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ANALYSIS OF DUAL MODE SYSTEMS IN AN URBAN AREA

VOLUME III: DESCRIPTION OF THE ANALYSIS TECHNIQUES AND DATA SOURCES

Peter Benjamin et al.

DEPARTMENT OF TRANSPORTATION ★ UNITED STATES OF AMERICA ★

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16. Abstract

Various forms of Dual Mode transportation were analyzed in order to assess the economic viability of the Dual Mode concept. A Dual Mode vehicle is one which operates under manual control on a street network for some portion of its trip, and operates under automatic control on an exclusive guideway for some other portion. Specially designed new small Dual Mode vehicles, modifications of existing automobiles, and pallet systems, all operating in conjunction with Dual Mode buses, were examined. The study was conducted in a Boston 1990 scenario, in which an extensive Dual Mode system providing service for the entire urban region was presumed to exist. This study was not intended to be a proposal for Dual Mode in Boston. The following conclusions are considered to be generally applicable to other large urban areas as well: (a) Dual Mode systems appear to be sufficiently attractive to warrant further technological development; (b) for urban-wide applications, a Dual Mode system which includes both buses and personal vehicles is more effective than one consisting of either fleet of vehicles alone; (c) a Dual Mode transportation system benefits from the use of various Dual Mode concepts throughout its development.

An effective first step might be to install a limited network Dual Mode minibus system, with capacity for ultimate growth to a longer guideway network with personal vehicles and buses.

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PREFACE

This coordinated Department of Transportation program for the analysis of Dual Mode systems was initiated by Dr. Robert H. Cannon, Jr., Assistant Secretary for Systems Development and Technology, in the Spring of 1971. It was undertaken to provide sufficient insight into the benefits, impacts and costs of Dual Mode concepts so that the Department of Transportation could assess (1) the potential of Dual Mode as an urban transportation alternative, and (2) whether further research and development was warranted, and if so, in which areas.

The analysis was conducted using a 1990 Boston scenario in which an entensive Dual Mode system was presumed to exist. The scenario in a specific city was chosen to provide meaningful base data for this analysis. The study is not a proposal for a Dual Mode system for Boston; nor is it a transportation planning analysis for that city. The study was intended to evaluate the Dual Mode concepts in an urbanwide application to assess the relative merits of the various general design types, to determine the economic viability, and to conduct an assessment of technology required.

This report is made up of four volumes having the following general content:

- Volume I - Summary
- Volume II - Study results
- Volume III - Description of the analysis techniques and data sources (Volume IIIA, under separate cover)
- Volume IV - Program documentation of the Transportation Economic Analysis Model which was developed and used for the cost/benefit portion of this study.

The study was performed by the Transportation Systems Center under the sponsorship of the Office of the Assistant Secretary for Systems Development and Technology in conjunction with, and including participation by, the Federal Highway Administration, the Federal Railroad Administration and the Urban Mass Transportation

Administration. Close coordination was also maintained with the Office of the Assistant Secretary for Policy, Plans and International Affairs, and the Office of the Assistant Secretary for Environment, Safety and Consumer Affairs.

The Office of Systems Engineering in the Office of the Assistant Secretary for Systems Development and Technology was responsible for the management of the study. Overall program direction was provided by R. L. Maxwell; the Program Manager was R. L. Krick. Program coordination was achieved by the Dual Mode Transportation Working Group which reported to the Program Manager. The following Department of Transportation personnel served on the working group: R. Bruton, V. DeMarco, R. Fisher, S. Jackson, N. Kamalian, J. Leep, M. Miller, K. Okano and R. Reymond.

The cost/benefit, economic, and systems analysis portions of this study were conducted by the Systems Analysis Division of TSC, under the direction of C. H. Perrine. The primary contributors to the analysis were: P. Benjamin - task manager, analysis-team leader; J. Barber - performance, system characteristics, network analysis, final report; R. Favout - cost/benefit model; D. Goeddel - cost/benefit model; C. Heaton - impacts, network analysis, final report; R. Kangas - performance; G. Paules - ridership estimation; E. Roberts - network synthesis, scenario definition, ridership estimation; L. Vance - costs, fares, systems comparisons.

TSC direction of the Dual Mode Program and the technology assessment portions of the study were conducted under the guidance of G. Pastor, Chief of the Ground Systems Programs Division. The following persons contributed: J. Marino - task manager; A. Malliaris - technology assessment; S. Pasternack - command and control; C. Toye - command and control.

In addition, D. Glater was responsible for the section on legal and administrative issues, and J. Wesler for the noise analysis. The firm of Peat, Marwick, Metchell and Co. assisted in the analysis of potential system demand.

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1. INTRODUCTION TO PROCEDURE

The descriptions of the methodologies used in the various portions of the analysis are presented in this volume of the report. The areas covered include the synthesis of the guideway network, estimation of ridership, performance and physical design considerations, impact analysis and the structure of the cost/benefit model.

The analysis was performed for three generic Dual Mode baselines in the city of Boston, Massachusetts in the 1990 time frame. Each baseline was measured against Boston's 1990 transportation plan. The baselines are a pallet system, an automated highway vehicle system, and a new small vehicle system.

The pallet system consists of special pallets that carry conventional automobiles on the guideway and 20-passenger Dual Mode buses. The use of pallets permits any automobile, without the requirement for special modifications, to use the system. The buses provide transportation to those unable or unwilling to purchase or drive a car. The pallets and buses are electrically powered.

The automated highway vehicle system is similar in operation to the pallet, except that the automobiles interface directly with the guideway. This eliminates the need for acquiring a fleet of pallets, but conversely requires that automobiles using the system undergo special modifications. The bus operation is similar to that in the pallet system. The buses and automobiles are powered by internal combustion engines.

The new small vehicle baseline consists of electrically powered, publicly owned Dual Mode minicars called "small personal vehicles" and 12-passenger electrically powered Dual Mode minibuses. The small personal vehicles are rented by drivers and would perhaps substitute for a second or third car.

The analysis proceeded in the following manner. The 1990 origin/destination data for the city was used as a basis for the modal split model, which determined for each baseline the Dual Mode, automobile and transit ridership. The Dual Mode ridership was influenced primarily by the fare charged or perceived cost, the time components of a trip on the Dual Mode network, and various operating policies (e.g., regarding transfers to transit). The ridership data of the various modes and the network configuration were supplied to the TEAM cost/benefit model, which in turn calculated the capital and operating costs and most of the benefits and impacts. Parametric analyses were carried out to determine the sensitivity to variations in the input parameters. The results were analyzed, evaluated and summarized as costs and benefits. For each baseline, statistics for the Dual Mode system, the highway system and the transit system were calculated. The results were then compared with those for Boston's 1990 plan for conventional transportation.

2. NETWORK SYNTHESIS

2.1 GENERAL APPROACH

Network synthesis refers to the process of defining the Dual Mode guideway routes in the geographical study area, relating the guideway to the details of the local topography and the existing transportation system, locating interchanges and stations, and defining the basic functions of the stations.

Many considerations determined the synthesis of the networks for the Dual Mode study. Serving projected high density trip patterns, providing an appropriate amount of connectivity,* relieving congestion in existing systems, providing adequate access and egress facilities to the new system, and minimizing land acquisition and construction costs, are some of the principles which guided the network design. Some preliminary estimates of ridership potential - who might ride the new system, when, where and how frequently were also useful in laying out the guideways.

Since local transportation planners for Boston have spent more time and have more knowledge of that city than the analysis team, it was decided that the local 1990 transportation plan** should be the primary source of the required inputs to network synthesis, and that the network should conform to the local planning philosophy in terms of general orientation. The proposed highway and rapid transit

*Connectivity in a mathematical sense is a measure of the minimum number of disjoint paths connecting any pair of origins and destinations. This agrees quite well with the intuitive notion of connectivity as being a measure of the flexibility of a network, for example: meeting changing trip patterns, redistributing trips to alleviate temporary local overloads, and avoiding the development of "bottle necks."

**As proposed in 1968 by the Eastern Massachusetts Regional Planning Project (51).

construction for Boston is shown in Figure 2-1. In designing the Dual Mode network, portions of the conventional facilities planned for 1990 were assumed not to be built, on the rationale that the capacity and connectivity these would provide would not be necessary with Dual Mode present. In Boston, 64 miles of freeways, 50 miles of surface arterials and 29 miles of rapid transit facilities which were recommended for 1990 were assumed not to have been built.

In addition to satisfying the above and other transportation planning criteria, network design had to conform to the objectives and resource limits of the study at hand. In the Dual Mode study a single network configuration was designed, common to all Dual Mode baselines, except for minor adjustments to meet the peculiarities of specific systems. Although this procedure had the disadvantage that the network was not optimized for any particular baseline, it allowed the study of a wide range of baselines.

2.2 THE BOSTON NETWORK - OUTSIDE THE CBD

The Dual Mode network designed for Boston is depicted in Figure 2-2. The network conforms in general to the philosophy of the EMRPP 1990 recommended plan.[51]

Radial links serve the main radial transportation corridors (51, page 4), with specific routes and guideway concentration chosen to serve the trip density forecasts shown in the 1990 highway assignments (51, pages 42 and 113). Circumferential links are laid out in a similar manner. In order to minimize right-of-way (ROW) acquisition costs, radial links are located primarily along existing rail rights-of-way (see Figure 2-3). (Since automated systems potentially have extremely high lane capacities, Dual Mode guideways will require narrower rights-of-way than freeways designed for a similar purpose. Consequently, it is likely that Dual Mode routes might be able to utilize abandoned rail and other existing rights-of-way which would be inadequate for freeways of comparable capacity design.*) A circumferential route is located along the northern

*In laying out the Dual Mode network on existing rail or highway right of way, the exact orientation of the system within these facilities was not defined, other than to specify construction type (elevated vs. at-grade).

Figure 2-1. Boston Proposed Highway and Rapid Transit Construction

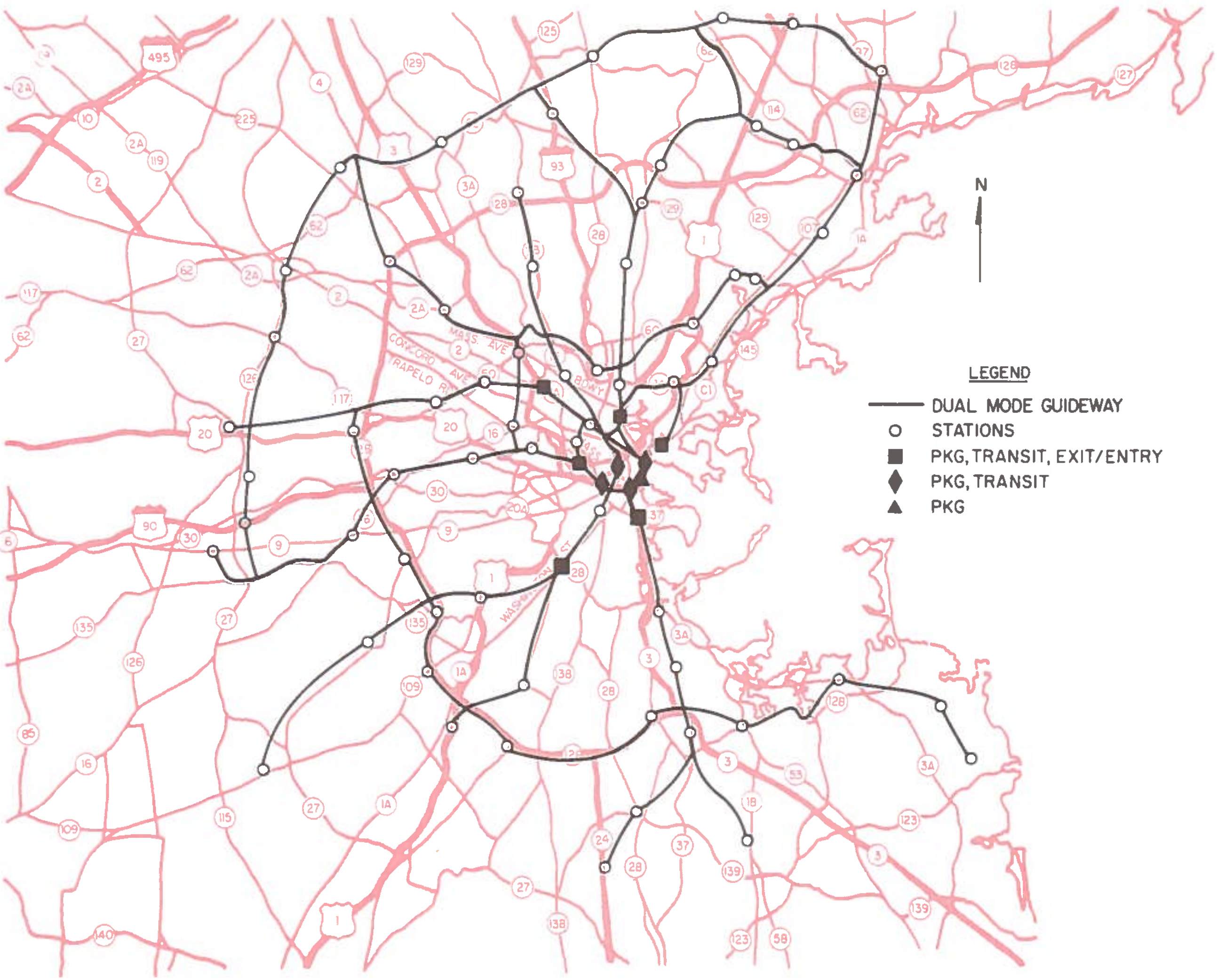


Figure 2-2. Boston Dual Mode System Guideway

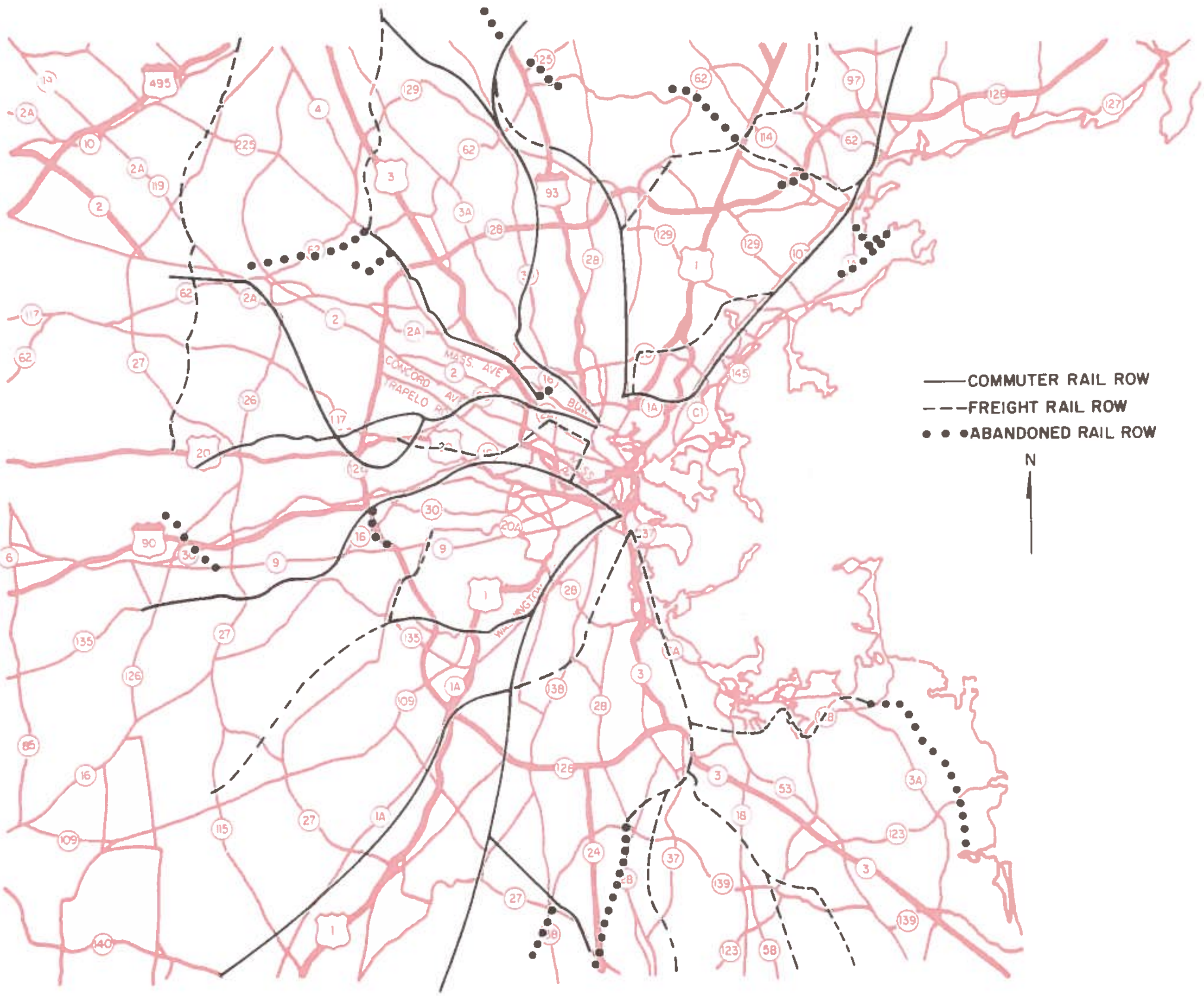


Figure 2-3. Boston Highway and Rail Rights-of-Way

half of the proposed 1990 middle circumferential, and is assumed to supplant that portion of the planned roadway.

Another circumferential route is located along the southern half of the existing Route 128; the Dual Mode guideway is situated in the median strip, along either side of the present highway, or over the present highway, depending on the extent to which additional usable land exists within the existing right-of-way.

Closer to the urban core, another circumferential Dual Mode route extends from Lynn westward along existing rail ROW through Saugus and Malden to Medford, where it runs along the Mystic River Basin until it rejoins rail ROW in Arlington and proceeds southward through Cambridge and Watertown, joining the main western radial Dual Mode route at Brighton.

The Central Business District (CBD) is depicted in Figure 2-4, and is defined in this study to be the peninsula bounded on the west by Massachusetts Avenue and surrounded on the north, east and south by the Charles River, Boston Harbor, and Fort Point Channel, respectively. Outside of the CBD the stations are located so as to provide maximum access between the Dual Mode guideway and the conventional road system at a minimum of land and construction cost. In addition to entrance and exit stations at major town centers and other activity centers, one or more exits and entrances to the Dual Mode guideway are provided along most of the major freeways and arterials serving the area. Among these are Routes 3A, 3, 28, 24, 138, I-95 and U.S. 1 to the south, Route 209, 109, 9, I-90 (Mass. Turnpike), I-290, U.S. 20, 117, and 2 to the west, and Routes 4, 3A, 38, I-93, 28, U.S. 1, I-95, 1A, and 107 to the north of Boston.

Interfaces between the Dual Mode system and existing rail rapid transit are provided, for certain baselines, by parking garage/stations described below.

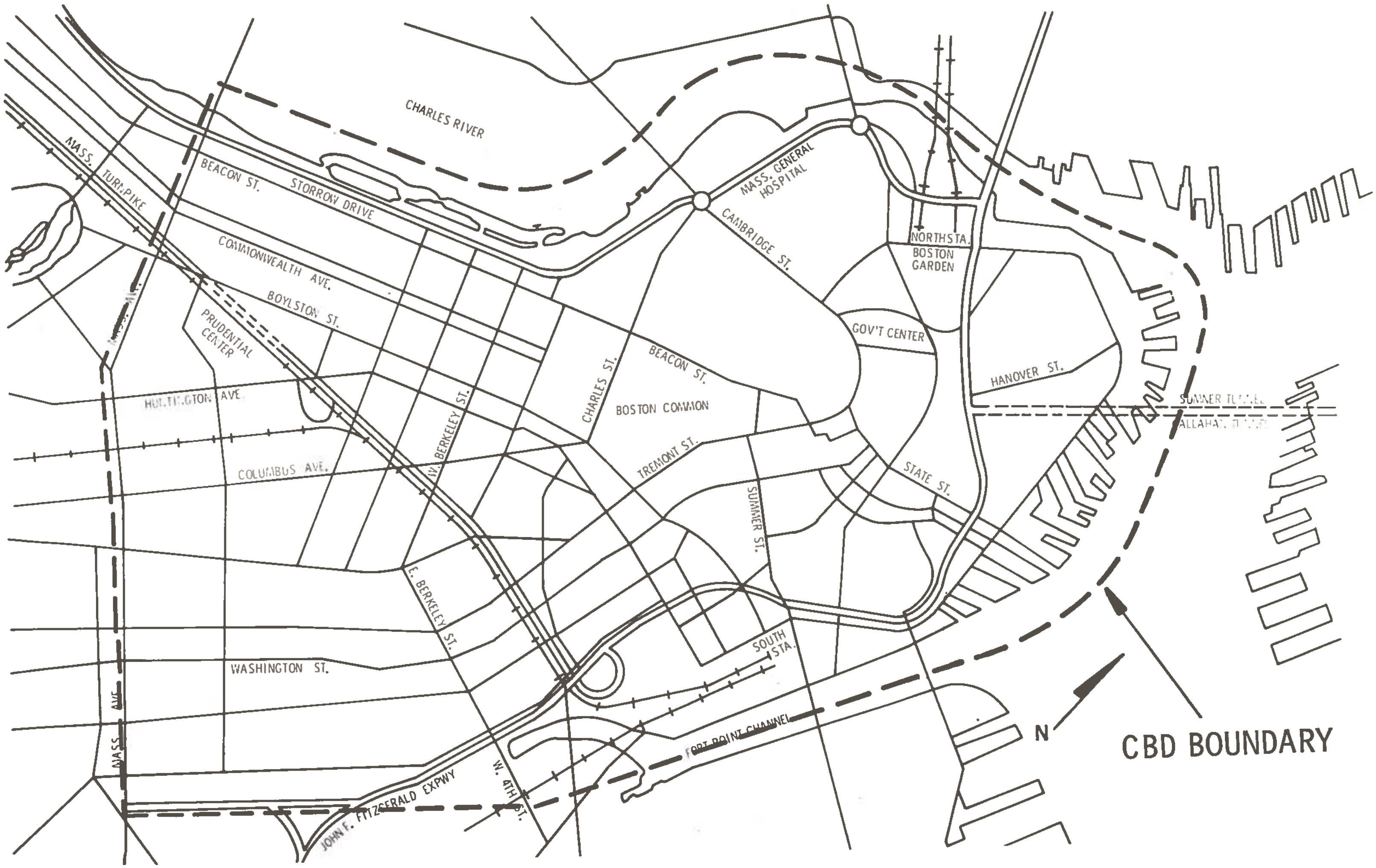


Figure 2-4. Boston Central Business District (CBD)

2.3 THE BOSTON CBD NETWORK - PALLET AND AUTOMATED HIGHWAY VEHICLE BASELINES

The network adjustments needed for specific baseline treatment arose mainly in the distinct requirements of large vehicle baselines versus small vehicle baselines in the CBD. Since one of the objectives of the Dual Mode system was to reduce congestion in the CBD, the analysis team decided that due to Boston's inadequate CBD street network, Dual Mode vehicles would not be allowed to leave the guideway within this area. The consequences of this for the pallet and automated highway vehicle systems were that parking facilities connected to the Dual Mode guideway had to be provided for privately owned vehicles in or near the CBD, and that a distribution system connecting Dual Mode passengers to the many attracting and generating areas within the CBD was also necessary. The solution adopted was to use the rather extensive existing rapid rail system as a distributor, connecting it to the Dual Mode guideway with a system of combination station/parking garages. The exceedingly high cost of land in the CBD made it desirable to minimize the number and size of garages downtown. Furthermore, the existence of several radial rapid rail routes to the suburbs enabled the location of peripheral garages connected to transit along each of the six major radial Dual Mode routes coming into the city. Differential pricing was used in the demand modeling to encourage significant numbers of CBD-bound passengers to utilize the peripheral garages in lieu of the more costly CBD structures. The garage locations chosen are depicted in Figure 2-5. The square symbols represent the peripheral station/garages, where transfer facilities to the rapid transit are provided, and where pedestrians and Dual Mode vehicles are allowed to enter and exit from the Dual Mode system. Table 2-1 identifies the peripheral stations and the rapid lines with which they interface.

The diamond symbols in Figure 2-5 represent CBD parking garages for vehicles arriving on the Dual Mode guideway, which provide facilities for transfer to the rail rapid transit and allows pedestrians, but not vehicles, to enter and exit from the Dual Mode system.

TABLE 2-1. PERIPHERAL PARKING GARAGE/STATIONS

Station	Connecting Rapid Transit Lines
Airport	Blue
Sullivan Square	Orange North
Alewife Parkway	Red North
Kenmore Square	Green
Forest Hills	Orange South
Columbia	Red South

The single triangle represents the State Street garage/station which provides neither vehicle exit/entry nor transfers to the transit system, but provides Dual Mode parking and pedestrian exit/entry in the main financial district. The five downtown garages are listed in Table 2-2, showing the various rapid transit lines with which they interface.

TABLE 2-2. DOWNTOWN (CBD) PARKING GARAGE/STATIONS

Station	Connecting Rapid Transit Lines
North Station	Green, Orange
South Station	Red
State Street	None
Park Street	Blue, Green, Red
Auditorium	Blue, Green

Note that the Dual Mode guideway in the CBD provides efficient routing for all through trips, and an adequate interface with the rapid transit. The extent of the guideway was deliberately minimized in this high density area, however, in order to economize on land and construction costs. There are essentially only two main Dual Mode guideway routes through the CBD. One originates at the terminus of three Dual Mode northern radial lines, in the vicinity of the existing railroad yards in Charlestown. This route proceeds across the Charles River to the North Station area, follows

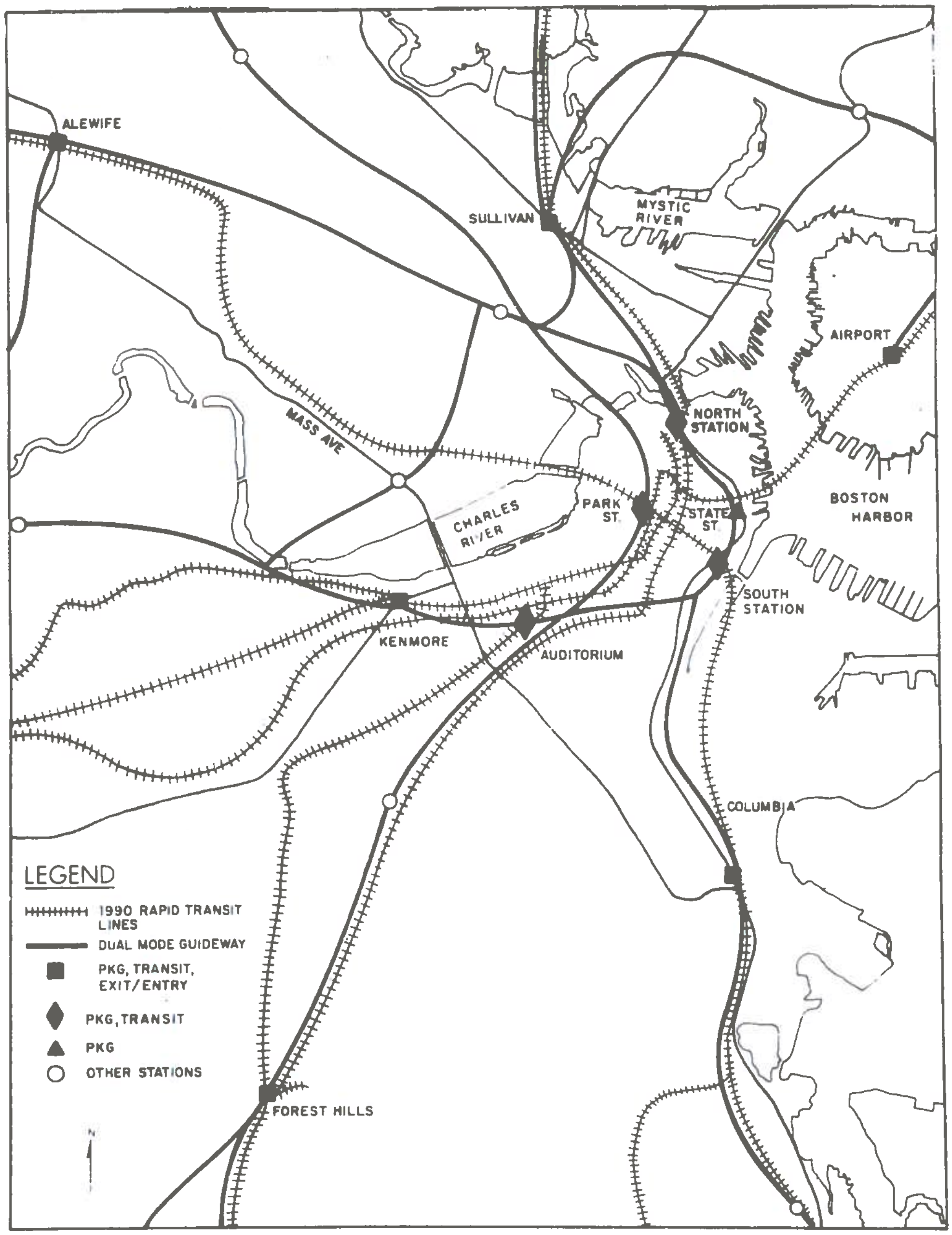


Figure 2-5. Dual Mode CBD Network

the J.F.K Expressway viaduct south and then westerly to the vicinity of South Station where it is joined by the major southern Dual Mode radial, then proceeds west along existing rail right-of-way to meet the terminus of a major western Dual Mode radial route. The location of this route takes major advantage of existing structures and right-of-way. The other CBD route begins in Somerville at the terminus of major northwest and western Dual Mode radial routes. It proceeds across the Charles River in the vicinity of the existing dam and enters the CBD at the foot of Beacon Hill. It proceeds south through the Common to join existing rail right-of-way in the Back Bay area, and continues southwest to meet two major southwest Dual Mode radial routes. This route is tunneled under Beacon Hill and the Boston Common.

2.4 THE BOSTON CBD NETWORK - NEW SMALL VEHICLE BASELINE

The network designed for the new small vehicle baseline in the CBD is depicted in Figure 2-6. Since the small personal vehicle is envisioned as a rented vehicle which is reclaimed by the system whenever it is vacated at a CBD guideway station, there is no need for CBD or near-CBD parking garages in this version of the network. In order to exploit (and explore) the personal rapid transit (PRT) potential of the new small vehicle baseline, an extensive distribution system was designed for the downtown area. One of the criteria followed was to require no more than a quarter-mile walk between the Dual Mode guideway and all significant activity or residential areas. The guideway links were located almost entirely along existing streets to allow for cut and fill tunneling or elevated construction, and to reduce the effect of construction on existing buildings and property. (The guideway was assumed to be tunneled in this area, but the cost effect of an alternate elevated design was considered.)

The distribution system provided by the downtown new small vehicle guideway is very adequate and therefore no interface was provided with the existing rapid rail system. Instead the conventional transit system was allowed to compete as a separate system, in order to provide a measure of effectiveness for the Dual Mode CBD system.

Certain key links, as shown in Figure 2-6 were designated as higher speed express links, to provide good service for through trips.

