).

Circulation in the downtown area is provided in two ways. The radial busways terminate just inside the perimeter of the CBD. After the inbound buses on the busways reach this terminus, they drive on local streets towards the center of town until they reach a circumferential route of local streets about one-quarter mile in radius. They then traverse this route, receiving and discharging passengers. After completing the circuit, they travel radially outward through the downtown to the terminus for their busway, and resume their busway operation. The second means of downtown distribution and collection is by a circumferential local bus route at about the 3/4 mile radius, which connects with all the busway terminals.

- 50 PASSENGER EXCLUSIVE BUSES
- INTERNAL COMBUSTION
- 25 PASSENGER FEEDER BUSES
- RADIAL EXCLUSIVE EXPRESS
- RADIAL AND CIRCUMFERENTIAL EXCLUSIVE LOCALS

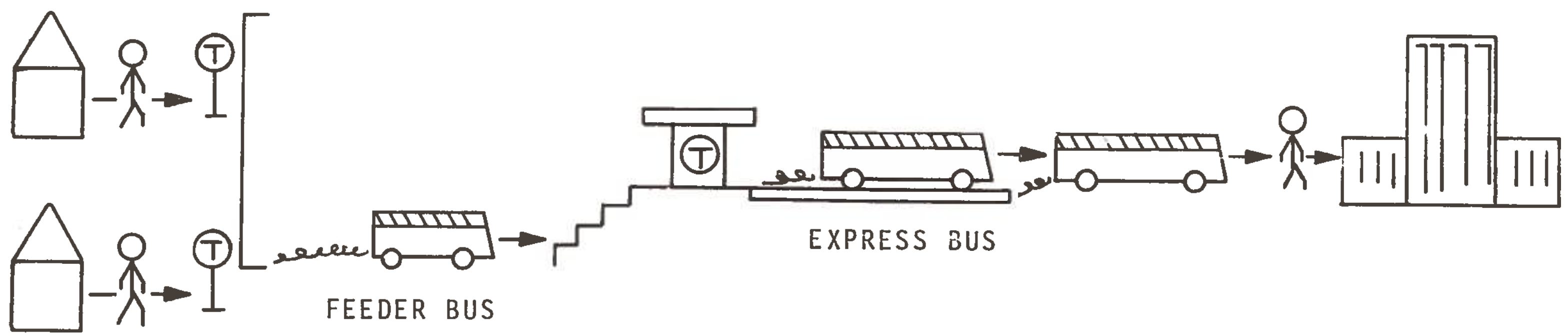


Figure 9. Typical Exclusive Bus Trip to CBD

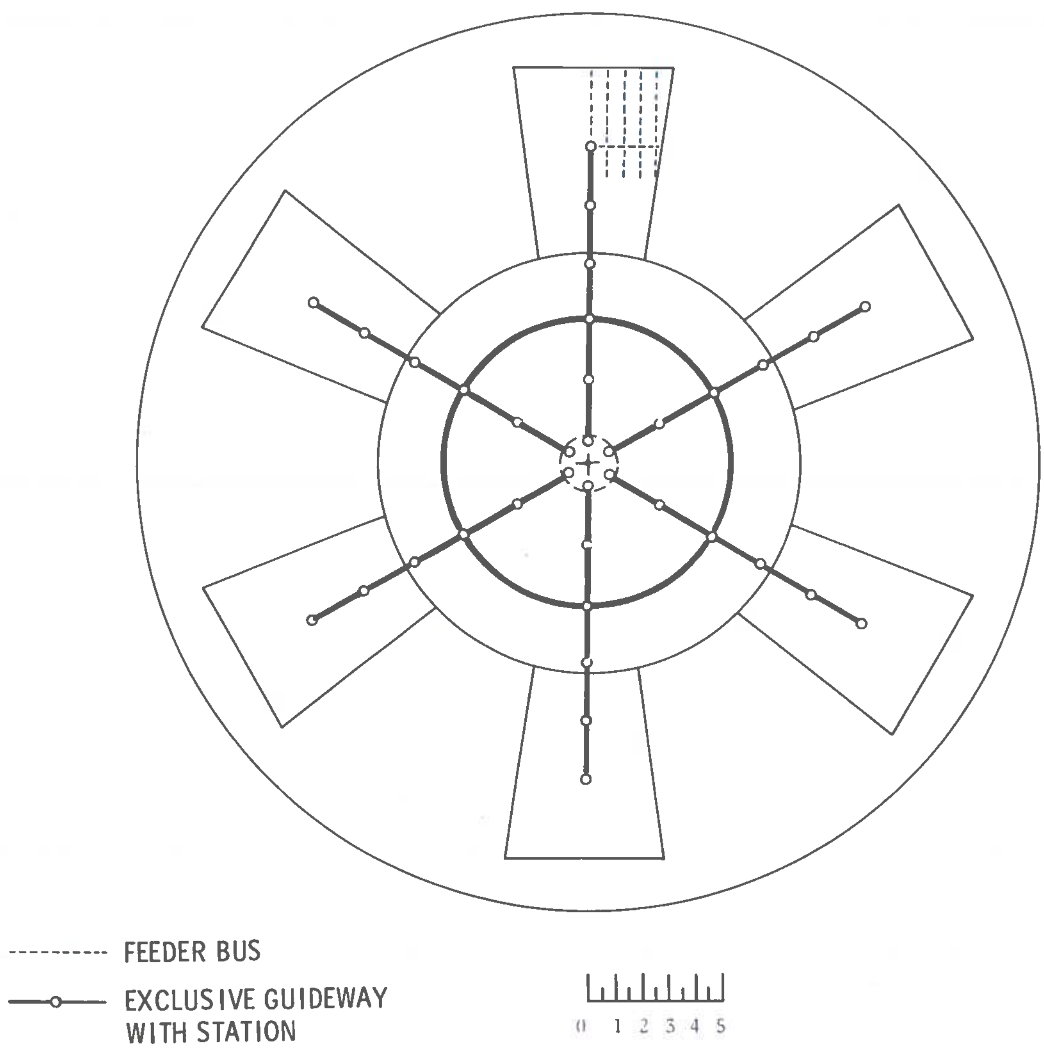


Figure 10. Exclusive Bus Network

All buses, both those on the busways and the locals, are diesel-powered and travel on fixed routes and schedules.

4.5 RAPID RAIL

The Rapid Rail system is virtually identical in coverage to the Exclusive Busway, with the line-haul function performed by rapid rail vehicles instead of buses operating on an exclusive busway network. The rapid rail network, shown in Figure 11, has the same form as the busway, but the rapid rail lines extend underground through the downtown area instead of terminating near its outskirts. Several transit stations are provided in the downtown, eliminating the need for bus service there.

The feeder bus operation is the same for the Rapid Rail and the Exclusive Busway systems. Rapid rail trains stop at all stations along their routes, and the central downtown station serves as a major transfer center. All buses and trains operate on fixed routes and schedules. A sample trip on the system is schematically illustrated in Figure 12.

4.6 DIAL-A-RIDE

The Dial-A-Ride system employs 12-passenger gasoline-powered minibuses, operating in a demand responsive mode, to provide local and express service throughout the region. The city is divided into "tour areas" of approximately .5 square miles each with a fleet of local buses serving each area. "Many-to-Few" service was provided, i.e., within each finger or quadrant, all buses traveled to a few assumed activity centers plus selected interchange points. Long or circuitous trips required one or more transfers to other locals or to express buses at the interchange points. Some of the express buses serve the downtown area (a downtown-bound trip is illustrated in Figure 13) and the others provide circumferential service. All transfers to other locals or to express buses are assumed to be coordinated, so that transfer delays for the passengers can be minimized and so that buses will not waste time stopping at transfer points unless there is a need

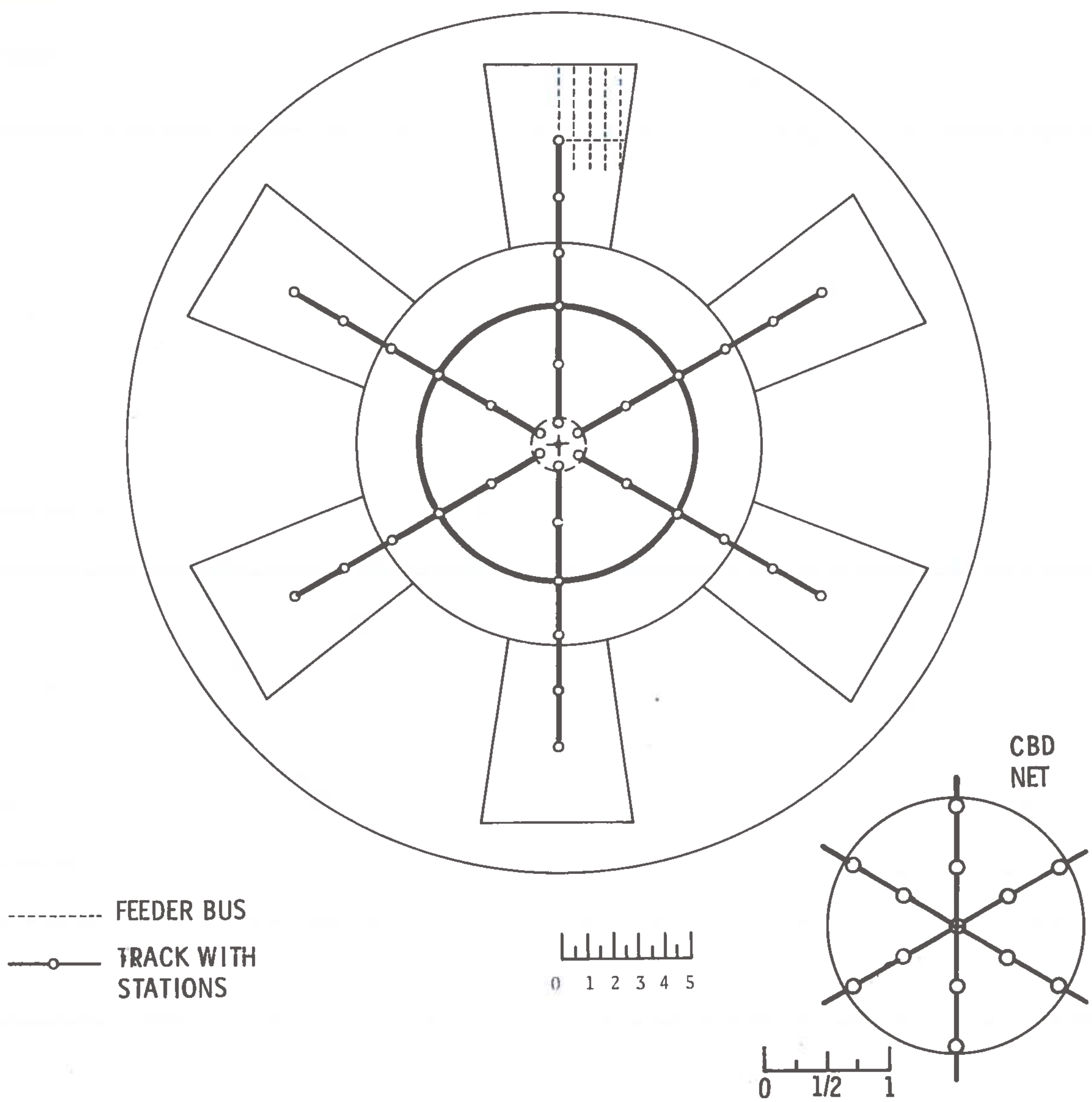


Figure 11. Rapid Rail Network

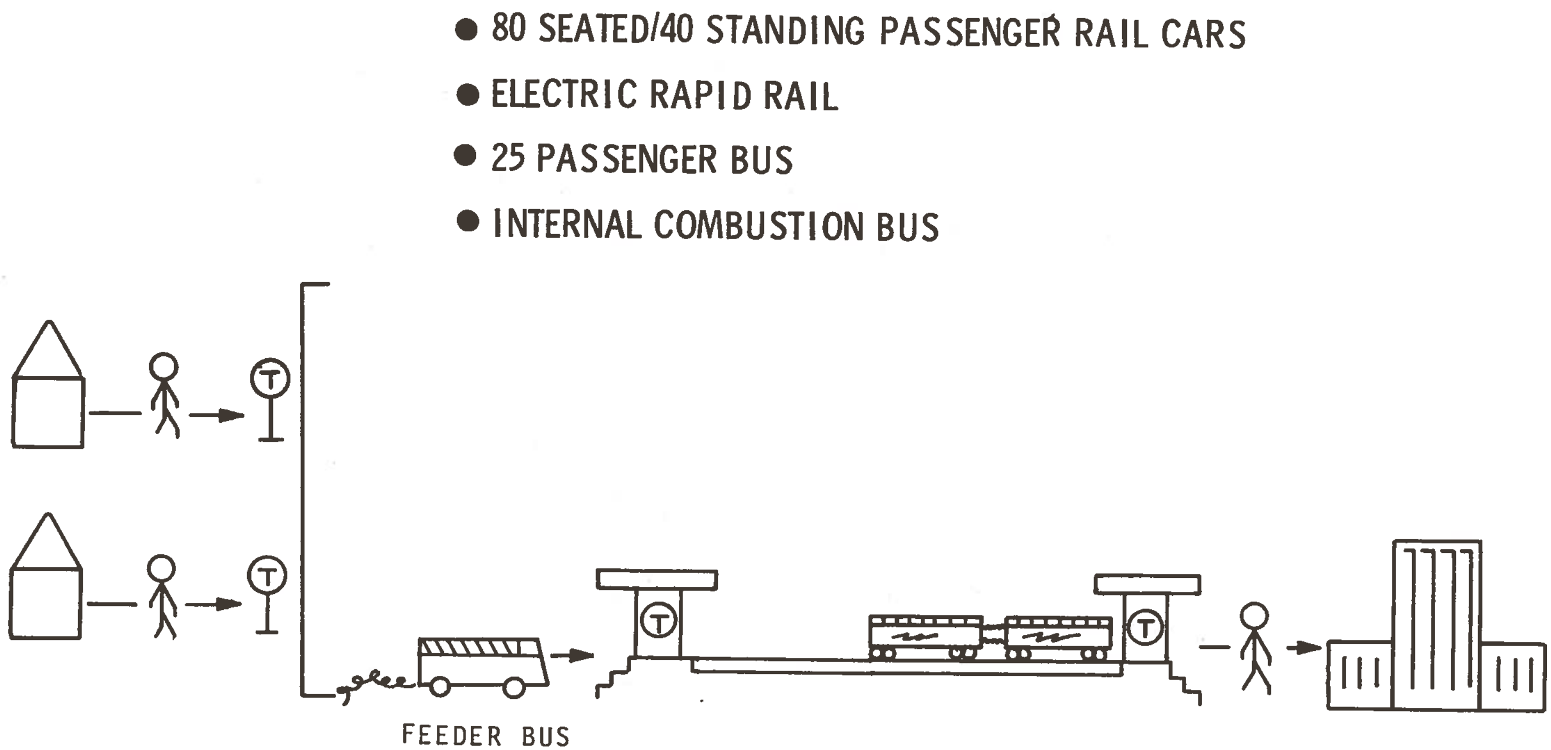


Figure 12. Typical Rapid Rail (With Bus Feeder) Trip to CBD

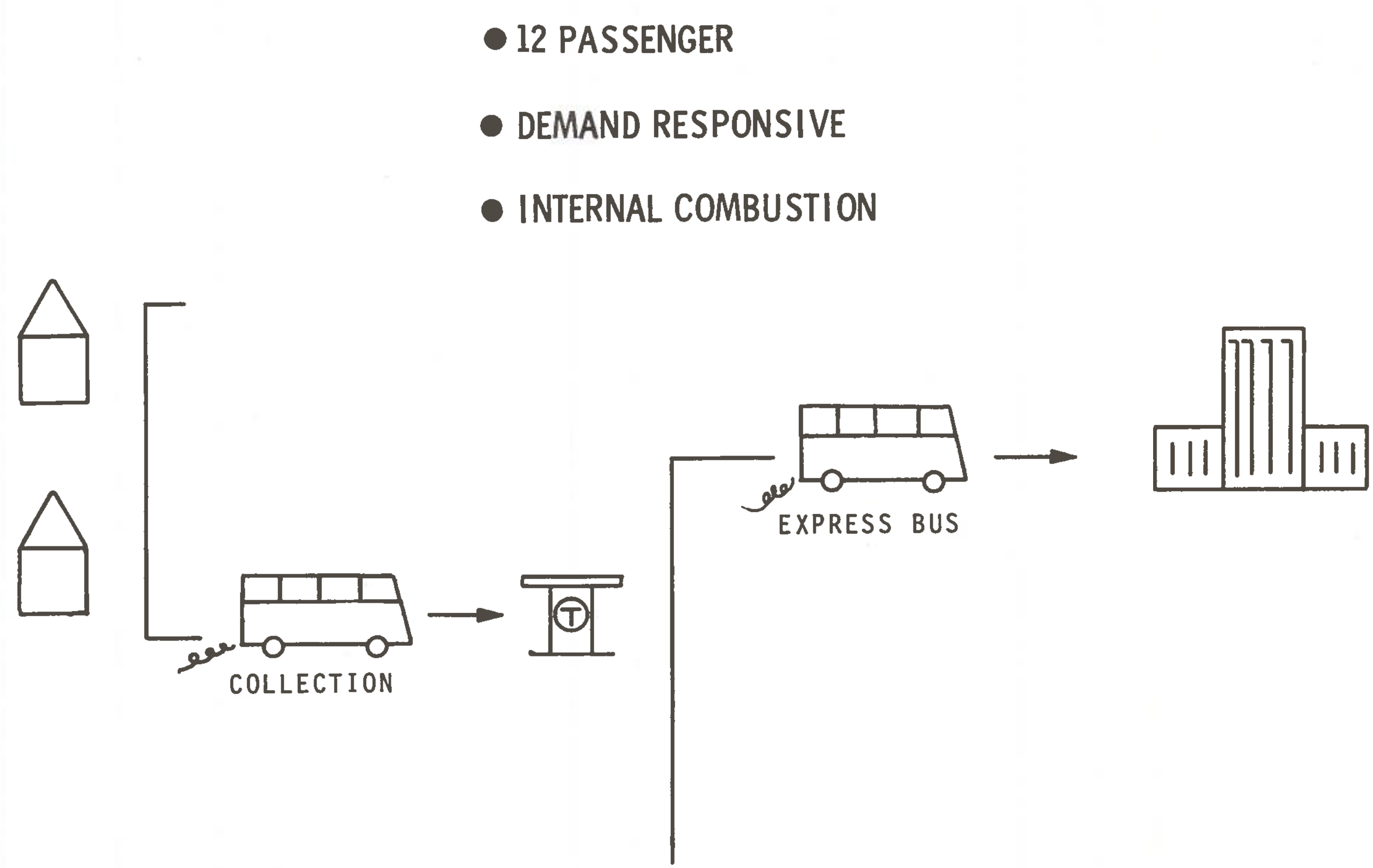


Figure 13. Typical Dial-A-Ride Trip to CBD

for them to. All buses, even the expresses, travel on existing streets and highways, since no special busways are built for the system.

4.7 DUAL MODE

The Dual Mode concept refers to a transportation system in which vehicles are operated by manual control on existing streets to access an exclusive guideway where they travel under automatic control.

The Dual Mode system analyzed in this study consists of a mixed fleet of small personal vehicles and 12-passenger minibuses both using a network of guideways extending throughout the city. Figure 14 shows the layout of the guideway network, and Figure 15 depicts typical trips between a suburban or urban origin and a downtown destination on both types of Dual Mode vehicles.

The small personal vehicle is electrically powered, capable of seating 4 passengers, and is rented from the system. Having been obtained from the system on some previous occasion, it 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. For a trip to the downtown area, the user leaves the vehicle at this station and walks to his destination (in an effort to alleviate street congestion downtown, vehicles are not allowed to exit the guideway there); 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, but not necessarily the same one, 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 guideway network is less dense, the vehicles are allowed to exit the guideway. Upon reaching the station closest to the user's destination, the vehicle is returned to manual control and driven along local streets to the final destination.

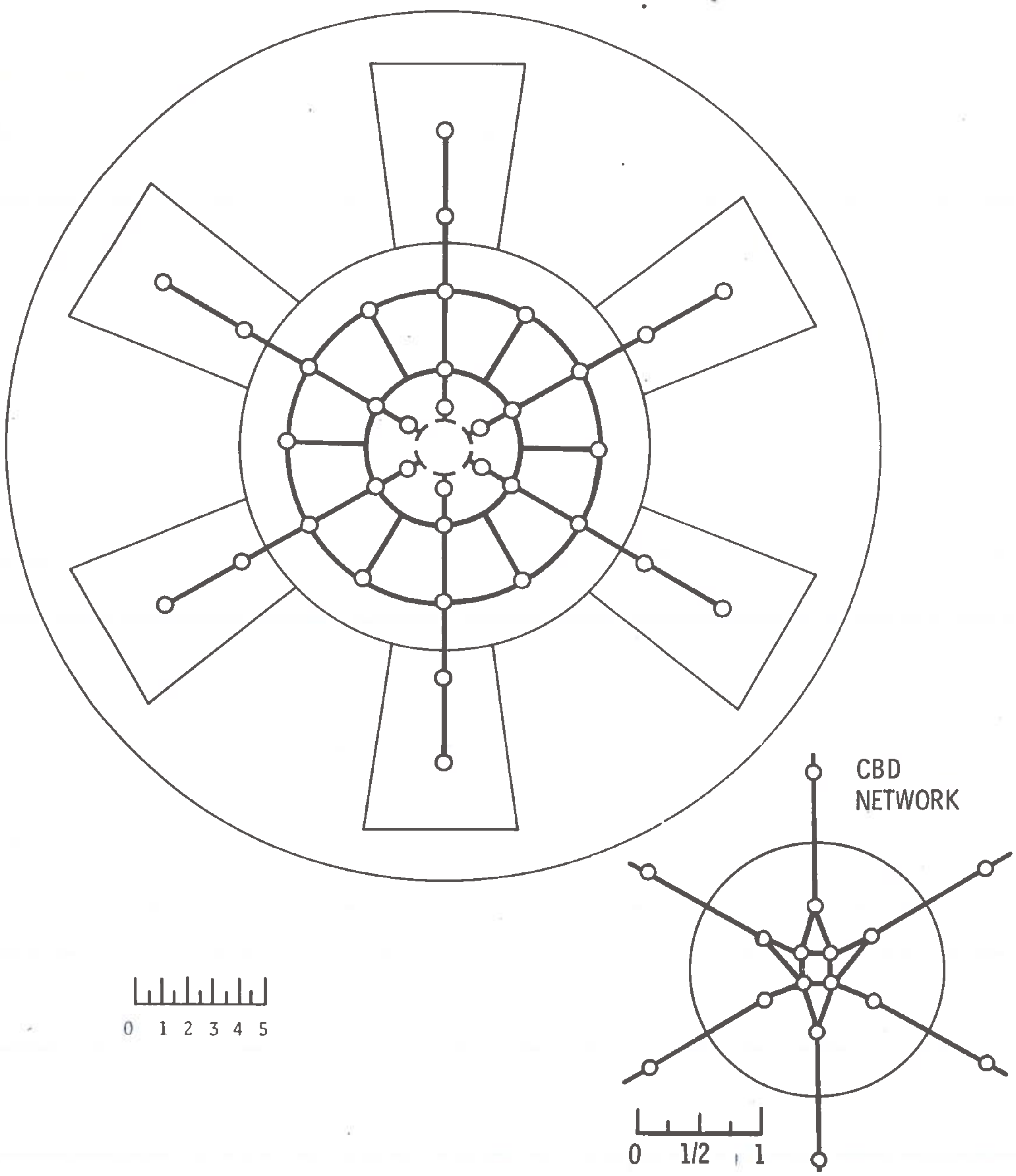


Figure 14. Dual Mode Network

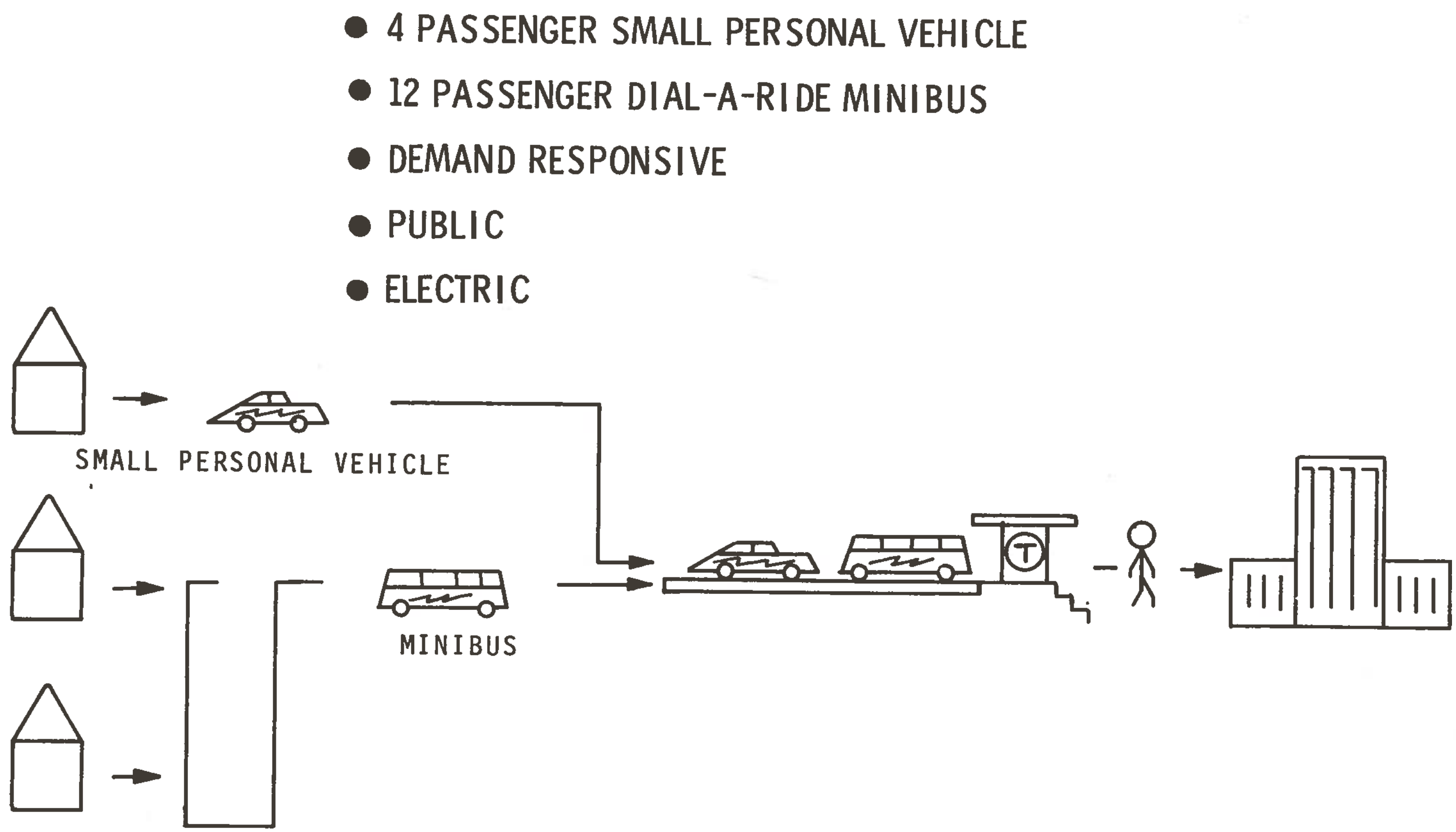


Figure 15. Typical Dual Mode Trips to CBD

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", each with a fleet of minibuses serving each area. After picking up a certain number of passengers 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.