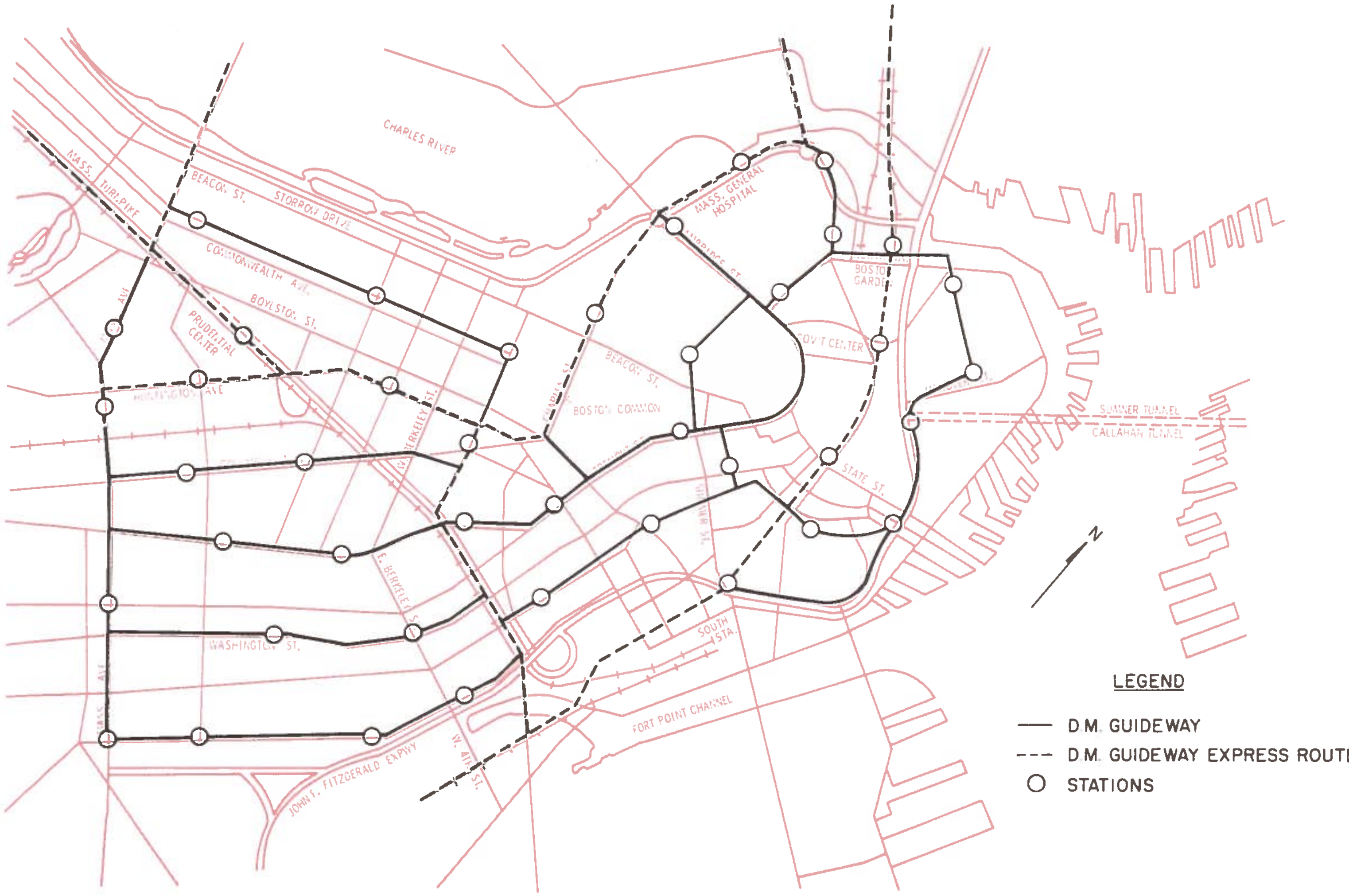


Figure 2-6. Downtown Network for the New Small Vehicle System Baseline

3. RIDERSHIP ESTIMATION

3.1 OVERVIEW

Patronage was a critical variable in the evaluation of the Dual Mode baselines, influencing all major phases of the tradeoff study -- network synthesis, capital and operating costs comparisons, accessibility measurement, and regionwide benefit estimation. A ridership estimation process was developed which took advantage of the traditional techniques employed by regional or city transportation planners. It was taken to a level of detail sufficient to distinguish among the spectrum of Dual Mode baselines.

In order to relate the Dual Mode baselines in a realistic scenario the Boston metropolitan region was selected as a test case and the baselines evaluated with respect to a 1990 highway and transit plan projected by the Eastern Massachusetts Regional Planning Project (EMRPP).[51] Base year and projected year total trip making data were obtained from the EMRPP.

Following layout of the basic Dual Mode guideway network, the metropolitan region was subdivided into service areas having access to the guideway at each terminal. Flexible, efficient network design routines allowed significant redefinition of the Dual Mode time- and cost-related components. At the analyst's option redefinition of base network components could range from individual service area modifications to region-wide network changes. Combinational changes to level-of-service variables were easily accomplished. Possible level-of-service time components included walk times, schedule sensitive wait times, off-guideway driving times, terminal processing delays (including destination sensitive Dual Mode system reservation delays), speed sensitive on-guideway line haul times, transfer delays to or from conventional transit and auto park'n'ride delays. Out-of-pocket cost components included trip distance rate or fixed fares, zone sensitive parking charges at origin (park'n'ride) or destination, and fares to connecting modes.

To properly distinguish among the various Dual Mode baselines a disaggregate logit form modal choice model was calibrated using historical travel behavior of individual tripmakers. Middle-income travelers making the home-to-work trip in the A.M. peak period were modeled since this segment represented the largest of several trip-making groups being considered. The Logit Model was calibrated using a random sample of trips recorded in the 1963 base year historical file. For each trip all reasonable alternatives were constructed. The final model was calibrated for four modes -- conventional auto, conventional bus, commuter rail and rapid rail transit. Calibration of the four modes provided data to guide synthesis of the Dual Mode model characteristics.

A unique and reasonably uncomplicated technique was developed for extending the results of the theoretical Logit Model over all incomes, trip purposes and daily time periods.

The two-step process allowed a flexible, in-depth analysis using the calibrated Logit Model to distinguish among the transportation alternatives. This was followed by a more aggregate extension of the model to obtain total regional trips for each transportation mode during the peak and daily time periods.

Since the number of station-to-station trip combinations for the Dual Mode network was large (approximately 18,000), a sampling technique was employed for selecting representative service areas used in the analysis. The procedure involved stratifying the Boston region into five large districts which represented grossly different levels of Dual Mode service.

Movement between any two of these districts defined a trip orientation category. Additionally, trips between any two interchanges were measured and categorized as long, medium, or short distance. Each service area was classified by average income (i.e., high, middle, low), and all 18,000 trip combinations were then categorized by income of the origin service area, trip length and orientation giving 45 possible trip stratifications.

The analysis sample group was randomly selected from all combinations in the 15 middle-income orientation and distance categories. Detailed modal split analysis was based on this sample set and the results extended over the region using trip data from historical records.

All base year trip records were categorized into the 45 groups and for auto and transit the middle-income, home-based work trips in the peak period were related to all other incomes, trip purposes and time periods. This would allow up to 90 separate measures of modal split (peak and daily) to which were applied the theoretical modal splits obtained by averaging the samples in the 15 middle-income categories.

To perform "quick look" revenue/cost analysis, the total daily regional trips for 1990 were summed for the 45 categories, the test case modal splits applied to each category group, and estimates of revenue computed from the resulting trips. Parametric analysis of several policy and system variables guided selection of the most reasonable combination for further analysis.

The most reasonable combination modal split fractions were then applied to each trip interchange table and all resulting trips assigned to the Dual Mode network for detailed cost, revenue and impact analysis in a cost/benefit model. Total trips by highway and transit were determined similarly but more aggregate measures of network performance were employed since these conventional modes are better understood.

The Dual Mode network programs were also used for measuring accessibility between particular service areas of interest and any other area or the community at large.

3.2 BACKGROUND AND OBJECTIVES

An efficient yet flexible analytical process was required to examine several Dual Mode system policy options. System design characteristics as well as various revenue gathering schemes were to be studied.

The Dual Mode baselines were characterized by various combinations of public and private ownership, off-guideway collection/distribution techniques, vehicle capacity, terminal processing delays, on-guideway performance, post-egress vehicle handling procedures, and policies regarding transfer to connecting CBD transit. Understanding traveler sensitivity to these trip components was essential to measurement of ridership levels.

The level of acceptance by various market segments contributes to the criteria allowing cost/benefit tradeoff among the various baselines. For instance, the work trip at peak period is influential in system sizing, whereas the non-work, off-peak tripmaking reflects on the baseline's potential for total revenue gathering.

Following basic project definition, a detailed review of demand analysis techniques and data requirements was completed. Leading analysts in the Federal Government and industry were interviewed relative to the complexities inherent in analyzing new public or private systems which are to supplement or compete strongly with the automobile. All levels of analysis, from extremely fine-grained total urban area analysis to broad, limited-detail approaches, were examined.

The conclusions relating to analytical technique and study resources were:

A. <u>Analytical Technique</u>

1. A fine-grained disaggregate analysis is necessary to verify system ridership sensitivity factors.
2. A flexible method of integrating network and modal choice analysis is required to cover the desired matrix of system characteristics and policy variables.
3. The method for analysis of ridership sensitivities should use a mathematical technique which can be consistently applied in different urban areas for more confident comparison of the different baselines.

4. The approach should take full advantage of previously developed analytical methods. Research into new modeling concepts is beyond the scope of the current effort.

B. Study Resources

1. Automatic computation should be used only where it would clearly be cost effective in light of study objectives.

2. Data collection requirements can be costly and time consuming. All possible short cuts to data handling, aggregating and formatting should be employed. Use of existing data is mandatory.

3. Network quantification is costly and time consuming. It should involve only those links necessary to determine relative measures of traveler response among the baselines being evaluated.

Four objectives were specified for the general area of network and ridership analysis -- policy decisions, cost model inputs, accessibility analysis inputs, and mode choice sensitivity analysis. Based on guidelines established in review, detailed study objectives were stated and interfaces among these four major analysis elements defined.

C. Policy Decisions

Because of labor and time involved it became clear during the methodology definition that baseline policy decisions would be required as early as possible in the ridership analytical process. Baseline operating characteristics were established, e.g., off-guideway tour length and headways for large Dual Mode buses.

Fare and parking charge policy was then coupled with the system operating characteristics for examination of the impacts on total ridership. This process of network synthesis and evaluation was followed by a gross estimation of revenues and costs. Based on these data the final operating characteristics and policy options for detailed analysis using the cost model were selected.

D. Cost Model Inputs

Since a primary interest in the study was comparison of the Dual Mode baselines relative to one another, disaggregate detailed data was required for each baseline. Ridership levels flowing through terminals, into parking areas and along guideway links were required for system sizing and cost estimation. Peak period and daily statistics were necessary. Dual Mode vehicle occupancy (as a function of capacity) and off-guideway tour distances, speeds, and frequencies implicit in modal choice decisions had to be specified as essential inputs to fleet size and performance estimations. Traveler delay times encountered during a trip were measured for computation of total system effects when considered with highway and transit.

To examine the viability of Dual Mode relative to the 1990 highway and transit plan, information on the latter systems were also necessary. Because highway and transit impacts and costs are better understood, a less detailed analysis of ridership was considered adequate. Following a detailed modal choice analysis total ridership estimates were made for automobiles on freeways and surface arterials. Similarly, statistics for submodes of transit were generated. Dual Mode baseline influence on both auto and transit was measured. Person and vehicle miles traveled on highway and transit were computed without assigning travelers to a detailed network, by using more aggregate peak and daily approximations.

E. Accessibility Analysis

A measure of Dual Mode's impact on a region is change in point-to-point accessibility -- e.g., how many more (fewer) people can reach a place of interest within an established time frame by Dual Mode vs. conventional systems. Since point-to-point travel times were required as part of the planned mode choice analysis, the same analytical tools were designed to provide accessibility (travel time) information from any origin to specific destinations of interest.

F. Mode Choice Sensitivity Analysis

As in any study of this nature, understanding the sensitivity of certain variables can assist in system design and also be valuable for future use should a change in the base value of a variable be desired. Traveler sensitivity to the various components of time and costs were examined for each baseline, e.g., transfer delays and fares. Where necessary, sensitivities for one baseline were qualitatively deduced from the analysis of another.

Bounded by the project scope and the noted methodological constraints, a sequence and process of analysis was designed to satisfy the stated objectives.

3.3 METHODOLOGY

3.3.1 Introduction

The technique used for estimating ridership on the Dual Mode systems, conventional transit and highways closely followed the procedure described in the Federal Highway Administration manual entitled "Urban Transportation Planning".[98] This set of techniques (or slightly modified versions thereof) have been used in virtually every urban transportation study in the U.S. Since various urban study projects constituted the main sources of data available for the Dual Mode study, it was particularly useful to adopt a methodology and a battery of computer programs compatible with these data. A few innovations were introduced into the process to reduce the effort involved and to circumvent the problem of missing data. Peat, Marwick and Mitchell's N-Dimension Logit Model[70] was used to predict the modal splits. A description of that model and the calibration process, based on Boston data, is discussed in Section 3.4 of this chapter entitled "Mode Choice Model Development" and also in Appendices A and B.

The traditional procedure described in the FHWA manual consists of four steps: trip generation, trip distribution, modal split and trip assignment. Generation is the process of predicting the number of trips originating and terminating in each traffic analysis zone (TAZ) of the study region for a fixed time period (usually one day or less) in the (future) study year. Distribution is the process of estimating, for each TAZ, how many of the originating trips go to each of the other TAZ's and how many of the terminating trips come from each of the other TAZ's (i.e., - "distribution" of the trip ends). The output of the distribution process is a trip table of estimated average total person trips during some period of time (usually 24 hour or a 3-hour peak period) for the target year. The trip table is a matrix $T=(t_{ij})$ where the ij-th entry is the number of trips orginating in the i-th and terminating in the j-th TAZ. (The TAZ's in a study region are numbered consecutively, beginning with TAZ number 1.)

Modal split is the process of estimating, for every pair of distinct TAZ's, the percentage of the trips between these TAZ's by each available mode. These percentages are used to prepare trip tables for each mode, showing the distribution of trips traveling by that mode.

Assignment is the process of assigning the trips contained in a trip table for a given mode to a particular path through the network corresponding to that mode. All the trips between any pair of TAZ's are usually assigned to the minimum total time path connecting the TAZ's (the so-called "all or nothing assignment"). The output of the assignment process is a loaded network, i.e., each link has an estimated number of trips associated with it for a particular time period. There is a provision in the FHWA programs that allows an iterative assignment procedure which accounts for congestion effects. If the i-th assignment loadings result in the capacity of one or more links being exceeded, the total traverse time for every path passing through the overloaded link(s) is adjusted upward to account for congestion. Presumably, the i+1st assignment, with a changed set of minimum time paths, will result in fewer trips assigned to the overloaded link(s). There is no guarantee that this process will converge to an assignment with minimal overloading, but the method (called "capacity constraint") has been used with satisfactory results in many urban highway planning studies. The capacity constraints feature was not required in the Dual Mode study due to the high capacities of the automated guideways. The trip generation and trip destination steps were not performed in the Dual Mode study. Instead the target year trip tables estimated by the local transportation planning study were used.

Thus, latent (or induced) demand was not explicitly estimated, but was studied parametrically as described in Volume II of this report.

3.3.2 Assumptions

The development of patronage prediction techniques for the Dual Mode study was shaped largely by such considerations as: scope and aims of the study, availability of data and availability of appropriate tools. Several basic decisions were made in order to adapt the patronage prediction process to these realities:

1. The TAZ level of disaggregation was too great. The urban area under consideration had 894 zones which result in about 800,000 distinct origin-destination combinations. This level of detail was much too great for the aims and scope of the Dual Mode study. Accordingly, superzones consisting of clusters of contiguous TAZ's were defined, and only intersuperzone trips were analyzed. This was done in such a manner that no potential Dual Mode trips were eliminated from consideration.

2. The input requirements of the cost/benefit model necessitated a traffic assignment to the Dual Mode network, with volumes reported on a directional, per-link basis. For highway and conventional transit, on the other hand, no assignment was necessary.

3. There was no need to perform traffic generation and distribution, with their enormous data preparation and computing demands, since the regional transportation group had developed trip tables for the 1990 time frame. The advantages of using local trip tables were utilization of the enormous amount of work that had been done previously as well as the special insight of the local planning team. This precluded the direct consideration of induced demand, but none of the devices (such as "direct generation" models) for dealing with this component of demand were considered operational in any event. The problem of induced demand was to be handled parametrically.

4. Highway and transit skim trees* were to be used as the source of superzone-to-superzone travel impedances for those modes. For each superzone, a constituent TAZ located as near as possible to the centroid of trip densities in the superzone was chosen as a "representative" TAZ. The travel impedances between superzones were then taken to be the impedances between corresponding representative TAZ's.

5. The skim trees for conventional transit in Boston existed for only a limited number of destinations clustered about the CBD. This meant that for a regional analysis of the type planned most interzonal impedances would have to be prepared by hand. A task of this magnitude was clearly beyond the scope of this study, so a sampling technique based on a regional categorization of trips was adopted.

6. Data preparation for the N-Dimensional Logit Model was a task of such magnitude that calibration was done on Boston data selected from middle-income, A.M. peak, home-based work trips alone. An elaborate set of scaling factors was developed to modify the Logit Model outputs to account for different income groups, temporal periods, and trip purposes.

The major conceptual elements of the patronage perdiction process are discussed in the next few sections. For a comprehensive description of the data processing procedure, refer to Appendix C. Appendix D contains the detailed documentation of the computer programs used.

3.3.3 Network Preparation and Processing

The network representing the Dual Mode system was coded in detail, following the standard urban transportation planning procedure outlined in the FHWA manual.[98] One basic set of links was coded to represent all Dual Mode baselines outside the CBD. Two different

*A skim tree is a table of minimum time paths between various origin-destination pairs.

versions were coded for the portion of the network within the CBD in order to distinguish different CBD distribution philosophies for large vs. small vehicle baselines. (See Volume III, Chapter 2).

For large vehicle baselines, the Dual Mode network was linked to the existing rapid rail transit by means of parking garage/stations. In the representation of this network, CBD rapid transit line haul and wait links taken from the regional planning study's 1990 transit network were coded as part of the Dual Mode network and linked to the parking garage/stations and the downtown superzones. (Prior to the modal split analysis, interzone minimum paths in the Dual Mode network were inspected to determine which ones used rapid transit links only. Subsequently, these trips were not counted as Dual Mode trips.)

Within the two basic network configurations, the individual baselines were distinguished by entering different impedances in the link data cards for each baseline.

In order to facilitate the changing of impedances (times and distances), to provide an indexing system to allow extraction of link volumes for input to the cost/benefit model, and to permit automated summation of different types of impedances in a flexible manner, network links were classified by type. Ten classifications were established as follows:

0. Rapid transit access
1. Parking delay and cost
2. Access walk
3. Egress walk
4. Dual Mode off-guideway travel
5. Dual Mode station delay, wait time, or dummy link
6. Auto access to Dual Mode guideway or Dual Mode park'n' ride terminal
7. Conventional rapid transit line haul
8. Dual Mode guideway line haul
9. Dual Mode guideway merge delays

For convenience in describing data preparation all the links were placed in two broad classes: access links and line haul links. Access links were the complex of links connecting each superzone centroid to the Dual Mode guideway, including all links representing waiting times, station processing delays, walk time, auto access, transfers to conventional rapid transit, etc. Line haul links consisted of on-guideway line haul links and merge delay links. Since on-guideway speeds and merge delays were the same for all vehicle types, the only links which required different impedance values for different baselines were the access links. These consisted of a set of 7 links for each of 93 superzones outside the CBD, 3 links for each of 43 CBD superzones for small vehicle baselines, 3 links for each of 23 CBD superzones for large vehicle baselines, and 3 links connecting the Dual Mode guideway to the conventional rapid transit system at each of 11 parking garage/stations (for large baselines).

The ensuing sections discuss the formation of superzones in various parts of the study region, and the method of sampling origin-destination superzone pairs (O-D pairs) for calculation of the modal splits. For each distinct Dual Mode baseline, access link impedances were individually estimated and coded for those superzones appearing as an origin or destination in a sample O-D pair (sample superzones). For the rest of the superzones (non-sample superzones), average access link impedance values were calculated in the following manner: in the case of superzones outside the extent of the Dual Mode system, average link values were calculated using the "exact" values from the sample superzones outside the system extent.

The non-sample superzones within the system extent were handled similarly. A computer program was developed to insert these average impedances from copies of the link data cards onto direct access storage devices. This allowed the development of the large number of network versions necessary to represent the various baselines and to perturb network values for parametric studies. Note carefully that the use of average values in access link impedances did not affect the determination of minimum paths through the networks, since for each centroid, there was a unique sequence of links connecting the centroid to the line haul system regardless of the access link impedance values. Furthermore, no "average" impedance values were ever fed to the modal split model, since splits were calculated for sample O-D pairs only.

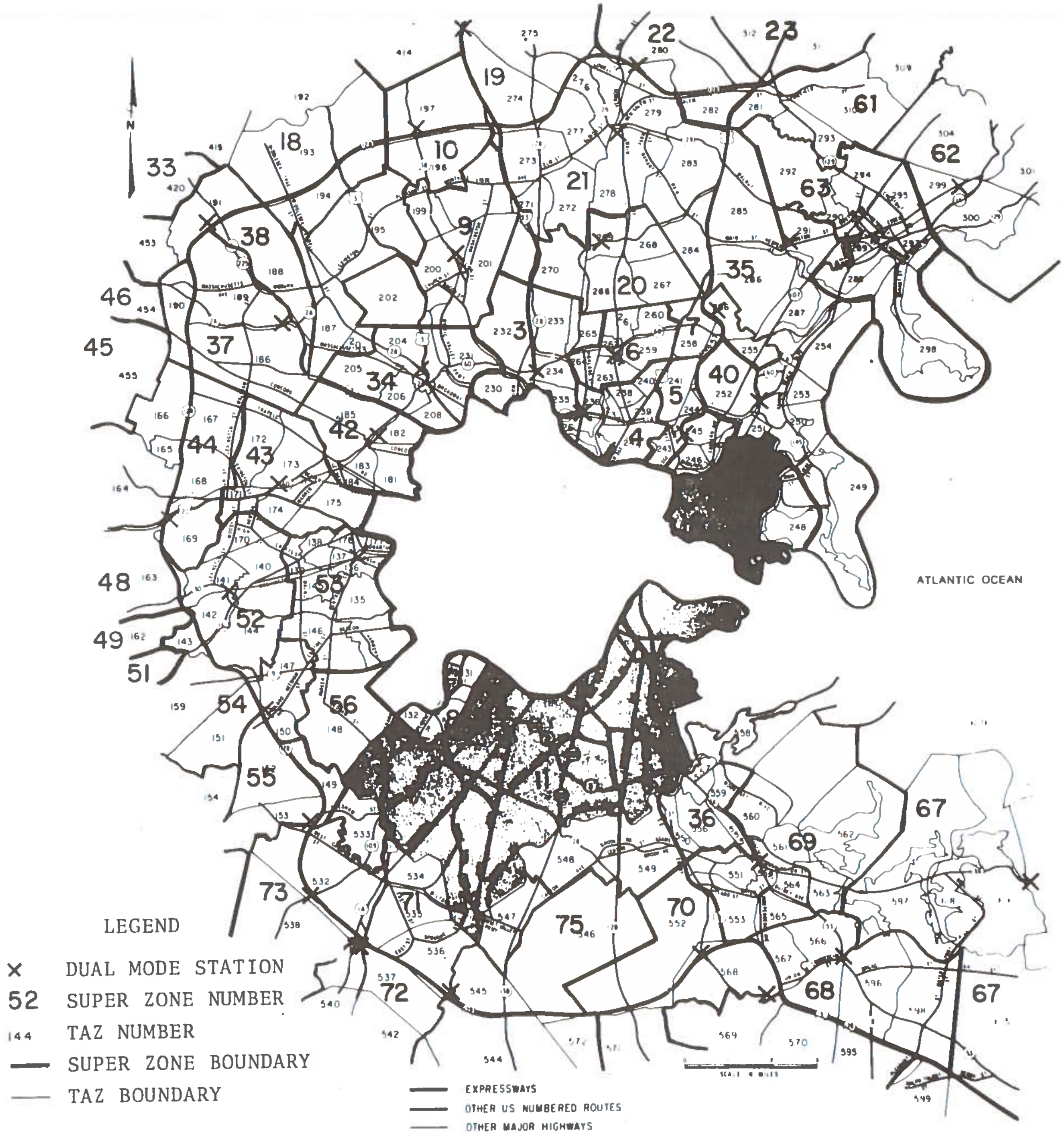
3.3.4 Zonal Aggregation Policy

The general principle followed in constructing superzones was to cluster TAZ's about pre-determined Dual Mode stations, so that all candidates for Dual Mode trips were contained in the trip table of superzone-to-superzone trips. By requiring that superzones be composed of an integral number of TAZ's, the superzone total person trip tables were easily constructed by aggregating the local planning agency's TAZ total person trip tables.

The superzones for the Boston study are as shown in Figures 3-1, 3-2, 3-3, and 3-4. Note that 23 CBD superzones were specified for large vehicle baselines, corresponding to 23 downtown rapid transit stations (Fig. 3-1). CBD superzones were specified for small vehicle baselines (Fig. 3-2) corresponding to the 43 downtown Dual Mode stations provided in those cases. Outside the CBD the number of superzones were fixed at 93 for all of the Dual Mode baselines. Figure 3-3 shows the area lying outside the CBD, but within the extent of the Dual Mode system. In this area, as in the CBD, the principle of clustering TAZ's into a superzone about each Dual Mode station was followed. In that portion of the study area lying beyond the outermost extent of the Dual Mode system (Fig. 3-4), it was necessary to handle the construction of superzones differently. In this region it was possible to define considerably larger superzones without adversely affecting the analysis, since the only trips lost by aggregation were intra-regional trips which were not likely to use Dual Mode, due to the remoteness of the system. These remote superzones were formed by clustering TAZ's around major radial arterial highways, which provided access to the Dual Mode system.

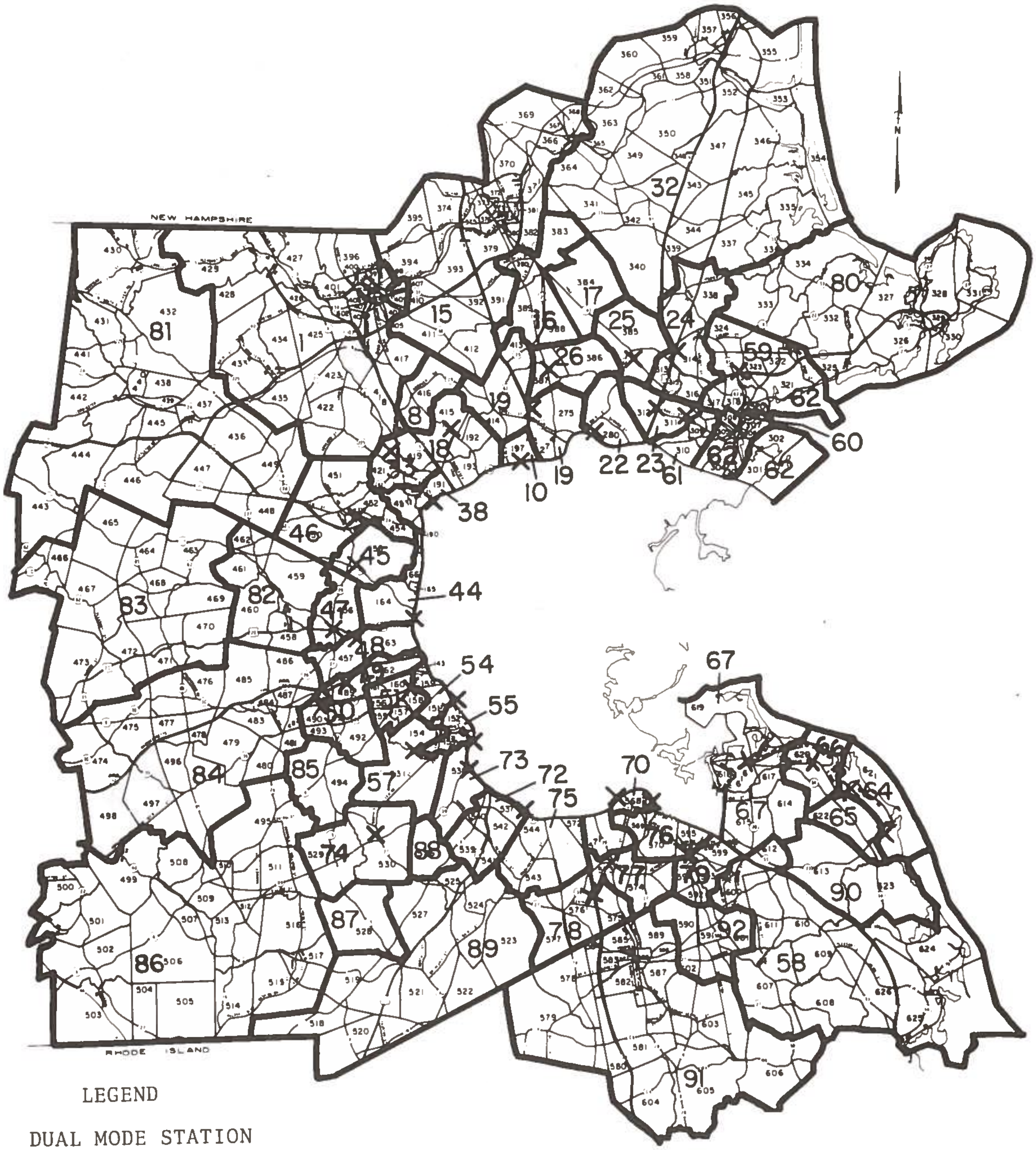
Figure 3-1. CBD Superzones (Non-SPV)

Figure 3-2. CBD Superzones (SPV)



NOTE: CONSULT SUPERZONE LISTING FOR EQUIVALENT TRAFFIC ANALYSIS ZONES 11, 13, 14, 36, 56, 71

Figure 3-3. Traffic Zones Within Route 128



LEGEND

× DUAL MODE STATION

87 SUPER ZONE NUMBER

506 TAZ NUMBER

SUPER ZONE BOUNDARY

TAZ BOUNDARY

Figure 3-4. Traffic Zones Outside of Route 128

3.3.5 Categorization and Sampling of Trips

As previously mentioned, relatively little trip impedance data was available for conventional transit. Because of this it was not possible to prepare a complete set of impedances (auto, transit, Dual Mode) for more than 100 to 200 O-D pairs. It was therefore necessary to choose a sample from the 18,000 (directional) O-D pairs and extend the results of the sample modal splits to the remaining pairs. Clearly, it was not proper to choose a random sample of O-D pairs and apply the average of the splits for the sample to all the pairs in the region. This would have been equivalent to assuming that the relative level of service among the competing systems is the same for all O-D pairs in the region.

Of several possible approaches, the most appealing one involved the stratification of O-D pairs (trips) into mutually exclusive categories. This had to be done in such a fashion that the trips within a category were similar with respect to characteristics affecting modal choice. It was decided that home-based, A.M. peak work trips would be categorized so that trips within each category were similar in the following trip attributes: trip length, average population density along trip path, and proximity of the trip or a portion of the trip to the major systems having limited extent, namely conventional transit and Dual Mode (as opposed to the ubiquitous highway network). The modal split model would then be applied to each of several sample O-D pairs in each category. The average of these sample splits was to be taken as a "base modal split" for each O-D pair in the given category. At a later stage, the base modal splits would be adjusted for temporal, trip purpose and income differences, using scale factors which will be described in the next section.

The specific categorization criteria used were distance and spatial orientation. Three distance stratifications were defined, corresponding to short, medium and long trips. The 1963 highway network off-peak skim tree times were chosen as the most convenient device for classifying lengths. Short trips were those taking less than 10 minutes, medium trips were from 10 to 30 minutes, long trips were 30 minutes or longer.

The spatial orientation stratification for Boston can be best illustrated by referring to Figure 3-5. The Eastern Massachusetts Regional Planning Project (EMRPP) area was divided into four large districts labeled I, II, III and IV. District I enclosed the proposed Dual Mode guideway network, while the other three districts comprised the rest of the region. Five trip categories were established. Category A (urban trips) were those trips whose origin and destination superzones were contained in district I. Category B (radial trips) were the trips having one end in district I and the other in districts II, III, or IV. Category C (intra-suburban) were the trips contained entirely within districts II, III or IV. Category D (circumferential) were the trips having one end in district IV and the other in districts II or III. Category E (trans-core) were the trips having one end in district II, the other in district III. The spatial stratification was a means of grouping trips according to their location relative to the Dual Mode and conventional transit systems. A computer program (DMACP) was written to create a data file which specified the category of each superzone O-D pair in the EMRPP area. In addition to distance and spatial orientation, the trips were also classified by median income level (low, medium or high) of the origin superzone. Superzones were classified as low, medium, or high income depending on whether the 1990 median annual income was less than $11,000, between $11,000 and $18,000, or over $18,000, respectively. (These thresholds were derived from 1990 income projections prepared by the Metropolitan Area Planning Council.[56]) The income level classification was to be used in developing scale factors for modifying the Logit Model results.

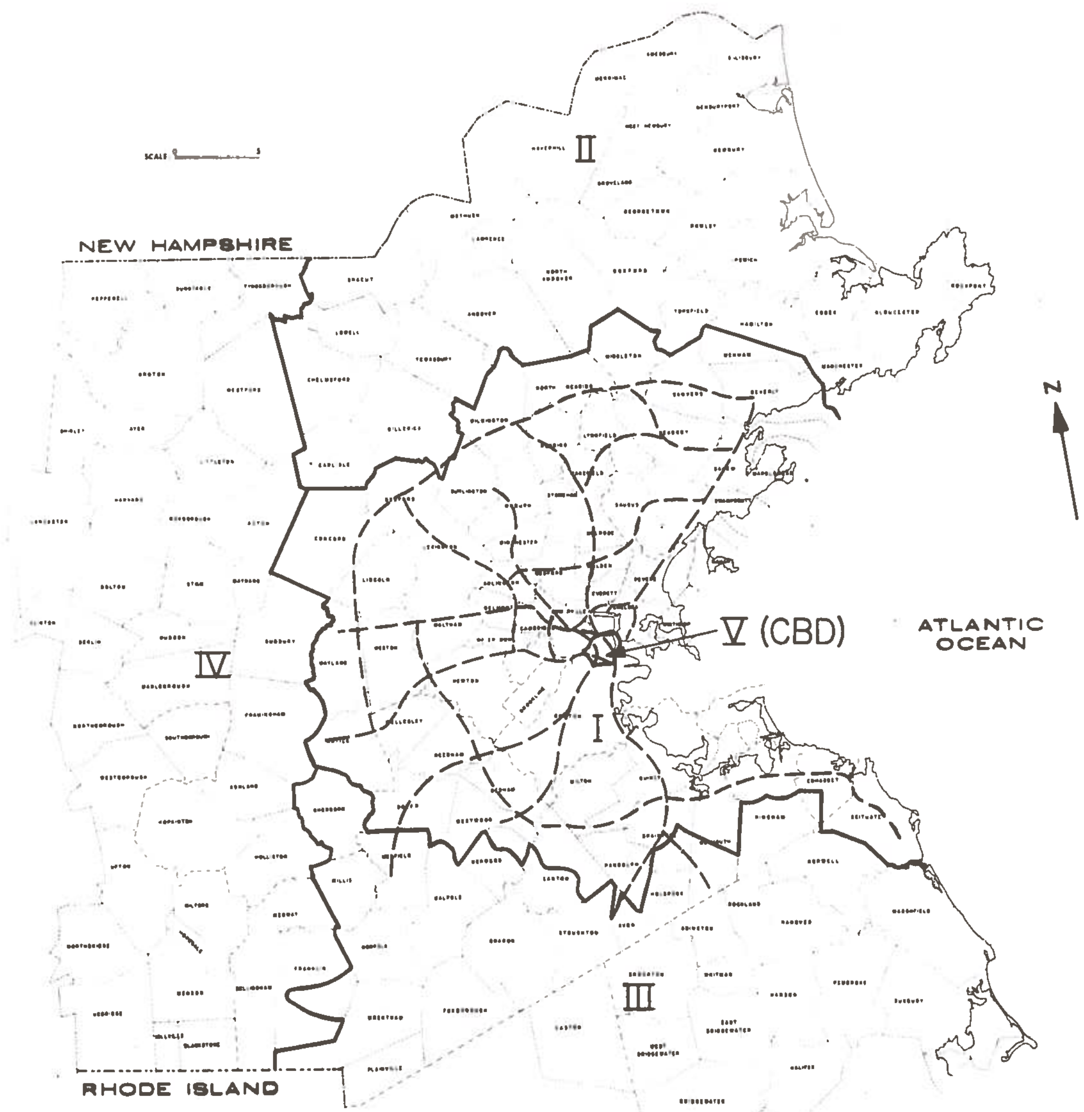
3.3.6 Extending Logit Model Results

In order to extend the results of the home-based, middle-income, A.M. peak work trip modal split model to other temporal periods (24-hour, total), other income levels (high and low), and all purposes, scale factors were developed for both the conventional transit and auto modes, using the 1963 EMRPP Household Survey data.

The total classification scheme for O-D pairs can be summed up by listing the defined stratifications: 5 spatial orientation stratifications (see Figure 3-5), 3 distance stratifications (short, medium, and long), 3 origin superzone income stratifications (low, middle, high), 1 trip purpose (all), 2 temporal periods (A.M. peak, 24-hour). This amounts to 90 distinct categories of O-D pair/time periods.

Following the modal split process each O-D pair was endowed with the "base" modal split corresponding to its spatial orientation-distance category. "Base" refers to middle-income, A.M. peak temporal period, home-based work purpose. In order to adjust the transit split for O-D pairs corresponding to other than "base" stratifications, scale factors were developed for the auto. Scale factors for Dual Mode were adapted from these factors by a subjective evaluation of how the baseline would be perceived.

The calculation of scale factors can best be illustrated by means of an example. Suppose one wishes to calculate the transit split scale factor for O-D pairs in the category described as follows: spatial orientation D, medium distance, low-income origin, 24-hour temporal period, all purposes (call this category C_1). Then a corresponding category C_B is specified, with the same (D, medium) spatial orientation and distance specifications as C_1, with income, temporal, and purpose specifications (middle, A.M. peak, home-based work) corresponding to the (base) modal split model. Next a historical volume of transit trips, $V_{TRAN}(C_B)$, is calculated by counting the transit trips in the EMRPP household survey corresponding to C_B. The total trips in the survey corresponding to C_B, denoted $V_{TOT}(C_B)$, are counted and the ratio $V_{TRAN}(C_B)/V_{TOT}(C_B)$ is taken to be the historical transit split for the base category C_B, and is denoted $S_{TRAN}(C_B)$. Similarly, the historical transit split $S_{TRAN}(C_1)$, for category C_1 can be computed from the household survey file. The transit scale factor $F_{TRANS}(C_1)$, category C_1 is defined to be the ratio $\frac{S_{TRAN}(C_1)}{S_{TRAN}(C_B)}$. Auto factors can be computed in an



CATEGORY GROUP	TRIP FLOWS
A	II - IV
B	I - I
C	I-II, I - III, I-IV
D	II-II, III - III, IV-IV
E	II - III
F	V - V
G	I - V
H	II-V, III - V, IV-V

LEGEND

DUAL MODE GUIDEWAY - - -

DISTRICT BOUNDARIES ——

Figure 3-5. Classification Scheme for O-D Pairs exactly analogous manner, except it is easier to calculate them by the relation:

$$F_{auto}(C_1) = \frac{1-S_{TRAN}(C_1)}{1-S_{TRAN}(C_B)} .$$

A computer program (MSTB) was developed to adjust the base modal splits and produce a modal split table for each mode and temporal period. The base splits are adjusted by multiplying the base split for each pair by the factor corresponding to the given pair's category, the desired mode and temporal period. For Dual Mode baselines, transit factors were used for public vehicle types, while auto factors were used for personal vehicle types. Appendix B is a detailed description of the software which was designed to calculate and apply the scale factors.

The major initial step in the patronage estimation analysis was the calibration of the N-Dimensional Logit Model for the Boston area. That procedure is described in the next section.

3.4 MODE CHOICE MODEL DEVELOPMENT

The basic approach was to perform a disaggregate, individual traveler mode choice analysis which would reflect the theoretical decision making process for a multimodal transportation system defined at a level considered essential to capture the various Dual Mode baseline differences. Once the theoretical modal splits were understood, a more aggregate scheme was employed to account for the effect over all decision makers. Total trips from all origins to all destinations were computed for each mode in the traditional fashion. Following this generation of mode specific trip tables, the Dual Mode trips were assigned to the network, and the conventional highway and transit system effects computed using a more abstract technique not requiring network assignment.

The following five sections describe the sequence of events required in developing and applying the modal choice process for the Dual Mode economic analysis:

- Selection of Disaggregate Model
- Variable Selection and Model Calibration
- Extension to Regional Totals

- Determination of Dual Mode Coefficients and Factors
- Individual Baseline Modeling

3.4.1 Selection of Disaggregate Model

Many approaches to mode choice analysis were examined prior to selection of the final technique. Leading practitioners in the Federal Government and industry were interviewed relative to the complexities inherent in analyzing new public or private systems designed to supplement and compete with the automobile.*

The review of various analysis alternatives resulted in a detailed list of model characteristics. A particularly fine-grained analysis was required to separate not only Dual Mode from non-Dual Mode (transit riders and auto) users, but to distinguish among the various Dual Mode baselines.

The following characteristics were considered essential:

- Handles all competing modes simultaneously.
- Deals with various transportation system characteristics in a flexible and straightforward fashion (essential when performing demand sensitivity studies).
- Allows granular treatment of terminal and prime mode access/egress time and cost considerations, areas which are strong discriminators among the Dual Mode baselines.
- Is derived from a unique set of plausible assumptions regarding causal relationships between transportation characteristics and traveler behavior.
- Employs explicit cross elasticity which facilitate system sensitivity analysis.
- Uses a mathematical form allowing consideration of independent variables having a wider range of reasonable values.

*References: 1, 4, 18, 22, 38, 46, 47, 52, 53, 55, 62, 67, 69, 70, 73, 74, 75, 77, 81, 87, 91, and 110 reflect appropriate literature reviewed during the survey.

New modeling approaches (e.g., abstract mode and direct demand generation techniques) were theoretically appealing but were eliminated because they were relatively unproven.

Data availability was also an influencing factor. Several models were bi-modal -- objectionable since the baselines involved competing Dual Mode combinations as well as the competition of conventional auto and transit. Occasionally, the model was integral within a larger planning methodology and the mechanics of separating the modal choice logic for integration into the Dual Mode analysis framework were uncertain if not impractical. Graphical techniques, such as diversion curves, become very large matrices to generate and deal with when considering the spectrum of alternatives requiring exploration.

Ultimately, the N-Dimensional Logit Model[70] developed by Peat, Marwick, Mitchell and Co. (PMM) was selected since it qualified under all the above guidelines.

As stressed by PMM, the advantages of such a behavioral stochastic disaggregate model are, specifically, that it can:

- model behavior at the smallest decision making unit - the individual;
- avoid the "ecological fallacy"* of aggregate models;
- allow aggregation at any desired level;
- offer greater predictive validity ("transferability");
- determine the probability of selecting a mode, given system and user characteristics;
- constrain each split between 0 and 1 and insure that their sum is equal to 1; and
- have smaller data requirements.

The principal advantages of the N-Dimensional Logit Model are that it:

- has a simultaneous multi-mode capability;

*Ecological fallacy - arises from attempting to use aggregate data to build models of the behavior of individuals.

- is an interchange model (modal split computed following determination of zone-to-zone distribution of travelers);
- provides a flexible structure;
- "mode" can be broadly interpreted as a combination of "access" and "main" modes;
- independent variables can be incorporated as "stratifiers" or directly;
- independent variables can be continuous or dummy ratios, differences, etc.;
- the sets of independent variables associated with each mode need not be identical;
- any group of coefficients can be constrained to be equal.

The logit is an exponential or log normal mathematical function which exhibits many properties which are desirable in a modal split model, such as being defined only over the interval from zero to one as modal splits indeed are. The logit function has its greatest sensitivity (steepest slope) at 0.5 and is asymptotic to zero and one, both characteristics which data and logic suggest that modal splits demonstrate.

Illustration of the multimodal properties can be found in Appendix A. The model has been applied in the following studies:

- Washington - Baltimore Airport Access Study
- San Diego Transit Study
- Los Angeles TACV Study

3.4.2 Variable Selection and Model Calibration

A. Variable Selection

Ideally one would prefer to model all independent variables which might influence each individual's mode choice decision. Two typical problems occur when attempting this: first, consistent time related historical data will not support calibration of the proposed model and, second, all the variables are not projected into the future to enable applications of the model. Both problems are compounded by the normal situation that the "modeler" was not involved in the data collection/generation process; hence, certain assumptions and facts about the data are not always available to allow clear definition/separation of all the interesting variables. Further, selection of variables is difficult if they are constrained to be identified for application across a range of urban regions -- again, a problem of data availability.

Figure 3-6 reflects a candidate shopping list of variables considered for the Dual Mode study. Both the trip and trip-maker market variables and the transportation system characteristics are itemized.

Two basic approaches to consideration of the variables come to mind. One could model each tripmaker and his trip characteristics as independent variables, thus creating a very complex and difficult model to calibrate. The second and simpler approach is to use a mathematical form having fewer explanatory independent variables which generally describe the transportation system characteristics, e.g., travel times, costs. To cover the remaining trip and tripmaker variables of interest (e.g., trip purpose, income), the data base could be subdivided into the number of characteristics supported by calibration. Each stratified set of data would then be operated on and a spearate model developed. To obtain a measure of the total modal splits, all models would be run and the results summed for each stratification.

The Dual Mode study required a modeling approach sensitive to a multimodal spectrum of alternatives. After significant review of Boston's inventory of transportation planning data and comparisons with other possible urban data bases, the decision was made to:

- Structure the N-Dimensional Logit Model using up to four competitive primary modes measuring behavior at the individual traveler level. Submodes could exist for access/egress from the prime mode.

MARKET STRATIFICATIONS

1. Socio-Economic
   - o Income
   - o Auto Ownership
   - o Age
   - o Sex
2. Trip Purpose
   - o Work
   - o Pleasure
   - o Vacation
   - o Shopping
   - o Business (with the "captive" influence of expense coverage)
3. Trip Length and Orientation (e.g., toward/away from CBD)
4. Trip End
   - o Home Based
   - o Non-Home Based
5. Temporal
   - o Peak/Non-Peak
   - o Day, Night
   - o Season
6. Residential/Employment Densities

Figure 3-6. Possible Mode Choice Model Variables

Transportation System Variables (per mode per trip)

1. Access times to (from) prime mode including, initial and egress walk, terminal delays and various submodes
2. Frequency of departure
3. Difference between scheduled and actual departures
   - o Demand and non-demand actuated
4. Reliability (predictability of arrival time)
   - o System queueing
   - o Capacity restraint
5. Number of transfers plus associated delays
6. Total line haul time
7. Perceived cost
   - o Access to (from) prime mode
   - o Line haul costs
   - o Parking costs
8. Travel comfort
9. Safety
10. Driver/passenger relationship
11. Mode captive/non-captive relationship

Figure 3-6 (Continued). Possible Mode Choice Model Variables

- Stratify the basic inventory data for calibration into trip and tripmaker characteristics. Select the stratified set representing the largest group of travelers. Since Dual Mode system size is predominately forced by peak period trip loads, that temporal period would additionally be used as a basic reference.

- Calibrate the Logit Model using all transportation system variables that were determined statistically sound.

- Extend the reference group model over all other trip and tripmaker variables based on modal split relationships derived from base year historical records.

Based on the above decisions, the Logit Model was calibrated considering the following four primary modes:

- Conventional Auto

- Rapid Rail

- Conventional Bus

- Commuter Rail

Walk was considered an access/egress submode to auto and transit. Treatment of submode access/egress to transit as a primary mode was accomplished using data generated for the Massachusetts Department of Public Works by PMM & Co.

All trips were categorized (see 3.3.5, "Categorization and Sampling of Trips") into three income groups (high, middle, low), two trip purpose groups (home-based, work, all others); and two temporal periods (peak and daily). The home-based work trip made by middle income travelers in the A.M. peak three-hour period was selected for calibration since it was the most significant group size represented by the various stratifications. All other trip-making was represented by the behavior of this group and its relationship to the other travelers based on the historical trip files available from 1963 base year transportation survey.

Table B-1 of Appendix B lists 47 independent transportation system variables initially tested. Definition of the tested variables follows:

- Line haul time - in-vehicle travel time.
- Egress - walk time at terminal end of the trip.
- Parking cost - one-half day parking charge at destination (origin, if park'n' ride).
- Driving cost - out-of-pocket auto operating costs divided by auto occupancy for origin zone.
- Reliability - a 0 to 10 value based on a subjective evaluation of the standard deviation of travel time in the prime mode. Besides Boston experience, factors analysis by Bock[10], a survey completed during the Northeast Corridor study[63], and a survey on urban demand for HUD[2] were used in establishing the scale value for each prime and significant connecting submode.
- Comfort - a 0 to 10 value based on a subjective evaluation of the individual trip considering environmental conditions of weather, ride quality, and ease of vehicle entry/departure/accomodations. Data for generating the scaled values was guided by the same studies as the reliability index.
- Core Orientation - a binary variable, "1" if significant portion of the trip was directed toward the CBD (A.M. peak), and "0" for all other cases.
- Ownership - a three state variable, "2" if a privately owned vehicle, "1" if leased or a taxi, and "0" if system-owned.
- Initial walk - walk time required to reach the first vehicle access point. The decision to consider walk time at the destination end of the trip as excess time but not origin end walk time was reached during an early forecasting study

done by PMM & Co. for the Massachusetts Bay Transportation Authority. During this study (when all walk time was regarded as excess time) it was discovered that the modeled transit modal splits for traffic analysis zones located close enough to stations for walk access were lower than surveyed data indicated and, in fact, were lower than modal splits for zones located near the stations but not close enough to work. The origin walk (excess) time was causing the modeled modal splits to be depressed. This apparent paradox could be explained by the fact that although everyone from a zone might walk to the station, other access modes (park'n' ride and kiss'n' ride) may still be potentially available. (This case does not normally occur at the destination end where everyone must walk.) The problem was effectively solved by removing walk time at origin from the excess time category.

- Auto access - auto in-vehicle time required to reach the point for transfer to the prime transit mode.
- Access Penalty - a trip time measure added to auto access time which reflects vehicle driving time (with respect to its suitability for kiss'n' ride), the parking availability at the transit station, and the quality of local bus service (measure of travel and wait time relative to auto when accessing a rapid transit station).[71]
- Wait - all wait time encountered during the trip.
- Line haul - in-vehicle travel time.
- Auto access cost - out-of-pocket auto operating cost required when driving to point of transit connection.

- o Fare - one-way transit trip fare.
- o Select - a binary calibration value used to flag selected mode alternative for each sample trip.

B. N-Dimensional Logit Calibration

As described in Appendix A the N-Dimensional Logit Model is capable of treating "i" variables for each or any of "j" modes. Obviously, the larger the number of variables the more difficult the calibration process. To optimize the calibration process a simple regression correlation analysis was conducted on pairs of disaggregate calibration variables. Figure 3-7 is a listing of pairs having correlations greater than 0.5. Variable abbreviations are defined in Table B-1 of Appendix B. It should be noted that "statistically significant" correlation is indicated only for r's greater than about 0.7.

Table B-2 of Appendix B gives the variable names and numbers and the means and standard deviations of the calibration variable data.

Table B-3 is the complete correlation matrix for all variables.

Because of the high correlation between several of the variables, e.g., auto line haul time (ALH) and auto driving cost (ADCS), only one was modeled as explanatory, ALH. Other variables were eliminated or aggregated as indicated by the calibration sequence. As noted earlier the "middle-income" trips from the Boston 1963 surveyed trip data were used in the calibration samples. Results of the 29 calibration runs are reproduced in Table B-4 of Appendix B. Seventeen of these (presented approximately in the order run) contain notes describing the relevant features of each. The remaining runs are not important to understanding the flow of the calibration process and are presented for the sake of completeness only.

The criteria used in the evaluation of each calibration run were the following:

1. Correct signs on coefficients
2. Low standard errors of coefficients (significance)

Variable	Variable	r(|r|>0.5)
RPEN	CPEN	.988
R AA	RACS	.944
A LH	ADCS	.936
RREL	RCOM	.931
CREL	CCOM	.905
ADCS	B LH	.862
A LH	B LH	.859
B WT	B LH	.809
BREL	BCOM	.713
A LH	B WT	.705
R WT	R LH	.693
ADCS	B WT	.685
R WT	C WT	.663
C LH	CFAR	.656
B LH	BFAR	.654
C AA	CACS	.648
C PK	CACS	.641
ADCS	BFAR	.640
A EG	A PK	.637
R WT	RREL	.608
RFAR	CFAR	.602
A LH	BFAR	.585
R AA	R LH	.584
R LH	RREL	.580
C AA	C PK	.559
C WT	C LH	.559
R WT	RCOM	.556
A PK	RREL	-.554
B WT	C LH	.546
R LH	RFAR	.545
A EG	R LH	-.533
RACS	RFAR	.532
R LH	RACS	.528
RREL	CREL	.524
RCOM	CREL	.523
R LH	C WT	.522
AREL	RACS	-.516
AREL	R LH	-.515
A PK	RCOM	-.514
B WT	BFAR	.514
BFAR	CFAR	.511
R AA	RFAR	.508
RREL	C WT	.508
RREL	CCOM	.506
C WT	CCOM	.506
AREL	RFAR	-.504
C IW	C AA	.503
R AA	C EG	.501

Figure 3-7. Dual Mode Calibration Variable Correlations

3. Logical relative and absolute magnitudes of sensitivities
4. Logical relationships between coefficients
5. Ability to duplicate sample modal splits
6. Constraints on coefficients minimized
7. Consistency of impedance types used between modes.

Of these seven criteria, the last are probably of less importance than the others.

Regarding the second criterion, significance of coefficients, T-Ratios were computed in each of the calibration runs. These T-Ratios are ratios of the estimated coefficients to the standard errors of the coefficients. If the absolute value of the T-Ratio for any coefficient is larger than about .67, it can be said with a probability of .95 that the coefficient is more reliable than a null value. This test is commonly used as a measure of the significance for coefficients.

Of the 494 observations (trips) comprising the sample data, 94 trips were by other than auto (40 rapid transit, 34 bus, 20 railroad). Of these 94, only 30 represented actual interviews, the remainder having been included by virtue of the random sample population. (This was necessary in order to minimize the number of O-D pairs for which impedances had to be calculated due to time constraints). In addition, lack of time prohibited any data "massaging" of the type normally done in similar calibration exercises. For these reasons, the calibrated models discussed below use variables for a more aggregate, less precise nature than was originally hoped for: i.e., although it was desired that time and cost variables be separated into several components each of which, it was felt, a traveler might regard differently, not enough reliable data was available to accomplish this as initial results indicated. Also, although it was hoped that several more innovative (and perhaps subjective) measures of travel impedance could be included, such as reliability and comfort, not enough time was available to establish strict guidelines for estimates of these variables to ensure that such estimates would be consistent and unbiased. Again early results with reliability as a variable bore this out. The orientation variable was eliminated since it could be handled by the process of extending the model over the stratification factors described in Chapter 3.3.6, "Extending Logit Model Results". Income is an aggregate surrogate for ownership and was also treated by the stratification factors.

From the calibration process and initial screening of results, four calibrated models emerged that appeared more appropriate than the others. Most of the others were rejected on the basis of the first two criteria mentioned above. (Refer to Appendix B for the coefficients and standard errors of these runs. The runs are in numerical order of run number, and the variables used are defined in Table B-2 of that appendix.) As seen below several of the original 47 variables were combined for modeling purposes. Table B-2 reflects the specific combinations as variables 48 through 74.

Run 13-1

Variables: Auto total time
Auto parking cost
Rapid transit total time
Rapid transit total cost
Bus total time
Commuter rail total time
Commuter rail fare

Run 43-1

Variables: Auto line haul time
Auto egress time (walk at destination)
Auto parking cost
Rapid transit total excess time (wait, egress/access penalty)
Rapid transit total non-excess time (initial walk or auto access, line haul)

Rapid transit total cost

Bus total excess time (wait, egress)

Bus total non-excess time (initial walk, line haul)

Commuter rail total time

Commuter rail fare

Run 42-4

Variables: Same as 43-1 except coefficients on transit constrained to be equal for like variables.

Run 44-2

Variables: Same as 42-4 with the addition of reliability (coefficients constrained to be equal for transit mode like variables)

Although Run 13-1 met all the criteria except the last fairly well, it was rejected in favor of calibrations distinguishing between excess and non-excess time because sensitivity analysis indicated this latter distinction was an important determinant of travel behavior.

Run 43-1 would have been the best if the coefficients on non-excess time for both rapid transit and bus had not exceeded those on excess time, a contradiction of transportation planning logic. Experience has shown that excess time is generally more important to the trip-maker than the other time components of the trip.

Run 42-4 produced a calibrated model which met all the criteria except the last two. Although the coefficients for the transit modes were constrained to be equal for like variables, this was perhaps justified in that the coefficients for each of the transit mode variables taken separately showed considerably higher standard errors than when constrained.

This model reporduced the sample observed modal splits as follows:

	Sample	Model
Auto	81.0%	75.2%
Rapid Transit	8.1	13.5
Bus	6.9	6.0
Railroad	4.0	5.3

Figure 3-8 shows the frequency tables for the differences between the sample observation modal splits (which were all 100% for one mode and 0% for the other three modes) and the Logit Model modal splits. Figure 3-9 shows sensitivities and elasticities of the modal splits on the basis of a unit change in each of the impedance variables. Here sensitivity is defined as the change in modal split for a one unit (minute, cent) change in the variable in question, and elasticity is the percentage change in modal split for a one percent change in the variable in question. Note that only the transit mode direct elasticities are greater than one. The auto direct elasticities and all mode cross-elasticities are less than one. For auto, excess times appear to have about six

ΔMS	No. of Observations	% Observations
0- 9.99	1,263	63.9
10-19.99	278	14.1
20-29.99	145	7.3
30-39.99	58	2.9
40-49.99	53	2.7
50-59.99	27	1.4
60-69.99	49	2.5
70-79.99	39	2.0
80-89.99	34	1.7
90-100	30	1.5
TOTAL	1,976	100.0

ΔMS = Absolute value of (model modal split - sample modal split)

$$\sqrt{\frac{\Sigma(\Delta MS)^2}{n}} = 26.4$$

where n = 1,976 observations

Figure 3-8. Modal Split Difference Frequency Table

SENSITIVITY AVERAGES $\Delta MS/$CENT OR MINUTE

	VAR	MODE 1 Auto	MODE 2 Rapid Transit	MODE 3 Bus	MODE 4 Railroad
Auto Driving Time	2	-0.586	0.258	0.196	0.131
Auto Egress Time	3	-3.930	1.731	1.317	0.882
Auto Park Cost	4	-0.307	0.135	0.103	0.069
Rapid Excess	61	0.283	-0.385	0.041	0.061
Rapid Non-Excess	63	0.246	-0.335	0.036	0.053
Rapid Total Cost	71	0.236	-0.321	0.034	0.051
Bus Excess	59	0.215	0.041	-0.272	0.016
Bus Non-Excess	64	0.187	0.036	-0.236	0.014
Rail Excess	62	0.144	0.061	0.016	-0.221
Rail Non-Excess	65	0.125	0.053	0.014	-0.192
Rail Fare	43	0.120	0.051	0.013	-0.185

ELASTICITY AVERAGES $\Delta MS/1\%\Delta VAR$

VAR	MODE 1	MODE 2	MODE 3	MODE 4
2	-0.289	0.757	0.757	0.757
3	-0.281	0.625	0.625	0.625
4	-0.144	0.062	0.062	0.062
61	0.112	-1.314	0.112	0.112
63	0.151	-2.490	0.151	0.151
71	0.164	-2.212	0.164	0.164
59	0.050	0.050	-4.311	0.050
64	0.055	0.055	-4.111	0.055
62	0.057	0.057	0.057	-1.885
65	0.052	0.052	0.052	-1.683
43	0.103	0.103	0.103	-3.308

All time variables in minutes
All cost variables in cents

Figure 3-9. Modal Split Sensitivity/Elasticity Averages times the sensitivity of non-excess times, but for all other modes and cross-sensitivity terms, excess time is only slightly more sensitive than non-excess times.

In terms of elasticities, cost appears to be less critical than time for those choosing the auto mode, whereas the importance of cost is about the same as or slightly greater than time for those using other modes.

Ultimately, run 60-2 was made using consistent transit cost impedances. In run 42-4 the transit cost impedances consisted of rapid transit total cost, commuter railroad fare only, and no bus cost. Since the transit cost coefficients were constrained to be equal (to each other), it was felt that the cost impedances should be computed on the same basis. Therefore, total trip cost was used for each transit mode. Results of this calibration are shown in Figure 3-10. Modal split difference frequencies as well as sensitivities and elasticities are similar to those in Figures 3-8 and 3-9.

Run 44-2 was made as a final attempt to capture the measure of reliability. The inclusion of reliability, while highly desirable theoretically, resulted in large decreases in the magnitude of most of the time and cost coefficients, thus greatly lowering the modal split sensitivities to those variables. In addition, the T-Ratios for the auto time coefficients decreased significantly. The former problem indicated that the reliability variable was trying to do all the work itself, i.e., attempting to explain the modal choice to the extent of almost eliminating the effects of travel time and cost. This may indeed be reflective of the importance of reliability as a variable, but it more likely simply demonstrates a bias in preparing the input data estimates on reliability.

The moderately high cost sensitivity of the calibrated equation has been noted. Discussed below are several models whose cost sensitivities are compared with the Logit Model. An overall measure of the Logit Model cost sensitivity relative to time sensitivity

```
PROGRAM LOGIT                                        030872
RUN  60                              SAME AS 42-4 BUT BUS COST INCLUDED

SUBPROBLEM   2  OPTION  0        RR TOTAL COST

FREQUENCIES

   400.    40.    34.    20.

LOG OF LIKELIHOOD FOR MULTINOMIAL MODEL =    -340.10
VALUE 1 ESTIMATE 0.810
VALUE 2 ESTIMATE 0.081
VALUE 3 ESTIMATE 0.069
VALUE 4 ESTIMATE 0.040

ITERATIONS TO TOLERANCE  0.2000E-01
ITERATION    0      LOG OF LIKELIHOOD FUNCTION =     -340.10
ITERATION    1      LOG OF LIKELIHOOD FUNCTION =     -281.67
ITERATION    2      LOG OF LIKELIHOOD FUNCTION =     -262.83
ITERATION    3      LOG OF LIKELIHOOD FUNCTION =     -256.82
ITERATION    4      LOG OF LIKELIHOOD FUNCTION =     -253.25
```

MAXIMUM LIKELIHOOD ESTIMATES

		ESTIMATES (coefficients)	STANDARD ERRORS	T-RATIO
Auto driving time	1	0.39880E-01	0.15260E-01	2.6133
Auto excess time	2	0.25833	0.16113	1.6033
Auto park cost	3	0.25760E-01	0.87201E-02	2.9541
Transit excess time	4	-0.30057E-01	0.12705E-01	-2.3657
Transit non-excess time	5	-0.27271E-01	0.14674E-01	-1.8585
Transit total cost	6	-0.32321E-01	0.90733E-02	-3.5622
Rapid constant	7	-0.95713	0.68559	-1.3961
Bus constant	8	-2.0690	0.61229	-3.3791
RR constant	9	-1.3038	0.69179	-1.8847

```
LIKELIHOOD RATIO  TEST     173.700     WITH     18  D.F.
                                                    END OF RUN
```

Figure 3-10. Final Logit Model Calibration Results can be achieved by computing implied values of time from the coefficients of the calibrated equation. A high value of time indicates relatively low cost sensitivity.

$$\frac{\text{auto parking (cents)}}{\text{auto driving(minutes)}} = \frac{.040}{.0258} = 1.55 = \$.93 \text{ per hour}$$

$$\frac{\text{auto parking (cents)}}{\text{auto excess (minutes)}} = \frac{.258}{.0258} = 10 = \$6.00 \text{ per hour}$$

Assuming 10% of the auto trip minutes are excess time, an overall weighted dollar per hour figure for auto is $1.44.

$$\frac{\text{transit cost (cents)}}{\text{transit non-excess(minutes)}} = \frac{.27}{.32} = \$.51 \text{ per hour}$$

$$\frac{\text{transit cost (cents)}}{\text{transit excess (minutes)}} = \frac{.30}{.32} = \$.56 \text{ per hour}$$

A weighted dollar per hour figure is about $.52 per hour. Assuming a one-third transit modal split (in the peak period), an overall value of time implied is $1.13 per hour.