4.8 PRT

The PRT (Personal Rapid Transit) system has a ubiguitous guideway network, providing walking-access service throughout the region. A portion of the network is shown in Figure 16. A sample trip from a suburban (or urban) neighborhood to the downtown area is shown schematically in Figure 17. The vehicles are electrically powered, automatically controlled, carry 4 passengers and are restricted to operating on the guideway. A person desiring to take a trip on the system walks from his origin to the nearest guideway station, where he summons a vehicle. If an empty vehicle is already available at the station he boards it; otherwise, the system dispatches one from the nearest possible location. After boarding the vehicle, the passenger travels in it to the station nearest his destination. Here, the passenger exits the vehicle and walks the remaining distance. The word "Personal" appears in the system title because a passenger (with his immediate party, if any) has exclusive use of a vehicle during the trip.

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*The load factor varies according to time of day.

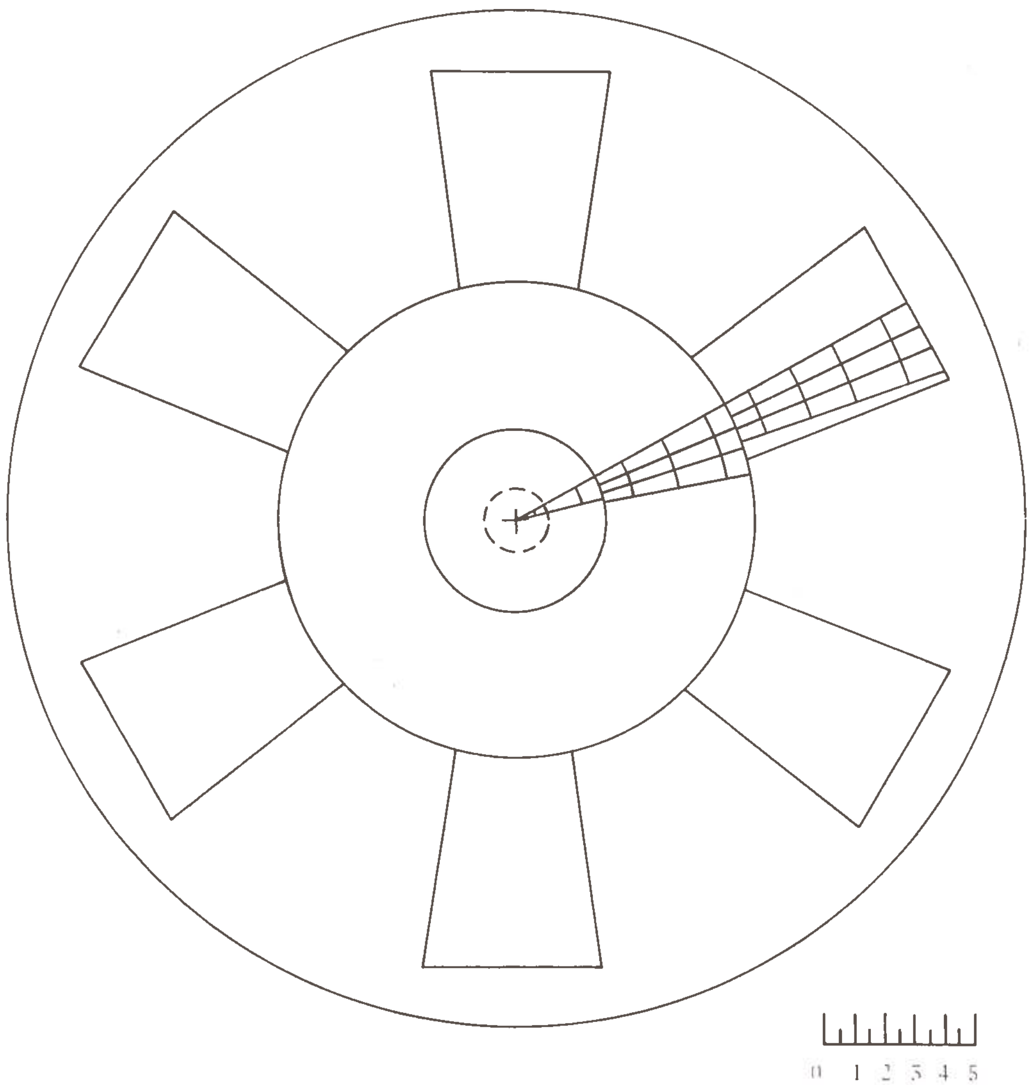

Figure 16. PRT Network

- 4 PASSENGER
- DEMAND RESPONSIVE
- ELECTRIC
- ONE-WAY RADIALS
- TWO-WAY CIRCUMFERENTIALS

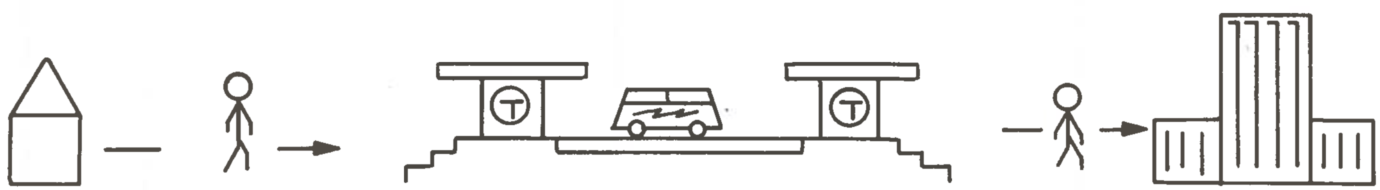

Figure 17. Typical PRT Trip to CBD

5. PATRONAGE ESTIMATION

5.1 INTRODUCTION

The patronage estimation technique used in this study closely paralleled that of the TSC Dual Mode study[1] except in level of detail. The N-Dimensional Logit Model* (calibrated in the Dual Mode study) was exercised to predict modal split (percent of travel by transit) in the peak period for each alternative. Since no networks were coded, alternative mode time and cost impedances used in the model were estimated from either mapped or mathematical representations of the baseline. 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.

5.2 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 by transit modes is defined here to be the sum of walking, waiting, 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 4 and 1, respectively.

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.

Auto impedances, although required for each alternative in the Logit Model equation, were determined only once and then held constant for all alternative mode analyses. The difference in auto impedances between baselines was not large enough to warrant readjustment, given the level of detail maintained in this study. Rather than performing a detailed network analysis (which would have exceeded the scope of this study), auto trip times (non-excess) were estimated with the use of a simplified equation relating auto speed to distance from city center:

$$V = 15 + 1.35r$$

where: V = mean auto speed (mph)

r = distance from city center (miles)

The auto times produced by integrating this equation 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 were 1.0, 1.5, and 5.0 minutes per trip end for the outer ring, middle ring, and CBD zone, respectively.

Time impedances for transit modes 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 4 describes the path for a typical Exclusive Bus trip (including feeder portion) to the CBD.

In order to remove effects of fare from patronage estimation, out-of-pocket fares did not vary by mode. Origin-destination 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 4. TYPICAL EXCLUSIVE BUS PERSON TRIP FROM MIDDLE RING TO INNER PORTION OF CBD (PEAK HOUR)

Time Component	Minutes	Miles
Walk to feeder bus stop	5.0	.25
Wait for feeder bus	3.5	-
Feeder line haul	9.4	2.3
Transfer walk	1.0	-
Wait for express bus	2.5	-
Express line haul	3.5	3.1
Express bus CBD distribution	3.7	0.5
Walk to destination	2.3	.12
TOTAL	30.9	6.3

Comparable auto door-to-door time - 21.6 minutes.

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

5.3 N-DIMENSIONAL LOGIT MODEL APPLICATION

The N-Dimensional Logit Model, developed by Peat, Marwick, 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 period HBW modal splits. Scale factors were used to relate all-purpose 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 (for a single transit mode):

$$M_t = \frac{\exp(T)}{\exp(T) + \exp(A)}$$

where M_t = transit modal split (fraction)

T = transit impedance function

$= \alpha_t X_t + \beta_t N_t + \gamma_t C_t + \delta_t$

A = auto impedance function

$= \alpha_a X_a + \beta_a N_a + \gamma_a C_a + \delta_a$

X_t, X_a = trip excess times for transit, auto

N_t, N_a = trip non-excess times for transit, auto

C_t, C_a = trip costs for transit, auto

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

For the Dual Mode alternative, a three-mode equation (auto, minibus, and small personal vehicle was used to compute modal split percentages.

The calibrated coefficients for auto and local bus service are given in Appendix A along with those selected for use with the alternative modes tested. Modal split sensitivities to the impedance values used for each of the modes are presented in Appendix B.

5.4 TRIP ESTIMATION

Application of the Logit Model produced peak period 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 necessary 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 scale 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 alternative mode 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), with individual mode adjustments dependent on the overall level of service expected during the day relative to the peak. The highest daily scale factor was for PRT, whose level of service would vary little, if any, throughout the day. Table 5 presents the peak and daily factors used.

The peak factor for each mode was applied to the peak period home-based work trip modal splits (from the Logit Model) 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 transit 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 totaled for peak period totals. Peak system loadings were approximated by assuming 50 percent of peak period travel to occur in the peak hour.

Regionwide daily ridership for each mode was computed by applying the daily scale factor to the regionwide peak period all-purpose modal split applicable to that mode, 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.

TABLE 5. MODAL SPLIT SCALE FACTORS

Mode	Peak Factor[1]	Daily Factor[2]
Local Bus	.75	.55
Comprehensive Bus	.75	.65
Exclusive Bus	.75	.65
Rapid Rail	.75	.65
Dial-A-Ride	.87	.82
Dual Mode		
SPV	.90	.75
Minibus	.90	.85
PRT	.90	.90

[1]Ratio of peak period home-based work modal splits to peak period all-purpose modal splits.

[2]Ratio of peak period all-purpose modal splits to daily all-purpose modal splits.

Figure 18 summarizes the basic steps involved in computing ridership statistics.

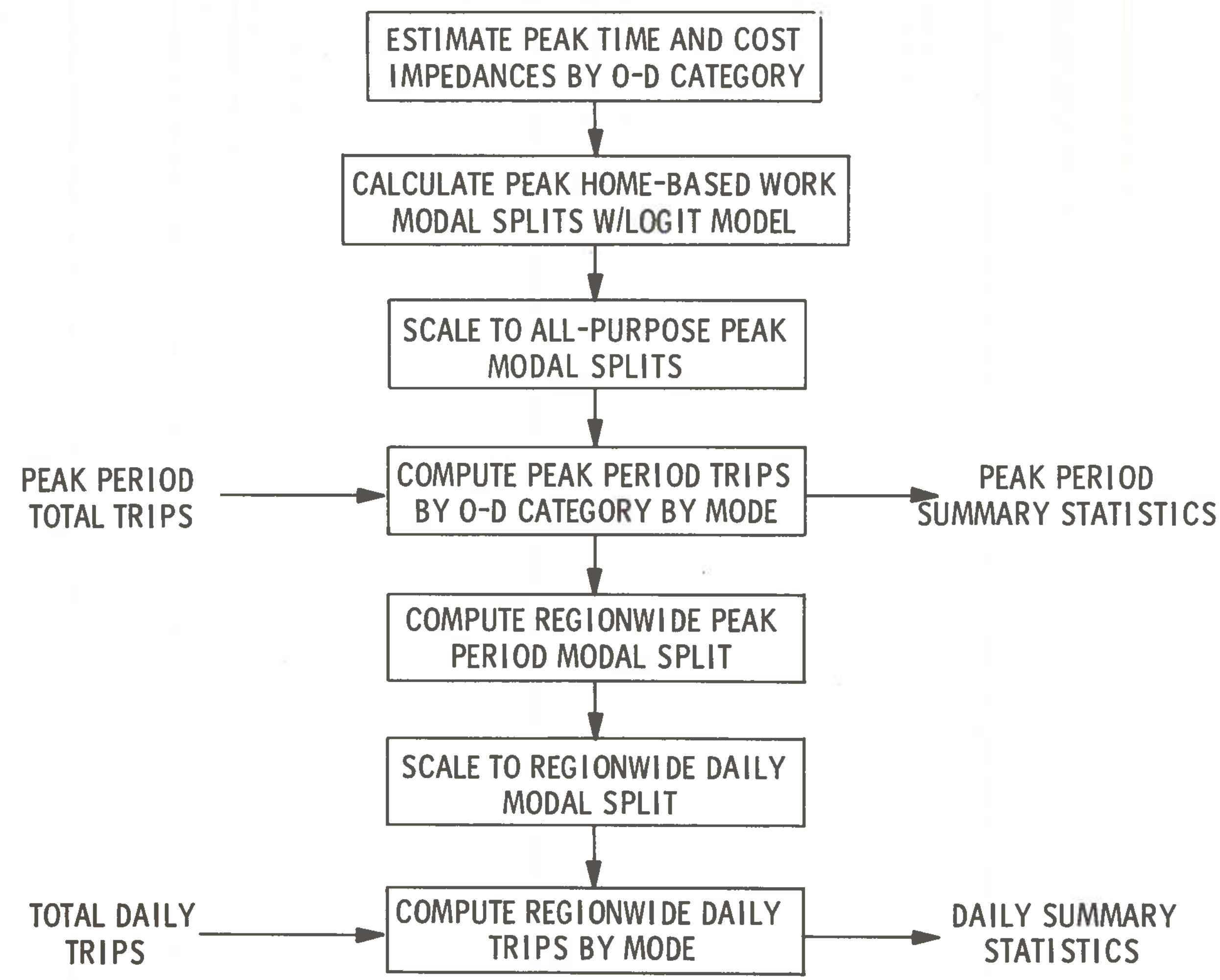

Figure 18. Demand Estimation Technique

6. SYSTEM SIZING AND PERFORMANCE

6.1 ACCESS TIME CRITERION

To provide a consistent base for the comparative analysis it was decided that all systems would provide comparable levels of service. The system extent necessary to satisfy the service criterion could then be determined. The service measure chosen was access time, defined as the time elapsing between a traveler's desire for service and his boarding of the first vehicle of the system. This criterion was applied to all but the downtown area, where high trip densities resulted in greater vehicle availability, thereby lowering the access time.

Because of system pecularities, the access time criterion had somewhat different meanings for the various transportation alternatives. For systems having buses operating on fixed routes and schedules, it represented the time required to walk to the bus stop and the average wait for the bus (one-half the headway). For the Exclusive Busway and Rapid Rail systems, it applied to the feeder bus portion of the trip only, in the manner just described. For the PRT system, the access time was that required for a traveler to walk from his origin to the nearest guideway station, and request and enter a vehicle. For the Dial-A-Ride system and the Dual Mode minibus (also a dial-a-ride operation), the access time referred to the time elapsing between the request for service and the arrival of the vehicle at the traveler's origin. For the Dual Mode small personal vehicle, it was the time required for the traveler to leave his origin, drive the vehicle to the nearest guideway station, and enter the guideway.

The service criterion was not applied to automobile travel in any of the alternatives examined, nor was it applied to the limited bus service in the highway alternative (because this bus system was intended to represent present-day bus service). A value of 8.5 minutes was chosen for the average peak period access time. The access time for the off-peak period was 17 minutes, twice that of the peak.

6.2 SERVICE CHARACTERISTICS

The access time criterion was instrumental in determining system service characteristics, which are presented in Table 6. Average access distances for the Comprehensive Bus system and for the feeder buses of the Exclusive Bus and Rapid Rail systems were assumed to be a quarter of a mile. This distance is equivalent to be a quarter of a mile. This distance is equivalent to 5 minutes of walk time, leaving 3.5 minutes for wait time. Since PRT is demand responsive, a lower wait time (1.8 minutes) was assumed, leaving a longer walk time (6.7 minutes) and a correspondingly longer access distance (a third of a mile). For the small personal vehicle portion of the Dual Mode system, average access distance was 2 miles, corresponding to the distance that could be driven in 8.5 minutes. For the Dial-A-Ride system and the bus portion of the Dual Mode system (also dial-a-ride), access distance is zero since the buses come directly to the door.

System extents for the Comprehensive Bus and the feeder buses of the Exclusive Bus and Rapid Rail systems were determined on the basis of route spacing. Given that buses can stop at every block and given the quarter-mile average access distance (which implies a maximum half-mile walk), bus routes were spaced at one-mile intervals. The stations for PRT and Dual Mode were assumed regularly spaced at intervals governed by their respective access distances. System extents for these alternatives were then determined by linking the stations with a guideway network designed to provide a reasonable compromise between the goals of maximum connectivity and minimum capital costs and dislocations. Since the buses of the Dial-A-Ride and Dual Mode systems can drive on any local street as needed, no meaningful value exists for their system extent.

Peak period headways for the Comprehensive Bus and the feeder buses of the Exclusive Bus and Rapid Rail systems were equal to twice the average wait time. Headways for the buses in the Dial-A-Ride and Dual Mode systems were equal to twice the access time criterion. Headways for the express buses of the Exclusive Busway

TABLE 6. SERVICE CHARACTERISTICS

VEHICLE	AVERAGE ACCESS DISTANCE, MILES	WALK TIME, MINUTES (PEAK)	WAIT TIME, MINUTES (PEAK)	SYSTEM EXTENT ROUTE MILES			HEADWAY, MINUTES (PEAK/OFF-PEAK)	FLEET SIZE	LOAD FACTOR (PEAK/DAILY)
				TOTAL	ELEVATED	TUNNELED			
Highway Limited Bus	- 1/4 (walk)	- (1)	- (1)	175 500	20 -	- -	- 12/30	- 300	0.53/0.40
Comprehensive Bus	1/4 (walk)	5.0	3.5	1,100	-	-	7/24	1,400	0.25/0.24
Exclusive Busway									
Feeder Bus	1/4 (walk)	5.0	3.5	750	-	-	7/24	1,100	0.28/0.22
Express	-	-	-	110 (busway)	40	-	2.5/6	800	0.40/0.30
Rapid Rail									
Feeder Bus	1/4 (walk)	5.0	3.5	750	-	-	7/24	1,100	0.32/0.24
Rail Vehicle	-	-	-	110 (rail lines)	40	10	4/8	200	0.45/0.46
Dial-A-Ride Bus	0	-	8.5	-	-	-	17/34	4,500	0.48/0.31
Dual Mode Small Personal Vehicle	2 (drive)	-	-	150 (guideway)	40	10	-	165,000	0.30/0.30
Minibus	0	-	8.5	"	"	"	17/34	3,000	0.30/0.30
PRT	1/3 (walk)	6.7	1.8(2)	825 (guideway)	770	20	-	16,000	0.30/0.30

(1) Access time criterion not applicable.
(2) Reservation and boarding delay.

system and for the Rapid Rail vehicles were set by the consideration of providing adequate service. Off-peak headways for all buses and Rapid Rail vehicles were considerably larger than the peak period values.

Fleet sizes were determined after the system extent, vehicle headways, and partonage were known. The load factors were obtained by dividing the passenger-miles traveled by the available seat miles.

The bus fleet in the Highway system was sized by determining an average size of present-day fleets for regions the size of Plastictown. For bus fleets in the other systems, fleet sizes were determined by the route structure established and the headway. The Comprehensive Bus system contained both radial and circumferential routes (Figure 8). The radial routes were spaced approximately 1 mile apart circumferentially, and this spacing was maintained by having routes branch as they radiated from the center. Circumferential routes were spaced one mile apart, starting at the one-mile radius.

The feeder bus system for the Exclusive Busway and Rapid Transit systems were identical (see Figures 10 and 11). In both cases, they fed six radial express routes aligned with the fingers of the outer ring of the city. The feeder routes served an area about 3/4 mile wide and 2.6 miles long (one-way). The patronage was such that 25-passenger buses were sufficient for these routes. The express bus fleet was sized to meet the peak hour passenger flow. With the Rapid Rail system, two-car trains were operated during the peak period at the established headways, while one-car trains were sufficient during the remainder of the day.

The bus fleets for the Dial-A-Ride and Dual Mode systems were sized by the same procedure as the other bus fleets, although the details differed slightly. The average tour area for these buses was about 0.5 square miles, and the average tour length round trip was about eight miles (including a run to and from a transfer point for the Dial-A-Ride system of the nearest guideway station for the Dual Mode system). With the Dial-A-Ride system, enough additional express minibuses to handle the demand were provided for longer trips. In the Dual Mode system the local collection and distribution minibuses, after completing their off-guideway tour and arriving at the guideway entrance station, travel to the downtown area. The determining factor in fleet sizing was the peak hour passenger flow rather than the headway.

The procedure for calculating the Dual Mode small personal vehicle fleet was the same as that used in Reference 1. One vehicle was provided for each A.M. peak period SPV person-trip (divided by the SPV load factor). It was assumed that these were primarily work trips and that the general pattern of behavior was that these vehicles would not be used for any other trips during the day but would be parked, instead. Also, one vehicle was provided for every three off-peak person round trips, to accommodate the home-based and business trips around town occurring during the course of the day.

The PRT fleet was sized to handle the peak hour passenger flow. From the demand analysis, information was obtained about the average trip length (which determines the amount of time a vehicle is tied up for a trip) and the balance of flow (how many people are going from A to B compared with those going from B to A). The balance of flow is important, since if people are heading predominately in one direction a vehicle can only handle one trip per vehicle round trip, whereas if the trips are distributed evenly in each direction each vehicle can handle two trips per vehicle round trip.

7. SYSTEM COSTS AND REVENUES

7.1 INTRODUCTION

Values for capital and operating costs were derived from current or recently completed projects whenever possible (e.g., BART, Boston MBTA Quincy extension), and drew heavily upon current estimates for new projects (e.g., Atlanta, Denver, etc.). The largest portion of the capital and operating costs for the various alternatives were for vehicles and guideways (including intersections) for the various alternatives. All cost values are in 1970 dollars. Capital costs were annualized by applying a 10% interest rate for the assumed lifetimes of the various components. Land was given an infinite lifetime, structures a 50-year lifetime, and power distribution, track and command and control facilities a 20-year lifetime. Vehicle lifetimes varied and are given in the appropriate sections to follow.

7.2 LAND COSTS

The land costs (exclusive of household displacement payments, discussed in Section 8.5) used in this analysis were derived from an average of land costs in the 30 SMSA's, obtained from 1967 Census of Governments data. The costs for Plastictown are as follows:

Ring	Cost ($/acre)
Inner	98,000
Middle	81,000
Outer	49,500

7.3 GUIDEWAY COSTS

The cost components for guideways are given in Table 7. The structural cost includes all supporting structure, tunnels (if any), and running surface (or track).

TABLE 7. GUIDEWAY COSTS AND CHARACTERISTICS

	Freeways	Busways	Rapid Rail Lines	Dual Mode	PRT
Capital Costs: Structure ($/lane mile)					
At grade	0.8×10^6	0.6×10^6	3.0×10^6	0.5×10^6	0.4×10^6
Elevated	1.0×10^6	1.0×10^6	3.0×10^6	1.5×10^6	1.1×10^6
Tunneled	---	---	10.0×10^6	5.0×10^6	5.0×10^6
Right-of-way width/lane (ft)	24	16	30	12	10
Command and Control ($/lane mile)	---	---	0.25×10^6	0.25×10^6	0.25×10^6
Power ($/lane mile)	---	---	0.5×10^6	0.4×10^6	0.4×10^6
Operating Cost: ($/lane mile/year)	13×10^3	12×10^3	36×10^3	20×10^3	20×10^3

Reference 1 was a primary source for the figures for freeway, busway, Dual Mode, and PRT costs. Rapid Rail costs were derived from both References 1 and 5. The Dual Mode and PRT guideways are generally narrower and need support less weight than do freeways and busways. This difference in size and strength is evident in the at-grade structural costs. However, the elevated guideway cost estimates are slightly higher per lane mile than for freeways or busways, reflecting the experience of the Morgantown system. The PRT guideway is slightly less expensive than the Dual Mode because it is somewhat narrower (6 feet vs. 8 feet) and need support a lesser load (a PRT vehicle is 12 feet long and weighs about 3000 lbs, giving a unit weight of 250 lbs/foot, whereas a minibus is 20 feet long and weighs about 10,000 lbs, resulting in a unit weight of 500 lbs/foot). Differences in power costs per lane mile reflect the fact that the rapid rail vehicles are considerably heavier than the Dual Mode and PRT vehicles.

7.4 STATION COSTS

The average operating and capital costs of the stations used in the analysis are shown in Table 8. Stations for the Exclusive Bus and Rapid Rail systems were given flat costs reflecting the size (fixed), type of structure, and elevation, while Dual Mode and PRT stations (catering to personal vehicles) were costed on the basis of passenger throughput, facilities and elevation, after the manner outlined in Reference 1. Consequently, because of these differences in cost bases, it was felt to be appropriate to merely list the resulting per-station average costs. It should be noted that no station structures were provided for the limited bus in the Highway Base Case, or for the Comprehensive Bus and Dial-A-Ride systems.

The figures in Table 8 represent average cost for all construction types and all sizes of stations. The capital costs include all structures, equipment, and land. The large difference in capital cost between Exclusive Bus and Rapid Rail stations is due to two factors. First, the Exclusive Bus stations are all above ground, whereas the Rapid Rail baseline has 13 stations

TABLE 8. STATION COSTS

Station Costs	Average Capital Cost ($ x 10^3/station)	Average Annual Operating Cost ($ x 10^3/station)
Highway	--	--
Comprehensive Bus	--	--
Exclusive Bus	25	25
Rapid Rail	3400	50
Dial-A-Ride	--	--
Dual Mode	2500	47
PRT	600	46

underground (out of a total of 43 stations). Further, one of the underground stations is a major terminus at the center of the CBD. These underground structures are extremely expensive and significantly increase the per-station average cost for the system. Second, the Exclusive Bus stations were envisioned to be relatively simple, small shelters, whereas the Rapid Rail stations were more elaborate and larger.

The equipment and complexity assumed to be inherent in a Dual Mode station resulted in its price being not too much less than that of the average Rapid Rail station. PRT stations do not have the guideway exit and entrance equipment associated with the Dual Mode stations, but do have control and communications equipment associated with summoning and dispatching vehicles and must also have passenger shelters and facilities. They are considerably smaller in both size and passenger flow than the Dual Mode stations, and the resultant cost estimate for them is about one-fourth of that of a Dual Mode station.

7.5 VEHICLE COSTS

The capital and operating costs for the various vehicles in the alternatives studied are shown in Table 9.

The difference in capital cost between the Dual Mode small personal vehicle and the PRT vehicle is due largely to the difference in the utilization of the vehicles during the course of their lifetimes. The Dual Mode vehicle is used in a manner similar to the automobile, whereas the PRT vehicle is shared by many users and thus is in operation continuously. Although the Dual Mode vehicle must have provision for manual control and for storage batteries to provide off-guideway power, it is driven only about 6,000 miles per year. The PRT vehicle, on the other hand, travels some 60,000 miles per year. Thus, the PRT vehicle needs to be built more to transit than to automobile standards, and these higher demands on design and reliability are reflected in its cost.

TABLE 9. VEHICLE COSTS

Vehicle	No. Pass.	Capital Cost $	Operating Cost $/VMT	Lifetime yrs.
Dual Mode small personal vehicle	4	4,500	0.05	6
Dual Mode minibus	12	30,000	0.12 - on-guideway 0.72 - off-guideway	12
PRT vehicle	4	10,000	0.05	6
Large bus for Highway, Comprehensive Bus, and Exclusive Bus (express bus) systems	50	45,000	1.00 - Hwy & Comp Bus 0.67 - Exclusive Bus	12
Feeder bus for Exclusive Bus and Rapid Rail systems	25	25,000	0.90	12
Dial-A-Ride bus	12	25,000	0.72	12
Rapid Rail vehicle	80	350,000	1.55	20

Operating costs vary for the Dual Mode minibus, depending on whether it is off or on the guideway. When on the guideway, the vehicle does not require a driver; whereas while it is off the guideway, it does, and this adds to its operating cost.