A report published by the U.S. Department of Commerce, Bureau of Public Roads, Office of Planning in December 1966 is entitled Modal Split, Documentation of Nine Methods for Estimating Transit Usage.[17] Of the nine methods, four are for trip interchange modal split (rather than trip end).

The first method involves the well-known National Capital Transportation Agency (NCTA) diversion curves done for Washington, D.C. Because the transit-to-auto cost ratio is used as a stratification variable, it is difficult to examine the cost sensitivity. However, by taking representative impedance values for a sample pair, the cost sensitivity at particular points can be determined. Figure 3-11 shows the Logit Model auto modal split as a function of the auto park cost for several values of transit cost for a typical origin-destination pair. Using the time values indicated and a middle income class, the NCTA curve modal splits are the following:

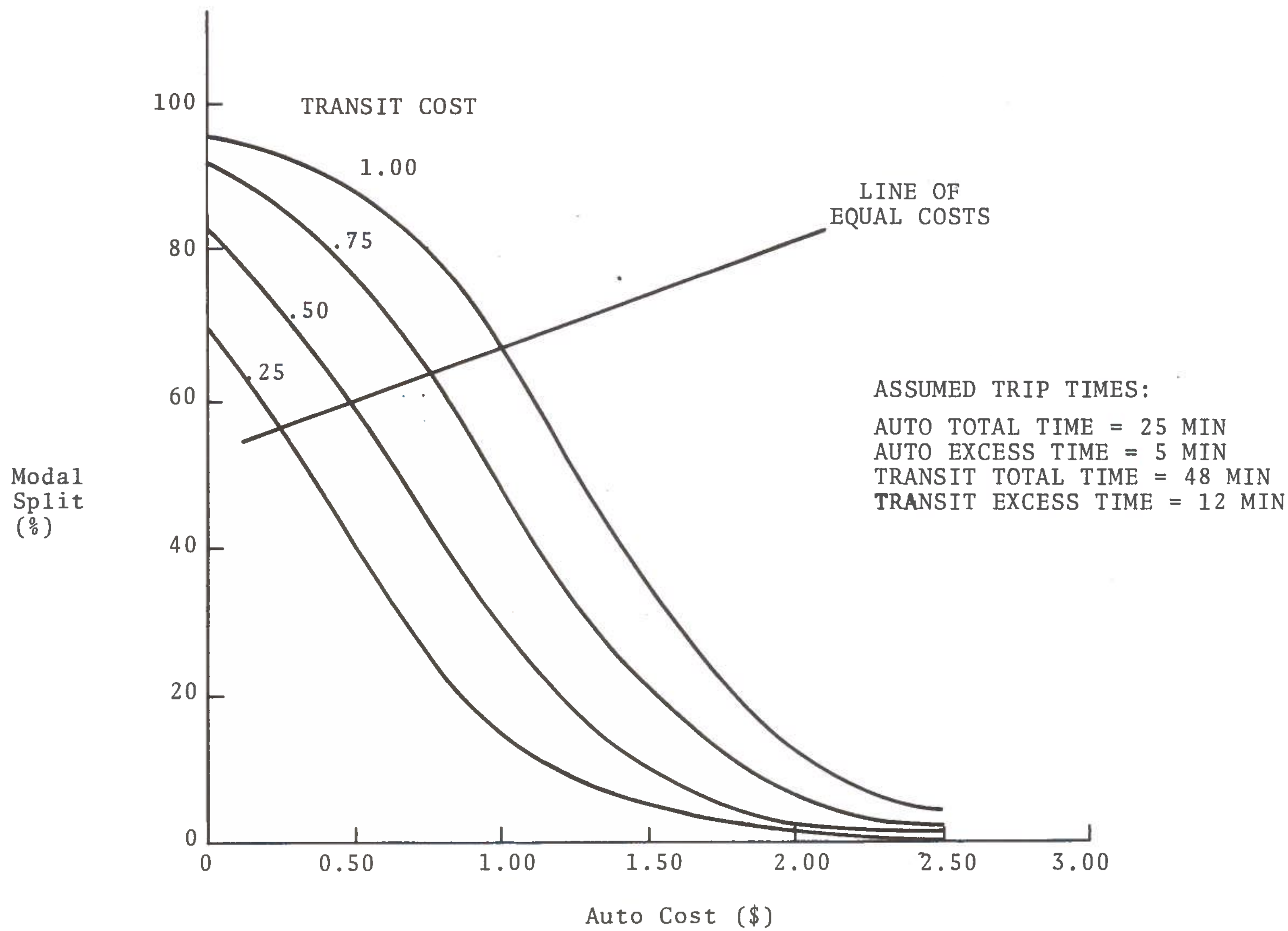


Figure 3-11. Logit Model Auto Modal Split vs. Auto Cost

Cost ratio:	0 to 0.5,	modal split = 58
	0.5 to 1.0,	modal split = 48
	1.0 to 1.5,	modal split = 42
	over 1.5,	modal split = 42

Within the range of each cost ratio class, the NCTA modal splits are perfectly inelastic, i.e., neither transit nor auto cost has any effect on the modal split; but across the cost ratio class boundaries, the cost sensitivity of the curves approaches that of the Logit Model for certain points. For example, in Figure 3-10 for an auto cost of 50 cents, as the transit cost goes from 25 to 50 cents (meaning that the cost ratio goes from 0.51 to 1) transit modal split falls from 60 percent to 41 percent. The NCTA modal split falls from 58 percent to 48 percent. However, because the NCTA curves are discontinuous with respect to cost ratio, a penny or two difference in either transit or auto cost can make a large difference in modal split. For an auto cost of fifty cents and transit costs of 25 and 26 cents, the NCTA modal splits difference is still ten percent. Similarly, for transit costs of 25 and 51 cents, the NCTA modal-splits are 58 and 42 percent, respectively, as compared with the Logit Model's 60 and 41 percent. Therefore, although the NCTA curves are, on the average, less cost sensitive than the Logit Model, their variance in degree of sensitivity is much larger.

The second model, done in Minneapolis-St. Paul by the Twin Cities Area Joint Program, uses an equation relating transit work trip modal split to the following variables:

- o travel time ratio
- o income
- o residential density
- o employment density
- o 9-hour parking cost.

The relationship between modal split and the parking cost is direct with a cost coefficient of 363.5 (dollars). Using an assumed trip time of 30 minutes, the implied value of time resulting is seven cents per hour. A curve relating work transit modal split to parking cost shows the transit percentage varying linearly from

0 to 80 percent as the parking cost increases from 0 to $1.98. Figure 3-11 shows the Logit Model transit modal split varying from 4 to 30 percent (as the transit cost varies) at 0 auto parking cost to 87 to 99 percent at $2.00 auto parking cost, a modal split difference of 69 to 84 percent.

The third method done by the San Juan Metropolitan Area Transportation Study, uses a cost difference between auto and transit for the cost variable. A work modal split versus cost difference curve shows transit modal split falling from 40 to 20 percent as the cost difference rises from -13 to +11 cents. On the Logit Model curve for an auto parking cost of 63 cents and transit cost varying from 50 cents to 75 cents, transit modal split falls from 52 percent to 34 percent; for an auto cost of 38 cents and transit cost varying from 25 cents to 50 cents, the transit modal split difference is about the same (from 52 percent down to 36 percent).

In the Niagara Frontier Transportation Study (Buffalo, New York), auto parking cost was the only cost variable used. However, it was converted to a time penalty and added into the time impedance. It is noteworthy that a conversion factor of $1.20 per hour (two cents equals one minute) was used.

Finally, a recent modal split study done in a Pennsylvania city uses an equation similar to the Logit equation to produce a time difference (including wait and transfer) coefficient of -.0411 (minutes) and a cost difference coefficient of $2.24. The resulting value of time implied is $1.10 per hour.

Although in many of the above-described models, the time and cost impedances used are not strictly comparable with the Logit Model, it is clear that the Logit Model cost sensitivity is well within the range of that experienced elsewhere.

3.4.3 Extension to Regional Totals

To apply the Logit results over all income groups and trip purposes for peak and daily periods the modal split factors were developed as described in the following section.

Computation of Modal Split Factors

The technique for extending the middle-income Logit Model modal split fractions has been described in Section 3.3.6, "Extending Logit Model Results," which uses a program detailed in Appendix D.

Early analysis was conducted to select the most representative trip making group of the various categories. Figure 3-12 reflects the results of stratifying the 1963 historical trips files into low, middle and high income groups each then broken down into the home-based work trip and all other trips. The next stratification divided each of the resultant groups into the 6-hour peak and 18-hour off-peak periods. The trip length and orientation categories completed the stratification sequence.

Following an analyiss of the groupings, the middle income home based work tripmakers during the peak period stood out in all income levels as the group having the highest modal split fraction when weighted by group total ridership. The group of "other non-home-based work" trips occurring in the off-peak period represented the largest number of total trip makers though the percent of transit ridership was significantly lower than that of the middle income groups. Since the general assumption when using the logit form model is that the mode share is most sensitive as it nears 50% of the total ridership, the middle income peak group was selected as the most sensitive for modeling as a base group. All other groups were referenced to modal splits resulting from analysis of that group. Figure 3-13 reflects the factors computed from the base modal splits for the peak period middle income home-based work trip makers. Figure 3-14 is the tabulation following summing of categories where group ridership statistics were too small to be meaningful.

Since peak and daily totals were required for input to the cost/benefit model, the groups were further aggregated and the expansion factors calculated from the previously established peak period middle income home-based work statistics. Figure 3-15 represents the final tabulations used in the analysis.

Orientation Category	INCOME=	1=LOW				2=MIDDLE				3=HIGH					Off-peak Auto Driving Time
	PURPOSE=	1=HBW		2=OTHER		1=HBW		2=OTHER		1=HBW		2=OTHER			
	PERIOD=	1=PK	2=OFF	1=PK	2=OFF	1=PK	2=OFF	1=PK	2=OFF	1=PK	2=OFF	1=PK	2=OFF	TOTAL	
A	1 TRANSIT =	101862	61534	166789	301100	101162	39717	138504	204178	39399	12303	63398	65829	1245775	≤10 min.
	TOTAL =	532786	348784	1256023	2592742	679787	379836	2042756	3759177	372802	175909	1387197	2397986	15925795	
	M.S. =	191	176	133	116	149	105	68	54	106	70	46	27	31	
B	2 TRANSIT =	0	0	0	154	0	706	0	0	0	0	0	0	[illegible]	
	TOTAL =	7587	5360	20600	42324	11914	9623	30251	66966	7549	5323	22329	59303	289149	
	M.S. =	0	0	0	4	0	73	0	0	0	0	0	0	3	
C	3 TRANSIT =	21445	15139	26252	46079	15531	10229	14998	26185	4857	2913	3788	9236	196651	
	TOTAL =	356426	309763	1110029	1945433	436792	329148	1512191	2590267	212437	139037	742300	1209867	[illegible]	
	M.S. =	60	49	24	24	36	31	10	10	23	21	5	8	15	
D	4 TRANSIT =	0	0	0	0	0	0	0	0	0	0	0	0	0	
	TOTAL =	948	958	2069	3311	1595	637	1264	1906	326	0	0	0	13014	
	M.S. =	0	0	0	0	0	0	0	0	0	0	0	0	0	
A	6 TRANSIT =	573695	258394	322645	550890	603856	212791	252962	388870	391593	105176	179115	244375	4124362	10 to 30 min.
	TOTAL =	1262205	710790	1151539	2389958	1922125	898358	1582477	3127957	1355464	437551	1146084	2311120	18215628	
	M.S. =	455	364	280	231	314	237	185	124	289	240	156	106	225	
B	7 TRANSIT =	2213	1754	1870	3448	3844	1297	3853	5701	4164	565	3447	3238	35394	
	TOTAL =	107648	55672	135864	250083	237016	106448	232498	470170	166575	47102	154900	328297	2292273	
	M.S. =	21	32	14	14	16	12	17	12	25	12	22	10	15	
C	8 TRANSIT =	8668	9042	10031	17028	8037	4820	8149	14299	2323	1248	2764	5744	92753	
	TOTAL =	244001	217749	469775	935809	344804	264794	587971	1122121	168460	95980	306275	595998	5353737	
	M.S. =	36	42	21	19	23	18	14	13	14	13	9	10	17	
D	9 TRANSIT =	333	170	0	171	0	0	655	335	0	0	0	0	1664	
	TOTAL =	8966	9053	16798	37637	19906	9016	24429	49287	6955	5740	11403	22496	221687	
	M.S. =	37	19	0	5	0	0	27	7	0	0	0	0	3	

Figure 3-12. 1963 Trips by Low, Middle and High Income Groups

														≥ 30 min.
A 11	TRANSIT =	24698	7192	9929	14773	65455	13630	15862	14714	63927	11594	14041	11783	277578
	TOTAL =	94194	60566	51487	106493	267762	111658	100103	186079	221803	70426	84544	161613	1516725
	M.S. =	262	119	193	139	244	122	158	79	288	165	166	73	177
B 12	TRANSIT =	20099	9145	9527	10986	36801	9881	14708	14532	42130	6774	12802	13645	201030
	TOTAL =	130079	83205	74529	140314	303982	174893	147430	231913	224093	78398	110118	173946	1872900
	M.S. =	155	110	128	78	121	56	100	63	188	86	116	78	107
C 13	TRANSIT =	0	0	0	0	636	622	157	157	0	0	0	0	1572
	TOTAL =	12042	19106	11207	26455	29584	25884	16501	34126	15231	4268	10005	16149	220558
	M.S. =	0	0	0	0	21	24	10	5	0	0	0	0	7
D 14	TRANSIT =	0	0	0	0	0	163	373	373	0	0	0	0	909
	TOTAL =	6475	6938	6745	8619	15004	10535	7272	15796	6687	3492	2680	9030	99273
	M.S. =	0	0	0	0	0	15	51	24	0	0	0	0	9
E 15	TRANSIT =	0	0	0	0	0	0	0	0	0	0	0	0	0
	TOTAL =	152	152	0	308	1845	2539	1322	2543	834	703	158	343	10399
	M.S. =	0	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL	TRANSIT =	753013	362370	547043	945229	835322	293955	490221	669344	548393	140573	279355	353850	6218568
	TOTAL =	2763509	1828116	4306665	8479486	4272116	2323369	6256465	11653308	2757217	1063929	3977993	7286148	57005521
	M.S. =	272	198	127	111	196	126	78	57	199	132	70	49	109

Notes:

1. One decimal place implied in M.S., i.e. modal split of 191 = 19.1 percent.
2. Category groups 5 and 10 have no trips since the distance is too great to fall within the 0 - 30 minute time frame.

Figure 3-12. (Continued)

Orientation Category	INCOME=	1=LOW				2=MIDDLE				3=HIGH				
	PURPOSE=	1=HBW		2=OTHER		1=HBW		2=OTHER		1=HBW		2=OTHER		
	PERIOD=	1=PK	2=OFF	1=PK	2=OFF	1=PK	2=OFF	1=PK	2=OFF	1=PK	2=OFF	1=PK	2=OFF	
A	1 FACTORS =	1282	1181	893	779	1000	705	456	362	711	470	309	181	Auto driving time ≤ 10 min.
B	2 FACTORS =	0	0	0	0	0	0	0	0	0	0	0	0	
C	3 FACTORS =	1667	1361	667	667	1000	861	278	278	639	583	139	222	
D	4 FACTORS =	0	0	0	0	0	0	0	0	0	0	0	0	
E	5 FACTORS =	0	0	0	0	0	0	0	0	0	0	0	0	
A	6 FACTORS =	1449	1159	892	736	1000	755	589	395	920	764	497	338	10 to 30 min.
B	7 FACTORS =	1313	2000	875	875	1000	750	1063	750	1563	750	1375	625	
C	8 FACTORS =	1565	1826	913	826	1000	783	609	565	609	565	391	435	
D	9 FACTORS =	0	0	0	0	0	0	0	0	0	0	0	0	
E	10 FACTORS =	0	0	0	0	0	0	0	0	0	0	0	0	
A	11 FACTORS =	1074	488	791	570	1000	500	648	324	1180	676	680	299	≥30 min.
B	12 FACTORS =	1281	909	1058	645	1000	463	826	521	1554	711	959	645	
C	13 FACTORS =	0	0	0	0	1000	1143	476	238	0	0	0	0	
D	14 FACTORS =	0	0	0	0	0	0	0	0	0	0	0	0	
E	15 FACTORS =	0	0	0	0	0	0	0	0	0	0	0	0	

Note:

1. Factor for each category = Modal split ÷ HBW, peak, middle income modal split. Three decimal places are implied.

Figure 3-13. Modal Split Factors by Category

Factors Computed by Aggregating Categories

	Low Income				Middle Income				High Income			
	HBW		Other		HBW		Other		HBW		Other	
	Peak	Off-Peak	Peak	Off-Peak	Peak	Off-Peak	Peak	Off-Peak	Peak	Off-Peak	Peak	Off-Peak
Categories B-Medium + B-Long												
Transit Trips	22312	10899	11397	14434	40645	11178	18561	20233	46294	7339	16249	16883
Total Trips	237727	138877	210393	390397	540998	281341	379928	702083	390668	125500	265018	502243
Modal Split	9.386	7.848	5.417	3.697	7.513	3.973	4.885	2.882	11.850	5.848	6.131	3.362
Factor	1.249	1.045	:721	.492	1.000	.529	.650	.384	1.577	.778	.816	.447
Categories C-All Distances + D-All Distances												
Transit Trips	30446	24351	36283	63878	24204	15833	24332	41349	7180	4161	6552	14980
Total Trips	628858	563567	1616623	2957264	847685	640014	2149628	3813503	410097	248517	1072663	1853540
Modal Split	4.841	4.321	2.244	2.160	2.855	2.474	1.132	1.084	1.751	1.674	.611	.808
Factor	1.696	1.513	.786	.757	1.000	.867	.396	.380	.613	.586	.214	.283

Figure 3-14. Tabulation of Group Ridership Statistics

Orientation Category		Low Income Peak	Low Income Daily	Middle Income Peak	Middle Income Daily	High Income Peak	High Income Daily	Off-Peak Auto Driving Time
A	BMS	14.881						<10 minutes
	TQ	268651	631285	239666	483561	102797	180929	
	TOTAL	1788809	4730335	2722543	6861556	1759999	4333894	
	TQMS	15.018	13.345	8.803	7.047	5.851	4.175	
	TQF	1.00921	0.89679	0.59154	0.47357	0.39429	0.28053	
	ATF	0.99839	1.01804	1.07141	1.09204	1.10621	1.12578	
B	BMS	0.0						
	TQ	0	154	0	706	0	0	
	TOTAL	28187	75891	42165	118754	29878	94504	
	TQMS	0.0	0.203	0.0	0.595	0.0	0.0	
	TQF	0.0	0.0	0.0	0.0	0.0	0.0	
	ATF	1.00000	0.99797	1.00000	0.99405	1.00000	1.00000	
C	BMS	3.556						
	TQ	47697	108915	30529	66942	8645	20794	
	TOTAL	1466455	3721651	1948983	4868398	954737	2303641	
	TQMS	3.253	2.927	1.566	1.375	9.05	0.903	
	TQF	0.91474	0.82305	0.44053	0.38671	0.25466	0.25386	
	ATF	1.00314	1.00652	1.02063	1.02261	1.02748	1.02751	
D	BMS	0.0						
	TQ	0	0	0	0	0	0	
	TOTAL	3017	7286	2859	5402	326	326	
	TQMS	0.0	0.0	0.0	0.0	0.0	0.0	
	TQF	0.0	0.0	0.0	0.0	0.0	0.0	
	ATF	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	

Figure 3-15. Modal Split Factors for Peak and Daily Totals

MODAL SPLIT FACTORS FOR PEAK AND DAILY TOTALS[1]

Orientation Category		Low Income Peak	Low Income Daily	Middle Income Peak	Middle Income Daily	High Income Peak	High Income Daily	Off-Peak Auto Driving Time
A	BMS	31.415						10 to 30 minutes
	TQ	896340	1705624	896818	1498479	570708	920259	
	TOTAL	2413744	5514492	3504692	7531007	2501548	5250219	
	TQMS	37.135	30.930	25.589	19.897	22.814	17.528	
	TQF	1.18209	0.98457	0.81456	0.63338	0.72623	0.55796	
	ATF	0.91660	1.00707	1.08494	1.16792	1.12540	1.20247	
B	BMS	1.622	0.01622					
	TQ	4083	9285	7697	14695	7611	11414	
	TOTAL	243512	549267	469514	1046132	321475	696874	
	TQMS	1.677	1.690	1.639	1.405	2.368	1.638	
	TQF	1.03384	1.04230	1.01080	0.86612	1.45978	1.00990	
	ATF	0.99944	0.99930	0.99982	1.00221	0.99242	0.99984	
C	BMS	2.331						
	TQ	18699	45369	16186	35305	5087	12079	
	TOTAL	713776	1867334	932775	2319690	474735	1166713	
	TQMS	2.620	2.430	1.735	1.522	1.072	1.035	
	TQF	1.12392	1.04235	0.74446	0.65296	0.45972	0.44417	
	ATF	0.99704	0.99899	1.00610	1.00828	1.01289	1.01326	
D	BMS	0.0	0.0					
	TQ	333	674	655	990	0	0	
	TOTAL	25764	72454	44335	102638	18359	46595	
	TQMS	0.01293	0.930	0.01477	0.965	0.0	0.0	
	TQF	0.0	0.0	0.0	0.0	0.0	0.0	
	ATF	0.98708	0.99070	0.98523	0.99035	1.00000	1.00000	

Figure 3-15. (Continued)

MODAL SPLIT FACTORS FOR PEAK AND DAILY TOTALS[1]

Orientation Category		Low Income Peak	Low Income Daily	Middle Income Peak	Middle Income Daily	High Income Peak	High Income Daily
Σ BMD+ BHIGH	BMS	7.513					
	TQ	33709	59042	59206	90617	62543	86765
	TOTAL	448120	977394	920926	1904350	655686	1283429
	TQMS	7.522	6.041	6.429	4.758	9.539	6.760
	TQF	1.00124	0.80404	0.85572	0.63336	1.26961	0.89983
	ATF	0.99990	1.01592	1.01172	1.02978	0.97810	1.00814
Σ C+D	BMS	2.855					
	TQ	66729	154958	48536	105718	13732	32873
	TOTAL	2245481	5766312	2997313	7450830	1482760	3584817
	TQMS	2.972	2.687	1.619	1.419	0.926	0.917
	TQF	1.04076	0.94116	0.56713	0.49693	0.32435	0.32116
	ATF	0.99880	1.00173	1.01272	1.01479	1.01986	1.01995

NOTE:
1. Abbreviations as follows:

BMS = base modal split = f(peak, home based work, middle income)
TQ = transit trips
TOTAL = total trips taken in category group
TQMS = percent transit modal split
TQF = transit factor = TQMS/BMS
ATF = auto factor = (1-TQMS)/(1-BMS)

Figure 3-15. (Continued)

3.4.4 Determination of Dual Mode Coefficients and Factors

A primary reason for calibrating the Logit Model for as many modes as possible was to measure the traveler-perceived differences among the modes. Line haul time, excess time and out-of-pocket cost were the calibrated variables. A mode specific constant was measured to reflect the effects not captured by the noted variables. As stated in the section on calibration it was necessary to constrain the variables for all three alternative transit modes in order to satisfy the required statistical tests. Only the mode specific constants were left unconstrained. This did, however, allow a reasonable and significant scale against which to subjectively evaluate aggregate values of reliability, comfort, safety and any other perceived characteristics that had not been reflected in the time and cost variables.

A summary of the selected baseline coefficients and factors is provided in Figure 3-16. Modal split sensitivity to each of the coefficients is seen in Figures 3-17 and 3-18. Particular Dual Mode coefficients are indicated when they differ from conventional auto or transit. The analysis reflects the unweighted average effect on the total application sample of trips for all orientation and trip length categories.

In general, the rationale for selecting the Dual Mode values was based on how each baseline would be perceived relative to conventional auto and transit (including the three transit alternatives). Variations and digressions from the calibrated values were used with the Dual Mode systems when the baseline characteristics were perceived differently relative to conventional auto transit.

A. Pallet Line haul time and excess time were assumed to be perceived equal to that of the conventional automobile, since the user characteristics are similar. Since the traveler pays a fare out-of-pocket in a fashion not unlike conventional transit, the transit cost coefficient was used. In terms of the less measurable variables the pallet is viewed as slightly more desirable than conventional auto. As seen in Figure 3-18, use of a pallet mode

	Baseline	α1-Line Haul Non-Excess Time	α2- Excess Time	α3- Out-of-Pocket Cost	α4- Mode Specific Constant	Extension Baseline[1]
Calibrated Modes	Automobile	-.03988	-.25833	-.025766	0.0	AT
	Conventional Transit	-.027271	-.030057	-.032321		TQ
	Rapid Rail				-.95713	
	Commuter Rail				-1.3038	
	Local Bus				-2.0690	
Dual Mode Baselines	Pallet	-.03988	-.25833	-.032321	+.1	AT
	Large DM Bus With Pallet or DM Auto	-.027271	-.07	-.032321	-.75	TQ
	SPV	-.03988	-.25833	-.032321	+.2	AT
	Minibus	-.027271	-.1	-.032321	-.5	TQ

1 Factors were used to extend Logit results for A.M. peak period, middle income, home-based work trips to all other time periods, income levels, and purposes: where TQ=Transit factors used, AT=Auto factors used.

Figure 3-16. Logit Modal Split Coefficients and Factors

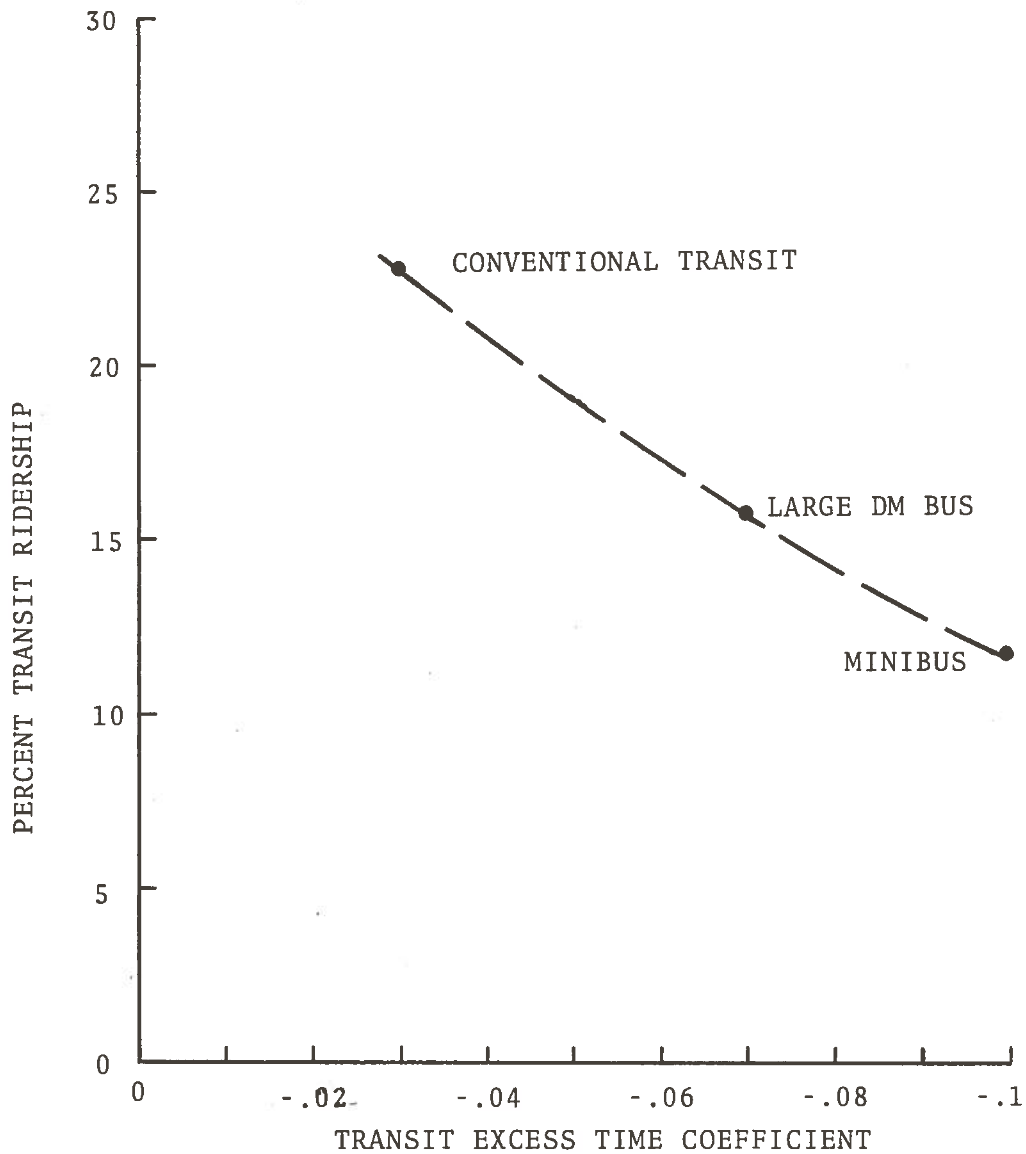
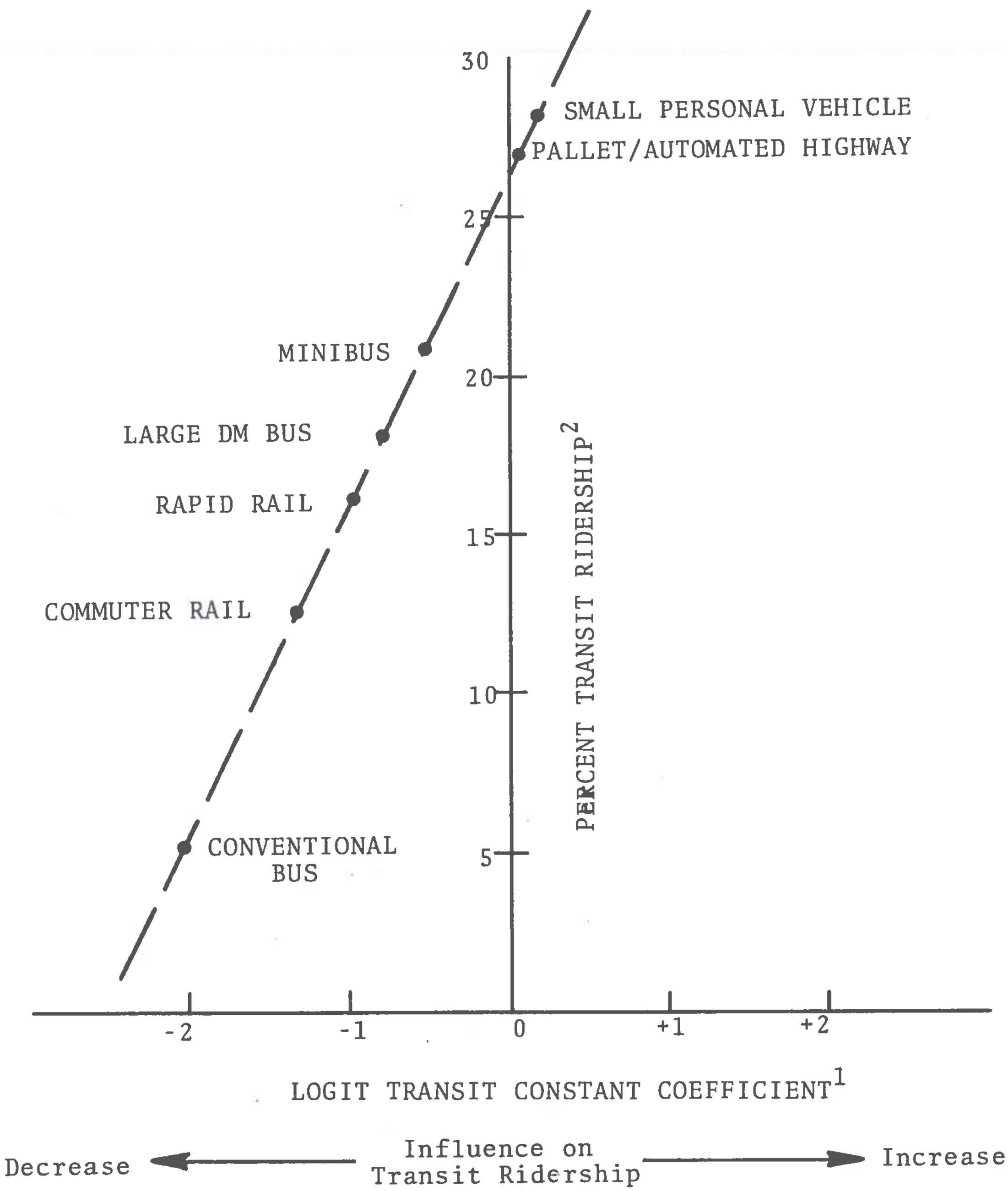


Figure 3-17. Influence of Excess Time Coefficient on Transit Sample Ridership



[1]Measure of unexplained system variables relative to the automobile (whose coefficient equals 0).

[2]Based on averaging the results from applying the coefficient to the total trip sample set used in logit calibration.

Figure 3-18. Influence of Constant Coefficient on Transit Sample Ridership specific constant equal to +.1 (auto=0) only increases the average percent modal split approximately one percentage point. The auto factors were used for extending the pallet results over all trip-making in the region.

B. Dual Mode Auto - The use of a modified auto is perceived similarly to the pallet since it exhibits almost identical trip characteristics.

C. Dual Mode Bus - This bus operates on the guideway in combination with the pallet or the Dual Mode auto, providing service via local off-guideway routes. As such the line haul time and cost parameters were viewed similarly to conventional transit. Since single-mode, no-transfer service is the dominant characteristic, excess time is perceived as less onerous than for transit and the effect considered somewhere between conventional auto and transit. Total trip times noticeably exceed those of the pallet or Dual Mode auto user having the same origin/destination. As such, the likely user is one who accepts the level of service provided by the Dual Mode bus and is less sensitive to any trip times than the conventional auto, Dual Mode auto, or pallet user. Because single mode service is available to the Dual Mode bus rider (except to the CBD) a portion of the ridership is attracted away from the more excess time sensitive auto user and a coefficient of -.07 was selected to represent this mix of former transit users and former conventional auto travelers. A mode specific constant of -.75 reflects the fact that the Dual Mode bus provides more comfort, convenience and schedule reliability than any formerly existing transit mode but still does not compete strongly with the auto in these areas. Transit factors were used to determine region wide ridership.

D. Small Personal Vehicle - Though as widely available and as flexible as the pallet system or the auto designed for use on the automated highway vehicle system, the small personal vehicle (SPV) has a significant perceived advantage in that the "system" owns it. This feature undoubtedly would relieve users of the traditional maintenance headaches. Comfort would be similar to that expected for pallet or Dual Mode auto users. Convenience might not rate as high for travelers to the CBD since they cannot be guaranteed the same vehicle for use on the return trip. For the total regional scenario, the mode provides truly point-to-point service better than any other baseline. For these reasons the SPV was assigned a more specific constant of +.2, indicative of this greater qualitative appeal. As with the other personal vehicle baselines the auto factors are required when generating regional total ridership.

E. Minibus - The minibus, operating off-guideway as a dial-a-ride system, is the only form of public transit providing door-to-door service. This Dual Mode option can be visualized as a multiple occupancy private vehicle operated not unlike a carpool. Since there are no transfers, all occupants from one service area near a station are bound for a common destination station and likely, for home-origin trips, are bound for an average of one, two or no more than three stops in the destination zone. Since this mode has line haul and fare charge characteristics similar to a transit operation, these two coefficients are equal to the transit values. However, because of its door-to-door service, the minibus appeals to the auto-oriented traveler who is more sensitive to excess trip time. An excess time coefficient of -.1 was assigned, this value being higher in absolute value than that of any other public oriented baseline but still less than half the value obtained from calibration of the confirmed auto user (-.258). All significant qualities subsumed in the mode specific constant are improved over any of the other public transit modes but the total trip quality is still less desirable than that of the private auto. The selected constant was a conservative value (-.5), halfway between the calibrated auto (0.0) and rail rapid transit (-.957). The transit factors were selected for generating the regional total ridership. Since the minibus has many features similar to the automobile it was felt that the transit factors would produce somewhat conservative total ridership figures. A brief analysis was conducted to measure the impact of using auto factors. The results indicated that total daily ridership would increase approximately 70% if the auto factors were used -- gauging therefore, the maximum projected ridership.

F. Summary - Selection of all coefficients for the Dual Mode baselines was based on the reaction of 1963 travelers in the Boston environment where public transit provided a reasonable alternative to the automobile. As with any "new mode" analysis, assumptions must be made when the service characteristics differ radically from the calibrated year base modes. The assumptions deal with how the traveler perceives the new mode relative to his measures of mode utility -- in this case excess and non-excess time and out-of-pocket cost. Selection of the coefficients described for each baseline were based on trends observed among 1963 Boston travelers provided with four basic alternatives.

3.4.5 Individual Baseline Modeling

Because trip time for the on-guideway portion of each Dual Mode trip is insensitive to baseline configuration, that portion of the trip occurring off-guideway provides the greatest insight into individual system differences. As noted in Section 3.2.4, "N-Dimensional Logit Calibration," many components of an individual trip were modeled in terms of three major variables: perceived "out-of-pocket" cost, excess time involved with walking or waiting, and nonexcess time (that portion of the trip generally described as in-vehicle line haul time). Figure 3-19 provides a matrix of the system characteristics modeled as components of the three major variables. The matrix indicates which components were analyzed parametrically for the various baselines. As seen, most baseline characteristics were selected from a detailed analysis performed only on one baseline -- e.g., CBD parking charges were studied for the pallet baseline and extrapolated to the automated highway vehicle baseline due to the similar operating characteristics. Fare policy was the only variable investigated parametrically for each baseline. Though the combined vehicle baselines were of primary interest, several characteristics were investigated while operating only the personal vehicle or bus portion of the particular combination. This simplified the analytical process while establishing nominal rates and service levels to be used in the combined mode analysis. Following is a discussion of how each baseline was

SYSTEM CHARACTERISTICS		1990 Plan		NEW SMALL VEHICLE SYSTEM			PALLET SYSTEM		AUTO HWY.
		Auto	Transit	SPV	Mini-bus	Combin-ation	Pallet Alone	Pallet w/Bus	Veh Sys
Merge Delays				P	N	N	N	N	N
Line Haul Speed (time)				P	N	N	N	N	N
Fixed				P	P	P	P	P	
Distance Rate		I		P	P	P	P	P	P
DM Terminal Processing Delay	CBD			P	N	I	N	N	N
	Non-CBD			P	N	I	N	N	N
Destination Parking Cost and Time	CBD	G					P	P	I
	Non-CBD	G		G		P	I		I
	Vehicle Occupancy	N	N	N	N	N	I	N	I
DM Service Factors	Minimum Demand Level				G	G		G	
	Schedule Frequency		G		P	I		P	
Walk Distance (time)		G	G	G	N	I	I	P	I
Line Haul Distance (time)		G	G	G	P	G_I	G	P	I
Park 'n' Ride Cost & Time		N	N		P	I		I	
Transit Connection	CBD		G				G	G	I
	Non-CBD		G					G	

G = Geographically Determined

P = Parametrically Analyzed

I = Implicitly Derived from Previously Analyzed Baseline

N = Nominal Value Established

Blank = Not Applicable

Figure 3-19. Individual Baseline Analysis of System Characteristics modeled. System characteristics common to several baselines will be described for the first baseline having that characteristic. Results of the parametric analysis are detailed in Volume II of this report and will not be emphasized here unless pertinent to the modeling approach.

A. Small Personal Vehicle

The Small Personal Vehicle (SPV) is viewed in all respects as similar to a four-passenger private automobile. It is maintained at home in a garage, and except in the CBD faces the normal parking problems at trip destination; therefore, all vehicle access/egress times are similar to the auto. Walk times and processing times involved with parking were considered for each TAZ, and a demand weighted superzone average determined. Destination parking charges, where required, were computed likewise. Average values are 1.2 minutes and an $.80 daily parking charge.

Driving time to (from) the Dual Mode guideway station from (to) home or business was determined from the 1990 highway network available from EMRPP. All superzone origin/destination pairs used as samples in the Logit analysis were coded explicitly as follows. For each superzone, location of the Dual Mode terminal was determined relative to the demand centroid of the traffic analysis zone (TAZ) in which it resided. Average highway driving time from each superzone TAZ to the reference TAZ was determined from EMRPP network print-outs. The driving times were weighted by total trip productions and attractions and an average driving time determined for all TAZ's in the superzone. If the terminal was located away from the reference TAZ demand centroid, appropriate adjustments were made. Average superzone driving distance was obtained in a similar fashion. Average time and distance for the sample set were 7.1 minutes and 2.4 miles for those users operating from zones encompased by the network. For users from areas outside the guideway, the average access time was 25.1 minutes and 8.4 miles.

Parking was not allowed in the CBD; however, a dense network was designed with walk as the primary access/egress mode. For an average station spacing of less than half a mile, resultant CBD walk time was five minutes for a distance of one quarter mile. Walk values were determined by using demand weighted TAZ averages for superzones around the CBD stations.

Dual Mode station processing and route scheduling created tripmaker delays of measurable significance. Exact measures of the delay are not known at this time since specific hardware configurations and scheduling philosophies have not been selected. A study design guideline established that guideway and station capacities would be unconstrained. Base time delays for station processing were established as a design specification.

Figure 3-20 illustrates the flow from station area entry to guideway entry. Both suburban and CBD timelines including possible variation are shown. A detailed discussion of station design may be found in Section 4.2, "Headway Capacity and Routing," of Chapter 4, Design and Performance. The component modeled for driving from the suburban gate or from the CBD parking slot to the loading queue point are functions of average terminal areas (levels) in each location. The CBD delay includes all intra-parking garage time for those baselines allowing CBD parking. The range of 40-120 seconds accounts for times from a five-story CBD parking garage entry point to the vehicle queuing point and vice versa. As seen in the figure, the time spent waiting to enter the loading bay can be as great as that required to process two vehicles through the bay.

Guideway preparation and loading time is the same for all Dual Mode baselines. It includes vehicle guideway connection and system checkout time.

Scheduling algorithms have not been defined; however, projections are that route scheduling can be accomplished in parallel with and in the time frame of the vehicle checkout period. Minimum times of six seconds plus six seconds per guideway intersection have been modeled for each baseline. For each origin/destination pair all intersections are summed along the minimum time path. This is added to the minimum reservation delay for each trip interchange. Due to general uncertainty in areas of guideway control and terminal pro-

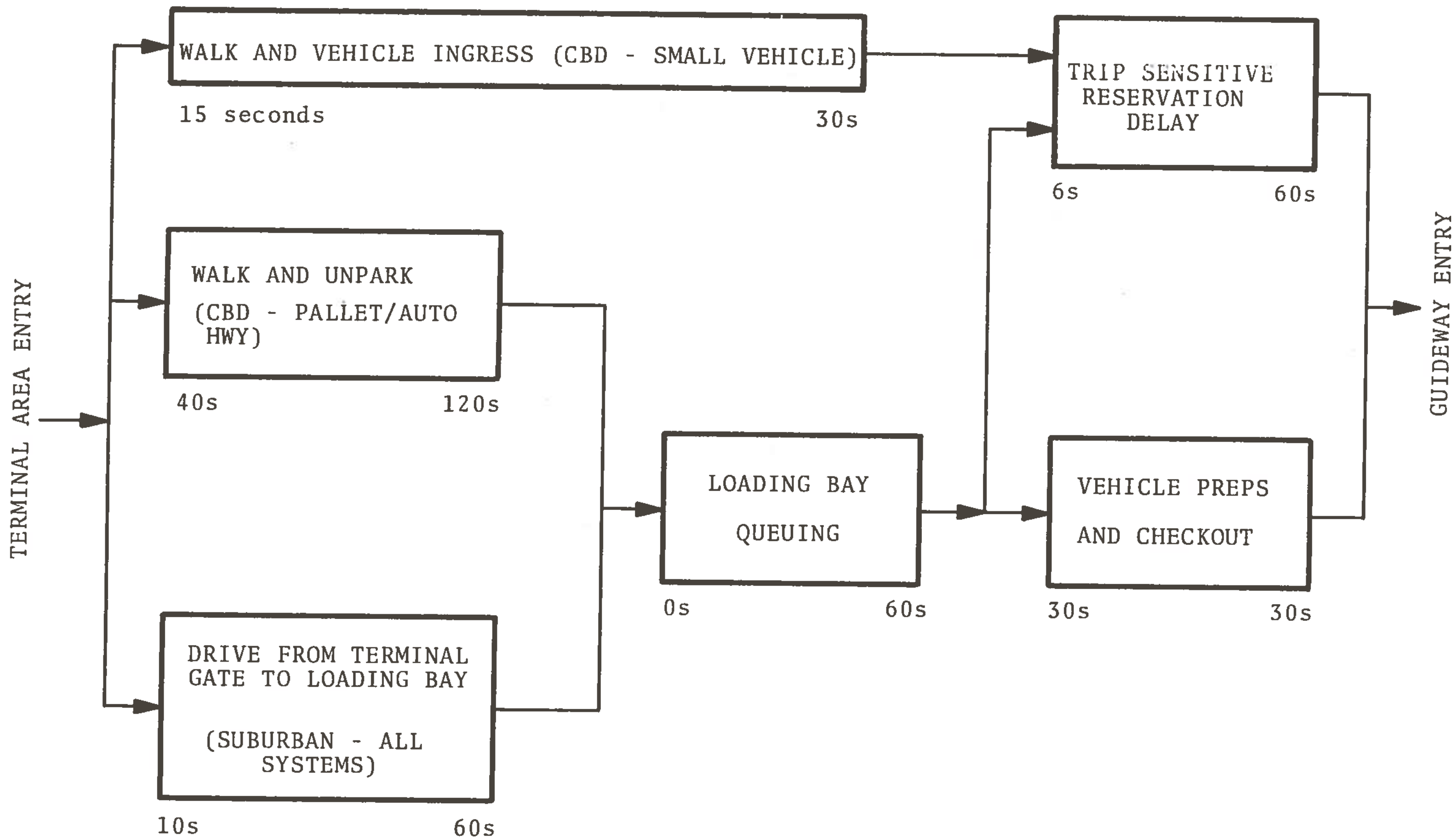


Figure 3-20. Dual Mode Terminal Load Cycle Times[1]

[1]Sequence shown is for guideway entry; guideway exit sequence is similar

cessing delay, a parametric analysis was conducted where reservation delay and total terminal delay were varied around nominal SPV values. Figure 3-21 indicates that a 10% increase in SPV ridership would be possible if all scheduling delays were reduced to zero. Reservation delays of 12 seconds were assumed for the SPV to account for the much larger vehicle volumes which the system must deal with. For all other baselines, intersection merges were assumed to require the basic six second delay. Average SPV terminal delays, exclusive of reservation time, were 1.7 minutes when entering and 1.2 when exiting the guideway in the suburbs. The difference is primarily the lack of checkout requirement when departing. In the CBD, three-tenths of a minute are the nominal delays for either direction. Parking is not required in the CBD thereby minimizing traveler processing time.

Auto occupancy rates for the SPV were derived from a study of urban travel by time of day sponsored by the Federal Highway Department.[72] 1963 historical data for the Boston area was used. Actual occupancy factors for three trip purpose categories (home-based work, home-based non-work, non-home-based) were weighted by A.M. and P.M. peak period ridership statistics to give an average occupancy factor of 1.31. A similar analysis of off-peak travel produced an average occupancy of 1.64. These compare with a daily average for the conventional auto of 1.44 which was used in the estimation of auto vehicle miles traveled.

Guideway speed was parametrized to examine effect on SPV ridership. Figure 3-21 shows that 50% decreases in average network speed, i.e., doubling the travel time, alienated approximately 30% of the previous ridership.

It is generally accepted that transportation users base a component of mode choice on their individual perception of cost -- how much it costs them to use the mode. How each perceives his "out-of-pocket" cost is then the forcing criterion which must be considered in estimating mode choice. The amount which travelers perceive an automobile to cost per mile is a much lower figure than the true figure. Overall costs/mile to <u>own and operate</u> automobiles

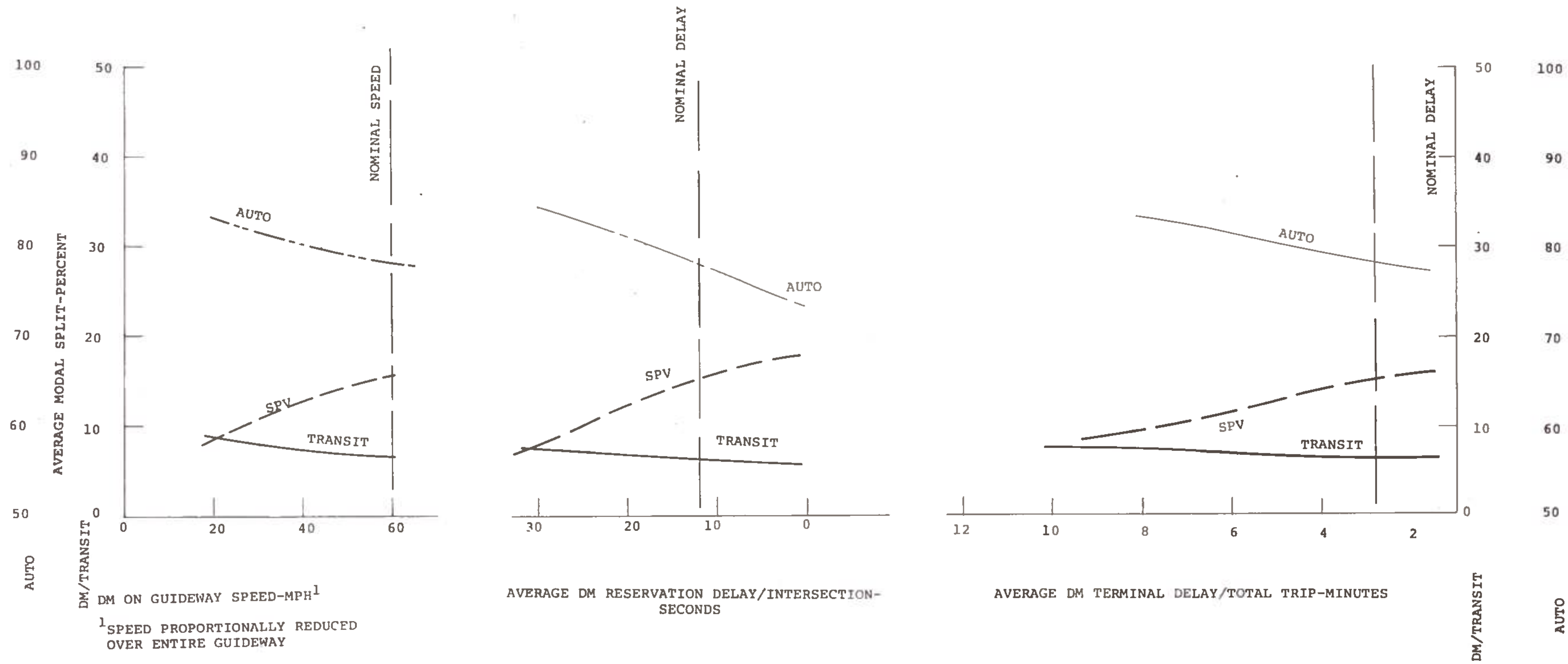


Figure 3-21. Effects of Varying System Operating Characteristics on Small Personal Vehicle Modal Split

average approximately 12¢/mile as determined in 1970 by the Federal Highway Administration.[97]

How much of that cost is perceived as a per-mile operating cost in tripmaking decisions continues to be the subject of research. The Logit Model was calibrated assuming all automobile drivers perceive per-mile operating costs the same. A generally quoted number for the 1960-70 time frame is $.03/mile. Using this rate, the variable for auto per-mile operating cost was highly collinear with auto travel time. Further subjective evaluation of the auto user indicates that per trip costs are seldom considered whereas the time to make the trip is. This is primarily because short daily trips are paid for several at a time whenever the gas tank is filled. To compound the "perceived trip cost" estimation, the current trend is toward credit card use. An automatic monthly billing using a multipurpose card further dilutes any consideration of individual trip costs. It has often been informally stated and is possible that confirmed auto users perceive trip costs to be direct "out-of-pocket" charges per trip, e.g., parking or tolls. This would imply that little or no concern exists for auto operating cost in the mind of the confirmed user. Some credance to this postulate is lent by the statistical relevance of the variable "auto parking cost" which accounts for all direct "out-of-pocket" charges less auto operating costs.

If Dual Mode revenues are collected periodically through an automatic billing scheme, the assumption that travelers perceive an equivalent portion of the trip cost identically to that of driving their own car is a valid one, and can be modeled similarly to the private auto. However, if the system revenues are collected immediately "out-of-pocket" there is a strong argument that the total cost is perceived as in the conventional public transit case and should be modeled likewise. A likely collection system for future use is one similar to the San Francisco BART system where a customer buys a card credited with an initial dollar value. This card is debited at trip end as a function of trip origin and charged at the designed fare rate.

Dual Mode baselines may employ any one or a mix of the above concepts. For purposes of this study, the fare structure was based on a per mile rate as a function of the trip length even though portions of Dual Mode trips may not require physical operation of the private vehicle (as in the pallet case). Additional per mile charges may be incurred as a Dual Mode system requirement, e.g., additional vehicle maintenance costs/mile for the private vehicle operated on the Dual Mode automated highway. These charges are perceived as additional rates to be accounted for when using the Dual Mode guideway. Undoubtedly, the private vehicle user will reconsider his trip by Dual Mode for whatever fare rate structure is charged. A range of considerations exist. He may view it similarly to the base year transit rider who weighed exactly what it cost him "out-of-pocket" to ride. Or - this is the more reasonable case - he will mentally "adjust" the rate charged by whatever he has traditionally perceived his auto trip to cost him, resulting in a differential rate charge. For study purposes, only the amount perceived as being greater than the assumed per mile operating costs are modeled--this would include the additional guideway maintenance charges. Parking fees, tolls, costs of transfer to complementing modes, etc. are still modeled as additional "out-of-pocket" charges per trip. The mode choice then reflects total perceived costs to the individual tripmaker. Since these different charges plus other direct charges are considered taken "out-of-pocket" similar to the transit fare box, transit Logit coefficients were selected for all Dual Mode baselines. It might be argued that the rental charge for the small personal vehicle would cover all use of the vehicle on and off the guideway and that the vehicle's coefficient would fall somewhere between that of the calibrated auto coefficient and that of transit. Transit coefficients create a slightly smaller Dual Mode ridership than auto if a common fare structure is used. For private baselines a distance rate structure was charged as being more aligned to conventional auto. Public mode baselines were charged a flat fare per trip. All fares were charged at Boston 1963 base year rates for modal split purposes. Obviously, revenue rates paid to the Dual Mode system operator are different from those modeled when determining model split influence. Appropriate adjustments are made for revenue calculations in the TEAM* cost/benefit model. A rate structure of $0.02 per mile was used for the SPV, pallet and automated highway baselines. A flat fare of $0.25 was charged the large Dual Mode bus. A flat fare of $0.45 per trip was modeled for the dial-a-ride minibus in the small vehicle combination.

B. Twelve Passenger Dial-a-Ride Minibus

The minibus was designed as a dial-a-ride demand responsive system. Its tour area is the off-guideway region in which it performs collection or distribution of passengers.

Tour area service characteristics are based on a "many-to-one" concept where the "many" riders are randomly distributed in the tour area (origin or destination) bound to or from the "one" nearby Dual Mode station. Off-guideway distribution of passengers is always performed prior to collection of riders bound for some new destination. This provides the best overall service to the average user.

The system is configured for door-to-door operation with no transfers allowed -- a prime Dual Mode design criterion. As with the SPV, the minibus is not allowed off the guideway in the CBD. Park 'n' ride facilities are provided at the extremes of the Dual Mode guideway. The station is located no greater than a two-minute drive from the guideway entrance.

Modeling of the minibus off-guideway service was derived from work by Mason and Mumford of the Ford Motor Company, Transportation Research and Planning Office.[98] Average passenger wait and in-vehicle travel times were computed as functions of service area dimensions and the average number of stops during a vehicle tour. Passenger distributions were assumed random (i.e., uniform) over the off-guideway service area.

*TEAM -- Transportation Economic Analysis Model.

Service area dimensions were calculated for superzones by use of the Boston 1990 Empiric Land Use Data Set. Land areas for various uses were summed to get total demand-generating or demand-attracting potential for TAZ's within the superzone surrounding a particular Dual Mode station. Residential area was used to establish collection service area requirements. The attraction of manufacturing and commercial areas was used to compute distribution area dimensions. These were chosen since the Logit Model was being applied to home-based work tripmakers in the A.M. three-hour period. Measurement of several typical Boston region TAZ's showed that for an assumed rectangular shape, the average x·y dimensions had a ratio of 3:1. An average minibus speed while in the service area was assumed to be 20 mph. Minibus access to the edge of the service sector from the Dual Mode station averages two-thirds of the direct auto access to the station from the TAZ centroid.

An average vehicle occupancy of 75% (9 passengers) was assumed for study purposes. This required nine stops while collecting the initial passenger loads destined for work. However, only three stops were required on the average for distribution at the work end of the trip including the CBD. Figure 3-22 summarizes the average service statistics experienced by minibus users. The CBD wait times are longer on the average than those observed by non-CBD origins. This occurs because the three random origins in the CBD are on the average farther apart than those in the non-CBD service areas.

Time spent waiting for a public service vehicle is considered excess time in the total trip and is generally weighted heavier than non-excess or line haul time. In the traditional modal split calibration process, waiting is assigned the value of one half the available bus headway, i.e., half the time between bus arrivals. However, if bus service is poor, waiting time is assigned a maximum value (~20 minutes). In the past, this technique of assigning waiting time has been accepted as realistic since transit service has been generally no more predictable than the assumption allowed. As a result there is no data to support assumptions nor proper weighting of schedule reliability where the schedule is very

	NON-CBD TRIP ENDS (Vehicle leaves guideway)	CBD TRIP ENDS (Vehicle remains on guideway)
TRAVEL TIME/PASSENGER - MINUTES	13.2	6.0
TOUR LENGTH/PASSENGER - MILES	3.7	.3(1)
TOUR SPEED - MPH	20	15
TOUR AREA - SQUARE MILES	1.14	2.5
NUMBER OF STOPS/TOUR	9(2)	3
WAIT TIME - MINUTES	7.2	8.4
WALK TIME - MINUTES	NA	2.8

(1) Represents the excess distance, imposed by guideway circuity, over the most direct possible route.
(2) Assumes 75% bus load factor.

Figure 3-22. Average Dial-A-Ride Minibus Off-Guideway Service Data predictable but the headways may be very poor. For example, a vehicle pickup time $\pm$ 5 minutes around a scheduled time 7:43 A.M. may be perfectly satisfactory to low demand area users. However, if only two are scheduled per hour, the headway is 30 minutes, or an assigned waiting value of 15 minutes, for standard modal split purposes. This creates an unfair environment for Dual Mode that is designed for use with an accurate, reliable scheduling system.

Another consideration has contributed to acceptance of the half-headway assumption. Temporal unpredictability of demand is forced by use of aggregate trip tables. That is, demand data is not available to a level finer than in total trips/hour. Available data will not support more accurate prediction of scheduling requirements. As a result, current models are calibrated without specific accountability for schedule reliability. Waiting for pickup really has two dimensions of time delay. One is the physical wait required once the traveler is ready to depart; the other is the predictability of mode departure/arrival time, which reflects reliability of mode schedule. Dual Mode public system schedules allowing transfers are assumed very reliable. Because reliability is not considered in the calibrated models, the resultant ridership estimates would be conservative, reflecting lower patronage. To minimize this effect a compromise value of headway and schedule reliability was assumed. For low demand areas, the maximum wait time was 10 minutes no matter what the headway. For any service more frequent than once per hour a wait time of five minutes was used. Where headways are less than 10 minutes, the actual half headway value was used. The apparently optimistic wait values did not seem unrealistic because individual stations will have demand peaking which should be supported by scheduling strategies available in the 1990 time frame.

Fleet size requirements for minibus were based on ten minute headways resulting in reasonably short wait times. Wait times at the home origin are generally more acceptable than that usually experienced while waiting at a station platform. However, the minimum mean wait time is only five minutes; therefore, an individual waiting at home must be prepared to leave within that time frame. There is also the antagonistic wait required at each passenger's doorstep. The range here can vary greatly for each stop. Because of any lack of certainty on how individuals might perceive these new forms of wait time, all wait time was summed and considered in the traditional fashion, i.e., no special weighting functions were applied.

Park'n' ride was modeled with similar considerations as above including average headways of ten minutes. This service was provided only at the extremities of the network since level of service within the network would be adequate for door-to-door service. Daily parking charge was varied to examine the effect of ridership (Vol. II), minimum demand levels were established to secure Dual Mode service consistent with the service parameters previously described. For an average of four TAZ's per superzone two would generate sufficient demand to justify establishing demand actuated minibus service. Minimum headways of twenty minutes were assumed as an average. Trends in Boston indicate that approximately fifty percent of the trips in the 7-10 A.M. peak period occur in a one hour span. Based on compounding these averages, a minimum demand level of 110 person trips were required to qualify an origin-to-destination superzone pair for minibus service. Following the modal assignment process, a listing of minibus users were generated in standard trip table format. All O/D pairs not meeting the 110 minimum required were eliminated during a second trip table generation. The remaining minibus riders were assigned to the Dual Mode network.

Minibus terminal processing was 1.7 minutes in the suburbs, the same as that for SPV. Delays in the CBD were slightly longer, 0.5 minutes per stop due to the average passenger loading delay for three people. Reservation delays equaled the system minimum of six seconds per merge intersection since the higher capacity vehicle would be given priority scheduling over the SPV.

C. Pallet

The pallet exhibits one of its major differences from the other baselines in the CBD where Dual Mode vehicles are not allowed to leave the guideway; as with conventional auto, parking must be provided at the trip termination point. The parking requirement implies costs and slightly higher vehicle recovery delays not required for the small personal vehicle baseline or any of the public vehicle baselines.

The pallet system was designed with parking garages located directly in the CBD and at locations peripheral to the CBD. Parking fee was designed as a policy lever to guide CBD-bound pallet users from the downtown garages to those on the periphery. The impact on CBD transit was to be measured since the pallet is dependent on rapid rail as a complementary collection/distribution mode.

The suburban collection/distribution process was modeled similarly to that of the SPV. Access time and distance to the guideway were identical. Vehicle occupancy was the same. Non-CBD parking charges and time delays were modeled identically. Reservation delays and guideway speed were established at the nominal levels described in the SPV section.

Terminal delays are greater for the pallet than the SPV because unloading times are greater. Suburban guideway access and egress require 1.7 minutes. In the CBD, with automated parking, guideway access/egress times are 2.4 and 3.4 minutes, respectively. The garage access requires approximately 0.7 minutes additionally to park the car. A full minute more, e.g., a total of 3.4 minutes, is required to request the car for pickup. Use of the peripheral terminals provides an option of parking within the garage of leaving the guideway for an ultimate destination within the peripheral superzone. Delays of 2.0 minutes were typical averages for either direction.

Modeling of available alternatives to CBD travelers was handled as follows. The Dual Mode network for pallet was coded with two primary paths available to CBD destinations -- one through the CBD parking garages, and the second through the nearest peripheral garage along the traveler's trajectory. Minimum time paths were skimmed for either option. As expected the great majority of minimum time paths were directly through the CBD parking garage. A second skim was generated with a very large time delay included at each CBD parking garage off-ramp. This clearly forced the minimum path to pass through one of the peripheral garages. Total line haul times, excess times, distances and "out-of-pocket" charges were summed for both options for each origin superzone to each CBD destination superzone. Both options were modeled with auto and conventional transit as competing modes. Four mode choices resulted. A second run of the Logit Model was required where only the Dual Mode option securing the largest mode split percentage was tested against auto and transit, i.e., only three modes. The second run generated the modal split fraction considered optimum for the baseline; the first run provided probability distributions between the two Dual Mode options. Total trip generation and initial assignment was a function of the second run. Final assignment to the few CBD links required manual link load adjustment weighted by the joint probabilities from the first (4 mode) run.