The operating cost of the large bus in the Highway Base Case and Comprehensive Bus system differs from that of the express bus in the Exclusive Bus system. The reason for this is that the operating cost is on a per vehicle mile basis, whereas the driver cost portion of the operating cost is on an hourly basis. The express bus covers a greater number of vehicle miles per vehicle hour, due to its speed, than do the local buses of the Highway and Comprehensive Bus cases. Consequently, the driver cost per vehicle mile of the express bus was reduced proportionately, so that the bus would experience the same effective driver cost per vehicle hour as do the other two buses.

7.6 REVENUE CALCULATION

Revenues produced by each alternative were derived from the fare structure used in mode choice estimation. For each transit alternative, base fares used were two cents per airline mile multiplied by 1.4 to account for deviation from straight line routings (1963 dollars). To maintain a consistent reference, these base fares, or out-of-pocket transit costs, were constrained for the mode choice process to be the same in all alternatives for trips between a common origin and destination.

Total revenues were computed by summing the products of the number of daily transit riders in each origin-destination pair category by the appropriate fare (adjusted to 1970 dollars).

8. IMPACTS

8.1 INTRODUCTION

A detailed quantitative evaluation of the impact of the various systems upon users and the community was carried out. Among the impacts quantified and, in certain cases, assigned dollar values were travel time savings, driver relief, regional energy consumption, regional air pollution, household and business displacements, land value changes, and tax revenue changes. Since the process of quantifying and monetizing benefits from these transportation systems involved a number of assumptions, the unit values of the individual elements of the benefit calculation are presented in the "Costs and Benefits" discussion in Section 9. The following sections contain a description of the methodology used to analyze each impact area.

8.2 TRAVEL TIME SAVINGS AND DRIVER RELIEF BENEFITS

Annual travel time savings consisted of the difference in regionwide passenger hours traveled* for each alternative vs. the Highway Base Case.

The dollar value of this form of time savings was computed using a rate of $3.00 per person-hour,[1] representative of an average value of time saved for all trip purposes and driver income levels.

Driver relief was measured in automobile vehicle (hence driver) hours traveled for each alternative compared to the Highway Base Case. For Dual Mode, this difference was further reduced by the off-guideway small personal vehicle hours traveled, since the driver is not relieved of the piloting chore during this portion of a trip. The value used to compute the dollar benefits arising from driver relief was $1.50 per driver hour.[1] Only half the hourly value of travel time savings was used to reflect the

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*A discussion of the method used to calculate speeds and passenger-hours traveled can be found in Appendix C.

that the use of time available to a passenger in a public vehicle is restricted since the passenger cannot leave the vehicle, whereas trip time saved can be used at the traveler's discretion.

8.3 ENERGY CONSUMPTION AND POLLUTION EMISSION

Consumption of energy and emission of pollutants by the elements of the various transportation systems were estimated by the same procedure used in Reference 1. Energy consumption was calculated by computing the energy necessary to overcome the aerodynamic drag forces on the vehicles (dependent upon vehicle speed) and the vehicles' rolling resistances. The energy necessary to move the vehicles was then converted into total energy consumption by taking into account the efficiencies of the various components of the systems. Internal combustion powered vehicles were assumed to have an efficiency of 80% for transmission of energy from engine to wheels, and a fuel consumption of 0.5 lb/hp-hr with fuel containing 20,000 Btu/lb. Electrically powered vehicles were assumed to have a 70% efficiency in the pickup, conversion, and transmission of energy to the wheels, and the power generation and distribution system was assumed to have an efficiency of 36%.

In the above method of determining energy consumption, the effects of winds and grades were ignored. Further, the average speed of a vehicle rather than a speed-time history was used to compute its consumption. This can lead to inaccuracies in two ways. First, aerodynamic drag is a non-linear function of velocity. Secondly, the use of average speed does not adequately account for fuel consumption of internal combustion powered vehicles in heavy traffic. The latter factor especially influences the energy consumption of automobiles, which is thus somewhat understated in this report.

Pollution emission was based upon the EPA standards currently planned for the time periods closest to 1990, as given in References 6 and 7. Pollution from internal combustion powered vehicles was calculated on a vehicle-mile traveled basis, while that resulting from the use of electrically powered vehicles was based on energy consumption and was determined by the standards set for coal-burning stationary power plants. A General Motors study[8] on propulsion system emissions, reflecting the currently envisioned standards, was used as a source of specific pollutant levels for diesel-powered buses.

8.4 DISPLACEMENT

The displacement analysis was intended to compare the relative intrusiveness of the various systems using new right-of-way taken as a proxy. Results are presented in terms of numbers of displacements saved (over the Highway Base Case) as well as dollars of benefits due to these savings.

The procedure for determining the number of household displacements consisted of first classifying the network mileage of each system by geographic area (i.e., density ring), construction type (at grade, elevated, tunneled), and status of right-of-way (new vs. existing). In addition, it was necessary to calculate as well as classify right-of-way acreage for interchanges, terminals, maintenance facilities, and other system components requiring land acquisition. The number of households displaced was determined by multiplying the combined mileage of network sections on new right-of-way having similar characteristics by the system right-of-way width, and then multiplying the resultant area plus the acreage for associated facilities by the appropriate ring density.*

The calculation on business displacements was based on network mileage on new right-of-way and a displacement rate per mile, both stratified by ring.

The reduction in household displacements for each alternative compared to the Highway Base Case was expressed in dollars by valuing relocation cost savings accruing to the system owner at $1,604 per household and "aggravation" cost savings accruing to

*Assuming 3 people per household, the average household density for the inner, middle, and outer (finger) rings was 7.8, 2.3, and 1.6 households per acre, respectively.

the displaced at $20,000 per unit. Business displacement savings consisted of relocation costs not incurred by the system owner ($3,076 per business). Relocation cost values were obtained from FHWA data on relocation assistance payments* to businesses and households in urban areas over the period October 1, 1970 to June 30, 1971.[9] The relocation cost per dwelling unit represents a weighted average for homeowners and renters. The "aggravation cost" was arbitrarily set at $20,000 per household** to account fully for the inconvenience and psychological disturbance associated with finding and adjusting to a new home, neighborhood, school, and friends.

Total displacement cost savings relative to the Highway Base Case were annualized at 10% assuming an infinite lifetime (same as land).

8.5 LAND VALUE CHANGES

Changes in land value were determined as a function of speed-related changes in accessibility to the CBD, since land value tends to increase with improved accessibility. The procedure for measuring this impact involved a number of steps. First, land value data for about 100 communities comprising the Boston region was used to generate a curve relating cumulative land value to distance (in miles) from the CBD. This curve was then normalized to show percent of total land value as a function of percent of total radius. Next, a Plastictown curve was derived from the Boston curve on the basis of Plastictown data on total land value and total land area within the central city and SMSA boundaries

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*Covering moving expenses, costs incidental to the transfer of property and, in the case of household relocation, additives to the fair market value for "decent, safe and sanitary" replacement housing.

**This value represents the average response from a limited group of people informally asked the question, "For what amount of money would you be willing to move from your present home to one of comparable quality?"

averaged from 1967 Census of Governments data for the 30 SMSA's). For the Plastictown radius of 17 miles, the resultant curve indicated a total land value of about $15 billion. Next, incremental land values (obtained by reading cumulative values off the Plastictown curve at fixed intervals) were divided by incremental annular areas (calculated from the radii) to yield a bar graph of value per square mile as a function of distance from the CBD.

To compute the change in land value due to each non-highway alternative each bar was shifted horizontally in accordance with the percent change in speed, and the new total land value out to the 17-mile radius was computed. The increase or decrease in total land value relative to the Highway Base Case was annualized on the basis of a 10% interest rate and an infinite lifetime.

8.6 TAX REVENUE CHANGES

For this analysis, two categories of tax revenue changes were calculated: tax losses associated with right-of-way acquisition and tax changes related to land value changes. The average 1966 tax rate for Plastictown, $20 per $1,000 of full market property value, was averaged from SMSA data contained in Reference 10. The calculation of tax losses due to right-of-way acquisition involved multiplying the acreage of land taken in each ring (determined in the same fashion as displacement acreage) by the corresponding 1966 land cost per acre and then multiplying the total land acquisition costs for each system by the tax rate. The procedure for determining tax revenue changes related to land value changes consisted of multiplying the incremental gain or loss in value due to each alternative (relative to the Highway case) by the average tax rate.

9. RESULTS

9.1 INTRODUCTION

It should be reemphasized that the results portrayed here for the systems examined relate to urbanwide service by relatively "pure" forms of the systems. The results are, therefore, somewhat simplistic, and are intended to provide insight into systems applicability and utility rather than definitive statements on the inherent worth of the systems. The systems are compared by maintaining for all systems an "access time" criterion of 8.5 minutes between initiation of travel (or request for service) and the motion of the first vehicle boarded (with the exception of dual mode personal vehicles for which the criterion is applied to the time between leaving the origin and entry to the automated guideway). Although this provides a consistent service basis upon which to evaluate systems, it certainly does not optimize any of the systems. These results, therefore, provide a basis for comparison of the systems, as opposed to a judgement of the value of individual systems per se.

9.2 SERVICE

Figure 19 indicates the service levels which were attained by the various systems. As a measure of system extent and density, route miles for each baseline are shown. A limited bus system with only 500 route miles accompanies the 175 miles of new freeway construction in the Highway Base Case. Twice the bus route miles are provided in the Comprehensive Bus case. Both the Exclusive Bus and the Rapid Rail systems have 110 system route miles on exclusive rights-of-way and 750 miles of bus feeder routes on local streets. A route mile figure for Dial-A-Ride is inappropriate, since this system has the potential to operate on all streets. The Dual Mode guideway has 150 route miles, with dial-a-ride buses and personal vehicles traveling on local streets providing access. PRT has the most extensive guideway, with 825 route miles providing comprehensive urbanwide coverage.

	HIGHWAY BASE CASE	COMPRE- HENSIVE BUS	EXCLUSIVE BUS	RAPID RAIL	DIAL-A- RIDE	DUAL MODE	PRT
SYSTEM ROUTE MILES	175 fwy. 500 bus	1100	110+ 750 fdr	110+ 750 fdr	-	150	825
TRANSIT MODAL SPLIT DAILY (%) PEAK CBD (%)	4 26	9 44	8 42	8 41	13 52	17 61	14 53
TRANSIT MODE AVERAGE DOOR-TO-DOOR SPEED (MPH)	9	12	15	16	15	22	23
PEAK PERIOD SURFACE ARTERIAL SPEED (MPH)	17	16	16	16	16	18	17
AVERAGE REGIONAL DOOR-TO-DOOR SPEED (MPH)	16	16	17	17	16	19	18
DAILY REGIONAL TIME SAVINGS (YEARS) RELATIVE TO HIGHWAY	-	-2	-2	-2	-13	+25	+23

Figure 19. Comparative Service

The 4% daily average modal split achieved by the bus system in the Highway case approximates that attained by contemporary limited systems common to cities the size of Plastictown. About a quarter of the persons traveling to and from the downtown area during the peak periods use this bus system. Exclusive Bus and Rapid Rail, with networks almost identical to each other and considerably better coverage than the limited bus in the Highway Case, double the daily modal split achieved in that case. Because buses are smaller and can be operated at higher frequency than trains, the Exclusive Bus has a slight edge in peak period CBD travel. The Comprehensive Bus system attains a slightly higher average daily modal split than the Exclusive Bus and Rapid Rail systems, primarily because it provides better local service and, in many cases, more direct service. It is interesting to observe that Dial-A-Ride, a labor intensive system, attracts almost the same ridership as the capital intensive PRT system. This is because overall trip time and convenience are approximately the same for both systems, implying that ridership is sensitive to level of service, whether that level is achieved through labor intensive or capital intensive means. Dual Mode, with its mixture of dial-a-ride minibuses and small personal vehicles, achieves the highest average daily modal split, and captures almost two-thirds of the peak period CBD trips.

Transit mode average door-to-door speed, shown in Figure 19, reflects the total travel time from origin to destination, including all waiting, transfer time, walking, etc. In the Highway case, the transit mode referred to is the limited bus system. For Dual Mode the average reflects both minibuses and personal vehicle travel. Better accessibility and higher line-haul speeds permit all modes to increase average speed compared to the limited bus, with PRT and Dual Mode more than doubling the speed for that case.

Congestion is greatest during peak periods, and one measure of the effectiveness of each of these systems in reducing congestion is speed on surface arterials during peak periods. Reductions in congestion due to the introduction of transit systems provide benefits to highway as well as transit users. As shown in

Figure 19, systems which rely heavily upon the use of buses on local streets have a lesser effect in reducing congestion than new technology systems or the Highway Base Case. The peak period surface arterial speed attained by building 175 miles of new freeway in Plastictown* is the same as that achieved by constructing 825 miles of PRT guideway. Introduction of the Dual Mode system results in slightly greater arterial speeds during peak periods.

Combining transit and highway travel times and distances permits the calculation of average regional door-to-door speeds, as indicated in Figure 19. In the bottom line of this figure, the travel times, reflecting both auto and transit mode travel of each alternative, are compared to the Highway case. The values shown represent the number of years of travel time saved by all travelers every day. Relatively small changes occur with the Comprehensive Bus, Exclusive Bus, and Rapid Rail systems. Travel by Dial-A-Ride involves increased trip distances, compared to direct auto trips, and the large number of small buses on highways contribute to congestion. Thus at the Plastictown demand levels this example of an urbanwide Dial-A-Ride system results in a considerable travel time penalty to the region. Dual Mode and PRT, being fast themselves and diverting previous highway users onto exclusive guideways, attain rather large savings in travel time -- as much as 25 years saved every day.

9.3 COSTS

Any savings in travel time are not achieved without a cost, as shown in Figure 20. Tables 10 and 11 show breakdowns of the system capital and annual costs, respectively. The system capital costs range from a low of less than $100 million for Comprehensive Bus to over $3 billion for the PRT. The $1.4 billion shown for the Highway case is primarily the cost of constructing the 175 miles of new freeway. (The cost of bus purchase for the limited fleet

*The secondary effect on limited bus speed of the relieved arterial congestion due to additional freeway capacity was not considered.

	HIGHWAY BASE CASE	COMPRE-HENSIVE BUS	EXCLUSIVE BUS	RAPID RAIL	DIAL-A-RIDE	DUAL MODE	PRT
SYSTEM CAPITAL COST ($ X 10^6)	1,400(1)	70	250	1,300	130	2,400	3,400
SYSTEM VEHICLE CAPITAL COST ($ X 10^6)	14(2)	64	63	82	110	830	160
SYSTEM ANNUAL OPERATING COST ($ X 10^6)	15(2)	64	88	82	260	120	160
SYSTEM ANNUAL NET REVENUE ($ X 10^6)	-1(2)	-10	-39	-33	-180	+13	-74
SYSTEM ANNUAL CAPITAL PLUS OPERATING COST ($ X 10^6)	17(2)	74	120	210	280	470	540
SYSTEM COST PER PASSENGER TRIP ($)	0.30	0.60	0.90	1.60	1.40	1.60	2.60

(1) HIGHWAY PLUS BUS

(2) BUS SYSTEM ONLY

Figure 20. Comparative Costs

TABLE 10. SYSTEM CAPITAL COSTS

	Highway Base Case(1)	Compre-hensive Bus	Exclusive Bus	Rapid Rail	Dial-A-Ride	Dual Mode	PRT
Total, Millions	1,400	70	250	1,300	130	2,400	3,400
% Guideway	99	-	74	76	-	52	74
% Stations	-	-	-	13	-	6	18
% Vehicles	1	98	25	6	86	35	5
% Other(2)	-	2	1	5	14	7	3

(1) Includes construction of new freeway and purchase of bus fleet.

(2) Includes maintenance, support, storage and control facilities

TABLE 11. SYSTEM ANNUAL CAPITAL PLUS OPERATING COSTS

	Highway Base Case*	Compre-hensive Bus	Exclu-sive Bus	Rapid Rail	Dial-A-Ride	Dual Mode	PRT
Total, $Millions	17	74	120	210	280	470	540
% Capital	21	14	24	61	7	74	70
% Operating	79	86	76	39	93	26	30

*Includes bus portion only.

required represents only $14 million of the total.) For the two bus systems which operate totally on the street network, capital costs are predominantly those for bus purchase. For all other systems, the costs of acquisition of rights-of-way and construction of guideway and associated station facilities predominate. The Dual Mode vehicle costs include the purchase of dial-a-ride mini-buses and small personal vehicles, the latter than being rented to users.

The same fare was charged for the same origin to destination trip in each system. Thus revenues reflect ridership and distribution of transit trip lengths typical of each system. System annual net revenue is the difference between revenues and the operating costs, excluding all debt service. This is portrayed graphically in Figure 21, which shows the annual capital and operating costs incurred by the system operator versus the revenues for each system. The bus systems are all dominated by operating costs, reflecting the intensive use of labor. The remaining systems, which rely more heavily on automation, are capital intensive. The only system for which revenues exceed operating costs is Dual Mode. Dial-A-Ride and PRT sustain large operating losses. The lowest costs are incurred by the limited bus system associated with the Highway case. This system also provides the lowest level of service. It is clear from the figure that some form of capital subsidy is required for all of the systems examined.

Figure 22 is a plot of the annual system operating plus capital costs of the urbanwide "clean" systems examined versus the modal split attained by each. The increasing trend shown by the band would seem to indicate that increased ridership for transit is attained through increased investment to improve service. Were these systems optimized for their service areas, or were appropriate combinations of systems introduced, it is expected that a given modal split might be attained with a lower investment, resulting in counter-clockwise rotation of the band (increased slope).

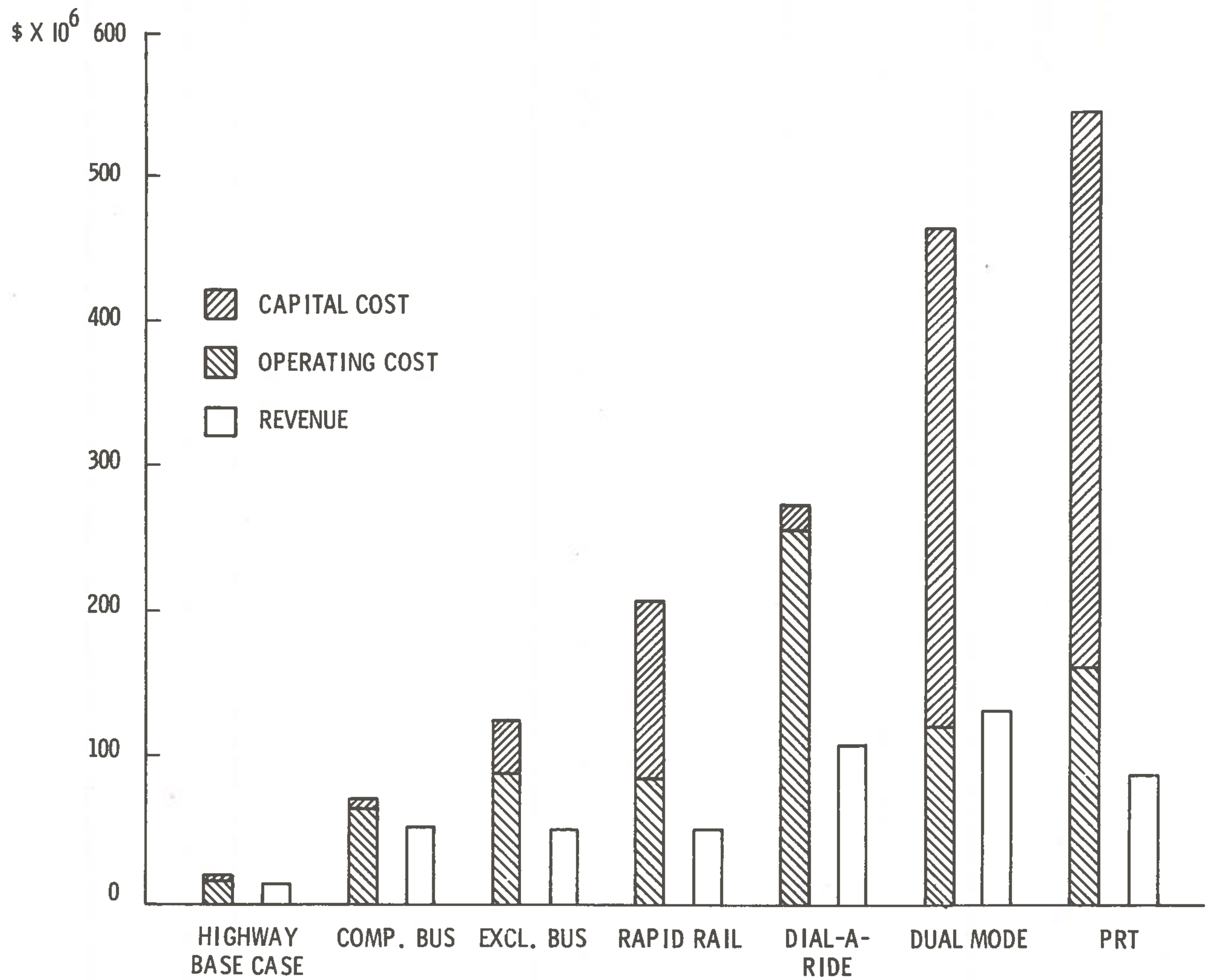


Figure 21. Annual System Operator Costs and Revenues

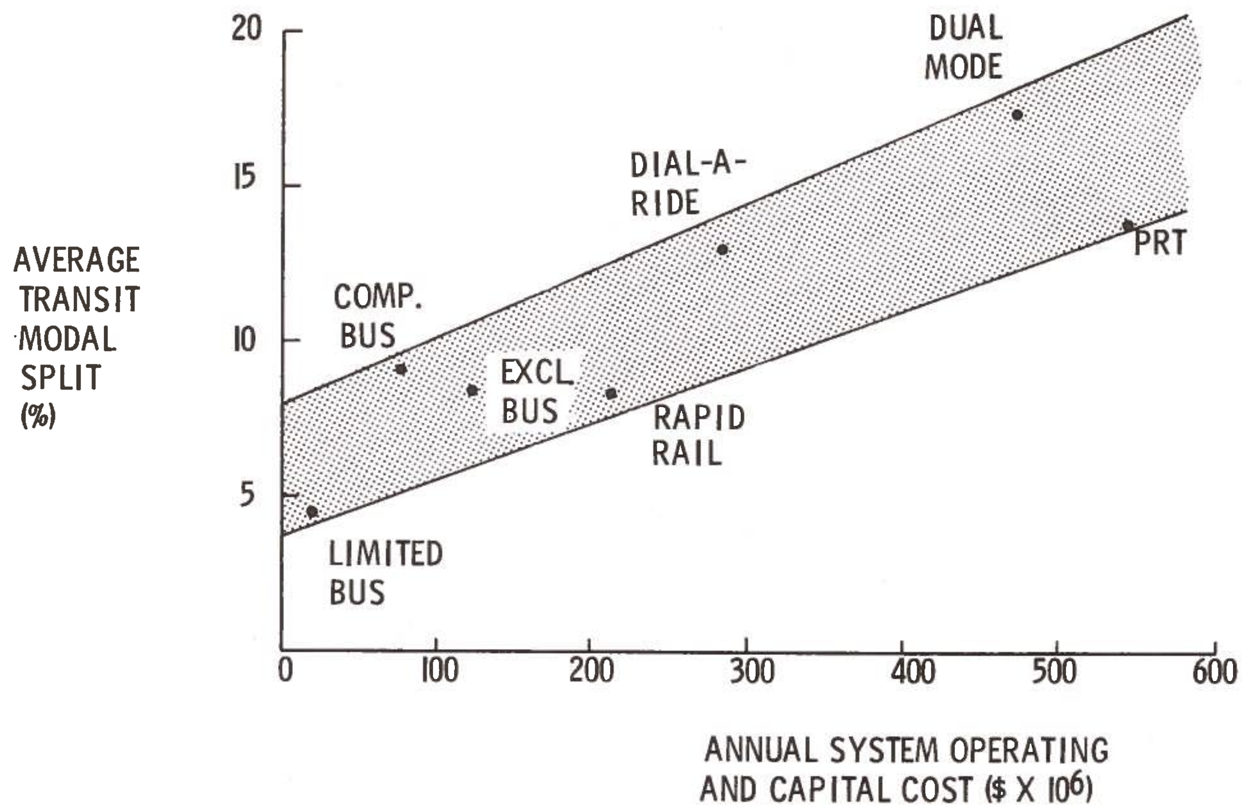


Figure 22. Relationship of Modal Split to System Annual Cost

9.4 IMPACTS

One of the primary objections to continued freeway construction in urban areas is the resultant community disruption. This is reflected by the estimated number of households displaced, as shown in Figure 23. Construction of 175 miles of freeway displaces almost three times as many households as 825 miles of PRT system.

Tax revenue changes throughout the region are greatest for those systems which permit the largest increase in accessibility. Energy consumption and pollution are calculated on an annual basis for all forms of transportation, except goods movement, within the region. Because of the heavy energy consumption rate of buses and the high level of service provided, introduction of the bus systems resulted in increased consumption of energy for regional transportation. The greater energy use of the Dual Mode and PRT systems compared to the Highway case reflects one price paid for higher speeds attained. Pollution figures mirror energy use, and reflect pollution at power generation stationary sources (for the electrically powered systems), as well as that produced by moving vehicles.*

9.5 COST AND BENEFITS

Figure 21 showed the cash flow of the system operator -- the annual costs and revenues associated with the operation of each system. Figure 24 shows the derivation of annual dollar benefits for each alternative relative to the Highway Base Case. The quantitative units of each type of impact relative to the Highway alternative are multiplied by the respective assumed dollar value per unit to obtain monetary benefits. Those benefits which accrue

*Caution should be taken in the interpretation of the energy and pollution figures presented. Because of the limited scope of this study, these values were calculated in a rather simplistic manner, as described in Chapter 8, and thus do not reflect some of the intricacies of what is admittedly a complex process.

	HIGHWAY BASF CASE (1)	COMPRE-HENSIVE BUS	EXCLUSIVE BUS	RAPID RAIL	DIAL-A-RIDE	DUAL MODE	PRT
HOUSEHOLDS DISPLACED	17,000	20	200	500	90	6,100	7,000
TAX REVENUE CHANGES (2)	-	+14	+22	+24	+6	+80	+63
ANNUAL TRANSPORTATION (3) ENERGY CONSUMPTION (BTU X 10^{12})	15	16	16	15	16	17	17
ANNUAL TRANSPORTATION (3) POLLUTION GENERATION (LBS X 10^{6})	55	59	65	56	58	60	58

(1) HIGHWAY PLUS BUS

(2) RELATIVE TO HIGHWAY

(3) GOODS MOVEMENT NOT INCLUDED

Figure 23. Comparative Impacts

Impact (Relative to Highway Base Case)	Quantitative Units	Dollar Value Per Unit	Total $ Benefits ($ x 10^6)	Annual $ Benefits ($ x 10^6)
DUAL MODE				
Travel Time Savings	66.6 x 10^6 hrs/yr	$3.00/hour	-	200
Driver Relief	44.3 x 10^6 hrs/yr	$1.50/hour	-	66
Displacement Savings				
Relocation (Household)	11,000 households	$1,604/household	18	2
Aggravation (Household)	11,000 households	$20,000/household	220	22
Relocation (Business)	1,500 businesses	$3,076/business	5	1
Total				25
Land Value Increase (Access.)	18.3% incr. in speed	Note 1	3,570	357
Tax Revenue Increase				
Savings in Land Acquisition	370 x 10^6	$20/$100 annually	-	8
Land Value Increase-Access.	3,570 x 10^6	$20/$100 annually	-	72
Total				80
Total Benefits				728
PRT				
Travel Time Savings	60.3 x 10^6 hrs/yr	$3.00/hour	-	181
Driver Relief	32.3 x 10^6 hrs/yr	$1.50/hour	-	48
Displacement Savings				
Relocation (Household)	10,000 households	$1,604/household	16	2
Aggravation (Household)	10,000 households	$20,000/household	200	20
Relocation (Business)	1,600 businesses	$3,076/business	5	1
Total				23
Land Value Increase (Access.)	13.9% incr. in speed	Note 1	2,720	272
Tax Revenue Increase				
Savings in Land Acquisition	382 x 10^6	$20/$100 annually	-	8
Land Value Increase-Access.	2,720 x 10^6	$20/$100 annually	-	55
Total				63
Total Benefits				587

(1) The percentage increase in speed was used to determine the percentage increase in land value, which in turn was applied to the base value on land in the affected region (about $15 billion) to obtain the net increase in land value.

Figure 24. Dollar Valuation of Benefits

Impact (Relative to Highway Base Case)	Quantitative Units	Dollar Value Per Unit	Total $ Benefits ($ x 10^6)	Annual $ Benefits ($ x 10^6)
DIAL-A-RIDE				
Travel Time Savings	-32.8 x 10^6 hrs/yr	$3.00/hour	-	- 98
Driver Relief	42.3 x 10^6 hrs/yr	$1.50/hour	-	63
Displacement Savings				
Relocation (Household)	17,000 households	$1,604/household	27	3
Aggravation (Household)	17,000 households	$20,000/household	340	34
Relocation (Business)	1,600 businesses	$3,076/business	5	1
Total				38
Land Value Increase (Access.)	1.2% incr. in speed	Note 1	-280	- 28
Tax Revenue Increase				
Savings in Land Acquisition	584 x 10^6	$20/$100 annually	-	12
Land Value Increase-Access.	-280 x 10^6	$20/$100 annually	-	- 6
Total				6
Total Benefits				- 19
RAPID RAIL				
Travel Time Savings	-4.1 x 10^6 hrs/yr	$3.00/hour	-	- 12
Driver Relief	14.1 x 10^6 hrs/yr	$1.50/hour	-	21
Displacement Savings				
Relocation (Household)	17,000 households	$1,604/household	27	3
Aggravation (Household)	17,000 households	$20,000/household	340	34
Relocation (Business)	1,500 businesses	$3,076/business	5	1
Total				38
Land Value Increase (Access.)	3.2% incr. in speed	Note 1	633	63
Tax Revenue Increase				
Savings in Land Acquisition	568 x 10^6	$20/$100 annually	-	11
Land Value Increase-Access.	633 x 10^6	$20/$100 annually	-	13
Total				24
Total Benefits				134

(1) The percentage increase in speed was used to determine the percentage increase in land value, which in turn was applied to the base value on land in the affected region (about $15 billion) to obtain the net increase in land value.

Figure 24. Dollar Valuation of Benefits (cont.)

Impact (Relative to Highway Base Case)	Quantitative Units	Dollar Value Per Unit	Total $ Benefits ($ x 10^6)	Annual $ Benefits ($ x 10^6)
EXCLUSIVE BUS				
Travel Time Savings	-4.3×10^6 hrs/yr	$3.00/hour	-	-13
Driver Relief	14.0×10^6 hrs/yr	$1.50/hour	-	21
Displacement Savings				
Relocation (Household)	17,000 households	$1,604/household	27	3
Aggravation (Household)	17,000 households	$20,000/household	340	34
Relocation (Business)	1,500 businesses	$3,076/business	5	1
Total				38
Land Value Increase (Access.)	2.5% incr. in speed	Note 1	493	49
Tax Revenue Increase				
Savings in Land Acquisition	577×10^6	$20/$100 annually	-	12
Land Value Increase-Access.	493×10^6	$20/$100 annually	-	10
Total				22
Total Benefits				117
COMPREHENSIVE BUS				
Travel Time Savings	-4.6×10^6 hrs/yr	$3.00/hour	-	-14
Driver Relief	15.2×10^6 hrs/yr	$1.50/hour	-	23
Displacement Savings				
Relocation (Household)	17,000 households	$1,604/household	27	3
Aggravation (Household)	17,000 households	$20,000/household	340	34
Relocation (Business)	1,600 businesses	$3,076/business	5	1
Total				38
Land Value Increase (Access.)	0.4% incr. in speed	Note 1	87	9
Tax Revenue Increase				
Savings in Land Acquisition	583×10^6	$20/$100 annually	-	12
Land Value Increase-Access.	87×10^6	$20/$100 annually	-	2
Total				14
Total Benefits				70

(1) The percentage increase in speed was used to determine the percentage increase in land value, which in turn was applied to the base value on land in the affected region (about $15 billion) to obtain the net increase in land value.

Figure 24. Dollar Valuation of Benefits (cont.)

only once (i.e., displacement savings and land value increases) are converted to annual values using a 10% interest rate and an infinite lifetime.

Expanding beyond the transit system operator or user perspective, Figure 25 compares the annual incremental costs and benefits to the entire region (Plastictown) for each of the alternatives examined.

These incremental values reflect the total annual capital and operating costs and aggregated benefits of all transportation systems in the region, including automobile as well as transit for each alternative, relative to the costs and benefits of the Highway alternative. Thus installation of the Comprehensive Bus system would result in an annual capital and operating cost savings of $100 million for all regional travel compared to the costs incurred by the Highway Base Case. Also, the benefits of the Comprehensive Bus system to the entire region would exceed Highway alternative benefits by almost $100 million, resulting in a regional net incremental gain of about $200 million per year for the Comprehensive Bus compared to the Highway system.

Only the Dial-A-Ride system results in a net incremental loss compared to the Highway Base Case, due to the high operating costs and relatively high time penalties of the urbanwide application of Dial-A-Ride. The largest net incremental gains are achieved by the Dual Mode and PRT systems, but at the highest costs. Dual Mode results in larger benefits and lower annual costs to the region than PRT. The Exclusive Bus system achieves almost the same benefits as Rapid Rail, but permits an annual cost savings compared to a cost increase incurred by the Rapid Rail system. Thus a greater net incremental gain is realized by the Exclusive Bus.

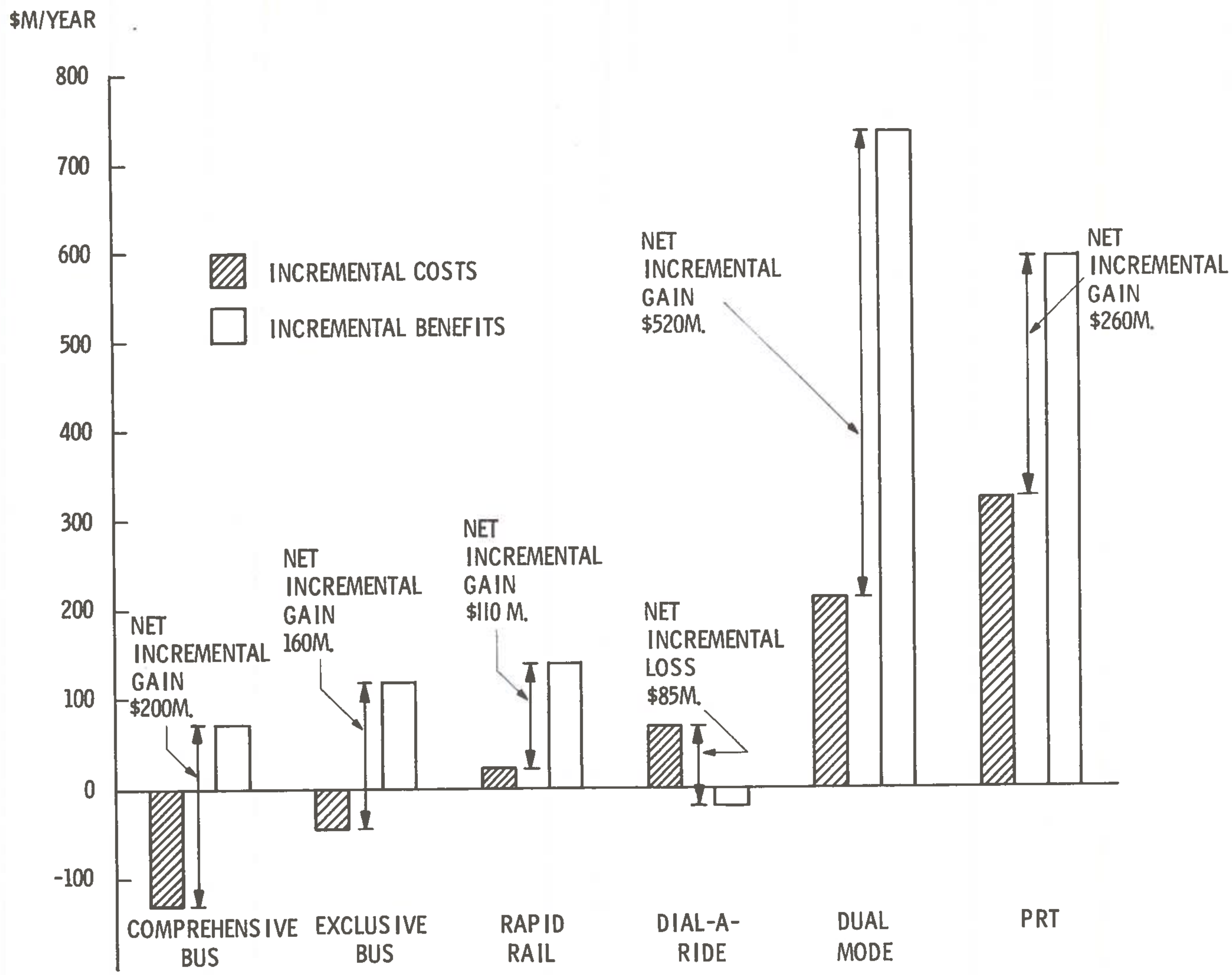


Figure 25. Annual Incremental Costs and Benefits (Relative to Highway Base Case)

10. IMPLICATIONS

This analysis has demonstrated that for urbanwide applications of specific transit systems, when access time is held constant, increased ridership can be achieved when quality and level of service are increased. Furthermore, such increases are obtained, either through increased service levels of an individual system or through introduction of more complex systems, by appropriately greater expenditures. In general, then, transit ridership seems to vary with system cost, assuming this investment buys better service.

Further, and more important, the insight obtained from the analysis suggested specific areas of effective application for each system. That is, each system seems to have a given application in which it appears to be most attractive. These qualities of system effectiveness can be characterized by attributes such as trip length, service area trip density, system loading* and coverage. Figure 26 portrays this relationship for the first two of these factors. Trips are characterized as short (neighborhood, local) versus long (across the urban area). Service area trip density varies from low (fringes between suburban corridors) to high (central business district).

A highway system -- that is, the automobile -- is represented by the dashed line which includes all trip lengths and almost all service area trip density categories. It is only in high population density areas where there is high system loading -- leading to congestion -- that the automobile is not an effective system. Throughout the rest of the range it provides fast, versatile, flexible, door-to-door, demand actuated, attractive service to those who can afford and can operate an automobile. To those who for some reason cannot drive, a limited bus system can provide a minimal level of service. Thus the highway is a system with

*Measured in load factor or vehicle density on the available right-of-way, depending on the system.

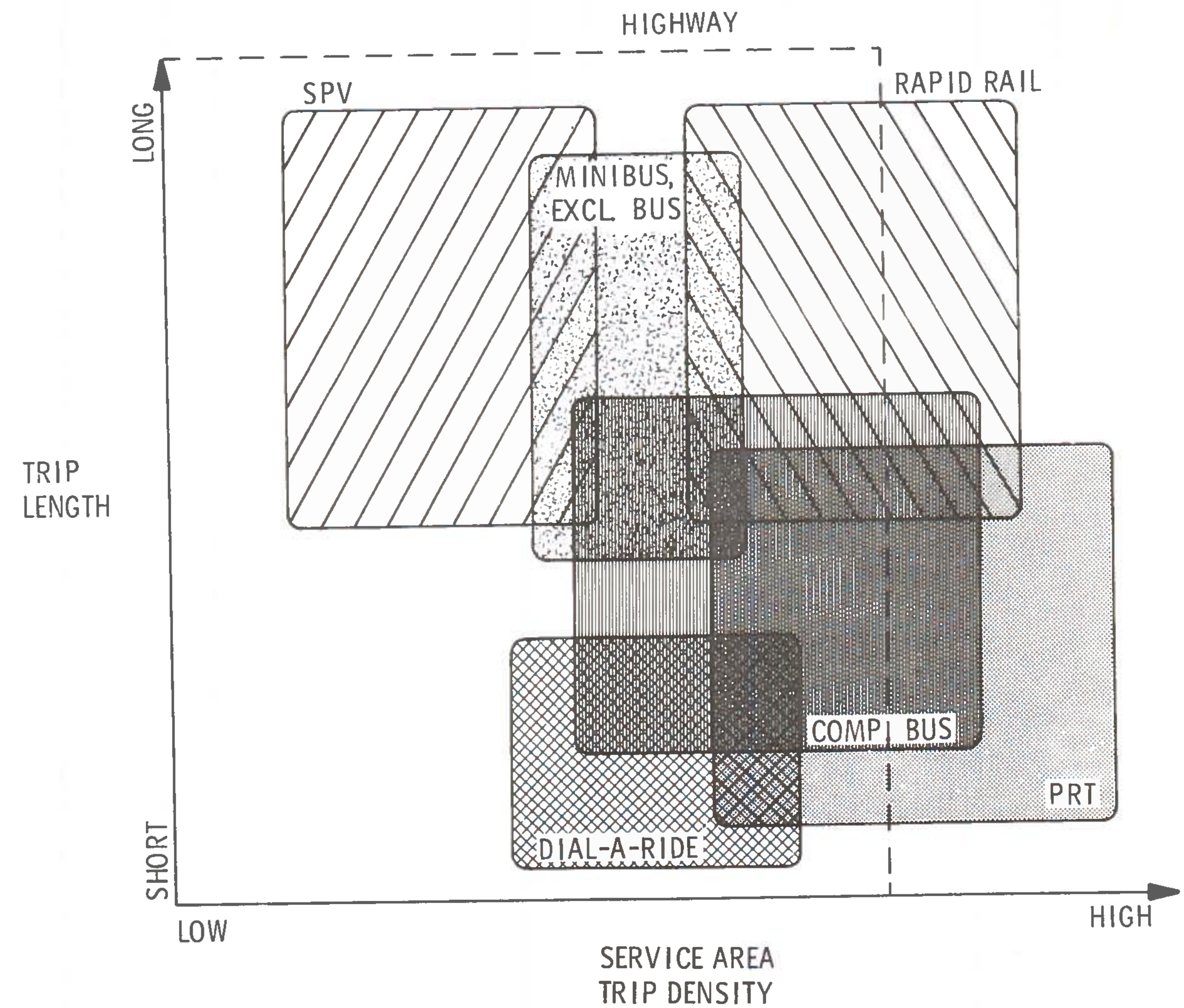


Figure 26. Effective System Performance

regional coverage and application in all but the densest areas.

A comprehensive bus network, with vehicles operating on existing streets with many stops, provides relatively slow service, and, even with high frequencies, results in large travel times. Only in serving short to medium trip lengths is it able to maintain relatively acceptable trip times. Medium to high trip densities are required to provide adequate load factors. Low frequency service discourages ridership, while very high frequency service generally results in unacceptably low load factors. Comprehensive bus is most effective as a local service system.

Since exclusive bus and rapid rail systems both use exclusive rights-of-way in order to increase trip speed, both require medium to long trip lengths to make this speed advantage apparent. Further, station spacing is typically relatively wide, essentially prohibiting short trips. At least a medium service area trip density is required to justify the cost of acquiring right-of-way and constructing exclusive guideways. As trip density approaches the higher regions, or as system loading increases, the higher capacity and lower labor costs of rapid rail begin to make it a more attractive system than exclusive bus. For moderate densities and loadings, however, exclusive bus would appear to be more effective. By their very nature, both systems find their best application in corridors, although such corridors need not be radial, nor lead to the CBD.

Because dial-a-ride systems provide demand-responsive, door-to-door service, they are especially sensitive to commonality of origins and destinations for all passengers in one vehicle, and minimization of diversions to accept or discharge riders. The longer the potential trips and the more diverse the possible origins and destinations, the more difficult it becomes to achieve reasonable load factors at acceptable frequencies. Thus dial-a-ride appears to be most suited for the service of short trips. In order to minimize diversions and maintain acceptable load factors, it would appear that medium trip densities may be required. However, it may be possible to design effective systems at low densities, with slightly differing operating strategies from those mentioned above, or with a combination of strategies. Dial-a-ride might then be the lowest cost option for providing public transportation for non-drivers in low density areas.

Since small vehicles are generally used and route structure is undefined, this system is sufficiently flexible to operate with low to medium system loadings. At higher loadings and with more concentrated demand, the larger buses and more structured service of a comprehensive bus system is more economical. Dial-a-ride is a local service system.

A dual mode system incorporates exclusive guideways similar to those in the exclusive bus and rapid rail systems. For the same reasons as described above for those systems, therefore, it is most effective for medium to long trips. Collection and distribution by the small personal vehicle is the same as the automobile, making it applicable in low to medium trip density areas. The minibus operates as a dial-a-ride collector/distributor, making it applicable in medium density areas, as described above. Use of an automated exclusive guideway permits high system loadings on some portions while low loadings for collection and distribution by small personal vehicles on local streets are also effective. Since dual mode combines a highway collector/distributor with an automated exclusive guideway, and encompasses personal vehicles and buses, it includes many of the functions carried out by the other systems examined. Thus, dual mode is really the only regional system examined; all things considered, it has a broader range of effective application than any of the other systems examined except the highway.

A PRT system provides personal demand-actuated origin to destination service (with short walks) on exclusive right-of-way. The high capital costs of an extensive automated guideway network are justified if they can be defrayed by heavy utilization of all guideway segments (medium to high system loading). Thus PRT requires fairly high trip volumes with diverse origins and destinations and medium to high service area trip densities. Because such trip densities are localized, PRT is most effective as a local system serving short to medium trip lengths. PRT stands out from all other systems in its ability to handle heavy traffic in highly congested urban cores.

It should be noted, in examining Figure 26, that only the automobile fills the need for short trip service in low trip density service areas. It is possible that systems such as dial-a-ride may have application in this region, or perhaps such trips are best served by walking, bicycle, and the automobile. It does seem, however, that further study should be devoted to the area of public transportation for short suburban trips.

Only a real transit system combination, dual mode, made a relatively positive showing in this analysis. It is apparent from the preceeding discussion that total urban transportation needs can best be filled by a combination of systems. From Figure 26 it is possible to choose system combinations which may be effective as urbanwide transportation forms. An example is shown in Figure 27.

For medium density areas, a dial-a-ride system may be very effective in providing local service as well as acting as a collection/distribution system for an exclusive bus system operating in high trip density (radial and circumferential) corridors. In higher density areas, a comprehensive bus system may provide better circulation and feeder service than dial-a-ride.

If overall trip densities are greater a combination such as that shown in Figure 28 may be more effective. A dial-a-ride system still provides service in the lower trip density areas, but if a larger number of trips occur along corridors, a rapid rail system may be more attractive than an exclusive bus. Again, in higher population density areas dial-a-ride may be supplanted with a comprehensive bus system. In very high density regions, PRT may be most applicable.

Another possible approach is depicted in Figure 29. In this case the dual mode small personal vehicle would be used for collection and distribution throughout the region, including fringes between suburban corridors. Dual mode dial-a-ride buses would provide service between origin/destination pairs with sufficient demand, while single-mode dial-a-ride buses would provide feeder service

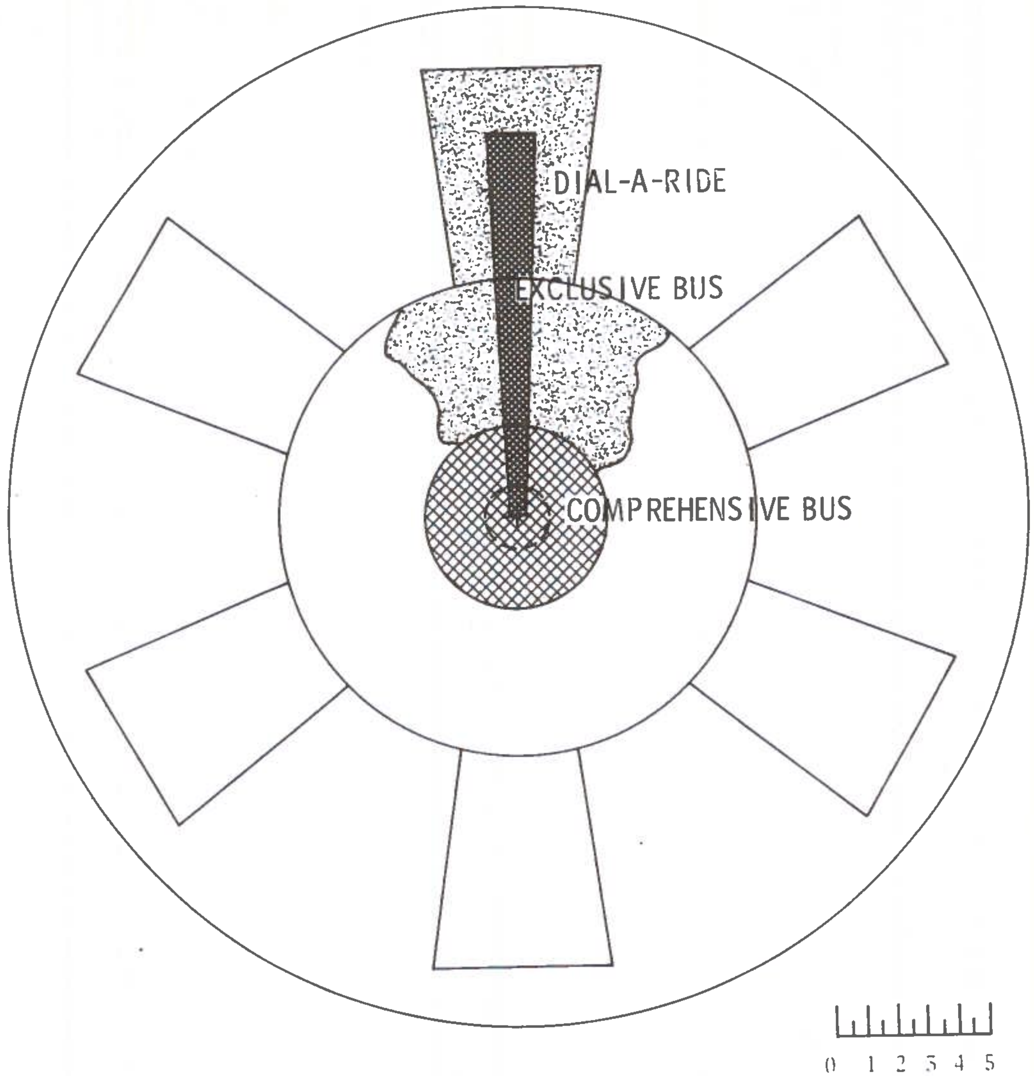


Figure 27. Sample Combination A

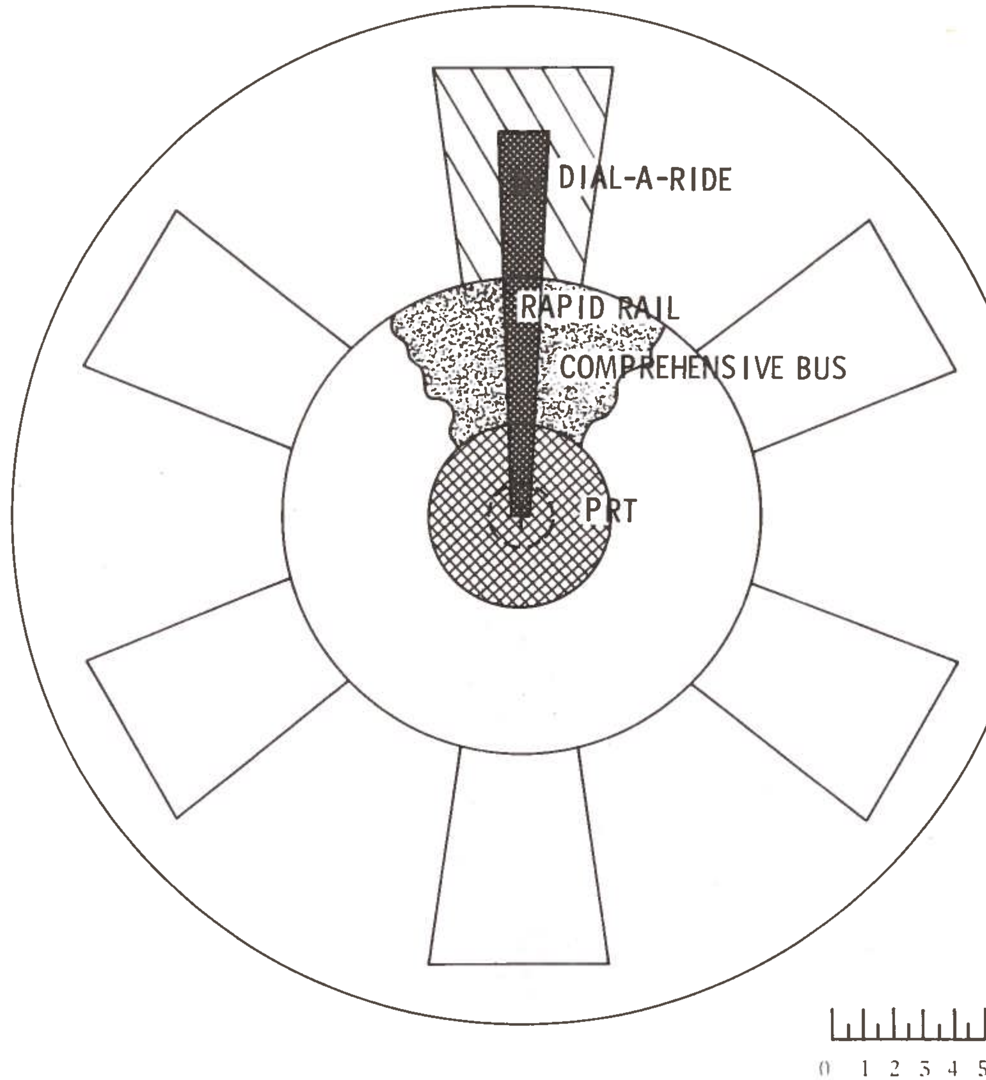


Figure 28. Sample Combination B

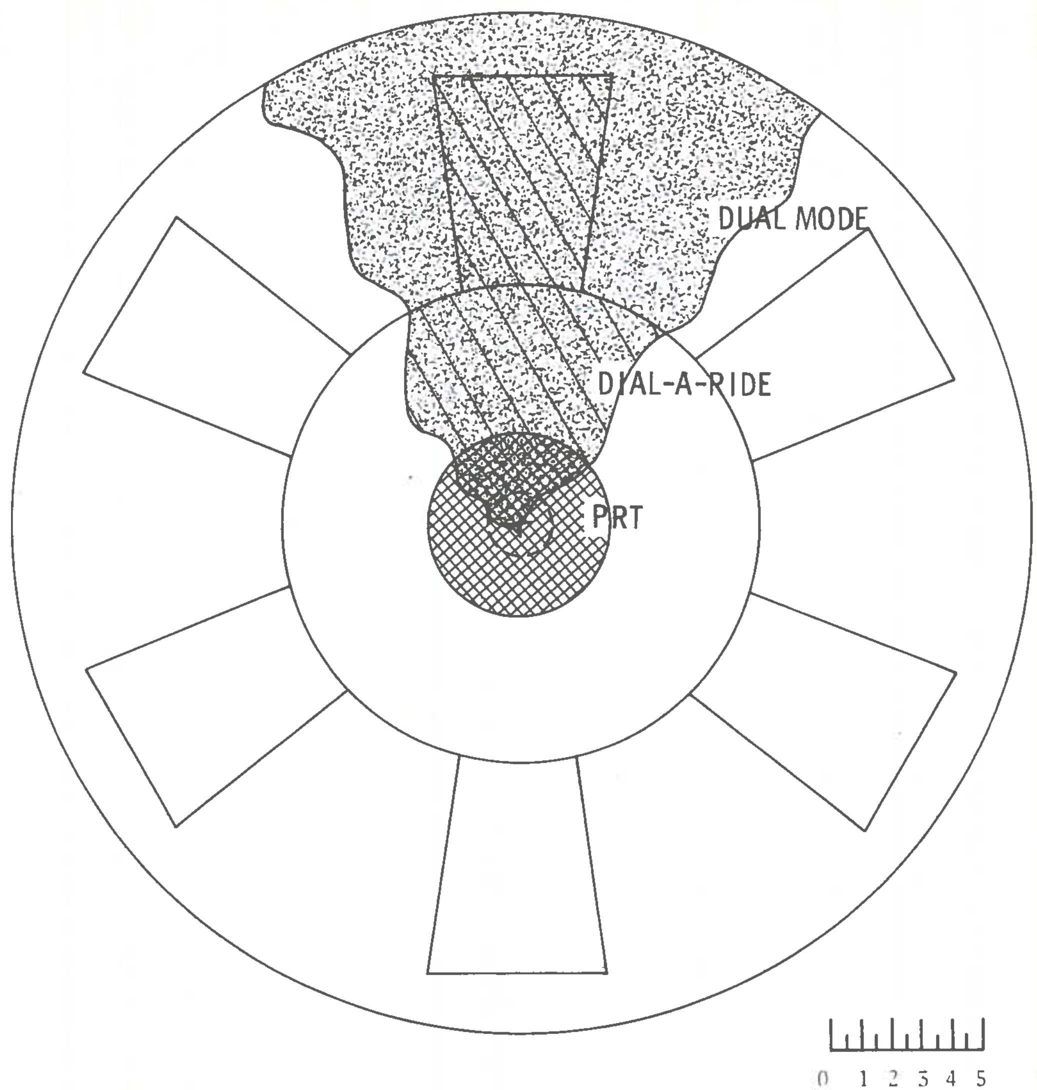


Figure 29. Sample Combination C

to the exclusive guideway. PRT would provide circulation in the core area, and PRT vehicles would be used throughout the dual mode guideway network. For trips where dual mode (origin to destination) dial-a-ride service was not warranted, the user could take a dial-a-ride bus to the guideway and there transfer to a PRT which would either go to the destination or to a station at which the user could transfer to another dial-a-ride for the final leg of the journey. The network would be as extensive as a typical dual mode guideway system, with a denser PRT network as an integral part in the core. The entire exclusive guideway network would be shared by dual mode small personal vehicles, dual mode dial-a-ride minibuses, and personal rapid transit vehicles, thus defraying the capital cost of the fixed facilities over a broad range of users.