Parking charges in CBD and peripheral garages were varied to examine the joint effect on ridership. Analysis of the Logit results weighted by total available tripmaking in the various stratification categories were used to establish a mix of one CBD parker to three peripheral parkers.

The great majority of pallet users required a transfer to rapid rail transit in the CBD. Summing of those Dual Mode travelers destined for CBD zones beyond the parking garage locations was required to determine the induced transit ridership. Trips originating in the CBD were treated similarly. All transit service and connections to the Dual Mode network were derived directly from the 1990 transit time and cost networks available from the Massachusetts Bay Transportation Authority (MBTA).

The pallet fare rate was charged only for guideway mileage and modeled as the SPV was.

D. Dual Mode Auto

With the exception of fare all characteristics of the Dual Mode auto were modeled identically to the pallet. Though terminal processing techniques differ greatly, the processing times were assumed to be similar.

Smaller system costs are conveyed to the user through fare charges since the Dual Automobile is privately owned and maintained. Because of this fares are lower to the automated highway vehicle system user; however, maintenance costs for the Dual Mode equipment are borne by the vehicle owner. A Dual Mode study by the Jet Propulsion Laboratory[39] arrived at 1.2 cents per mile as a nominal maintenance cost for a conventional automobile modified to accommodate Dual Mode operation. It is reasonable that the maintenance will be perceived as an additional cost only during guideway operation. Therefore, the fare that would generate the same operator revenue is perceived as 1.2 cents per mile higher to the Dual Mode user. Logit Model inputs were generated using 3.2 cents per guideway mile vs. the 2.0 cent figure used for the SPV and pallet. Clearly, this drives the Dual Mode ridership down. Since the automated highway vehicle system user bears the maintenance costs, operating profits increase when compared with the pallet. Even though fares were lower, i.e., $.04 versus $.10, the actual cost borne by the user was higher and ridership statistics bear this out.

Another facet of perceived cost encountered with the automated highway vehicle system is the issue of vehicle ownership. This baseline is the only one requiring a Dual Mode "buy" decision. Demand analysis is based upon perceived cost, and it was assumed that the increased cost of Dual Mode equipment (repair and maintenance) would be perceived in calculating the modal split. Since, however, one cannot use the automated highway with a private vehicle unless it has the appropriate equipment and since a decision to purchase a vehicle with this equipment is generally made based upon the purchase price, rather than a per mile or per trip cost, it is not clear how the modal split would be affected. One would assume that initial resistance to the purchase would be higher than the analysis technique reflects, but that once purchased the perceived maintenance cost would be lower than assumed (2.4 cents per on guideway passenger mile). Hopefully, these two effects balance; however, it must be stated that uncertainty in modal split prediction for the automated highway vehicle system is greater than for other alternatives, due to this consideration.

E. Large Dual Mode Bus

The large Dual Mode bus was designed to be a part of the pallet system and automated highway vehicle system. The bus operational scenario off the guideway is similar to that of conventional local buses, that is, a pseudo door-to-door mode where users walk to a bus stop and wait for the bus which is following some predefined route. Though travelers can use the Dual Mode bus for local off-guideway service, the primary service and route structuring is designed to provide point-to-point service between high demand activity centers at trip lengths requiring use of the guideway.

The large bus was modeled as a fixed route and schedule system off-guideway. Demand generating/attracting areas were determined using the 1990 land use areas as detailed in the dial-a-ride minibus description. Demand was assumed to be uniformly distributed over the land area of interest and land areas were assumed to be connected by local zoning restriction. For small TAZ's these assumptions are valid in the Boston area. For larger TAZ's and for TAZ's within superzones several tour areas were modeled to reduce off-guideway tour lengths.

Average walk distance to bus stops was selected and, by the uniform demand assumption, the total area was divided into smaller squares each having an area equivalent to a circular area with a radius equal to the defined mean walk time. Tour lengths were determined by connecting the centers of each square area with a minimum of route retracing. Bus route speed in the off-guideway collection area was 15 mph. As in the minibus case, an express run was generally required from the guideway terminal to the collection area. Express distance and time were derived from an average intrazonal auto travel time weighted by a service area relative to total TAZ size. Walk times of 2, 5 and 10 minutes were modeled for parametric analysis. Clearly, for increased walk distances the tour lengths decrease. Final off-guideway service statistics are summarized in Figure 3-23.

Park'n' ride service was provided at the outlying Dual Mode stations. Off-guideway service was established separately or as a stop along one of the tours operating from the terminal of interest. Demand levels dictated which schedule frequency was examined. Reductions of service frequency by one-half reduced ridership by 25-30 percent. Waits of five minutes were modeled because of the schedule reliability of the system. All five CBD stops were considered adequate to meet the destination requirements of so large a group of travelers.

	Walk'n' Ride Stops	Park'n' Ride Stations
Travel Time (minutes)[1]	10.3	2
Tour Length (miles)	2.6	1
Tour Speed (mph)	15.1	30
Auto Access Time (minutes)	N.A.	21
Auto Access Distance (miles)	N.A.	7
Auto Access Speed (mph)	N.A.	20
Wait Time (minutes)	5	5
Walk Time (minutes)	5	N.A.

[1]From bus stop to guideway terminal.

Figure 3-23. Average Dual Mode Bus Off-Guideway Service Data

Minimum demand levels required to provide off-guideway service were computed in the same fashion as minibus. A 30% load factor was attained using the 50-passenger bus and a minimum three-hour A.M. peak demand level of 180 origin passengers. Because of the low load factors a smaller 20-passenger bus was recommended increasing the average load factor to 75%.

All other bus service characteristics were in line with those of the minibus, e.g., terminal processing time. CBD delays were no larger at each terminal; however, there were five stops instead of three. A flat fare of $.25 was charged the bus user. Travelers to the CBD paid the additional rapid transit fare when connecting.

F. Conventional Highway and Transit

For Dual Mode study purposes the system characteristics of the conventional highway and transit modes were defined by Boston's recommended 1990 plan. As noted previously in Chapter 2 (Network Synthesis) the 1990 plan would be modified to account for the Dual Mode system layout.

The impact of these modifications was reflected in network analysis required for ridership determination, e.g., the 1990 origin-to-destination highway and transit trip alternatives reflected the system changes.

The system characteristics for the modified networks were not to be varied parametrically. Therefore, a technique was structured to handle the regionwide effect on the modes at a higher level of aggregation, avoiding expensive, time consuming network analysis at the traditional level of detail.

Five basic modes were projected for 1990 consideration:

- private auto
- truck
- transit
  - conventional bus
  - rapid rail
  - streetcar

1963 commuter rail was assumed to be eliminated by 1990. The streetcar was assumed to be retained and upgraded by 1990. Cost analysis indicated a sufficient difference between the three basic transit modes to account for them in separate ledgers. System parameters of interest for auto and transit were:

- o Vehicle capacity
- o Average vehicle speed
- o Vehicle load factor
    - o Peak six hours
    - o Off-peak eighteen hours
- o Total person trips (PT)
    - o Peak six hours
    - o Off-peak eighteen hours
- o Total person miles traveled (PMT)*
    - o Peak six hours
    - o Twenty-four hours
- o Average out-of-vehicle excess time per trip (ET)
    - o Peak six hours
    - o Off-peak eighteen hours

Truck vehicle miles traveled (VMT) was assumed to remain constant for the recommended 1990 plan and for each Dual Mode alternative, whereas auto and transit values varied among the baselines.

Data for developing the above relationships was obtained from three primary reports - a base year (1963) transportation inventory;[105] a transportation facts book for the Boston region[11], and the 1990 recommended plan developed by the EMRPP.[51] Massachusetts Department of Public Works (MDPW) and Massachusetts Bay Transit Authority (MBTA) representatives assisted by providing data not available from the three documents or the TSC contractor, PMM and Co.

*PMT was split into freeway and surface arterial components for all auto travel including park 'n' ride access to conventional transit and Dual Mode and for all off-guideway access to the Dual Mode terminals.

Values for vehicle capacity, average speed, and load factor were derived from historical Boston information modified by the gross impact of system changes planned for the 1990 time frame, e.g., new capacity vehicles, extended rapid rail facilities.

For modal split calculations, existing 1990 data files were used to obtain the point-to-point travel times, excess times and costs. Where network modifications were required by inclusion of Dual Mode, the auto and transit components were manually adjusted. Excess times and parking costs were determined for each superzone as demand weighted averages of the included TAZ's. 1990 projected origin zone auto occupancy figures were used to perform a second weighting of the destination parking costs. Transit was not split into three separate modes for modal split but treated as a "most logical" transit combination where minimum time trip paths dictated a transfer.

Following the Logit modal split calculations the total transit ridership was subdivided into the three previously listed components -- bus, rapid rail, and streetcar. The relative percentages for each of the three submodes were determined from historical statistics weighted by changes to the extent of the reference year transit system.

PMT for auto and the three transit submodes were calculated by multiplying total ridership for each group by the average trip length of travelers in the particular group. This was done for the six A.M. and P.M. peak hours and for the remaining off-peak eighteen hours. Transit trip lengths were park 'n' ride was feasible were corrected for the auto access portion of the trip. This auto PMT was returned to the auto ledger.

Average trip lengths for the PMT calculations were determined for the non-Dual Mode scenario projected in the 1990 plan. These trip lengths were used for an initial pass to calculate an area-wide daily auto and transit PMT. Dual Mode PMT was calculated explicitly through the network assignment process.

Auto and transit average trip length variations occurred as riders shifted to Dual Mode. To account for this, total regionwide PMT was normalized to the recommended 1990 plan level. The normalization required use of the modal split trip sample set for the three trip length stratification groups. Average trip distance by each competing mode was available from the sample set for any baseline including the parametric variations. The differential trip lengths between Dual Mode and auto or transit could be computed and each weighted by total per mode demand available from the trip tables generated from the modal split process. The resulting total differential PMT could be added to the total PMT of the recommended plan, providing a reasonable measure of the expected PMT for the baseline of interest. Since for all cases Dual Mode average trip lengths were longer than the competing modes (but the trip times were shorter due to higher average speeds), the differential PMT correction was always added to the 1990 plan PMT.

As noted above, an initial calculation of PMT for auto and the three transit submodes was made. It was based on the 1990 recommended plan trip lengths. Because these initial average trip lengths were derived from regionwide data stratified by various trip purpose groupings, they were not easily related to the specific distance/orientation categories defined for the modal split and trip table generations.

This was solved by assuming that the regionwide PMT would increase over the 1990 plan by the Dual Mode differential PMT computed for the specific baseline. Total Dual Mode PMT actually calculated from the assignment process was subtracted from the PMT sum of the 1990 plan plus the differential Dual Mode. The result was normalized over the auto and three transit submodes as a function of their individual modal ridership (the ridership resulting directly from the same modal split solution as the Dual Mode which generated the differential PMT).

Average out-of-vehicle excess time were derived for each competing mode for each baseline. Peak values were computed using the coded modal split sample set to establish average excess times for each of the distance/orientation category groups. The average excess times per group were then weighted by the ridership for the particular group as obtained from a category summation of the peak period trip tables. Thus, for each mode a regionwide average weighted excess time was computed. Off-peak excess times were derived from peak values weighted by differences in excess times for the two periods.

4. DESIGN AND PERFORMANCE

4.1 SYSTEM DESIGN RATIONALE

An analysis of a new system concept such as Dual Mode involves the problem of adequately defining the system characteristics to a level that will allow a meaningful investigation to be performed. Since a Dual Mode system has not been built, very little is known about how it will eventually look; items such as guideway design, station design, vehicle design, and vehicle routing and control systems are still in the conceptual stage.

These and a host of other unknowns permeated the study, and they needed to be resolved, defined, and quantified to some degree for the analysis to proceed. As an example, for the pallet system it was necessary to estimate the time required to load and unload automobiles, as well as the associated space, equipment and driver participation. The general procedure, therefore, was to try to arrive at reasonable answers to these problems, conservatively and sometimes even pessimistically, by consideration of physical con-traints and current technology, and extensions of technology that appeared possible and probable. The various components of the system were not designed in detail, but were envisioned to the level necessary to provide reasonable estimates of the inputs necessary for cost and performance analysis.

4.2 HEADWAY, CAPACITY AND ROUTING

The question of vehicle flow rates per lane on automatically controlled guideways is currently unresolved and has been a subject of considerable controversy in various studies. High capacities are desirable because they allow more vehicles to be moved with fewer lanes of guideway, but on the other hand the short headways necessary for this pose questions on safety and comfort. Thus, a compromise must be reached between capacity on the one hand and safety and comfort on the other.

It is difficult to define a "standard emergency" for this purpose since a variety of malfunctions can occur, most of which result in differing behavior of the vehicle. Probably the most catastrophic malfunction that could occur would be an instantaneous stop of a vehicle due to its being wedged into the guideway or to its running into some large object that had somehow gotten onto the guideway. Should this happen, the problem then is one of minimizing the number of following vehicles colliding with it. Figures 4-1 and 4-2 show the numbers of collisions for this case as a function of deceleration ability of the vehicles and guideway capacity (the guideway is assumed loaded to full capacity). Jerk limitations were not considered here. To prevent any collisions, vehicles must be spaced so far apart that capacity is reduced to levels approximating that of standard roadways, as is shown in Figure 4-3. A way of achieving higher capacities while localizing collisions is to run the vehicles in "trains," with spacing between the trains being sufficient to prevent any accidents from propagating from train to train. Figures 4-4 and 4-5 show the capacities that could be achieved in this manner, and they are considerably higher than for the no-crash case. However, a comparison with Figures 4-1 and 4-2 indicates that should the lead vehicle of a train experience an instantaneous stop, about as many vehicles would be involved in successive collisions as without trains. Because of this, and the potential complication of maneuvers, the train strategy was not considered further in the Dual Mode analysis.

It appears that the system can be designed to virtually eliminate the occurrence of instantaneous stop conditions. The guideway can be isolated from the surroundings so that objects cannot be thrown upon it, and a positive lateral control system and proper switch design can minimize the possibility of vehicles being wedged into the guideway. Thus the very low capacity required to meet the design criterion that vehicles following an instantaneously stopped vehicle not collide with it did not seem warranted. However, non-instantaneous emergency stops caused by system or vehicle malfunction were judged to be a more likely occurrence (in spite of efforts to minimize them) and thus formed the basis of guideway capacity calculations. For these situations,

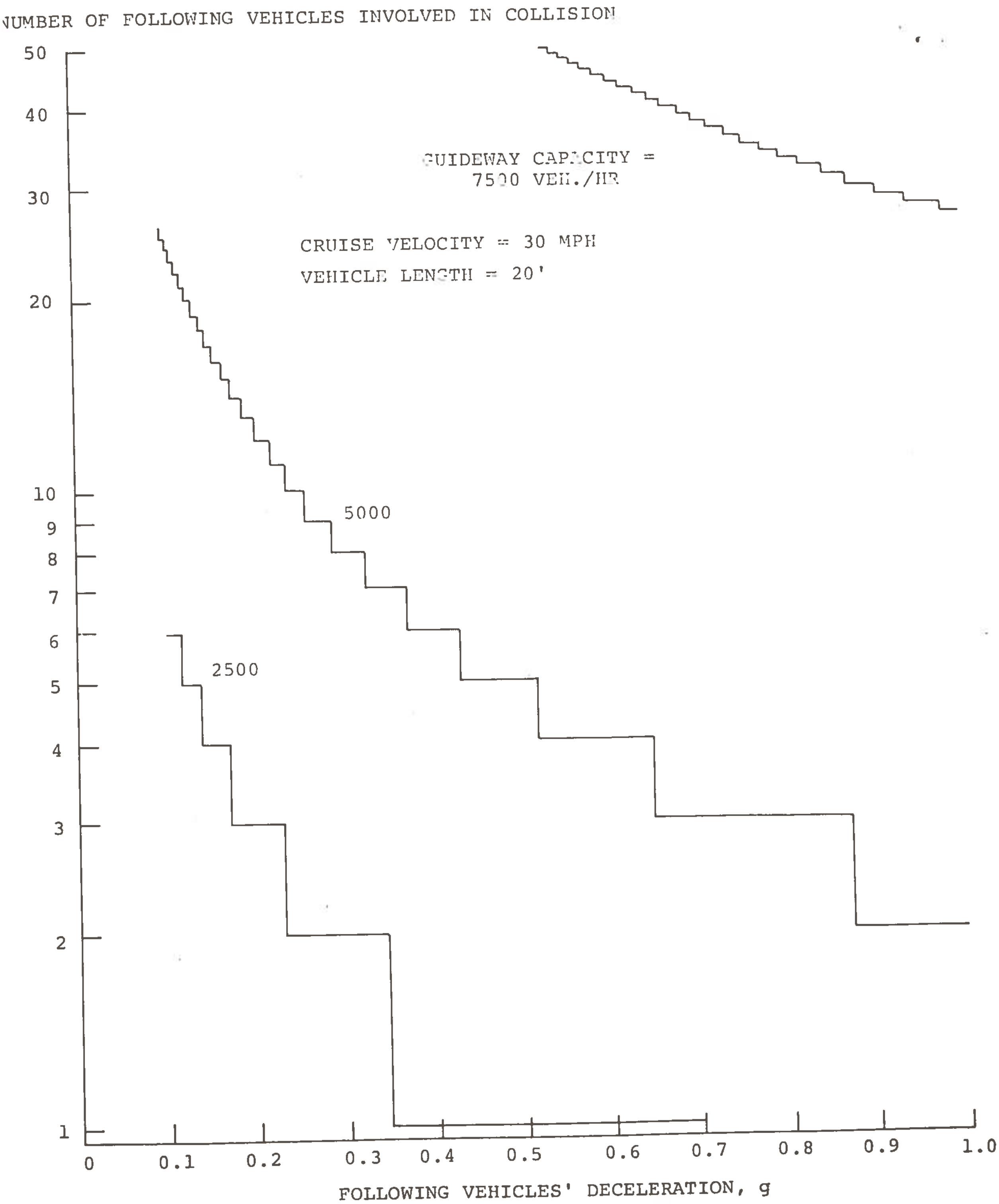


Figure 4-1. Number of Vehicles Colliding in Case of Instantaneous Stop of Lead Vehicle

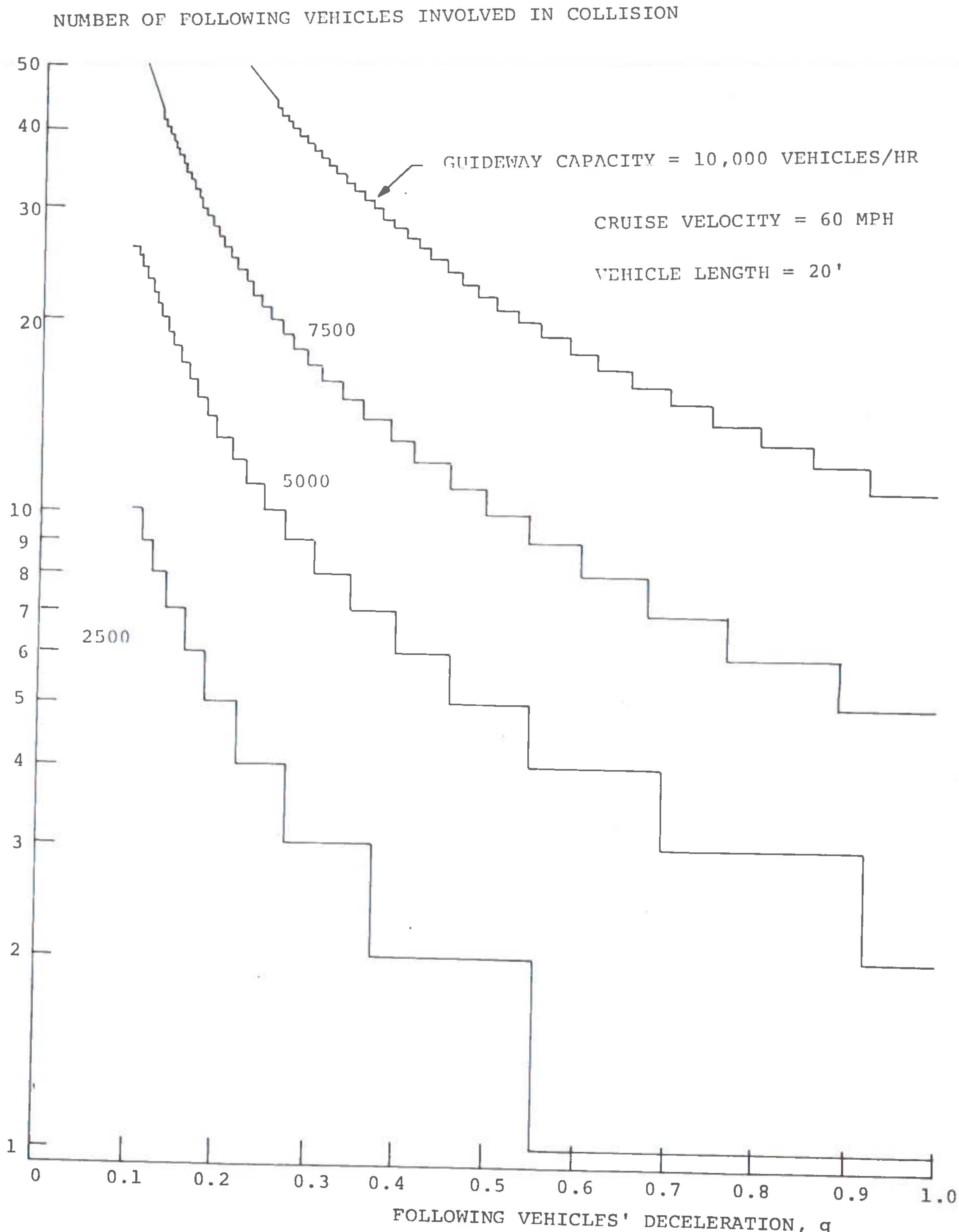


Figure 4-2. Number of Vehicles Colliding in Case of Instantaneous Stop of Lead Vehicle

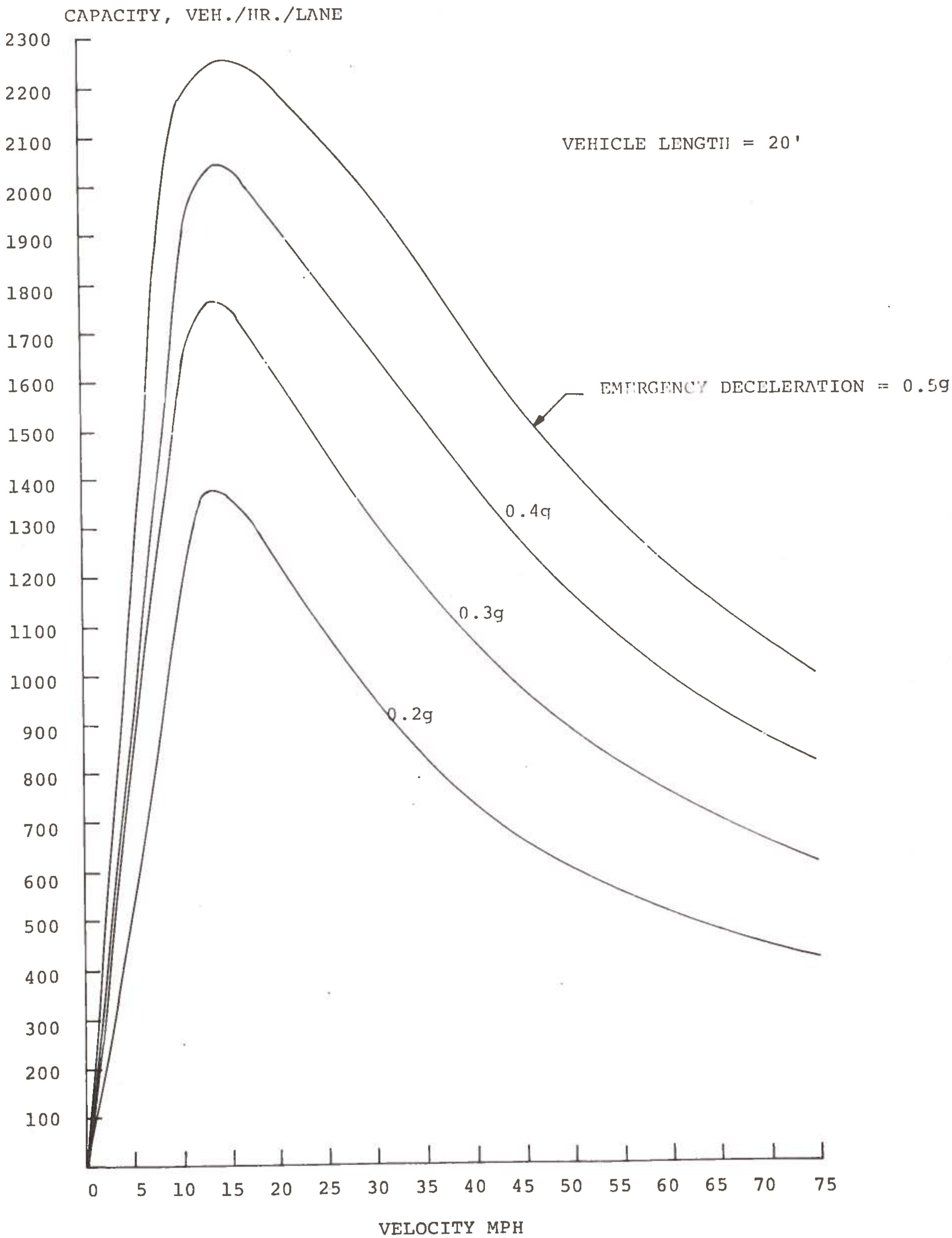


Figure 4-3. Capacity With Crash Free Operation in Case of Instantaneous Stop of a Vehicle

CAPACITIES WITH TRAIN OPERATION

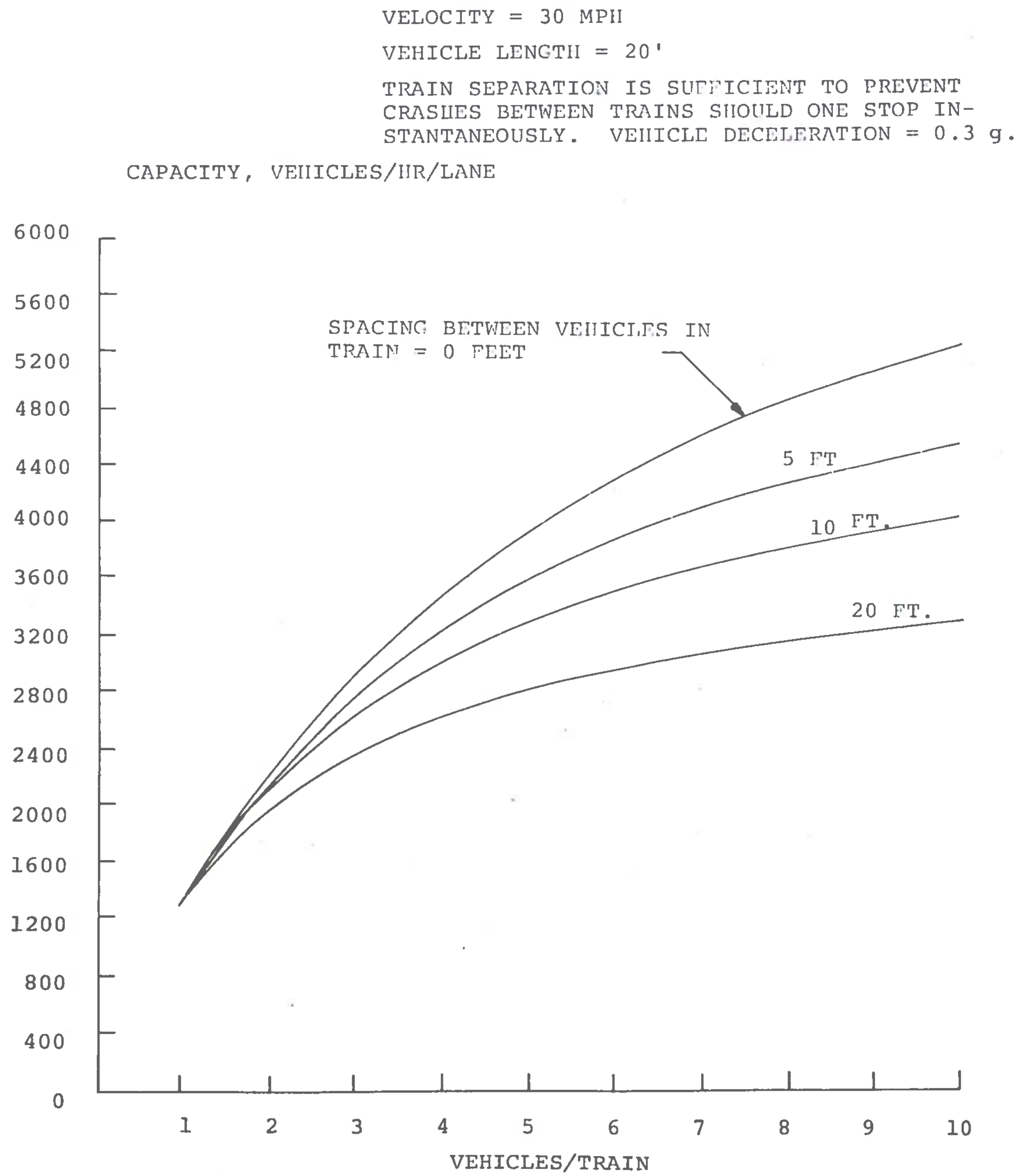


Figure 4-4. Capacity with Crash Free Operation in Case of Instantaneous Stop of a Vehicle

VELOCITY = 60 MPH
VEHICLE LENGTH = 20'

TRAIN SEPARATION IS SUFFICIENT TO PREVENT CRASHES BETWEEN TRAINS SHOULD ONE STOP INSTANTANEOUSLY. VEHICLE DECELERATION = 0.3g.

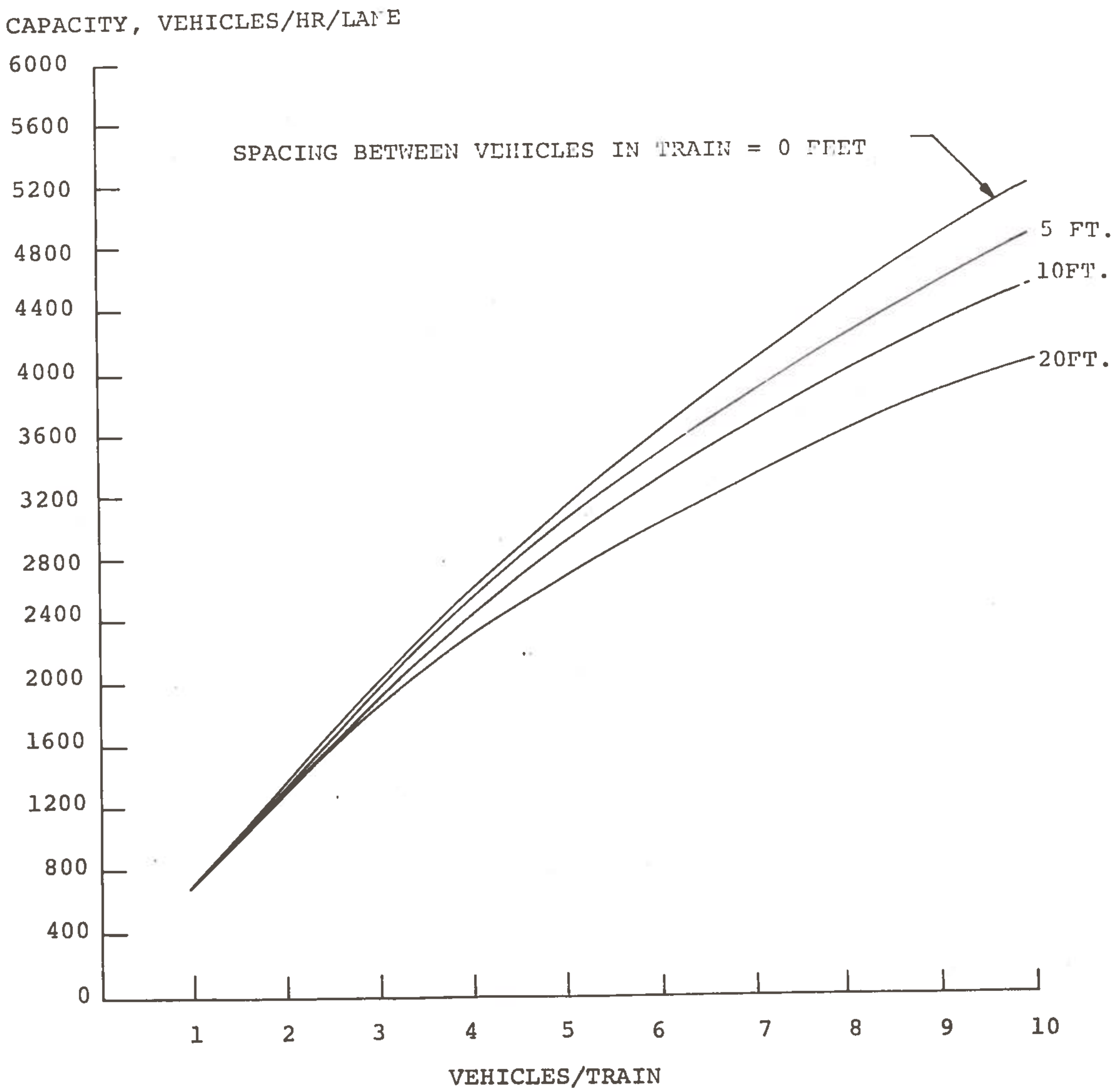


Figure 4-5. Capacities with Train Operation

friction would be the likely stopping force and the greatest friction would be that between tires and guideway (rubber tires are assumed to be used on all vehicles). Thus, no matter how fast a vehicle might stop due to a malfunction, those behind it could stop just as fast by application of brakes. The problem of headway then becomes a question of how fast a vehicle is likely to stop due to a failure and to what deceleration passengers in following vehicles should be subjected.