There are, of course, many other combinations which are possible, and it is expected that appropriate system combinations will depend heavily upon the detailed characteristics of specific areas to which they are to be applied. Research of the type performed here can only provide rough guidelines. Further research and analysis of the effectivenesss of system combinations is required.

11. CONCLUSIONS

This study provided insight regarding the relative effectiveness of alternative forms of transportation systems. In summary, the conclusions reached in performing this study were the following:

- Increased transit ridership is obtained when quality and level of service are increased, which, in turn, requires greater expenditures. In other words, increased ridership for transit is attained through increased investment to improve service.
- Each transportation system seems to have a given application for which it appears to be most suited. These qualities of system effectiveness can be characterized by attributes such as trip length, service area, trip density, system loading, and coverage.
- The study results and implications discussed in the preceding chapters tend to corroborate the contention that total urban transportation needs can best be filled by a combination of systems, each of which is utilized in the application for which it is most suited.
- Further research and analysis efforts should be devoted to: (1) obtaining increased understanding of the appropriate design and application of public transportation systems; (2) expanding public transportation options for service of short suburban trips; and (3) establishing the relative effectiveness of various regional transportation system combinations.

APPENDIX A
MODE CHOICE MODEL COEFFICIENT

A.1 SELECTION OF COEFFICIENTS

The calibrated coefficients for auto and local bus service are given in Table A-1 along with those selected for use with the alternative modes tested. Since the selection of 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:

- 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 for each alternative mode were selected primarily according to whether the mode might be perceived by the patron to be "transit-like" or "auto-like". This criterion therefore reflected both the service characteristics of the mode and the probable type of rider attracted to the mode (diverted from auto vs. from 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 low excess time coefficient for Local Bus (due primarily to a large captive ridership) was raised for all other systems to reflect higher sensitivity to excess time of the rider diverted from auto, the more "conventional" transit systems raised less than the "new technology" systems. Further, the Dual

TABLE A-1. LOGIT MODEL COEFFICIENTS

Mode	Excess Time (α)	Non-Excess Time (β)	Cost (γ)	Constant (δ)
<u>Calibration Values</u>				
Auto	-.258	-.040	-.026	0
Local Bus	-.030	-.027	-.032	-2.0
<u>Estimated Values</u>				
Auto	-.258	-.040	-.026	0
Local Bus	-.030	-.027	-.032	-2.0
Comprehensive Bus	-.050	-.027	-.032	-1.5
Exclusive Bus	-.050	-.027	-.032	-1.5
Rapid Rail	-.050	-.027	-.032	-1.5
Dial-A-Ride	-.100	-.027	-.032	-1.5
Dual Mode				
SPV	-.258	-.040	-.032	+0.2
Minibus	-.100	-.027	-.032	-0.5
PRT	-.200	-.040	-.032	-0.1

Mode small personal vehicle, which closely resembled the auto, was deemed slightly more comfortable and reliable than the auto since sutomated travel on the guideway eliminated driving and reduced the possibility of unforeseen delays; hence, the slightly higher constant (+0.2) than auto.

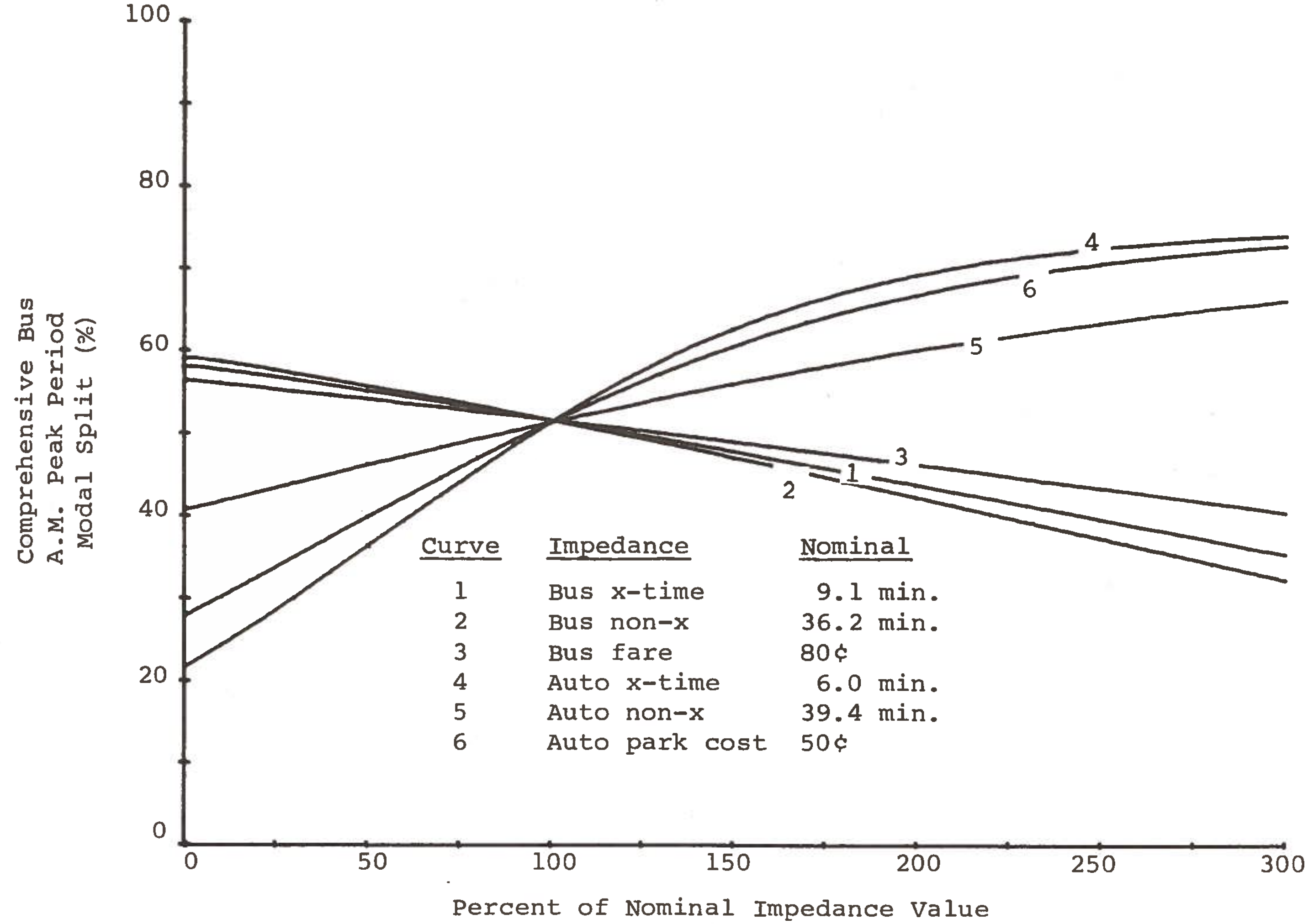
A.2 SENSITIVITY OF COEFFICIENTS

The curves shown in Appendix B can be used to assess the sensitivity of the coefficient values. Since the model is comprised of products of the impendances and the coefficients, a given percent change in an impedance value is equivalent to the same percent change in the associated coefficient. For example, in Figure B-1, the effect on modal split of doubling the bus excess time coefficient is equivalent to doubling the bus excess time and thus can be read from curve 1 at the 200 percent mark of the horizontal axis.

APPENDIX B
MODAL SPLIT SENSITIVITY CURVES

Figures B-1 through B-18 show, for each of the alternative systems (except Highway), the sensitivity of the transit A.M. peak modal split to each of the six trip impedances used in the modal split equation for three origin-destination pair categories: outer ring to CBD, middle ring to middle ring (intra-quadrant), and middle ring to CBD. These three categories comprise approximately three-fourths of the total transit trip ridership in each alternative.

For example, in Figure B-1, the Comprehensive Bus modal split is about 51 percent at the nominal impedance levels indicated (100%). If bus excess time (curve 1) were tripled (300% or 27.3 minutes), holding all other impedances constant, the bus modal split would fall to about 35 percent. Similarly, if auto excess time (curve 4) were tripled (to 18 minutes), the bus modal split would rise to about 73 percent. In interpreting the sensitivity curves, it should be noted that the shapes of the curves are determined by the exponential form of the Logit equation. This form results in the maximum slope occurring at a modal split of 50 percent; that is, the greatest sensitivity is achieved where the quality of service by one mode approaches that of the other. In addition, since the horizontal scale is in terms of percentages, slope comparisons between curves should be made relative to the base impedance values. For example, in Figure B-1 the greater slope of curve 2 (non-excess time) than curve 1 (excess time) indicates a greater modal split difference for a percentage change in non-excess time than for the same percentage change in excess time. However, a one-minute change in excess time will bring about a greater modal split difference than a one-minute change in non-excess time because it represents about four times as large a percentage difference in impedance.



Curve	Impedance	Nominal
1	Bus x-time	9.1 min.
2	Bus non-x	36.2 min.
3	Bus fare	80¢
4	Auto x-time	6.0 min.
5	Auto non-x	39.4 min.
6	Auto park cost	50¢

Figure B-1. Comprehensive Bus Modal Split Sensitivity to Times, Costs (Outer Ring to CBD Trips)

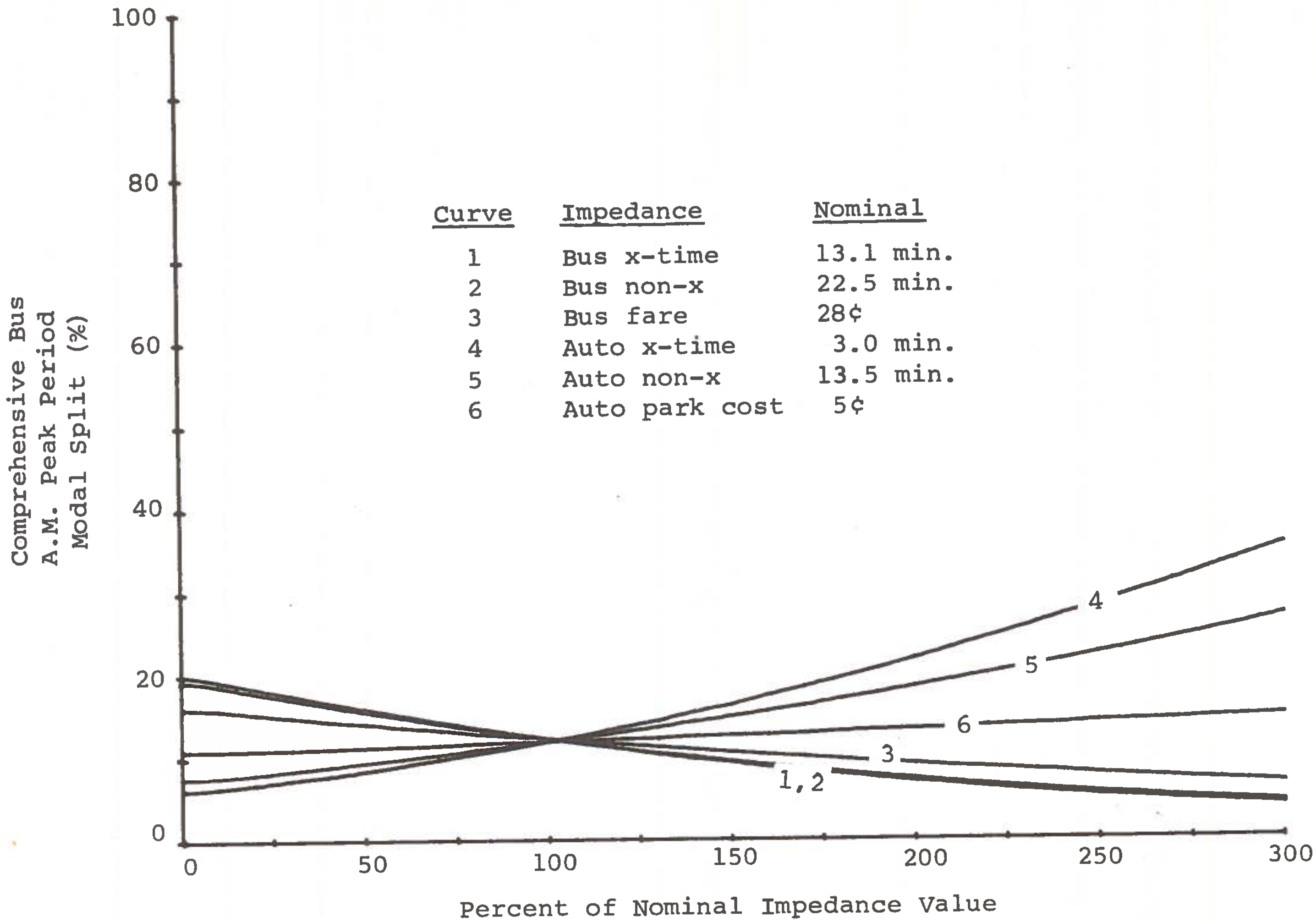


Figure B-2. Comprehensive Bus Modal Split Sensitivity to Times, Costs (Middle Ring Trips)

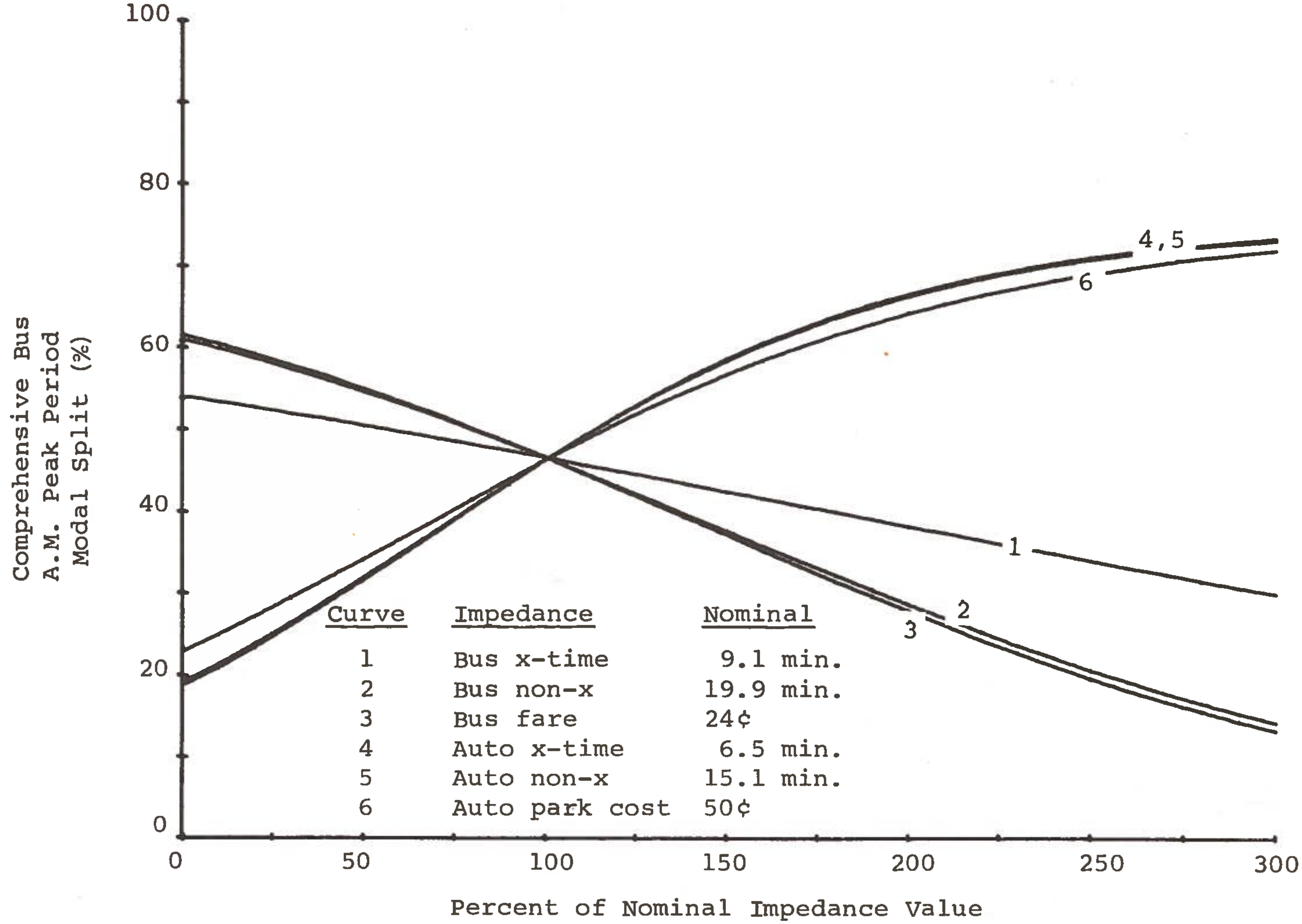


Figure B-3. Comprehensive Bus Modal Split Sensitivity to Times, Costs (Middle Ring to CBD Trips)

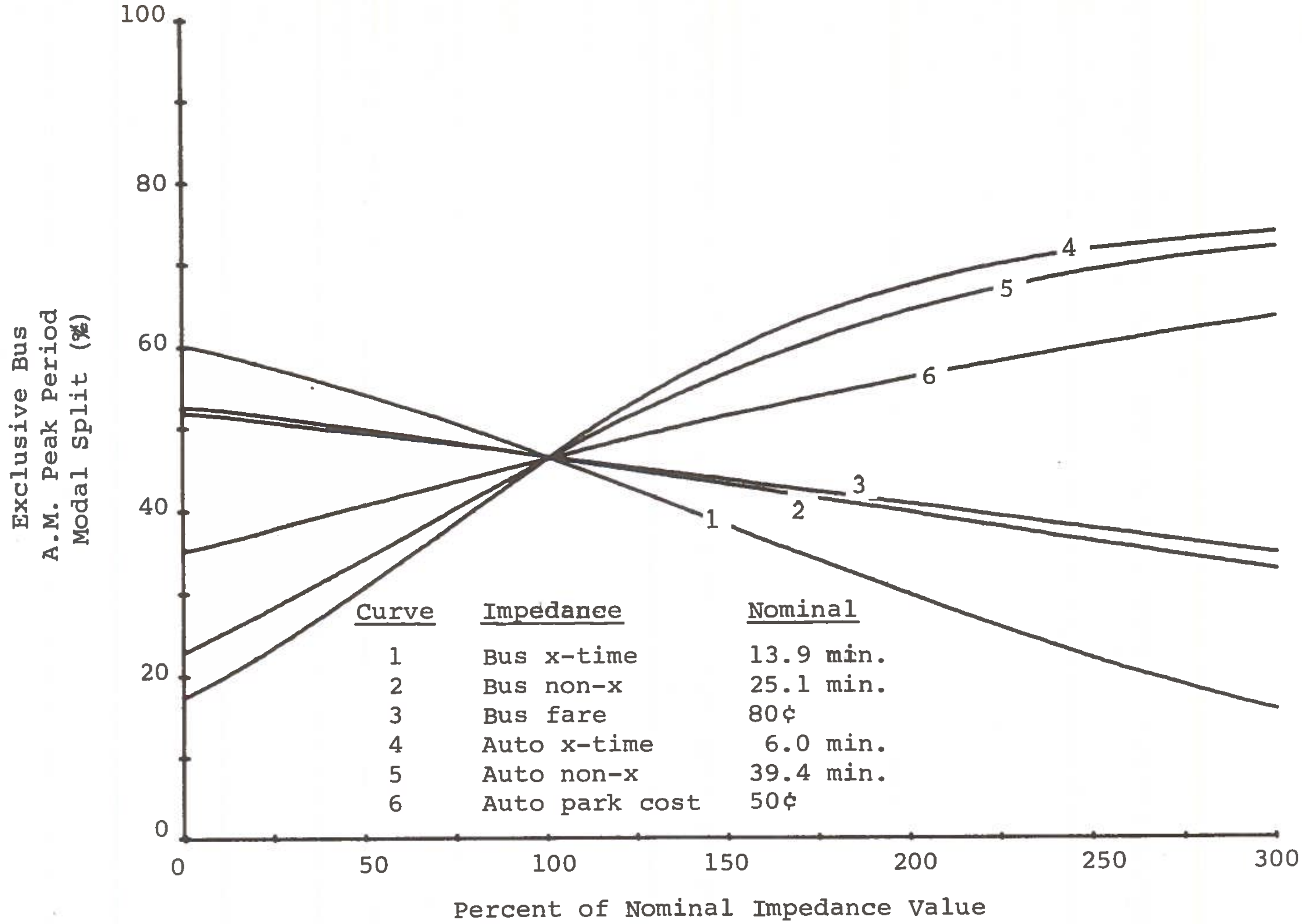


Figure B-4. Exclusive Bus Modal Split Sensitivity to Times, Costs (Outer Ring to CBD Trips)

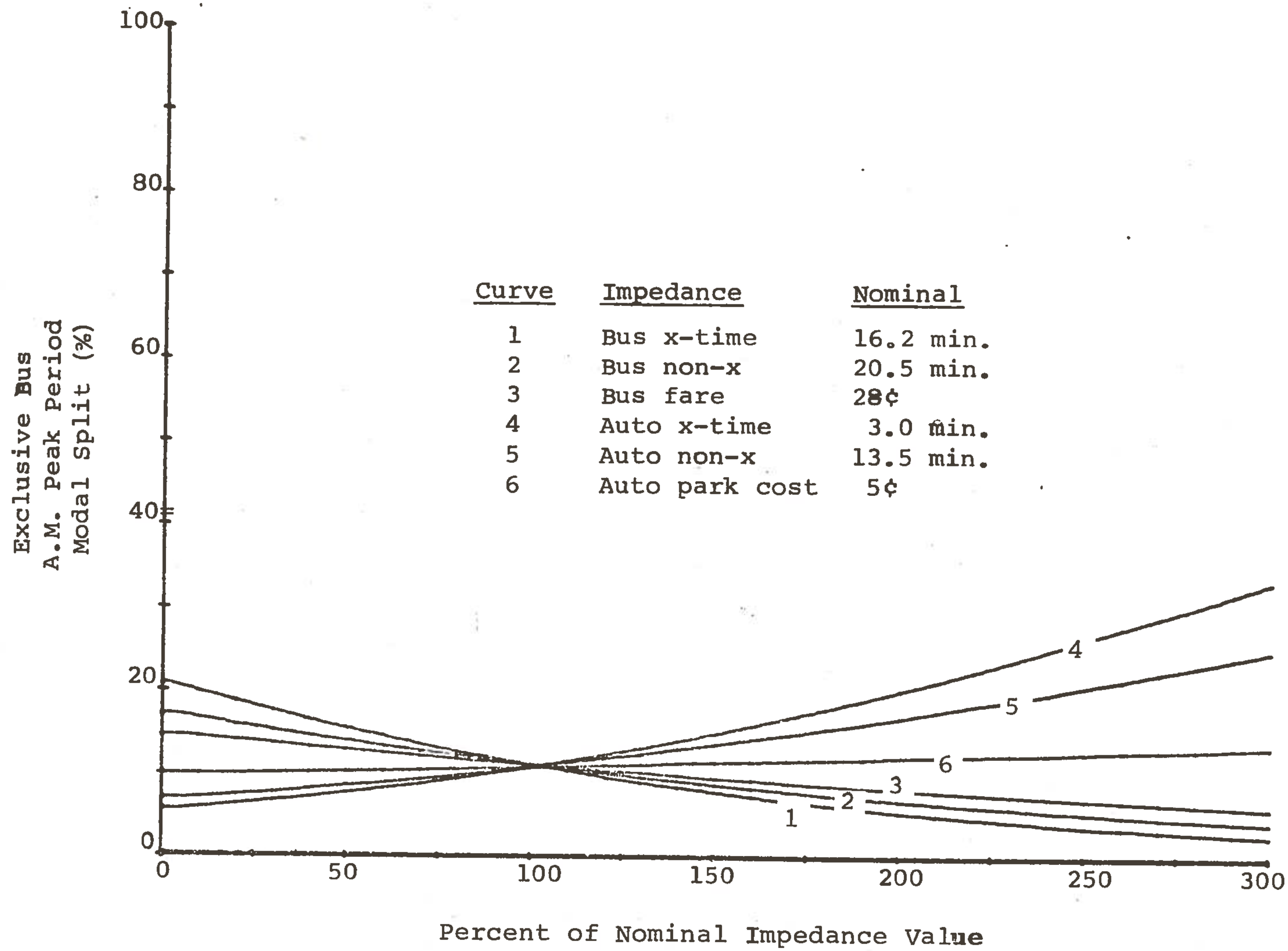


Figure B-5. Exclusive Bus Modal Split Sensitivity to Times, Costs (Middle Ring Trips)

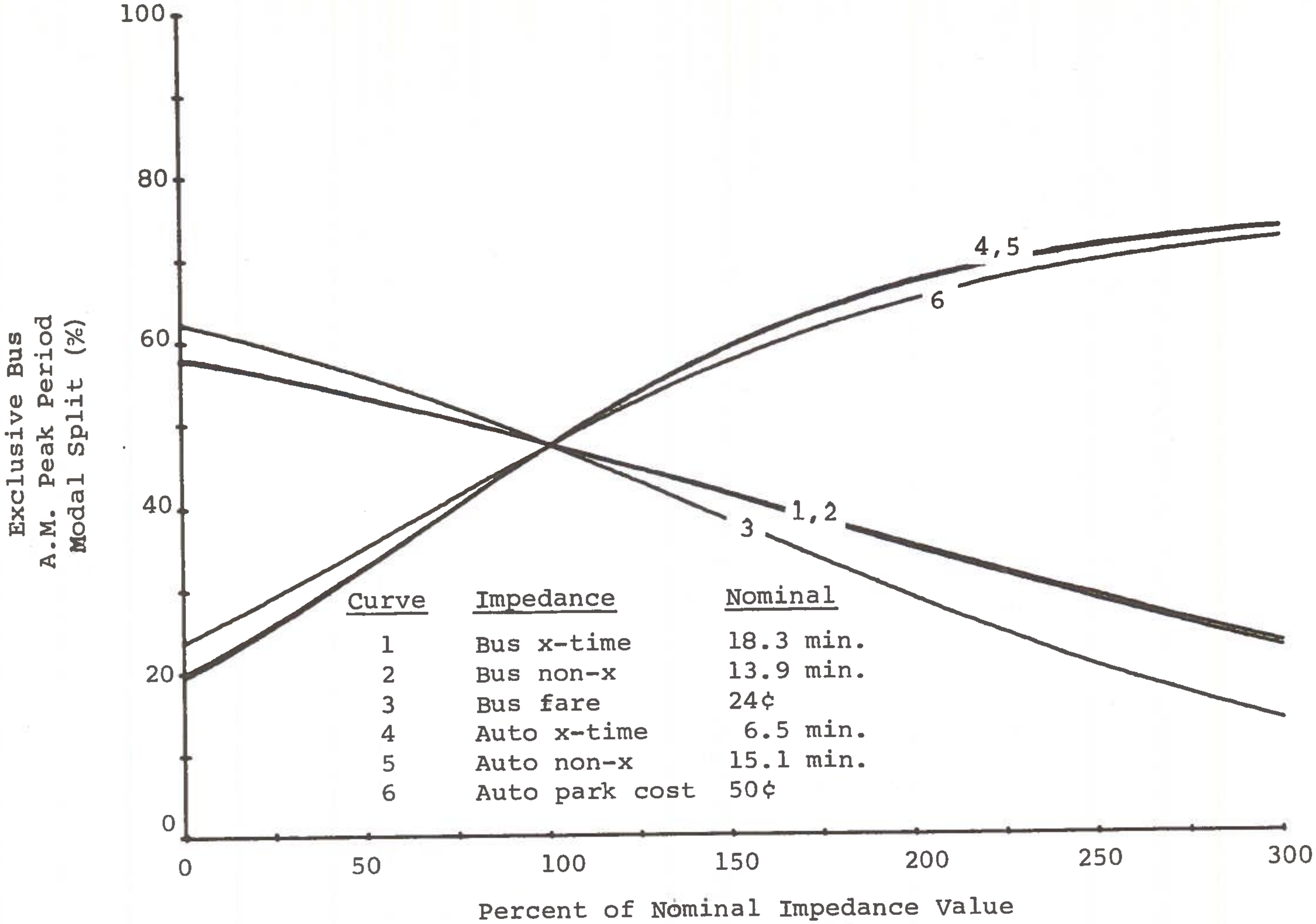


Figure B-6. Exclusive Bus Modal Split Sensitivity to Times, Costs (Middle Ring to CBD Trips)

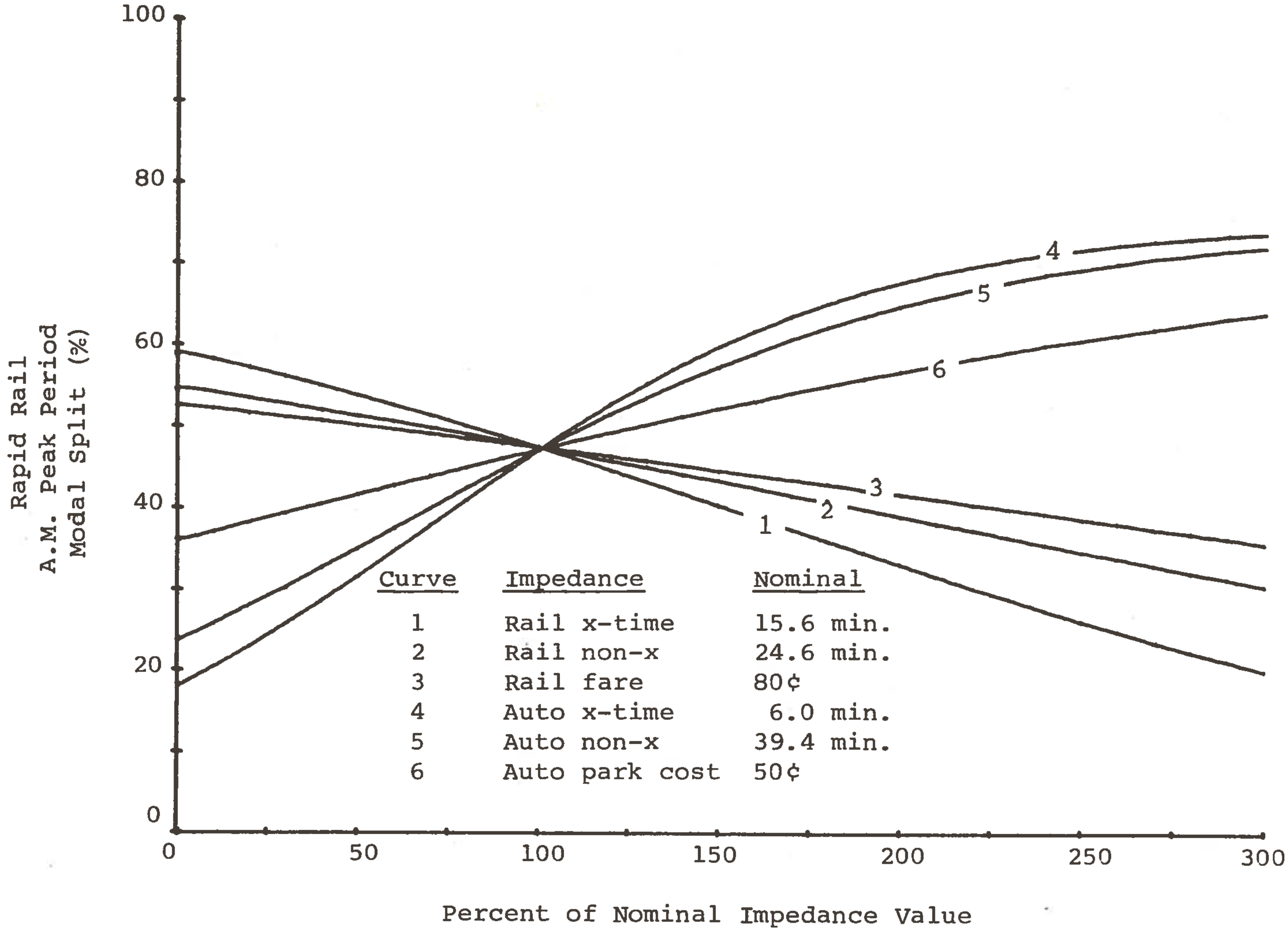


Figure B-7. Rapid Rail Modal Split Sensitivity to Times, Costs (Outer Ring to CBD Trips)

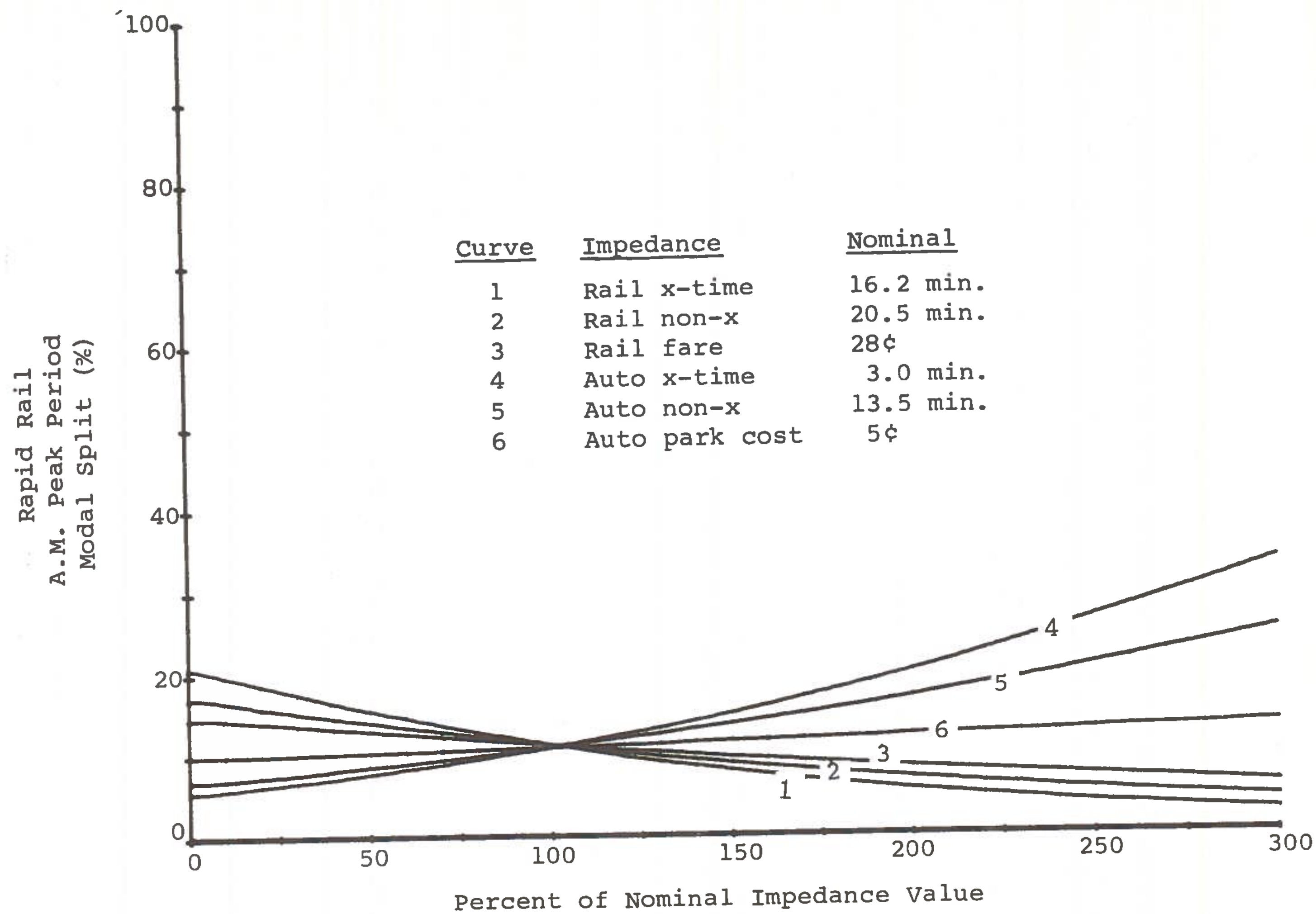


Figure B-8. Rapid Rail Modal Split Sensitivity to Times, Costs (Middle Ring Trips)

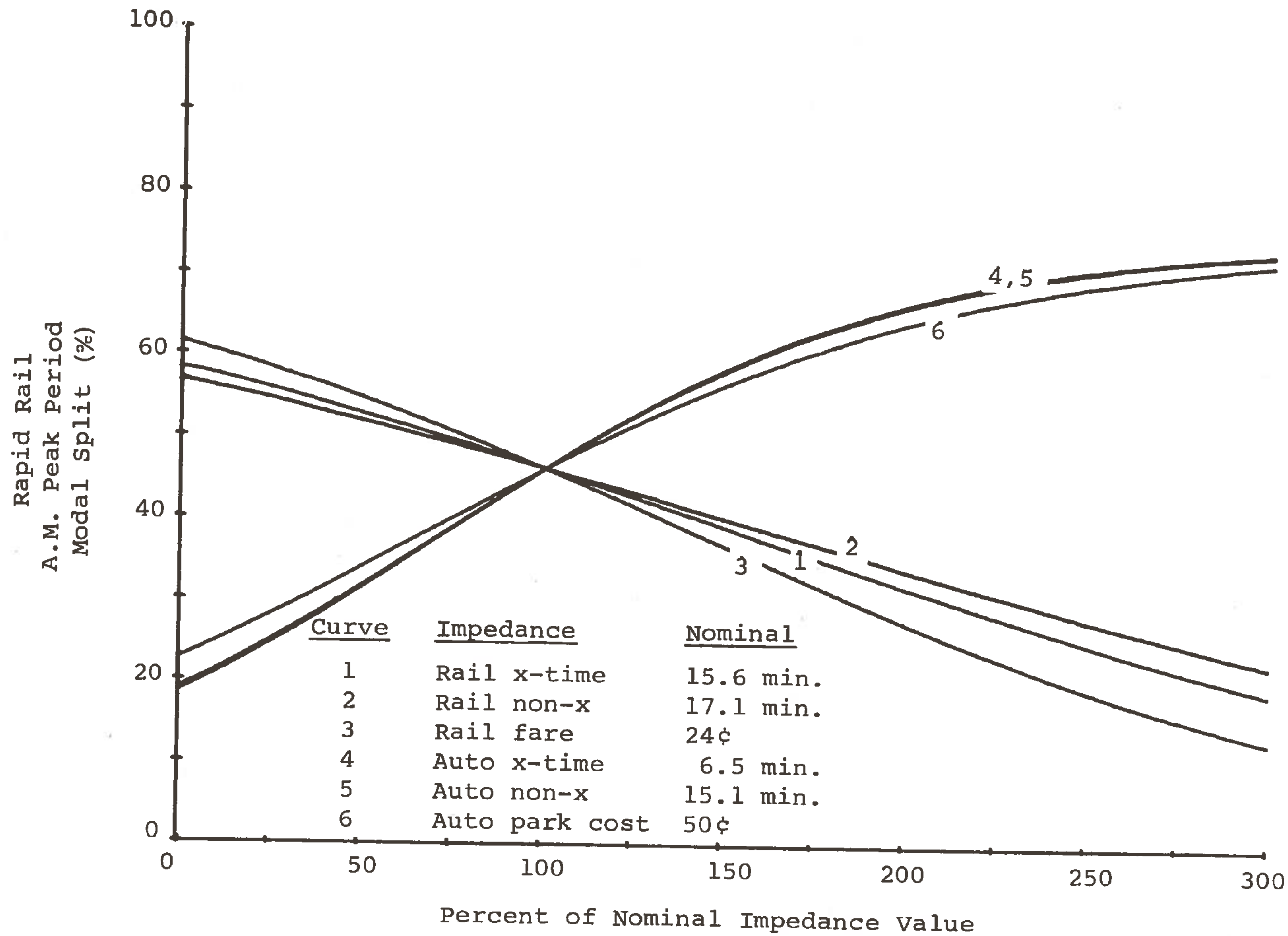


Figure B-9. Rapid Rail Modal Split Sensitivity to Times, Costs
(Middle Ring to CBD Trips)

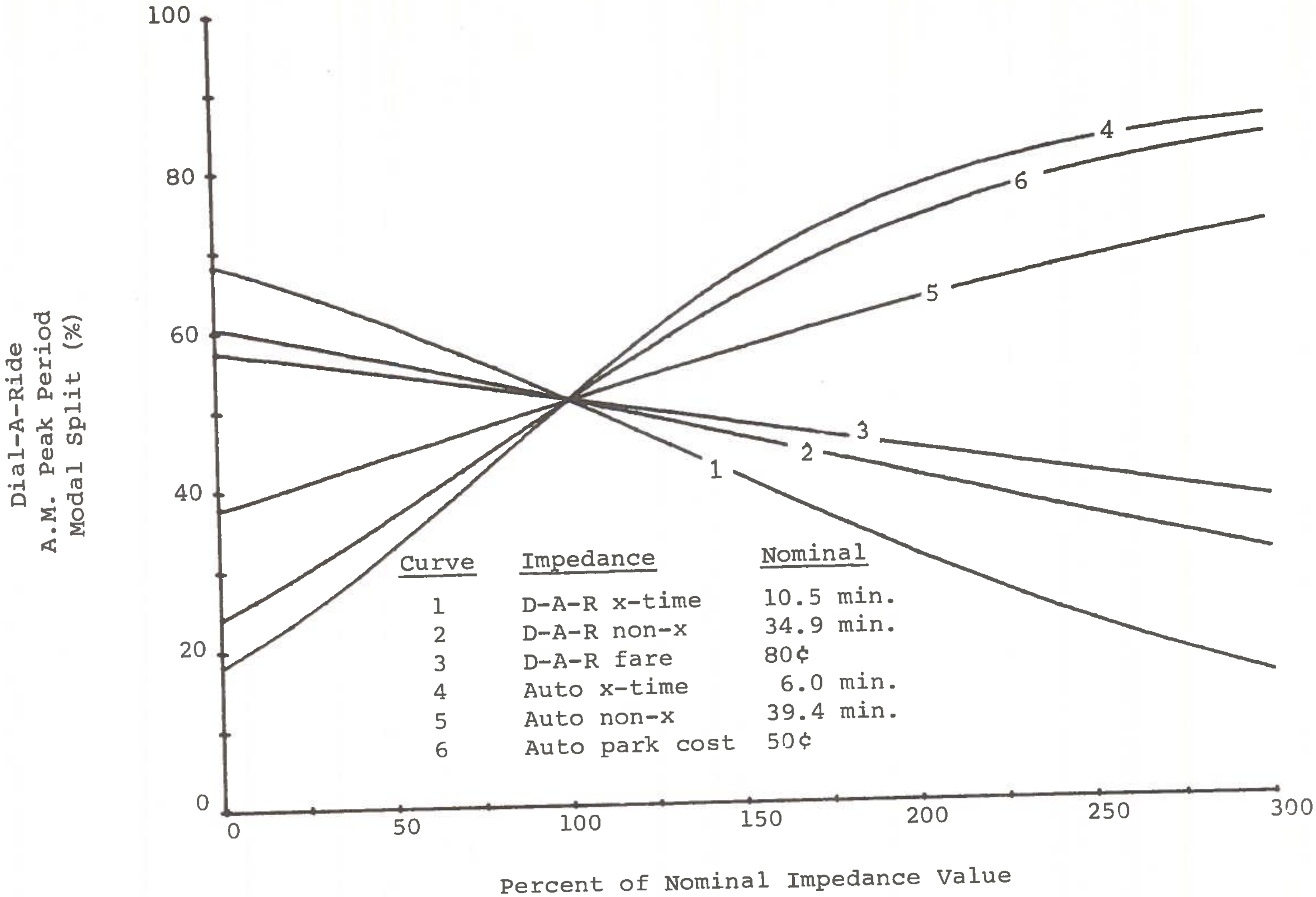


Figure B-10. Dial-A-Ride Modal Split Sensitivity to Times, Costs (Outer Ring to CBD Trips)

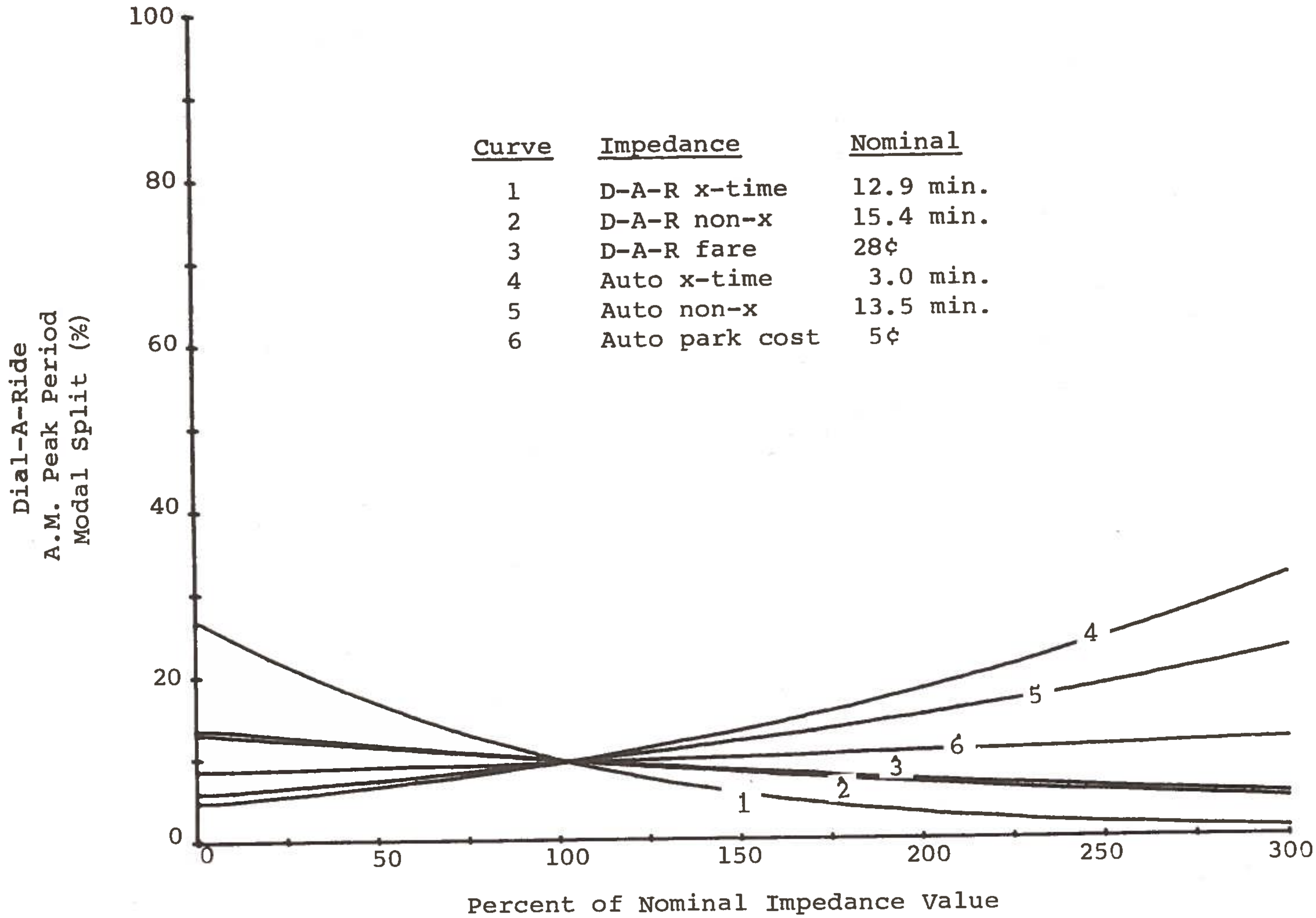


Figure B-11. Dial-A-Ride Modal Split Sensitivity to Times, Costs (Middle Ring Trips)

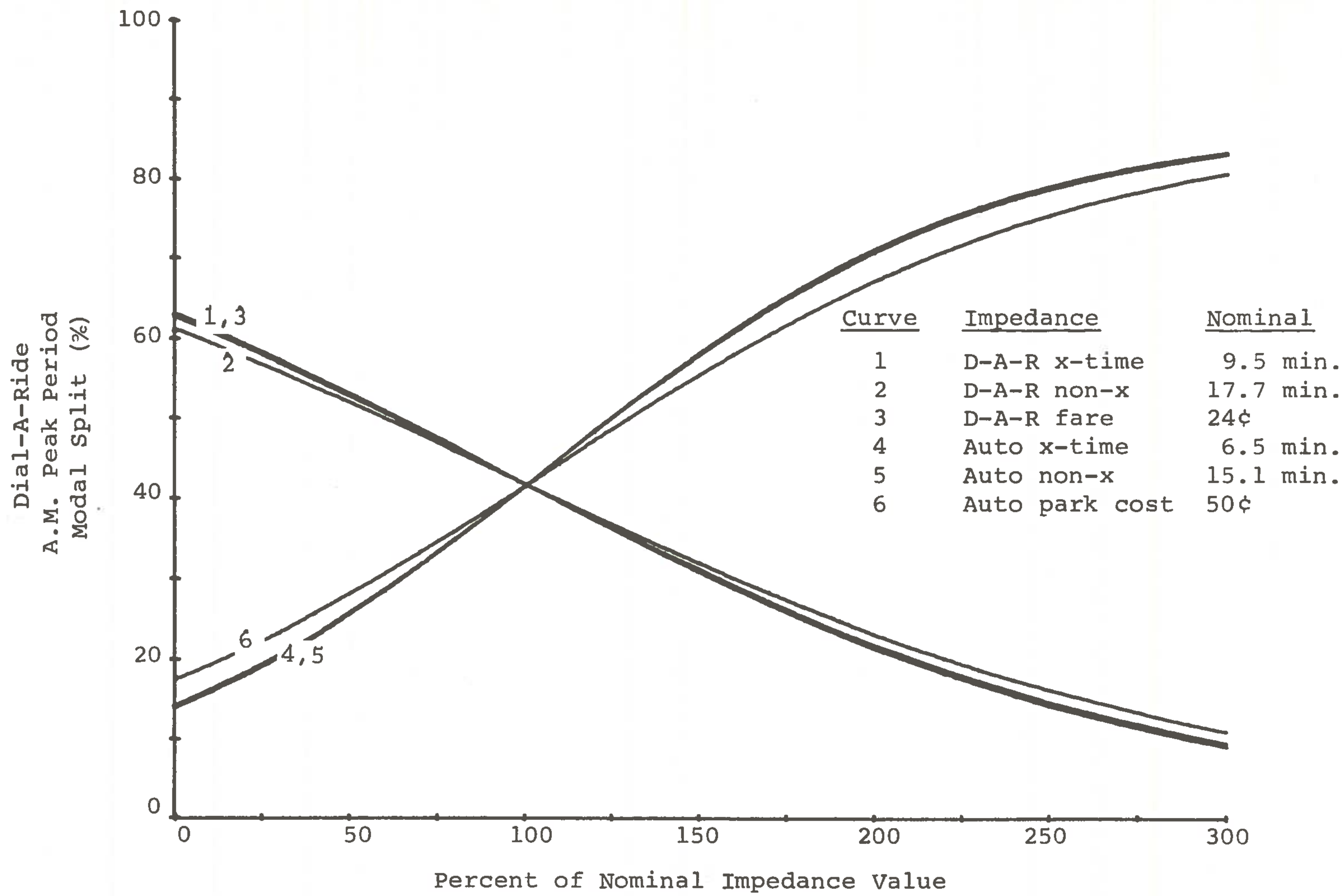


Figure B-12. Dial-A-Ride Modal Split Sensitivity to Times, Costs (Middle Ring to CBD Trips)