A TRW report[102] indicates that conventional tires can stop an automobile with about a 0.7g deceleration. General Motors performed a series of tests[112] in which panic stops were made from 70 mph, and average decelerations of 0.626g were achieved. The wheels of the car were not allowed to skid, so that this represented the upper limit of stopping ability of these vehicles from this speed. Somewhat higher decelerations are possible at considerably lower speeds, but for the purposes of this study a value of 0.7g was chosen as representing a reasonable maximum deceleration of a failed vehicle (brakes applied to almost the point of skidding).

With 0.7g taken as the reasonable expected maximum deceleration of a stricken vehicle, Figure 4-6 shows the resulting deceleration of a following vehicle (20 feet long) necessary to prevent a collision, as a function of guideway capacity and vehicle speed. The vehicles are assumed to have no time lag in braking response. A capacity of 6,000 vehicles/hour/lane was chosen from this as the "base capacity" for 20-foot vehicles on the Dual Mode system, since it appeared to represent a reasonable compromise between capacity and safe deceleration levels. Also, the deceleration level does not vary too greatly with speed for this capacity, meaning that a considerable speed change can occur without requiring a wide change in vehicle performance. The highest deceleration required is for the 30 mph case, because to maintain this capacity at such a low speed means the vehicles are getting rather closely bunched up and there is not much room for maneuvering. The minimum speed at this capacity is about 23 mph, at which the vehicles are bumper-to-bumper (20-foot vehicles). Shown below are the exact deceleration values

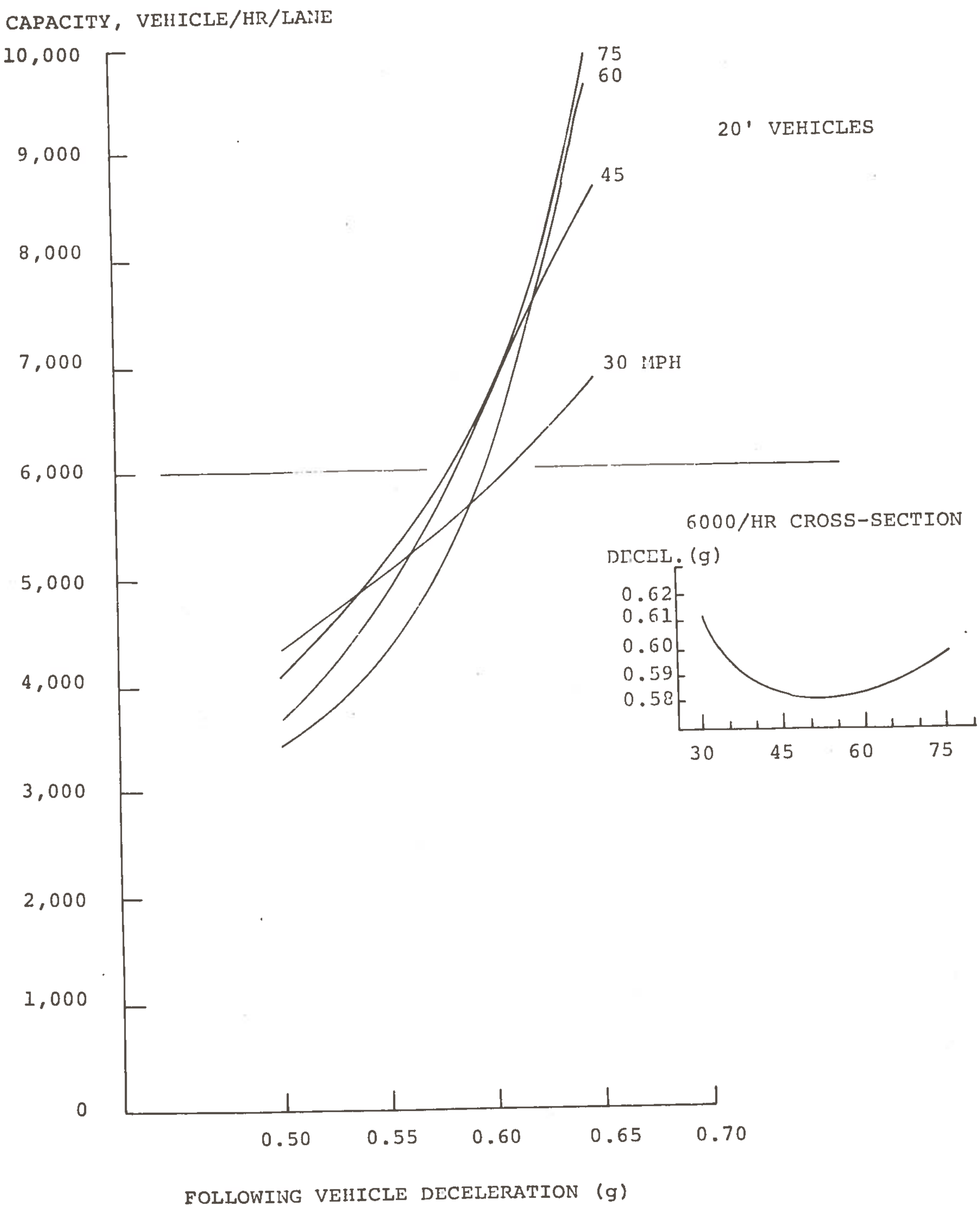


Figure 4-6. Required Decelerations of Following Vehicle for No Collision if Lead Vehicle Decelerates at 0.7g

required and the resultant stopping times.

Speed, mph	Deceleration, g	Stopping time, sec.
30	0.61	2.24
45	0.58	3.52
60	0.58	4.68
75	0.60	5.72

For the 30 to 75 mph speed range, the required deceleration values are all below that achieved with the emergency stop described in the General Motors study,[112] but are in a range that passengers find uncomfortable.

The vehicle directly behind the stricken one undergoes a more severe emergency deceleration than does the next vehicle back, and so on. Figure 4-7 shows this reduction for the first ten trailing vehicles at the 6,000 vehicle/hour/lane capacity. The 30 mph case has dropped to about 0.29g for the tenth training vehicle, and the 45 and 60 mph cases are down to about 0.23g. According to the GM study an average deceleration of 0.432g is "severe and uncomfortable to passengers", one of 0.344g is "undesirable, but not alarming to passengers" and a deceleration of 0.265g is described as "comfortable to passengers". Thus, the undesirable decelerations are limited generally to only a few vehicles behind the stricken one.

The small personal vehicles, being only about 10 feet long, experience slightly lower decelerations (when following a vehicle making an emergency stop) then 20-foot vehicles. The smaller length also allows them to be run at lower speeds at the 6000 vehicle/hour/lane capacity, making possible the 15 mph CBD speeds planned for them.

Dual Mode buses (including the minibuses of the new small vehicle system) were given larger headways than the automobile vehicles in order to allow for a greater vehicle length (except for the minibus) and to reduce the emergency deceleration rate necessary if a vehicle directly ahead of it makes a 0.7g stop.

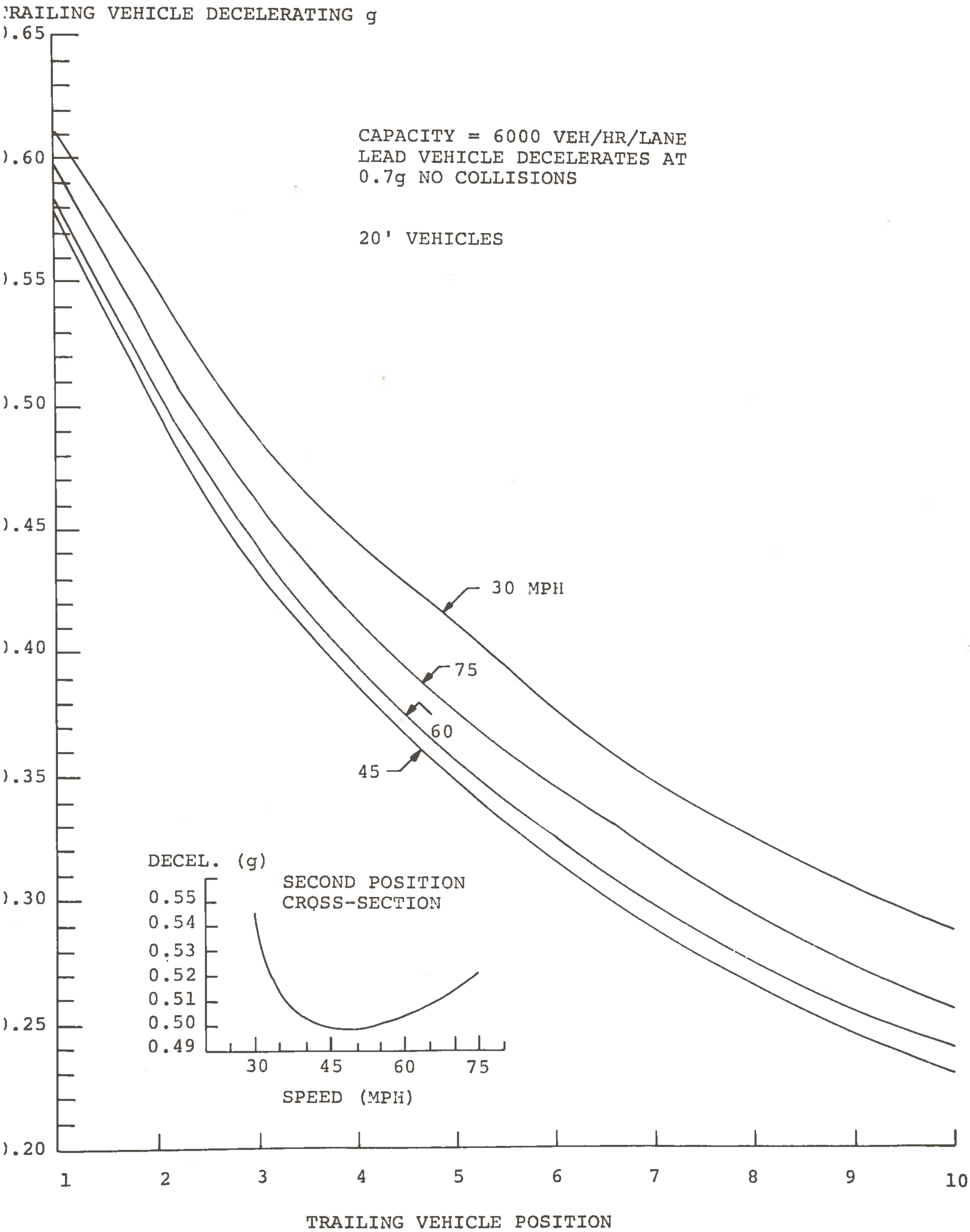


Figure 4-7. Deceleration Rate of Trailing Vehicles

This latter consideration was to accommodate standing passengers who, although assumed forbidden for this study, may nonetheless be present. The headway chosen for the bus provides a flow of 400 vehicles/hour/lane and the following emergency decelerations to avoid a collision with a vehicle directly ahead making a 0.7g stop:

Speed, mph	Deceleration, g
30	0.14
45	0.18
60	0.22
75	0.25

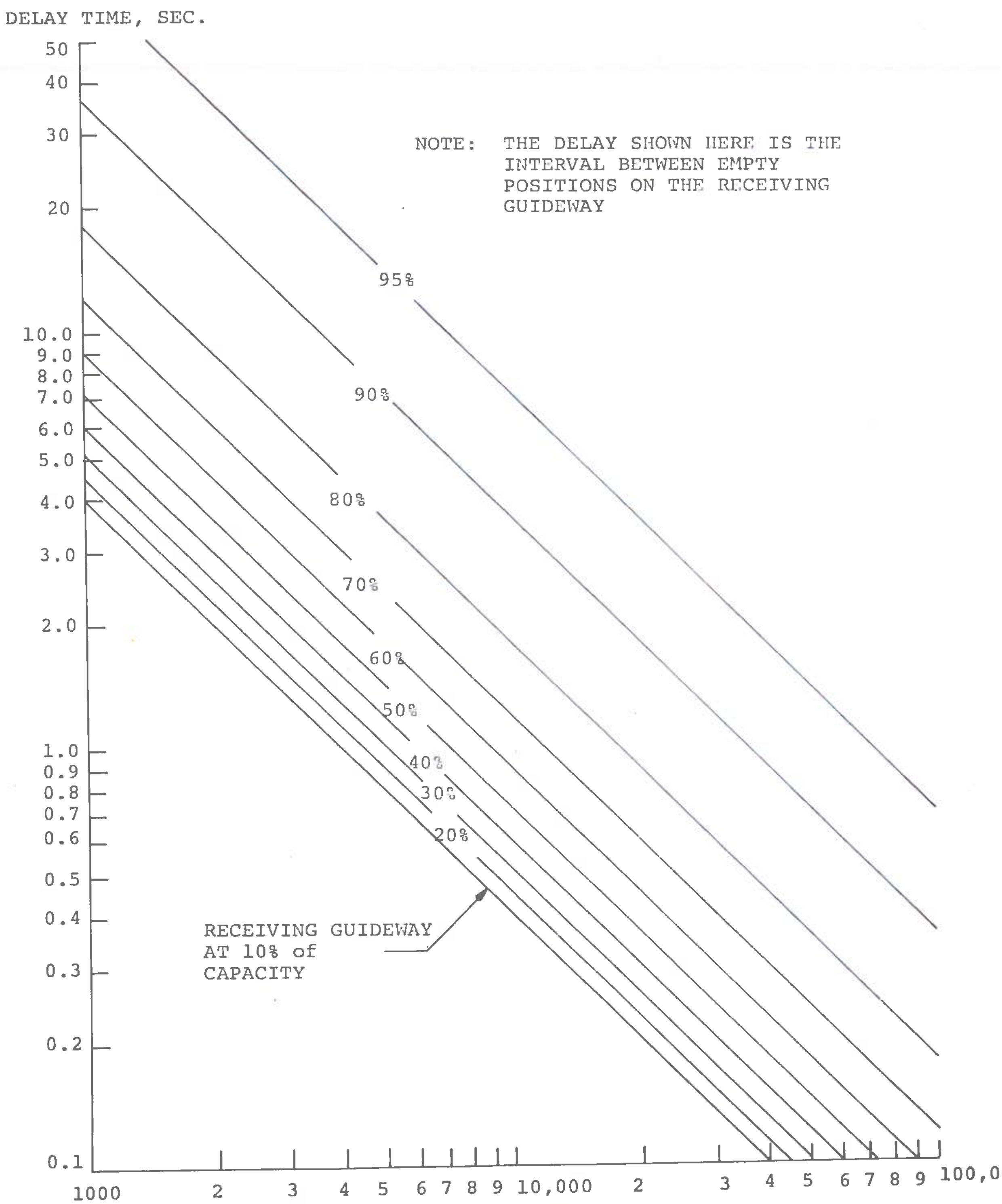
In contrast with the 20-foot vehicles, the 30 mph stop is no longer the most severe because of the greater space allotted. According to a recent study of passenger comfort[40] these decelerations would be considered tolerable for standing passengers.

Appendix E contains a discussion of headway and capacity if collisions are allowed to occur, and also presents the effects of vehicle braking time lags. Although a "crash-free" mode of operation was assumed for the present analysis, the matter is by no means settled and the various alternatives to this need to be examined.

The method of routing vehicles from their origin to destination and the consequent delays involved have significant effects on the cost and complexity of the command and control equipment and on the patronage of the Dual Mode system. Unfortunately, at the present time there is little consensus of opinion on the most promising routing techniques to employ. The two competing approaches are a deterministic type, wherein the vehicle's route and schedule is planned before the vehicle enters the guideway, and a stochastic type where the vehicle enters the guideway knowing only its desired destination while the route it takes is determined as it progresses along. It is likely that whatever scheme is finally chosen will not be either a pure stochastic or pure deterministic, but will be a compromise between the two extremes. A good discussion of the various options, as well as a bibliography on the subject, is presented in a recent TSC report.[43] None of the work to date, however, is of much assistance in determining the extent of delays likely due to heavy traffic on the guideway. Therefore, the approach taken was to calculate a statistical average waiting time per intersection or merge that would occur on the trip, and assume that whatever the routing system that is finally developed, it can at least match this in performance. It was further assumed that all vehicles are routed to their destination via the shortest possible path. The delay was calculated on the basis of a Bernoulli distribution of the vehicles on the receiving guideway, and the results are shown in Figure 4-8. The delay time shown is actually the interval between empty spaces on the guideway and thus represents twice the average delay time. It is apparent that higher guideway capacities result in considerably shorter wait times than do lower ones, due to a greater frequency of empty positions coming by. As the receiving guideway gets filled closer to capacity, the waiting times increase rapidly. For the 6000 vehicle/hour/lane capacity assumed for this analysis, a 6 second average waiting time exists if the receiving guideway is at 95% capacity (one half of the 12 seconds between empty positions) and that if the guideway is at 80% capacity a waiting time of only 1.8 seconds is experienced. The value used in this study for an average delay was 6 seconds per merge, whether it occurred at interchanges or stations. It should be noted that this analysis in no way adequately represents the dynamics of merging traffic streams, but time and resources did not permit a more suitable examination of the problem.

4.3 POWER AND PROPULSION REQUIREMENTS

The power requirements of various types of Dual Mode vehicles were analyzed in order to arrive at estimates of the size and weight of their propulsion systems. Power requirements were calculated as a function of speed for the vehicles under consideration



RECEIVING GUIDEWAY CAPACITY, VEHICLES/HR.

Figure 4-8. Maximum Delay Experienced by Vehicle Making an Inter-Guideway Transfer for four cases: a nominal cruising condition and a maximum power condition, each with and without a 30 mph headwind.

Five types of vehicles were examined, in accordance with the Dual Mode baseline definitions: pallets carrying automobiles, automobiles directly on the guideway, small personal vehicles (electric minicar), small (12-passenger) buses and large (20-passenger) buses. Nominal cruise condition was defined as maintaining speed on a 5% grade, and the maximum power condition as accelerating at 0.1g up a 5% grade at the speed of interest, except for the large bus which had a maximum power condition defined as accelerating at 0.1g on a level guideway at the speed of interest.

The maximum power condition for all vehicles except the large bus was based on the assumption that they will be required to maneuver longitudinally to some degree at guideway interchanges in order to accomplish and/or accommodate transfer from one guideway to another. This maneuvering is assumed to be done at a 0.1g acceleration, and ramps with 5% grades exist at these interchanges. Therefore, the vehicles have to be able to handle a 0.1g acceleration on a 5% grade at speed. Speeds through the interchanges could be lowered somewhat without affecting capacity, and this would reduce the power requirement. However, this was not considered to be the normal operating procedure in this study. The large buses are not required to perform this maneuvering because of the large amount of space per slot they occupy on the guideway. All other accelerations were assumed to be on level guideway (such as acceleration lanes at entrance points to the guideway) unless acceleration rates for all vehicles are reduced at certain guideway locations to accommodate the capability of the large buses.

The power required to maintain the vehicles at speed is given by the product of the vehicle's velocity and the propelling force necessary to overcome the drag and inertia of the vehicle, and takes the form:

$$\text{Power} = \left[W\ (k + \sin\theta + a) + \frac{C_D\ \rho\ V^2 A}{2} \right] V$$

where:

W = vehicle weight

k = wheel rolling friction coefficient

θ = angle of incline

a = acceleration of vehicle

C_D = aerodynamic drag coefficient

ρ = atmospheric density

V = vehicle speed

A = vehicle frontal area

The vehicles were all assumed to have rubber tires operating on concrete or asphalt, with a tire rolling friction coefficient of 0.015.[64] The other characteristics pertinent to power requirements are as follows:

1. 20 passenger bus
   a. Total weight = 15,000 lbs.
   b. Frontal area = 72 ft^2
   c. Aerodynamic drag coefficient = 0.6

2. 12 passenger bus (minibus)
   a. Total weight = 10,000 lbs.
   b. Frontal area = 56 ft^2
   c. Aerodynamic drag coefficient = 0.6

3. Pallet carrying automobile
   a. Total weight = 10,000 lbs.
   b. Frontal area = 48 ft^2
   c. Aerodynamic drag coefficient = 0.6

4. Small personal vehicle
   a. Total weight = 3000 lbs.
   b. Frontal area = 24 ft^2
   c. Aerodynamic drag coefficient = 0.4

5. Dual Mode automobile (operates directly on guideway)
   a. Weight = 4000 lbs.
   b. Frontal area = 33 ft^2
   c. Aerodynamic drag coefficient = 0.5

Results of the power requirement calculations are shown in Figures 4-9 through 4-13. In all cases, a significant increase in power is required over the nominal case if either the maximum power conditions prevail or the 30 mph headwind is present. Naturally, the combination of headwind with maximum power condition results in the greatest load on the vehicle. The power values presented are not the rated motor or engine powers, but are the actual horsepower values required at the wheels. The rated engine or motor powers would be somewhat higher, to account for drive train inefficiencies.

Electric motors are capable of significant overloads for short periods of time. Thus, for electrically powered Dual Mode vehicles it is possible to use motors with a continuous power rating considerably less than that required by the maximum power condition, and thereby achieve a significant weight reduction. For the purposes of this study, then, the electrically powered vehicles were assumed to have motors with a continuous power rating sufficient to propel the vehicle under normal power conditions at top cruise speed (60 mph) with no headwind, and an overload capability sufficient to satisfy the maximum power condition for 45 seconds (longer than it should ever be needed), again with no headwind. The main problem of motor overloading is heat generation, so additional cooling capability might have to be provided. This should represent a very small penalty. In the case of headwinds, speed can be reduced on those guideway links so affected so that the power requirements do not exceed the capacity of the motors. Speed can be reduced significantly below the top cruise speed of 60 mph, without affecting guideway capacity, and all vehicles should be able to travel into a 30 mph headwind without exceeding the nominal power condition if vehicle speed is reduced to 30 mph. Since winds of this magnitude are generally not an everyday occurrence and since wind directions change, no single section of guideway should consistently yield a lower average speed because of wind.

Internal combustion engines do not have significant overload capabilities, so Dual Mode vehicles powered by these must have