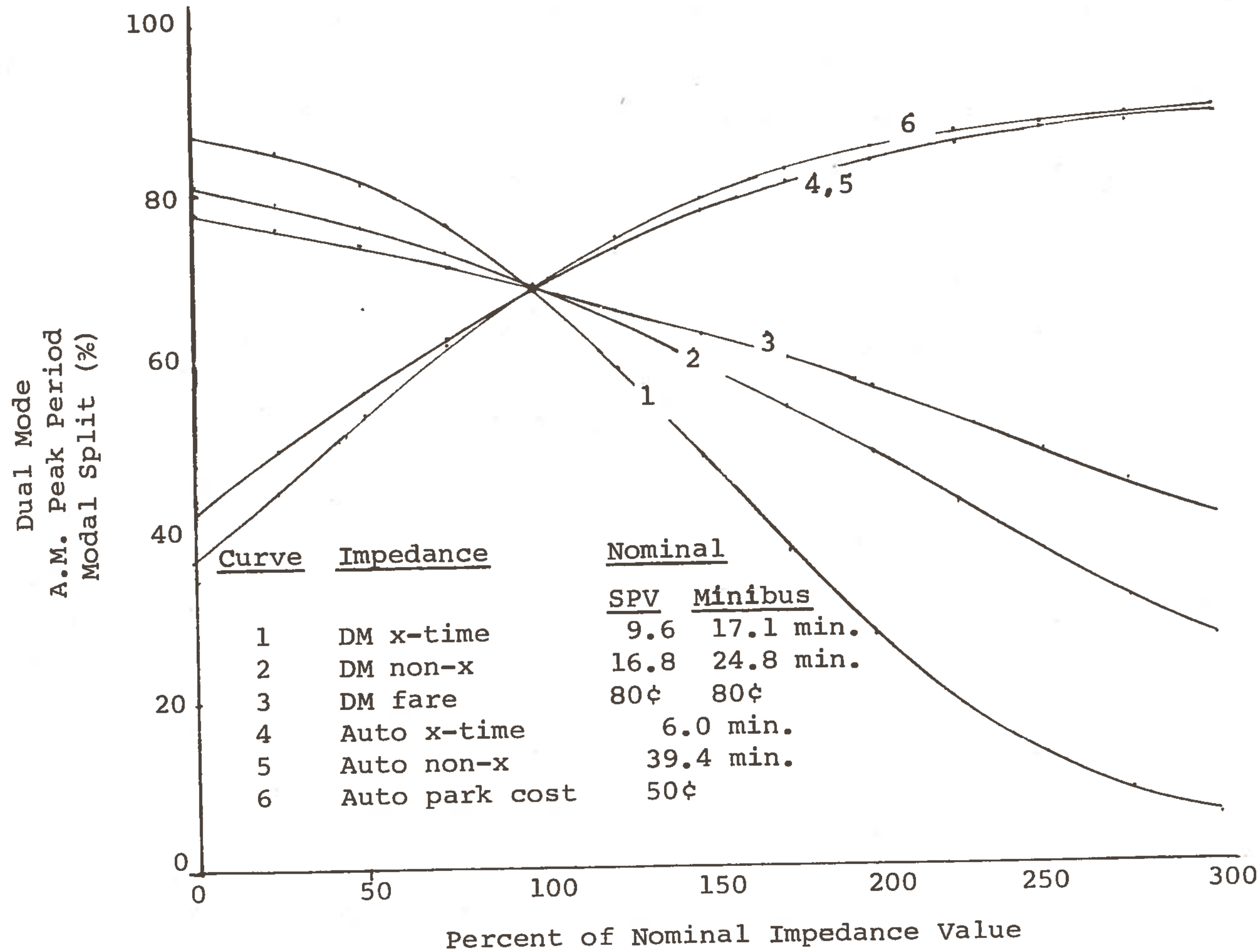


Figure B-13. Dual Mode Modal Split Sensitivity to Times, Costs (Outer Ring to CBD Trips)

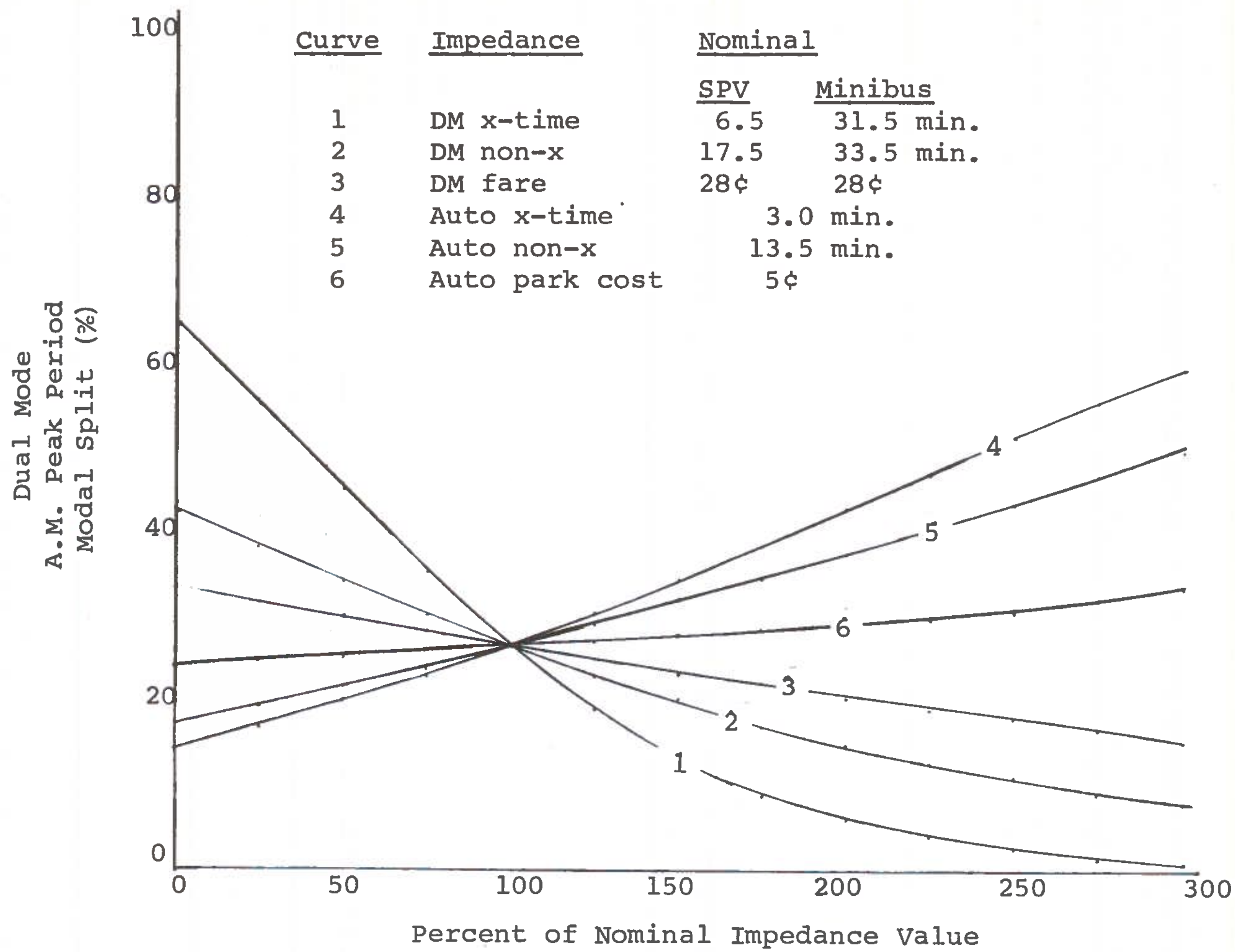


Figure B-14. Dual Mode Modal Split Sensitivity to Times, Costs (Middle Ring Trips)

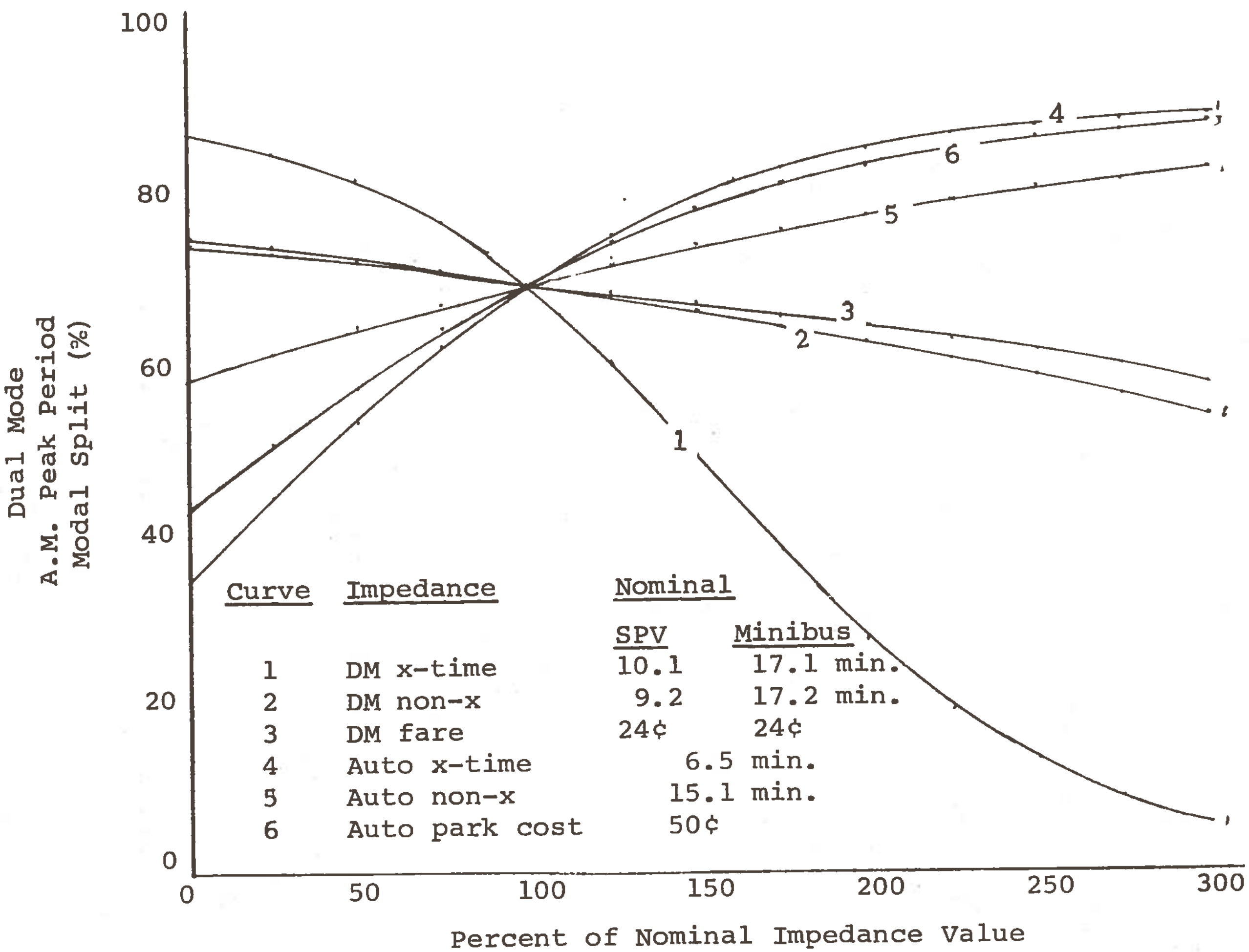


Figure B-15. Dual Mode Modal Split Sensitivity to Times, Costs (Middle Ring to CBD Trips)

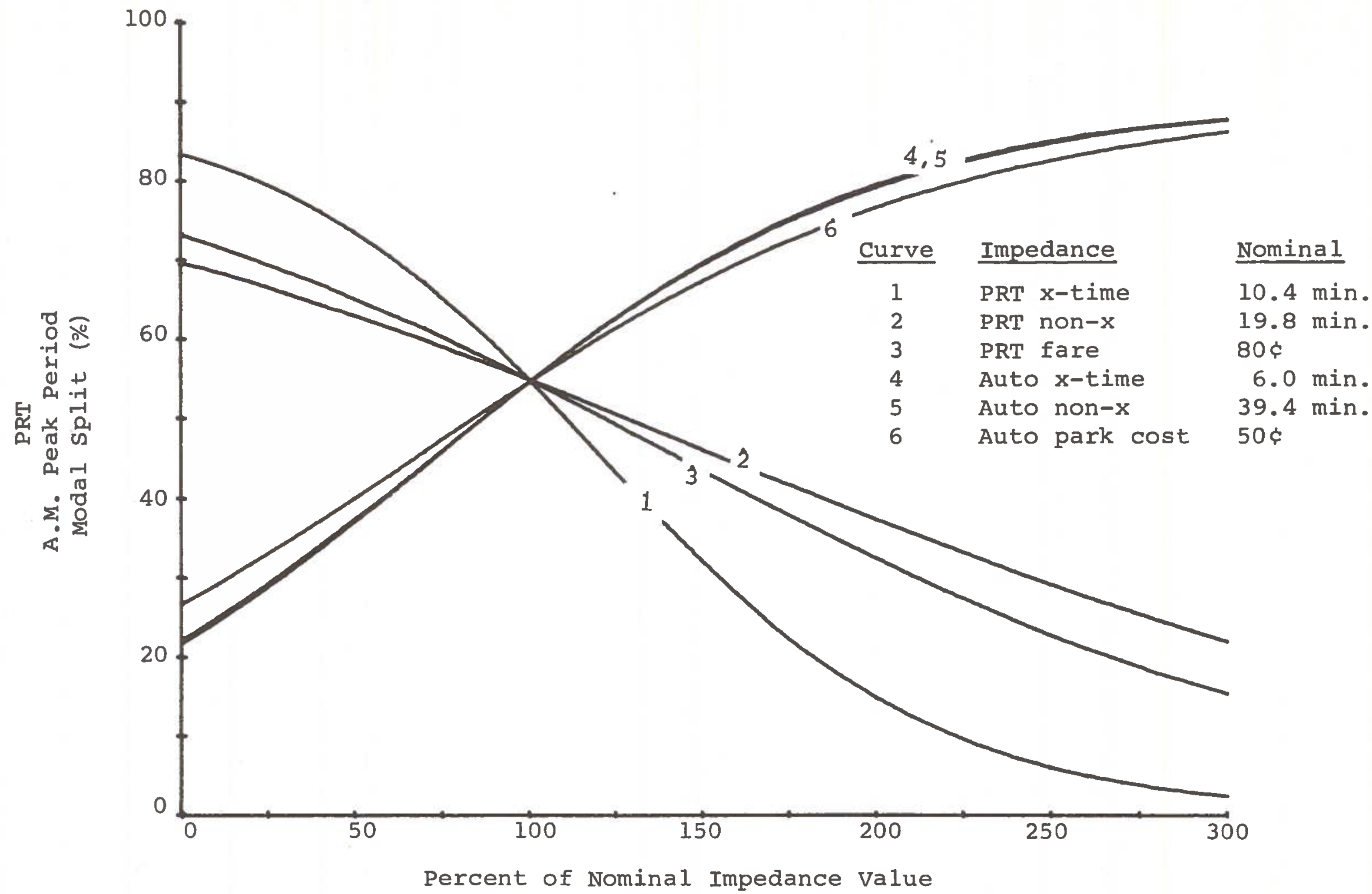


Figure B-16. PRT Modal Split Sensitivity to Times, Costs
(Outer Ring to CBD Trips)

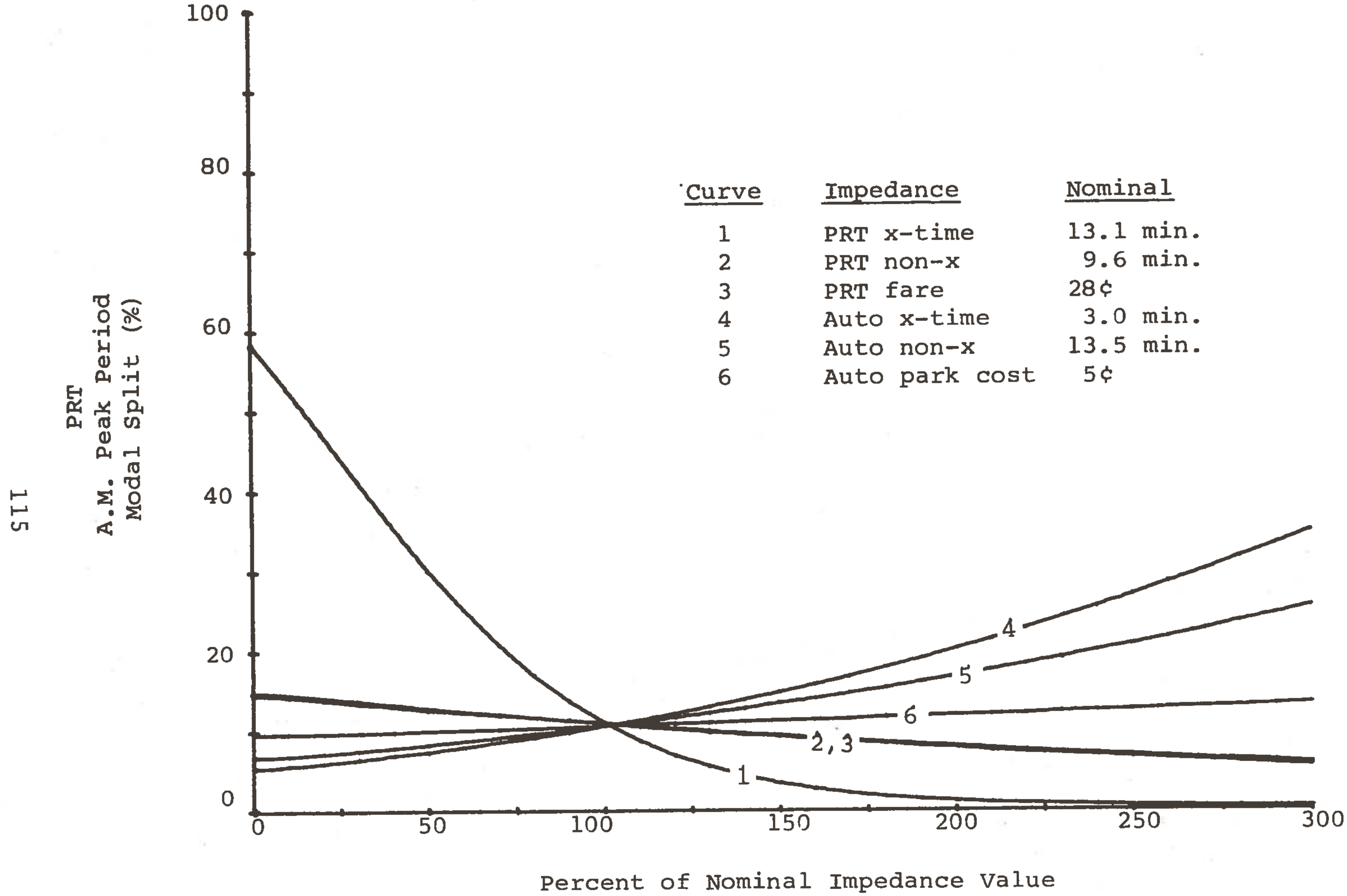


Figure B-17. PRT Modal Split Sensitivity to Times, Costs (Middle Ring Trips)

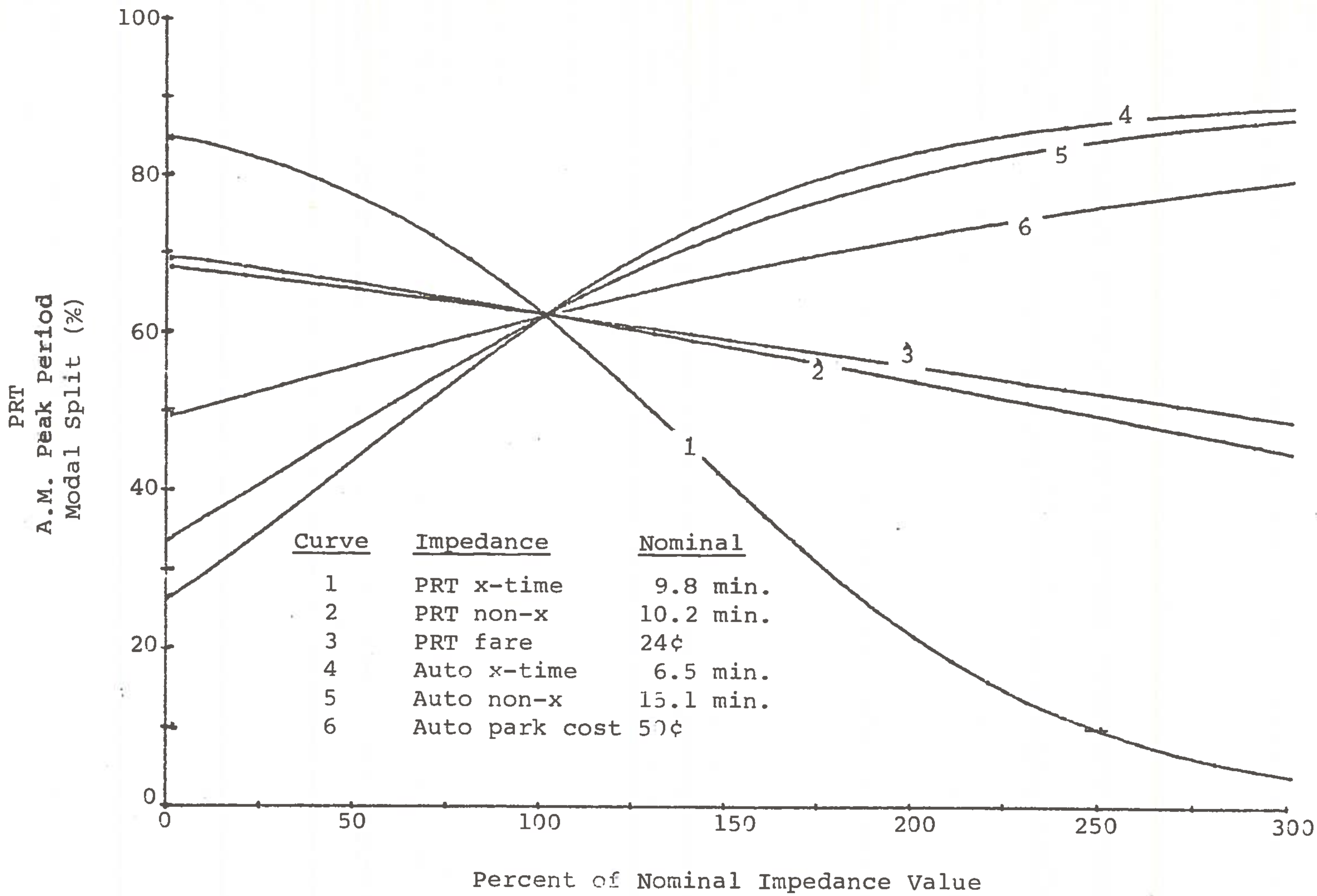


Figure B-18. PRT Modal Split Sensitivity to Times, Costs
(Middle Ring to CBD Trips)

Figures B-19 through B-26 show sample curves of modal split sensitivity to impedance ratio, i.e., the ratio of the transit mode impedance to auto impedance. In each case the nominal auto impedances (given in Figures B-1 to B-13) were held constant and the transit impedances were vaired to vary the ratios. On each figure the modal split for the set of nominal impedances is indicated.

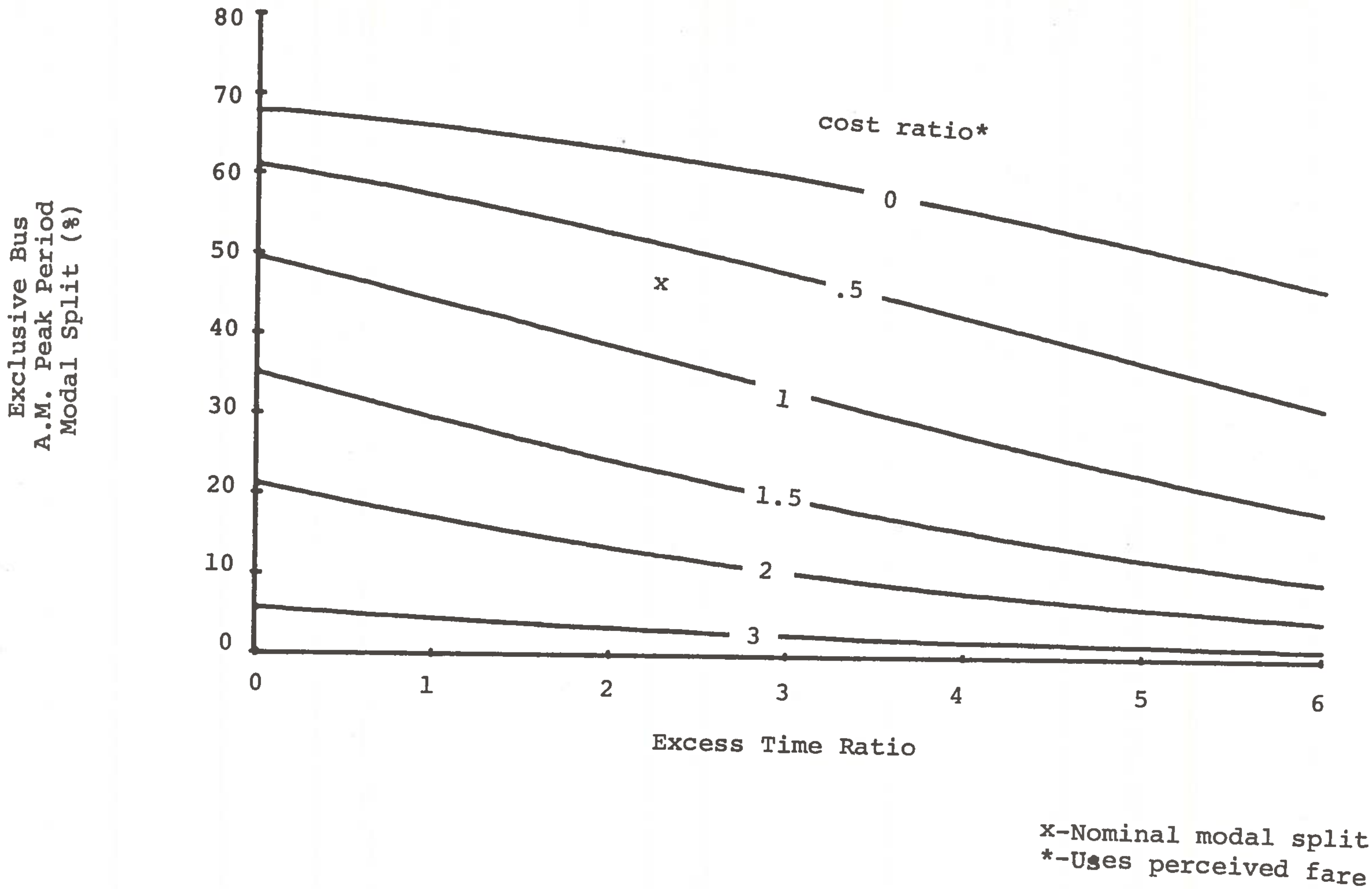


Figure B-19. Exclusive Bus Modal Split Vs. Excess Time Ratio (Outer Ring to CBD Zone)

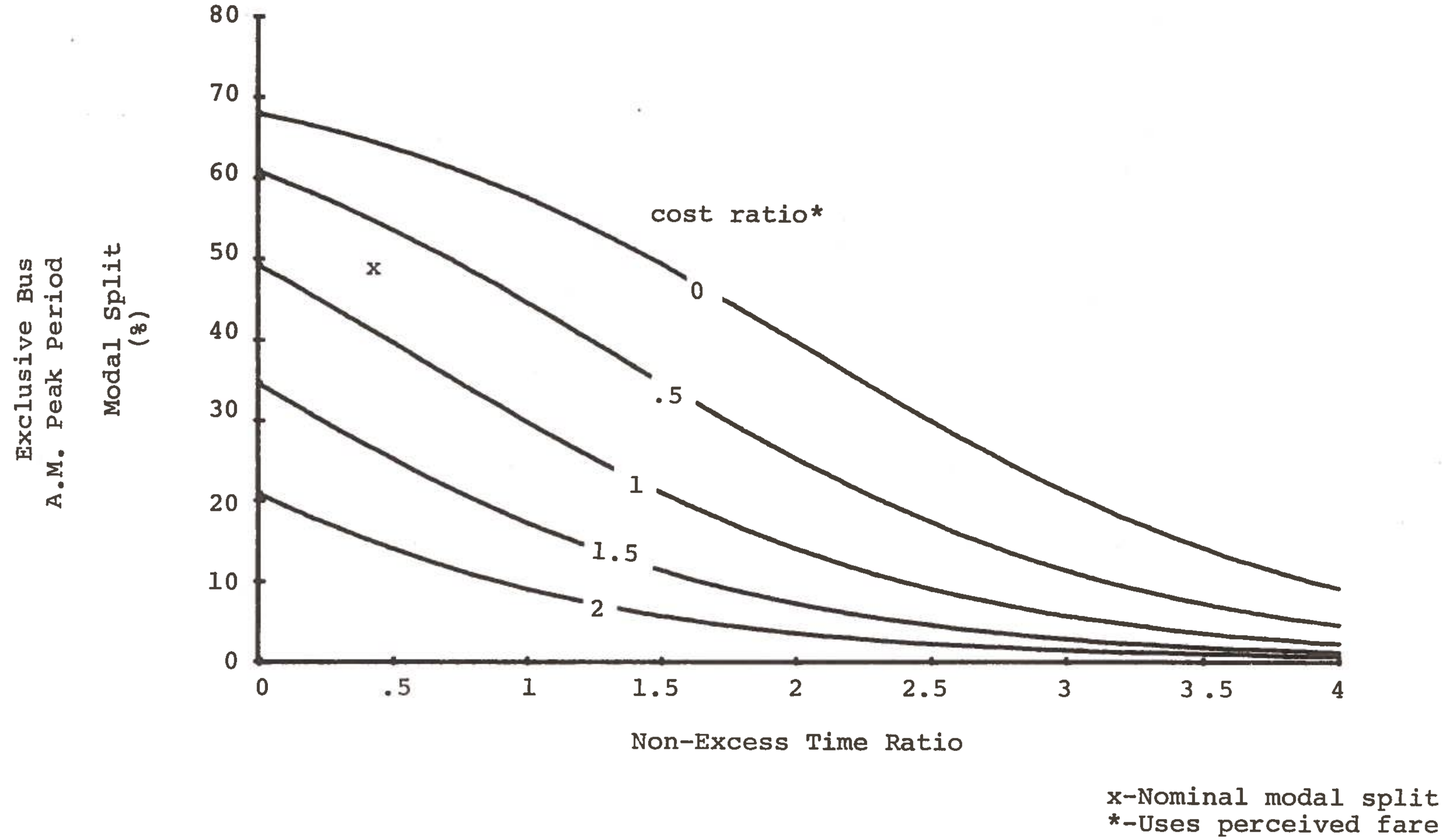


Figure B-20. Exclusive Bus Modal Split Vs. Non-Excess Time Ratio (Outer Ring to CBD Zone)

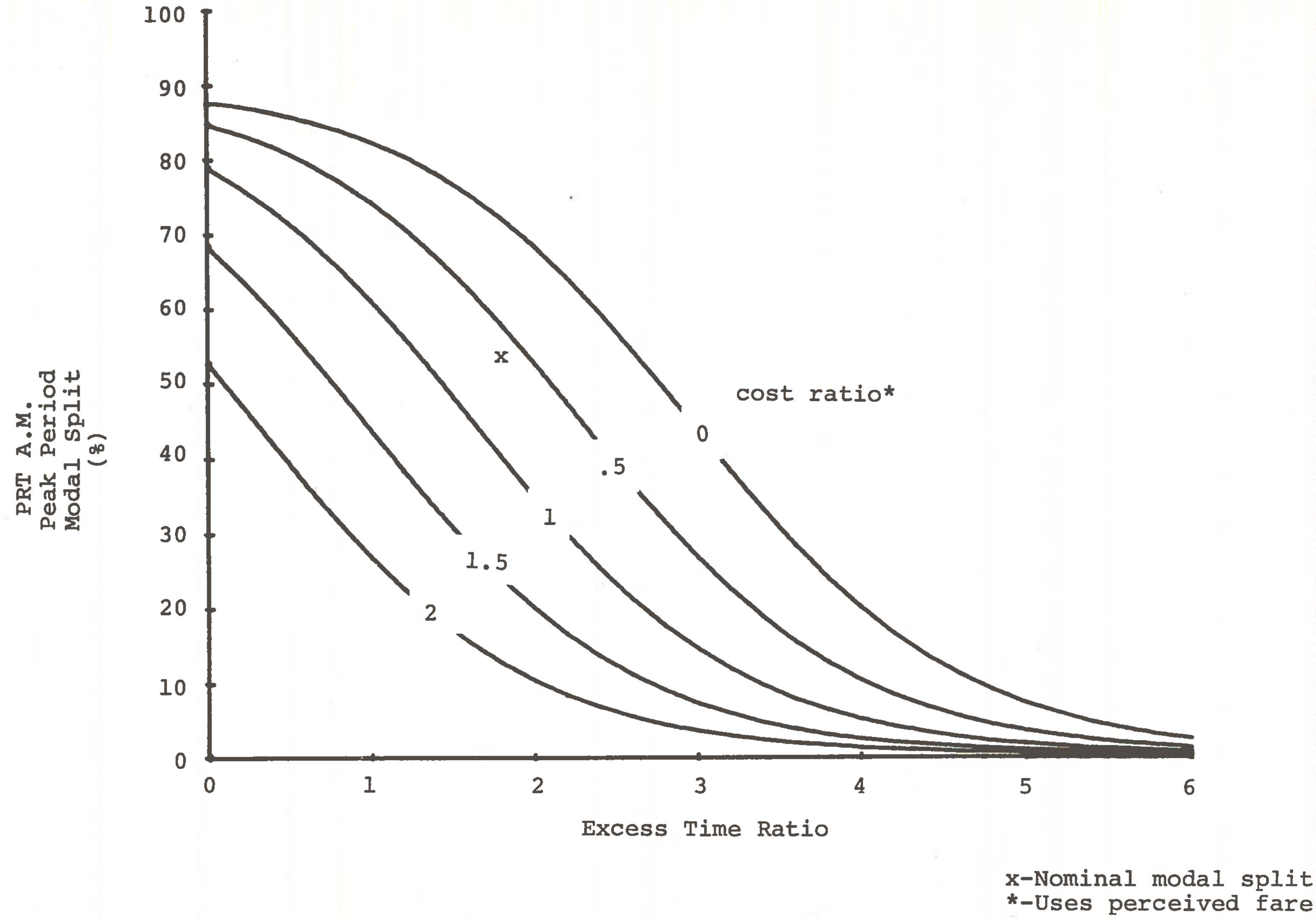


Figure B-21. PRT Modal Split Vs. Excess Time Ratio (Outer Ring to CBD Zone)

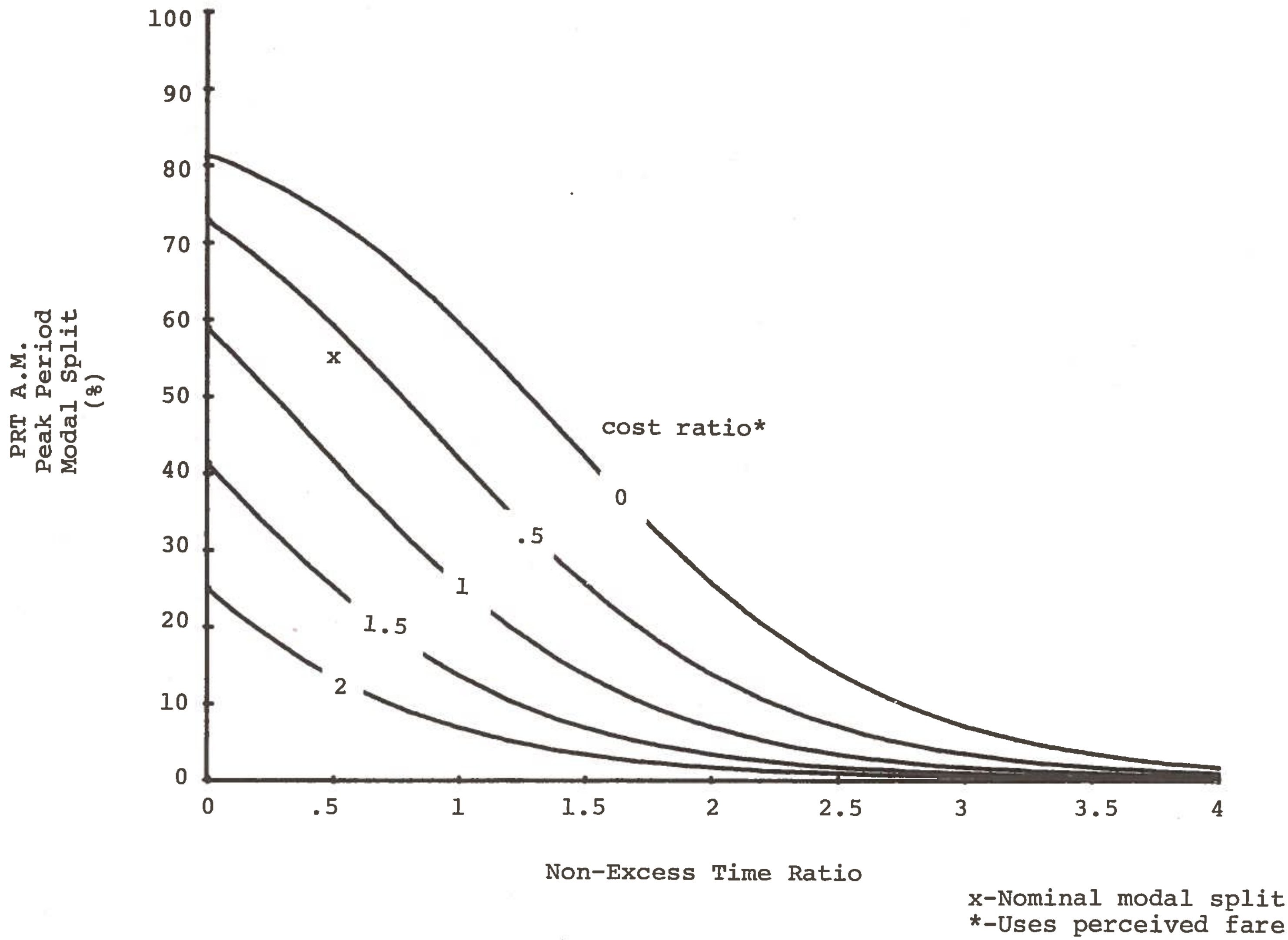


Figure B-22. PRT Modal Split Vs. Non-Excess Time Ratio (Outer Ring to CBD Zone)

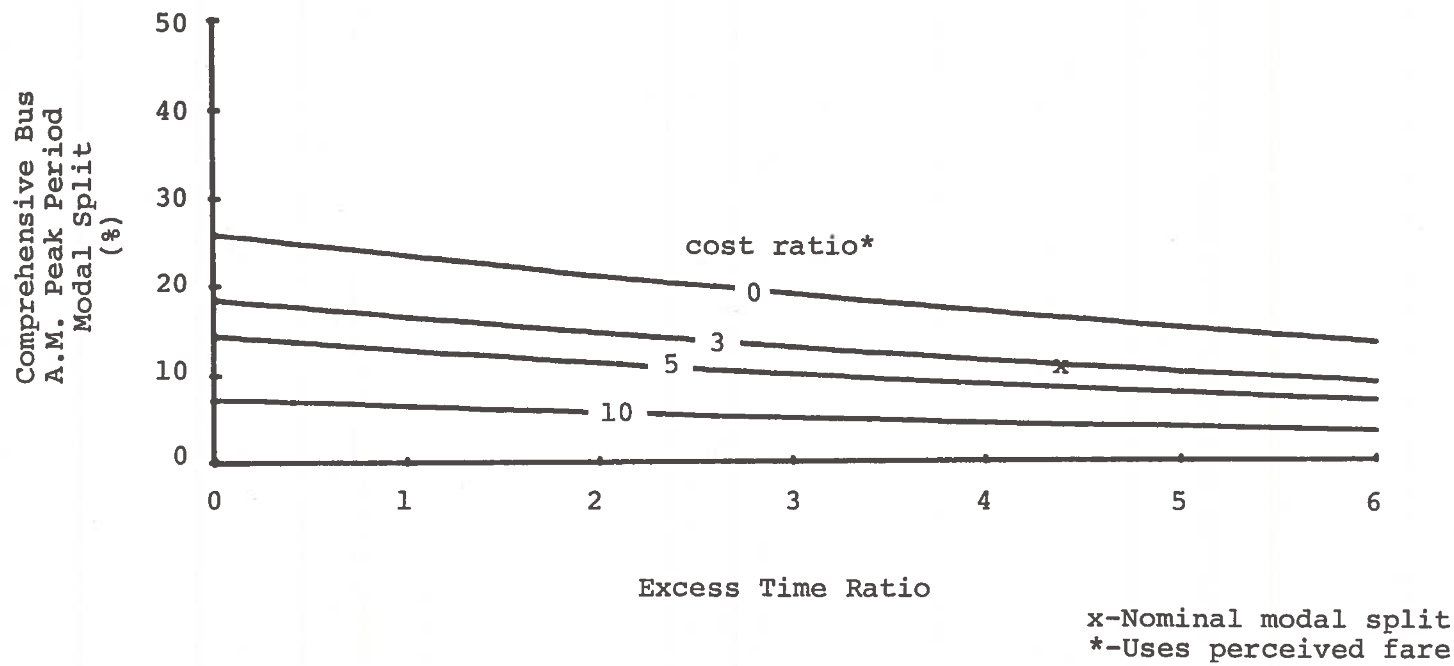


Figure B-23. Comprehensive Bus Modal Split Vs. Excess Time Ratio (Middle Ring Trips)

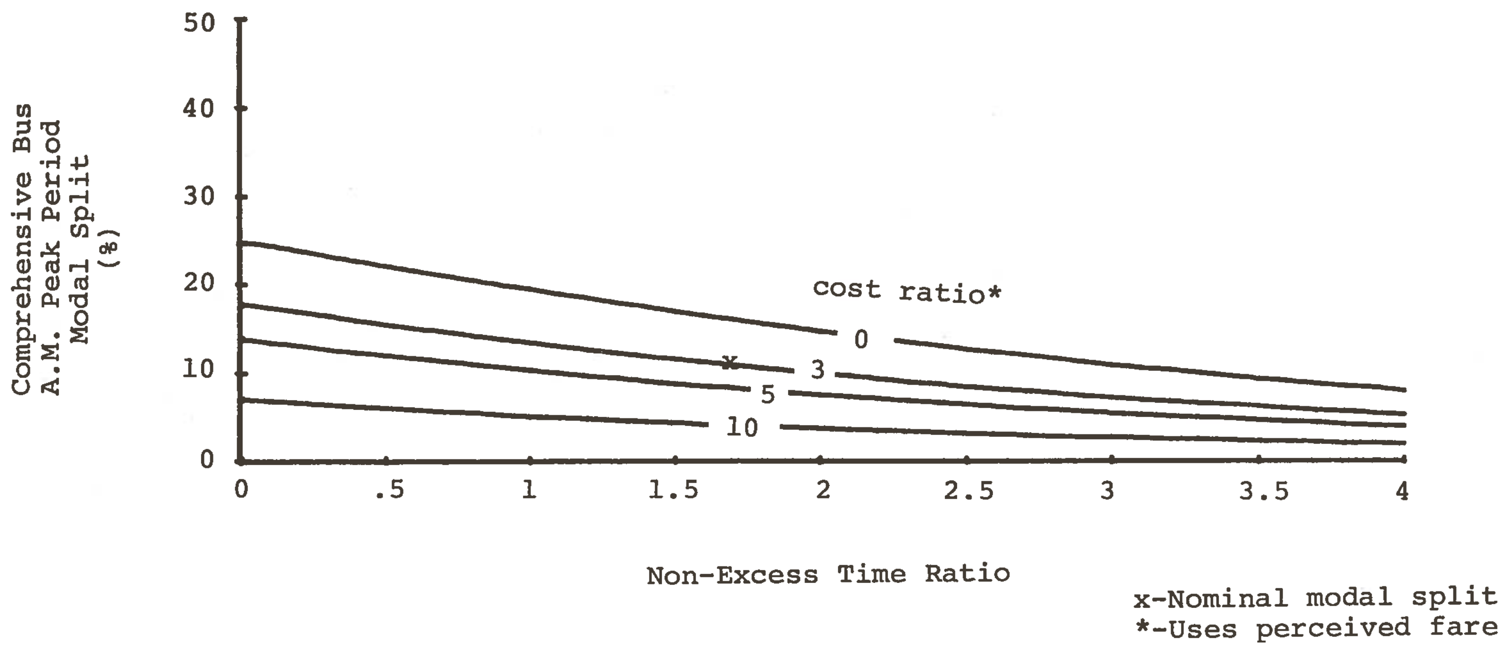


Figure B-24. Comprehensive Bus Modal Split Vs. Non-Excess Time Ratio (Middle Ring Trips)

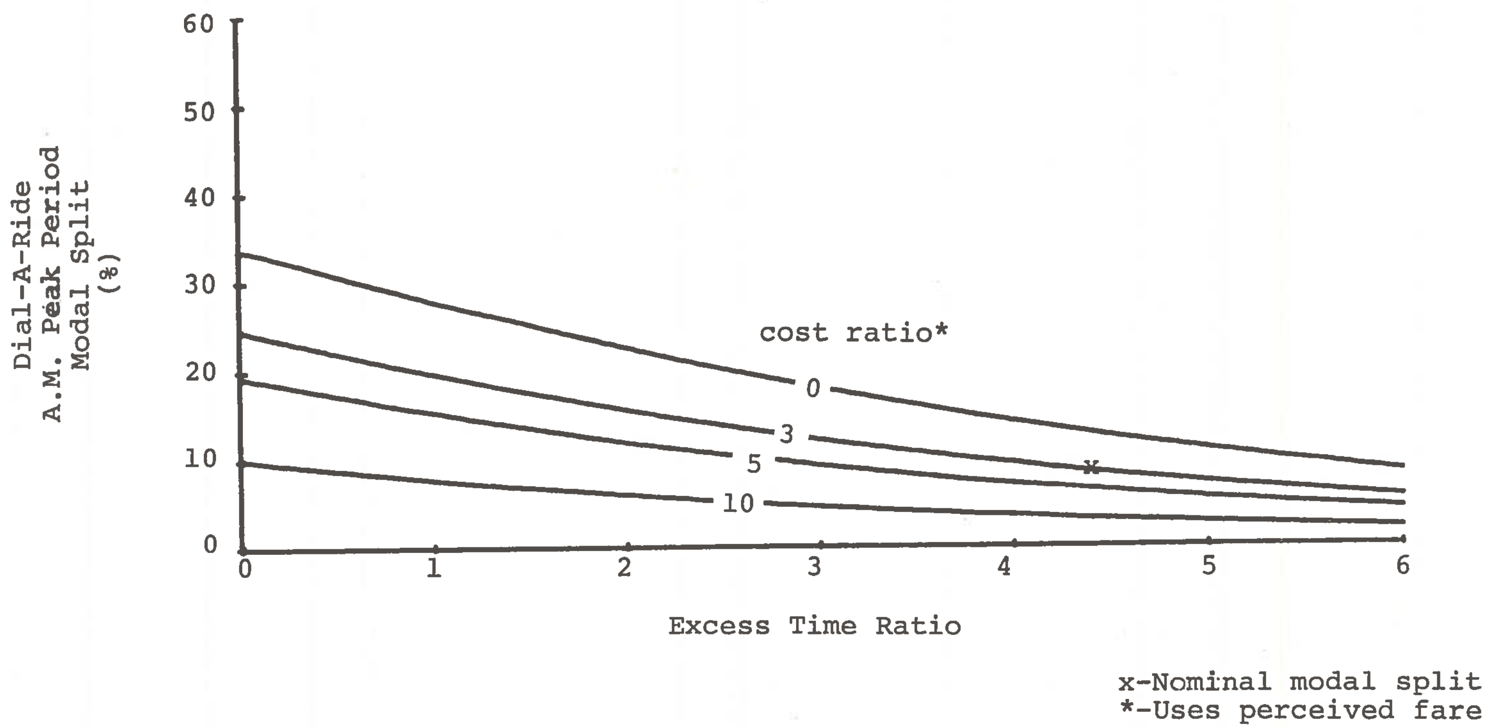


Figure B-25. Dial-A-Ride Modal Split Vs. Excess Time Ratio (Middle Ring Trips)

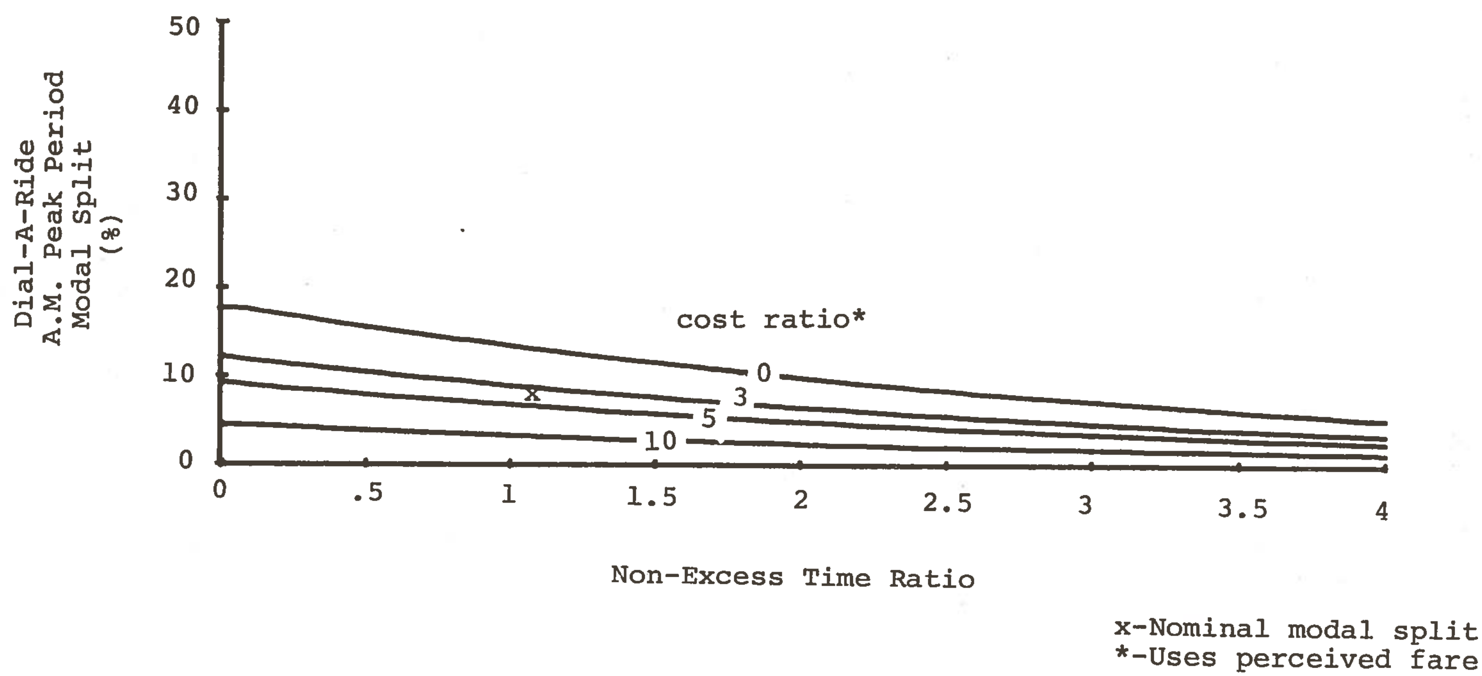


Figure B-26. Dial-A-Ride Modal Split Vs. Non-Excess Time Ratio (Middle Ring Trips)

APPENDIX C
CALCULATION OF SPEEDS AND TRAVEL TIMES

Based upon work performed by the Federal High Administration in the development of the TRANS model[11], speed of vehicles on surface arterials may be approximated by the equation:

$$V_{SA} = \sqrt{180\ (1-v/c)} + 12$$

where

V_{SA} = surface arterial speed in mph

v = traffic volume

c = traffic capacity

Similarly, speeds on freeways may be modeled by:

$$V_{FWY} = \sqrt{180\ (1-v/c)} + 30 \quad \text{for } v/c > .6$$

and by:

$$V_{FWY} = 54 - 10\ (v/c) \qquad \text{for } v/c < .6$$

Highway speeds in urban areas similar to Plastictown average 18 mph during the peak period and 19 mph during the off-peak period. Assuming that during the peak period 20% of the travel occurs on freeways and during the off-peak period 5% is on freeways this would correspond to:

$$(v/c)_b = .82 \text{ for the off-peak period}$$

and:

$$(v/c)_b = .95 \text{ for the peak}$$

The ratio for each alternative examined can then be calculated as:

$$(v/c)_i = \frac{VMT_i}{VMT_b}\ (v/c)_b$$

where:

VMT_i = vehicle miles traveled in alternative i

and:

VMT_b = vehicle miles traveled for the Highway case

Peak and off-peak speeds can then be calculated from the equations above, and the average highway speed is:

$$V_h = \frac{V_p \; VMT_p + V_{op} \; VMT_{op}}{VMT_p + VMT_{op}}$$

where:

$VMT_{p,op}$ = peak and off-peak vehicles miles traveled

$V_{p,op}$ = peak and off-peak velocities

Applying these speeds to all highway trips taken and adjusting for excess time permits calculation of person hours traveled on the highway (PHT_h). Thus the average speed is:

$$V_a = \frac{PMT_h + PMT_t}{PHT_h + PHT_t}$$

Where:

$PMT_{h,t}$ = person miles traveled on highway and transit

$PHT_{h,t}$ = person hours traveled on highway and transit

For the Highway case, the freeway lane miles are increased from the base case by a factor of 1.52; thus, for the freeway speed calcuations:

$$(v/c)_h = \frac{(v/c)_b}{1.52}$$

All other calculations are carried out as described above.

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