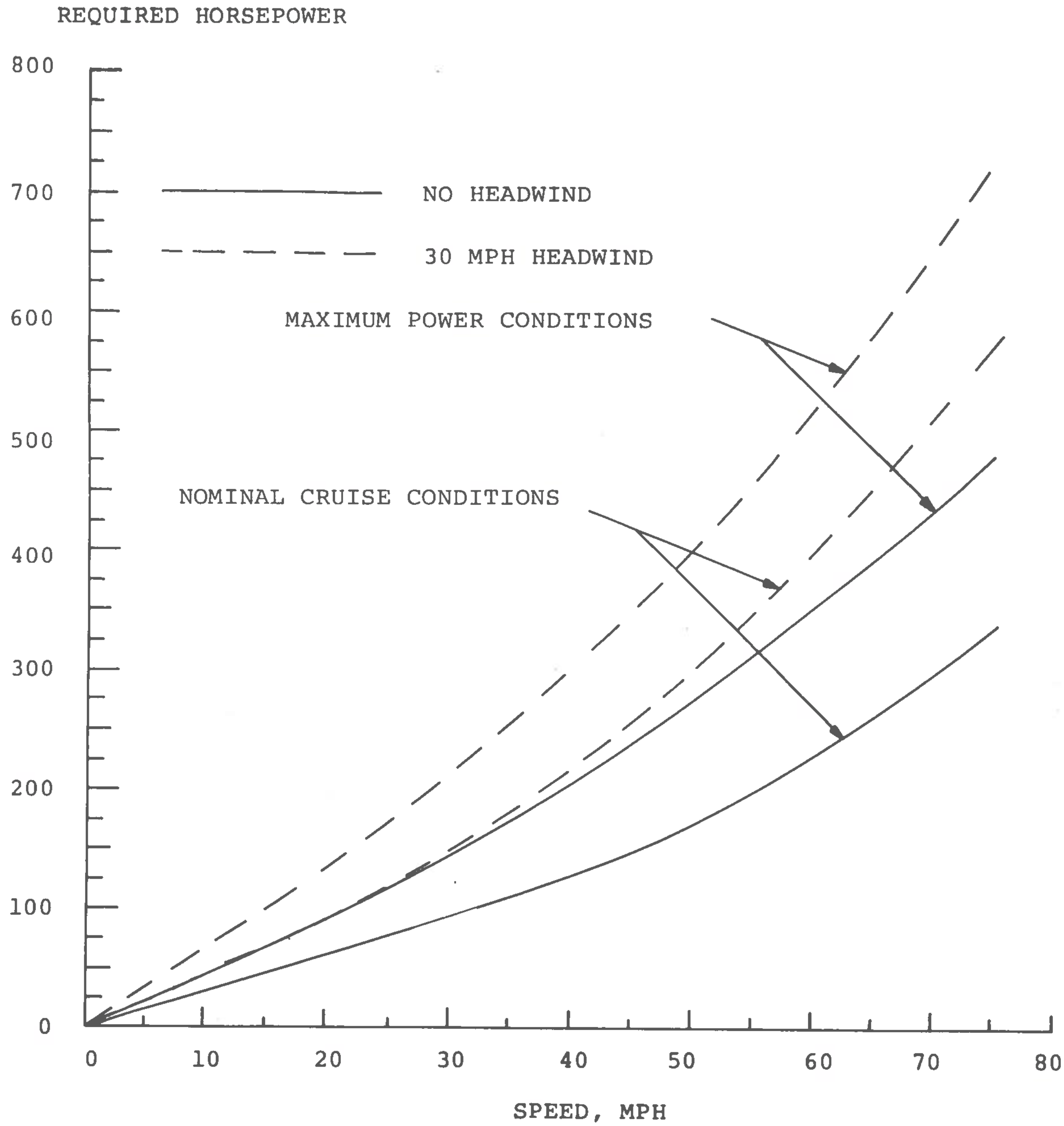


Figure 4-9. Power Requirements for 20 Passenger Bus

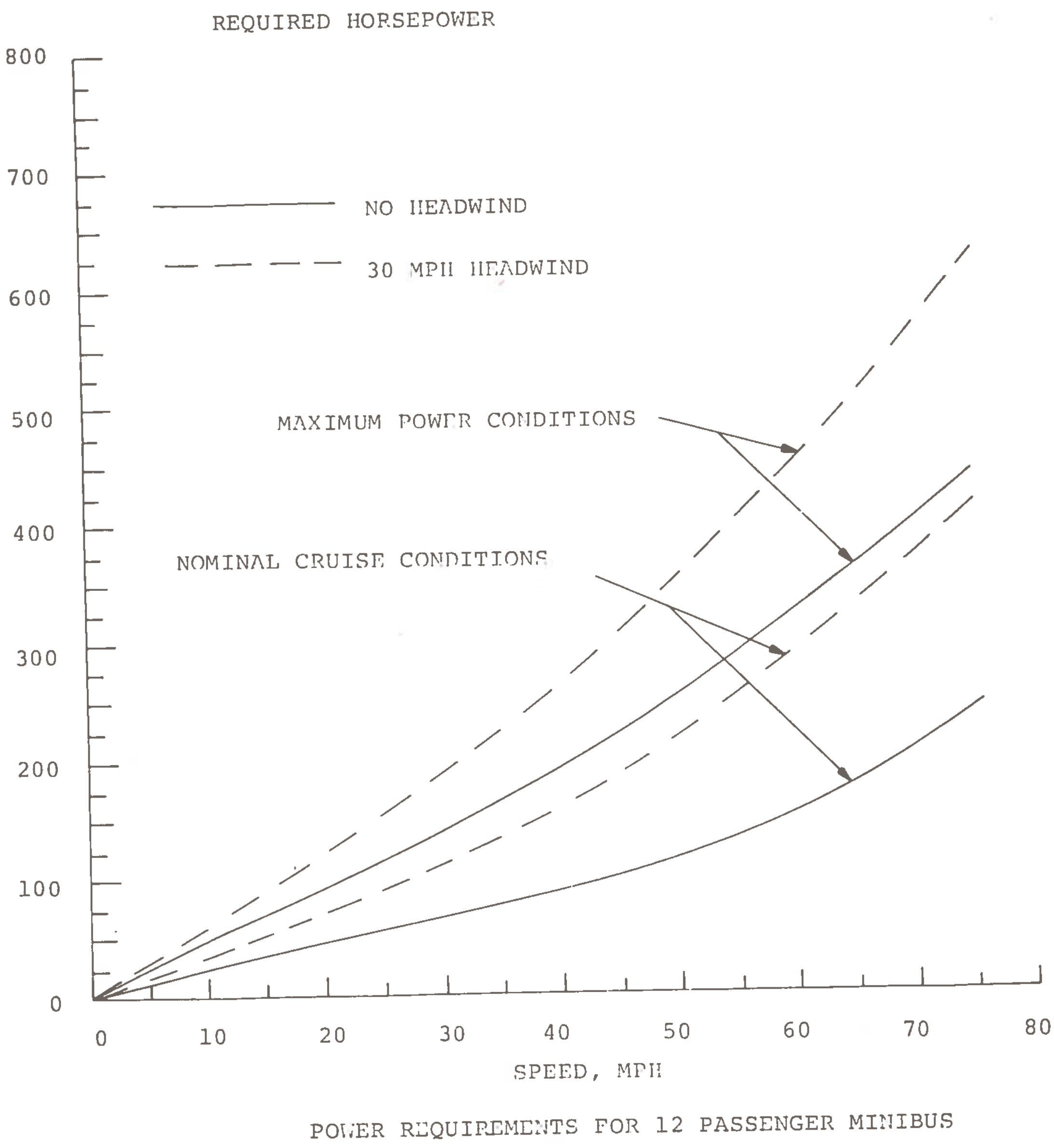


Figure 4-10. Power Requirements for 12 Passenger Minibus

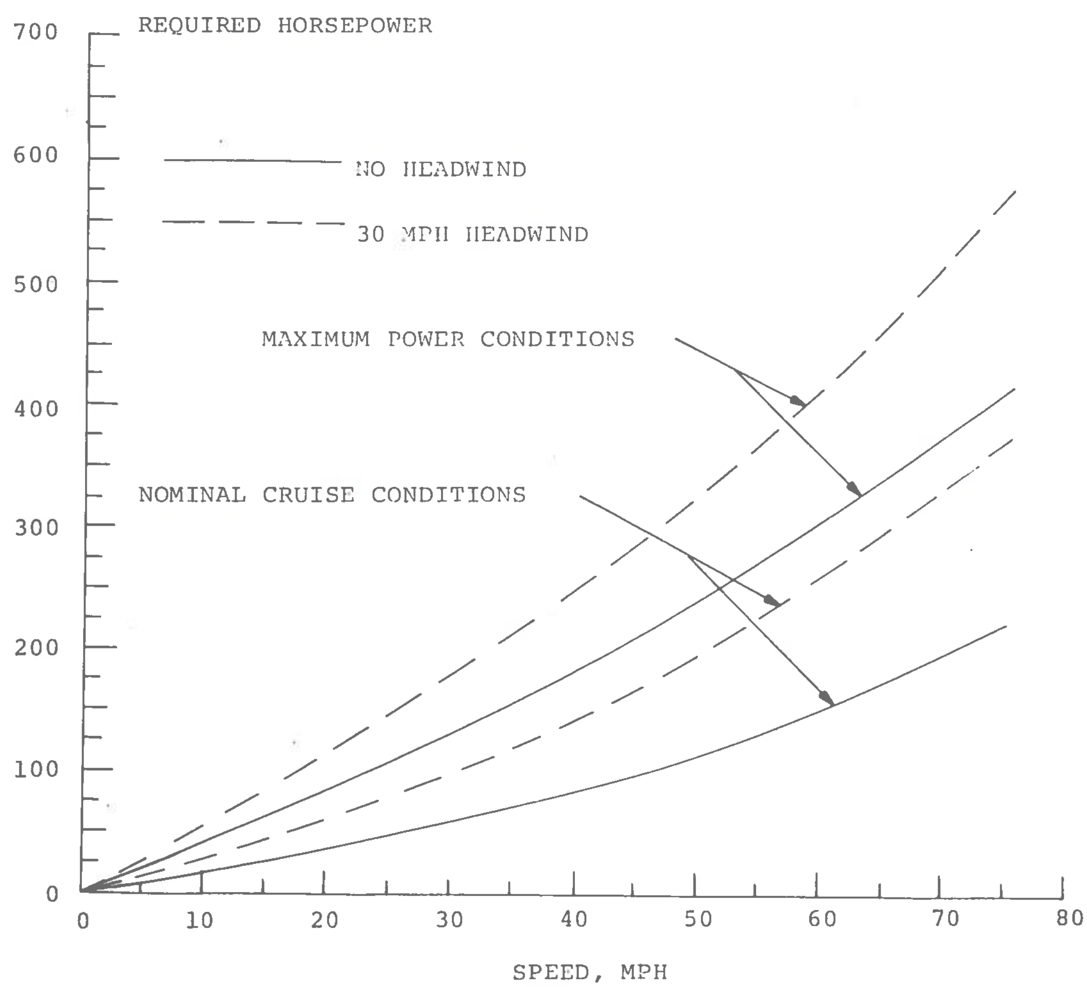


Figure 4-11. Power Requirement for Pallet with Automobile

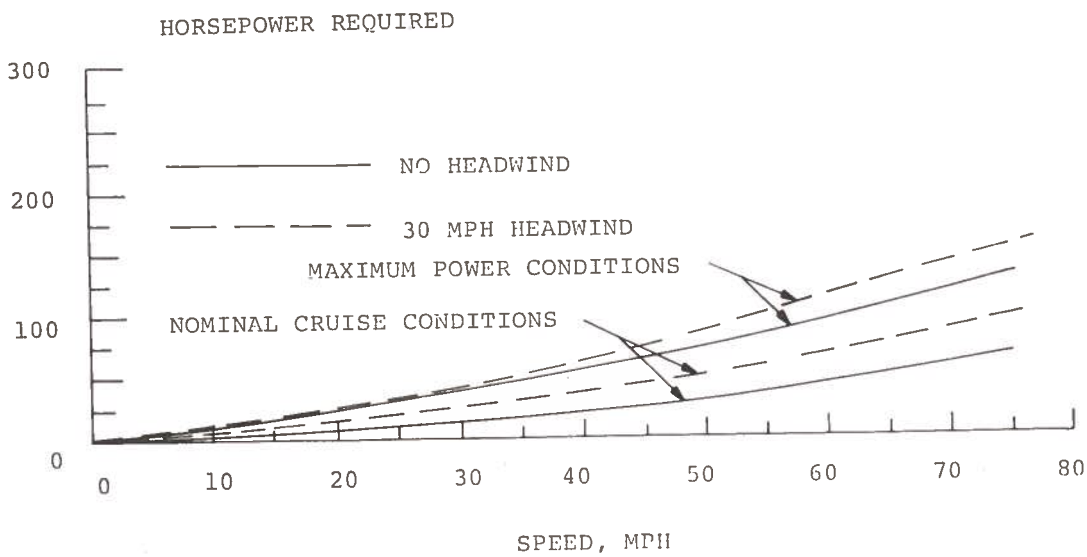


Figure 4-12. Power Requirements for Small Personal Vehicle

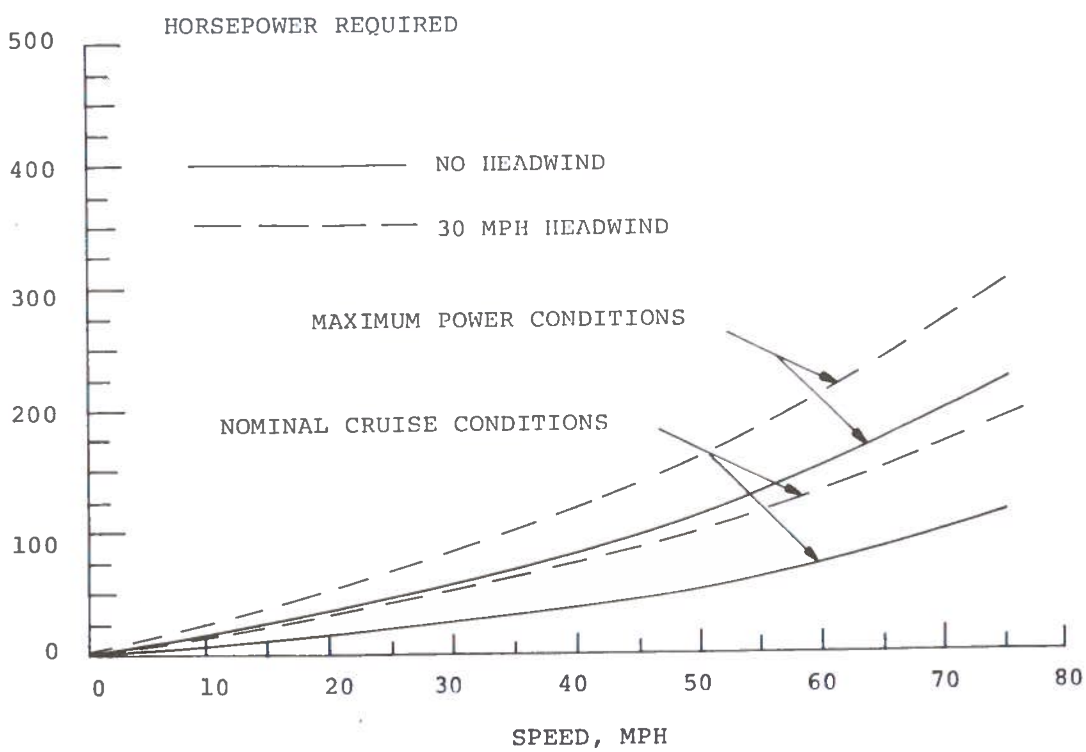


Figure 4-13. Power Requirements for Standard Automobile

engines sized to satisfy the maximum power condition at top cruise speed. The headwind policy was the same as for electrically powered vehicles.

Electric motors are assumed to be of the a.c. squirrel cage induction type, estimated as weighing about 2 lbs/hp including cooling, controls and power conditioning equipment.[3] There are a variety of internal combustion engines to choose from (and some external combustion varieties) with a wide range of weights, ranging from lightweight gas turbines and Wankel engines through medium weight gasoline engines to heavyweight diesels. As a compromise, a figure of 2 lbs/hp was chosen as the internal combustion engine weight.[64] Taking into account the operating requirements described earlier and drive line inefficiencies, the following motor sizes and weights were chosen for the Dual Mode vehicle:

Vehicle	Propulsion	Rated Continuous Horsepower	Maximum Overload Horsepower	Motor Weight (lbs.)
Pallet	electric	200	450	400
Dual Mode Automobile	internal combustion	250	-	500
Small Personal Vehicle	electric	70	120	140
20-Passenger Bus	electric	250	550	500
	internal combustion	550	-	1100
Minibus	electric	200	475	400

For off-guideway operation, the electrically powered vehicles were equipped with batteries with sufficient capacity to provide a range of 30 miles at a speed of 45 mph. Present day lead-acid batteries are inadequate in terms of energy storage capability.[64] Other, more efficient types of batteries are currently available that could conceivably meet the energy storage requirements, but they typically involve expensive materials such as silver and cadmium, and consequently their prices are prohibitive. A promising alternative to present day batteries appears to be the use of some of the "advanced" types of batteries currently under development. Of these, the zinc-air and sodium-air varieties appear attractive at the present time. The zinc-air battery, although somewhat lower in energy storage ability than the sodium-air, operates at ambient temperatures, while the sodium-air must be heated to at least 270°F. Thus the zinc-air battery appears the more useful for the small personal vehicle, since it would not require being hooked to a power or heat source when not in use (such as overnight or on weekends) or a lengthy wait to warm up the battery by some sort of heater if it were not kept warm when not in use. On the other hand, this would not present too great a difficulty with the electric buses (small and large), and in these cases the greater energy storage of the sodium-air battery makes it the logical choice. Both types of batteries contain dangerous materials, but it is felt[64] that they represent no more of a hazard than does the fuel tank of an automobile.

North American Rockwell Corp.[64] performed an analysis of some battery powered vehicles similar in size, weight and trip nature to the electrically powered Dual Mode vehicles for the off-guideway mode. From their results, the following battery characteristics for the Dual Mode electrically powered vehicles were chosen:

Vehicle	Battery Type	Battery Weight (lbs.)	Battery Cost
Small Personal Vehicle	zinc-air	450	$450
12-Passenger Bus	sodium-air	450	$560
20-Passenger Bus	sodium-air	675	$845

The battery costs assume a $1/lb. production cost for the zinc-air and $1.25/lb. for the sodium-air versions after they reach operational status.[64] The battery weights shown above represent a 50% energy storage margin over the minimum required. By comparison, the small personal vehicle equipped with 1,500 lbs. of lead-acid batteries has an estimated range of only 17 miles, at a cost of $750 for the batteries, and the 20-passenger bus would require nearly 25,000 lbs. of lead-acid batteries to achieve its range of 30 miles at 45 mph.

4.4 FLEET SIZING

A. Pallets

The pallet fleet was sized to be able to accommodate the peak hour traffic load. For purposes of calculating the fleet size it was assumed that each pallet operated back and forth between a pair of stations, and for each such station pair, enough pallets were provided to service the flow in the peak direction during the peak hour.

One-way trip times between the various stations were divided into two categories: "long" trips with average time of 17.6 minutes and "short" trips with an average of 8.9 minutes. The pallet round trip times were found by doubling the one-way times and adding 5 minutes for turnaround procedures. Thus, the round trip times were 40.2 and 22.8 minutes, respectively. Knowing the total number of peak hour trips in the two trip time categories, the round trip times for the pallets, (which determines how many round trips a pallet can make in the peak hour), and the average peak direction factor (the percentage of trips in the peak directions, ≈ 68%), the pallet fleet was then calculated. The resulting figure was increased by 10% to allow for maintenance and contingency situations.

B. Small Personal Vehicles

The utilization characteristics of the small personal vehicle are similar to those of an automobile except for PRT-type service (i.e., limited to the guideway) in the CBD. The fleet size was based on the number of vehicles required for peak period work trips and off-peak trips originating from households.

Peak period work trips were assumed to utilize a small personal vehicle kept overnight at the driver's home and parked during the day. The vehicles left at the CBD stations during the day are available for other service. Using the ratio of 1.5 people per vehicle and assuming that all peak period trips are work trips, one vehicle is required for every 1.5 peak period person round trips.

Estimating the number of vehicles necessary to service off-peak trips was somewhat more difficult. Although some of the off-peak trips were PRT-type trips in the downtown area (which could utilize vehicles parked at CBD stations), these represented a very small portion of the daily off-peak trips and did not enter into the calculation. The problem then, was to determine off-peak vehicle requirements by finding the total number of off-peak Dual Mode trips by an appropriate tripmaking factor.

A study of Boston transportation patterns[111] indicates that households without a car generate about one non-work person round-trip per day, those with one car generate about three, and those with two cars about five. A family using a small personal vehicle during the course of a day was assumed to have in addition a conventional automobile for work trips and therefore fell within the two-car tripmaking group. However, it was necessary to adjust the non-work trip generation rate for two-car households to an all-purpose Dual Mode trip rate per household by considering several factors of the non-work person round trips made each day by two-car families, since some can be made in the evening with the conventional automobile. Also, some of the trips made in a small personal vehicle take place entirely on local streets (e.g., short-distance shopping trips) and therefore are not considered Dual Mode trips. Further, the Dual Mode system carries a number of work trips and non-home-based non-work trips as well as home-based non-work trips during off-peak hours. Taking into consideration these points and likely load factors, it was decided that the off-peak small personal vehicle fleet would be based on the ratio of one vehicle for every three off-peak Dual Mode person round-trips.

C. Buses

Dual Mode bus fleets, including the new small vehicle baseline minibuses, were sized by routing and schedule considerations. Bus routes were established by the service demands between pairs of superzones, and a given bus was assumed to shuttle back and forth between a given pair of superzones, providing service only to these two. A minimum level of patronage was required between an origin and destination superzone pair before bus service was provided, and once service was provided in one direction it was assumed to be likewise provided in the opposite direction regardless of the patronage, since the buses have to make a round trip. A non-CBD superzone was assumed to have two bus circulation routes through it to minimize the off-guideway collection and distribution time. Therefore, two non-CBD superzones connected by bus service require four bus routes. A minibus going to the CBD from any origin (including CBD) was assumed to stop at three CBD stations, and the other types of buses when going to the CBD were assumed to stop at all the CBD stations. Headway between minibuses on a route was assumed to be 20 minutes, while the other types of Dual Mode buses were assumed to have 15 minute service. These represent a compromise between capital investment and patronage.

The fleet size was then calculated from the number of routes, the average round trip times for these routes and the frequency of service necessary. As an example, if there were 150 routes with an average round trip time of 30 minutes, and the service level was a bus every 15 minutes, then 300 buses would be required.

4.5 CBD PARKING FACILITIES

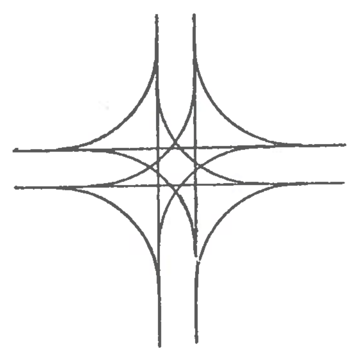
For baselines involving private automobiles (i.e., pallet system and automated highway vehicle systems), facilities for parking these automobiles in the CBD are provided as part of the Dual Mode system. This is to prevent them from entering the local streets in the CBD area and contributing to the congestion there. The parking is done manually by the drivers after their vehicles have been off-loaded from the guideway. No detail design or layout of the parking facilities was performed, but it was assumed that the total area enclosed, including ramps and driveways, amounted to 300 square feet per parking space and that the structures were 5 stories tall.

Parking is provided for all automobiles entering the CBD during the morning peak period via Dual Mode with the assumption that those cars will be parked all day. In addition, it is assumed that one-third of the off-peak automobiles entering the CBD by Dual Mode will be parking at any given time, so facilities are provided for these also.

4.6 INTERCHANGE, STATION AND GUIDEWAY DESIGN

A. Interchanges

The interchange design chosen for the Dual Mode guideway was an "iron cross" configuration, and the 4-way layout is shown in the following sketch:



Interchanges were sized by the conditions that vehicles could pass through the curves at cruise speeds (60, 15 and 30 mph) with no perceived lateral acceleration and that if a vehicle came to a stop on a curve the passengers would perceive a lateral force of 15% of their body weight, due to the bank angle. This latter value was chosen as a compromise between passenger convenience and required land area. A greater bank angle could be uncomfortable for passengers in a stopped vehicle and impede their exit in case of emergency, while a lesser bank angle results in a very large increase in area. These conditions led to a bank of 8.63° and curve radii of about 100 feet for 15 mph interchanges, 400 feet for 30 mph and 1600 feet for 60 mph. For the 15 and 30 mph layouts, an additional 80 feet of guideway was added on to each end of each "simple" merge lane to allow sufficient room for vehicle maneuvering (required by some of the control system concepts) and 140 feet on to each end of each over-and-under lane to achieve clearance with a 5% grade. The resulting land areas and merge guideway lengths for 4-way and 3-way (a T-configuration) are as follows:

	4-Way			3-Way		
	15 mph	30 mph	60 mph	15 mph	30 mph	60 mph
Area (acres)	0.5	7	115	0.25	3.5	57.5
Merge Guideway (miles)	0.58	1.3	3.8	0.30	0.66	1.91

The 60 mph interchanges occupy a considerable amount of land, although a highway cloverleaf pattern would have require approximately twelve times as much. The area required for the 60 mph interchanges can be reduced by dropping the speed through them, to 30 mph for instance, resulting in a slight increase in trip time. This speed reduction would not affect the vehicle flow capacity. This was not done for this study, except as a parametric variation for the new small vehilce, but does represent an option. The interchange design used in this study could conceivably cause a visual impact, since it is a 4-level structure. The sensitivity of the impact is not known at this time, but is presumably lessened by the fact that the maximum elevation occurs only near the middle of the interchange, which puts it the maximum possible distance from the surrounding area.

B. Stations

Stations for the various Dual Mode baselines were laid out only to the level of detail necessary to enable an estimate of the required area and guideway to be made. One standard configuration was used, typified by Figure 4-14, and local peculiarities and conditions were not considered. For all stations, single

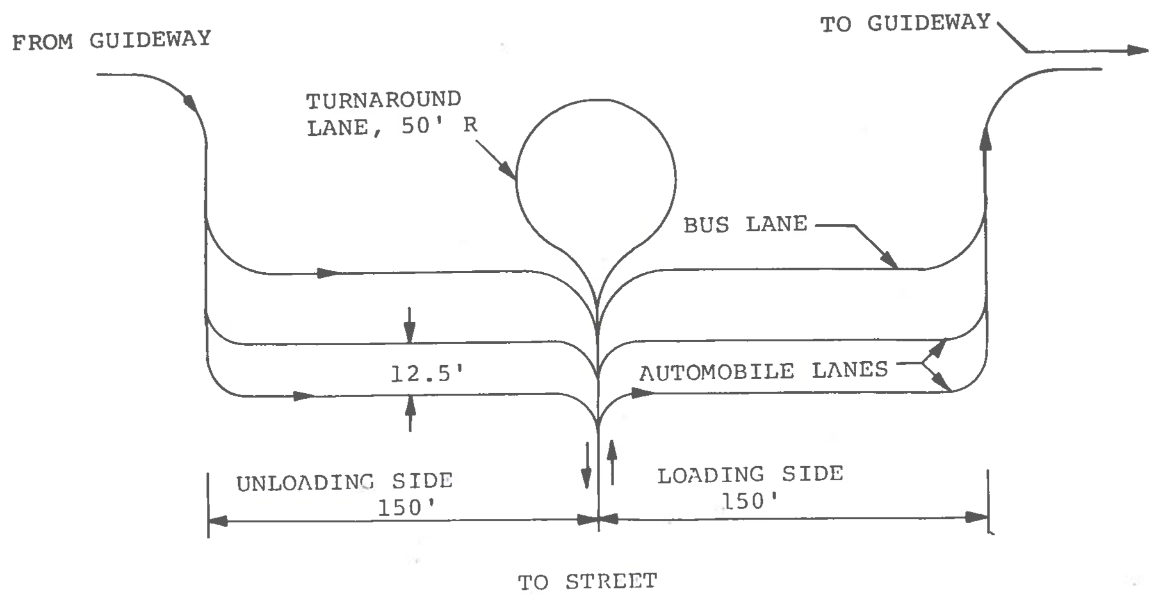


Figure 4-14. Pallet Baseline Station

acceleration and deceleration lanes were provided for each direction of travel possible on the adjoining guideway. These lanes were sized for a 0.1g acceleration and deceleration. For all baselines, suburban stations were assumed to be single story structures while CBD stations were two stories, in order to conserve land required. The two-story CBD stations were assumed to accommodate the loading function on one level and the unloading function on the other.

1) Pallet System

Stations for the pallet baseline require docks for loading and unloading automobiles on and off of the pallets. Each loading and unloading dock was assumed capable of accepting a new vehicle every thirty seconds. It was necessary to provide guideway to accept empty pallets from the unloading docks and to provide empties to the loading docks. In addition guideway links were provided between the loading and unloading docks, resulting in sufficient guideway to provide storage for as many as five empty pallets per loading stall (which could act as a cushion for demand peaks). One loading and one unloading stall were provided for each station over and above those required to satisfy demand. This provided a backup capability in case one of the other stalls is closed for some reason. At the CBD stations, facilities for manually parking the automobiles after they have been off-loaded from the pallets were provided. It is not known at this time what sort of arrangement would be used for loading and unloading the pallets, and consequently the amount of space required for stalls, and their configuration, were assumed.

Special stalls for bus access and egress were provided. Since the buses do not travel on pallets, but directly on the guideway instead, these stalls are not the same as those for automobiles. The access stalls will contain whatever equipment is necessary to inspect the buses prior to entry on the guideway. One access and one egress stall were considered sufficient to handle the bus traffic at a suburban station. For the purpose of this study, the CBD stations were assumed to always have at least one access and one egress stall, even if no buses leave the guideway there to circulate on the streets.

The sketch in Figure 4-14 of a pallet baseline station shows the routes followed by automobiles and buses, but does not include all the associated guideway for handling and storing the empty pallets. Included in the station is a turnaround lane, so that if a driver changes his mind about getting on the system after he has entered the station he can get back onto the local streets without having to board a pallet.

2) Automated Highway Vehicle System:

The automated highway vehicle stations have a bus access and egress stall arrangement similar in principle to that of the pallet baseline. Automobile access facilities consist of a number of parallel stalls for the inspection of automobiles and their conversion to automatic control. In addition, manual operation lanes (Figure 4-15) are provided for driving a vehicle that is refused entry, because of failure to pass the inspection,

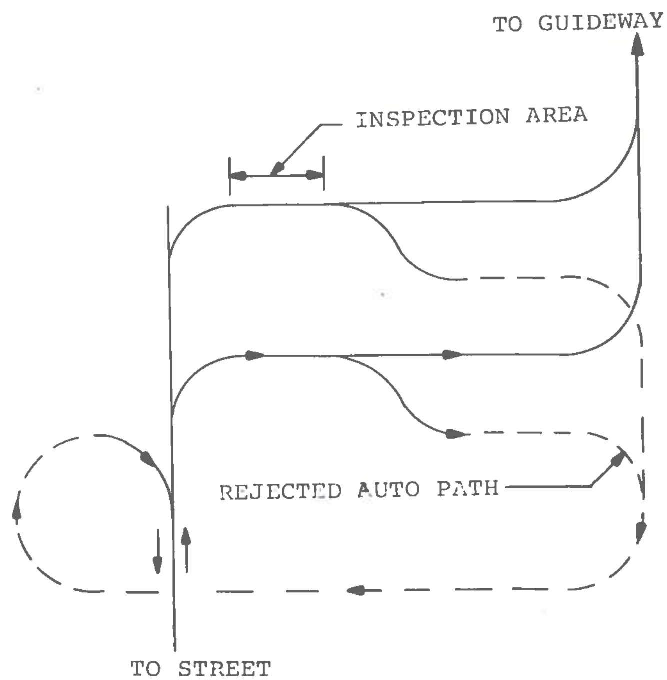


Figure 4-15. Automated Highway Inspection and Loading Arrangement

out of the access stall and back to the local street system. An access stall is assumed capable of handling a vehicle every thirty seconds. Egress stalls are somewhat simpler in design than the access stalls, since the only function they perform is to revert vehicle control back to the driver. An egress stall is assumed to be capable of handling a vehicle every ten seconds. As with the pallet stations, one access and one egress stall were provided beyond the number required to handle the demand. Manual automobile parking facilities were provided at the CBD stations.

3) New Small Vehicle Stations:

The minibus and small personal vehicle are near enough in size that they can share the same access and egress stalls. The number of stalls provided was determined the same manner as with the pallet and automated highway systems. Access and egress processing times were assumed to be thirty and ten seconds, respectively. Vehicles never leave the system in the CBD, so that instead of access and egress stalls, boarding docks are provided there. They were assumed to require the same guideway and area as the access and egress stalls, and their number was determined in the same manner.

C. Guideway

It was assumed that right-of-way widths for the guideway would amount to 12 feet per lane for up to 3 lanes, and 10 feet for every lane after that. Further, some sort of physical lateral constraint was presumed to be built into the guideway. In addition, each lane is a U-shaped channel with sidewalls, about 2-1/2 feet high, acting as noise barriers.

5. COST DETERMINATION

5.1 INTRODUCTION

Estimation of the cost of construction and operation of Dual Mode systems is fundamental to their economic analysis. For this project costs were estimated for the three Dual Mode baselines operating in conjunction with highway and transit systems. In addition, the 1990 highway and transit plan was costed.

All costs used in the Dual Mode comparative analysis were based on a 1970 price level. This obviously neglected possible inflationary effects between 1970 and 1990. However, since this analysis is comparative, the absolute price base year is irrelevant so long as the same base year is used for all alternatives and so long as relative price changes between market segments remain constant between 1970 and 1990.

Where historical cost data was used, it was scaled to 1970 price levels by means of an appropriate price index. Three indexes were used in this project: the Engineering News Record "Construction Cost Index" and the wholesale and consumer price indexes from the U. S. Department of Commerce, Bureau of the Census. Judgment dictated which index was appropriate for a particular system component -- for instance, the consumer price index was used for transit vehicles since their costs are escalating faster than the wholesale index would indicate.

All capital costs were converted to annual costs assuming a 10% interest rate and appropriate service lives. A 10% rate was used because it reflects the standard value of capital for decision making in private industry (see Office of Management and Budget Circular No. A-94, June 26, 1969). Parametric analyses were conducted to evaluate the effect of other interest rates.

Nominal fares were assigned to all Dual Mode systems. The fares were selected so that they would be competitive with existing modes. Fare variations were examined in the demand analysis portion of the study.

5.2 PROPERTY ACQUISITION COSTS

Property acquisition costs include fair compensation for land and improvements, easement rights where appropriate, and the administrative and legal costs incidental to property acquisition. Where the property taken is publicly owned, compensation is often made for major improvements such as buildings but often not for streets or other "vacant" public property.

Right-of-way (ROW) costs (i.e., property acquisition costs) in urban areas can be a substantial portion of the total way costs. For the Interstate highway system in urban areas ROW costs are about 25% of the total cost. Herbert Mohring reports Minnesota estimates of Interstate costs which indicate right-of-way accounting for up to 60% of total construction cost, excluding overpasses and interchanges.[59]

For BART, land and land rights are estimated to be about 8% of the total system capital cost (excluding cars).[44] The BART land costs are low relative to Interstate highway costs because:

1. In high land cost areas BART is underground with station access through public ROW.
2. The Trans Bay Tube and Berkeley Hills tunnel did not require land taking except at the ends.
3. Much of the at-grade and elevated portions of BART are located on existing railroad right-of-way which was purchased at nominal rates.

5.2.1 Alternative Methods of Determining Property Acquisition Costs

The most direct and probably most accurate means of estimating property acquisition costs is to estimate such costs on a parcel by parcel basis. An example of this procedure is the General Motors study on new systems done for HUD,[29] which estimated costs on small segments of right-of-way by using adjacent land value costs. This approach, however, requires an inordinate amount of time and effort.

Another method is to estimate property acquisition costs on an aggregate basis - for instance, using data on land value per acre. City-wide land value is reported by the Bureau of the[15] Census. 1966 data for the Boston SMSA, based on reference 16, is shown below:

	SMSA Area (Sq. Mi.)	1966 Gross Assessed Value ($Millions)	1966 Average Assessed Value ($/Acre)
Boston SMSA	987	7,799	12,620

An indication of the higher land value in core areas can be noted from the fact that the city of Boston with an area of 43.18 square miles had an average 1966 property value of $71,800 per acre[100] as compared to the Boston SMSA with an average value of $12,620 per acre.

For the purposes of this study it was desirable to have a means of estimating property acquisition costs by land use and by location in the city (CBD, urban, and suburban). For the Northeast Corridor study, the Resource Management Corporation[78] developed a set of regression equations for estimating land costs as a function of population density for five land use categories. These equations are shown below:

	Coefficient of Correlation	Standard Error of Estimate	Coefficient of Variation
$LIR = 32{,}100 \cdot PD^{0.59}$	0.89	0.20	0.58
$LIC = 104{,}000 \cdot PD^{0.52}$	0.93	0.14	0.38
$LII = 40{,}000 \cdot PD^{0.59}$	0.81	0.28	0.90
$LIF = 343 \cdot PD^{0.66}$	0.92	0.15	0.41
$LIA = 4{,}150 \cdot PD^{0.95}$	0.92	0.15	0.41
$LIU = 6{,}310 \cdot PD^{1.14}$	0.99	0.12	0.32

where:

PD = population per acre

LIR = urban residential land (dollars per acre)

LIC = urban commercial land (dollars per acre)

LII = urban industrial land (dollars per acre)

LIF = urban (SMSA) farm land (dollars per acre)

LIA = average rural land (dollars per acre)

LIU = average urban (SMSA) land (dollars per acre)

This method is somewhat inaccurate since both SMSA and city data were combined to develop the equations. These equations result in land values for Boston differing by a factor of 2 from actual data.

General Research Corporation (GRC), in a study for HUD,[31] used land cost estimating equations developed by Meyer, Kain and Wohl,[57] which in turn were based on work of Hyman Joseph.[42] The Meyer, Kain and Wohl (MK&W) relations give land cost as a function of net residential density. The original work at the Chicago Area Transportation Study by Joseph used the net residential density in analysis zones as the variable, each zone having an area of about 28 square miles. This variable has been used without change through the MK & W and GRC adaptations. Thus this estimating method can provide land costs by city area (CBD, etc.) but does not provide a breakdown by land use type.

The original Joseph estimating relationship predicts total construction cost (excluding ROW) for an 8-lane freeway as a function of net residential density. The function (shown below) was developed by regression analysis of data from three expressway projects in Chicago.

CC = \$999,000 + \$70,800 (NRD)

where:

CC = Cost of construction (excluding right of way cost) in \$/mile (for 8 lanes)

NRD = Net residential density in thousands of persons per square mile of residential land.

Meyer, Kain & Wohl examined Bureau of Public Roads records and found that right of way costs varied from 5 to 50% of total construction costs as net residential density varied from 10 to 100 thousand persons per square mile. Right of way cost can be calculated from the following equation:

$$ROW = \$5000\ (NRD) + \$354\ (NRD)^2$$

where:

ROW = Right of way cost in \$/mile for 8-land freeway.

To account for the land costs of freeways of less than eight lanes MK & W introduced a factor which reduced the costs in proportion to the change in ROW width. Introducing this factor, the above equation becomes:

$$ROW = [\$5000\ (NRD) + \$354\ (NRD)^2]\ (W_{ROW})$$

where:

W_{ROW} = 1.00 (8-lane)
.966 (6-lane)
.933 (4-lane)
.86 (2-lane)

This modified equation is also used for rail transit ROW costs by MK & W with appropriate values of W_{ROW}.

W_{ROW} = .436 (3-track)
.386 (2-track)

GRC used the MK & W model essentially as is except they updated the basic cost figures and used cost data for specific cities. For Boston, for instance, GRC developed the following average land cost figures:

Area	Land Cost \$/Acre
Central	428,000
Urban	72,500
Suburban	32,200

5.2.2 Adopted Procedure

The GRC figures were chosen for the Boston analysis because they were based on cost estimating relationships reflecting local conditions. A value of $11,000 per acre was used for acquisition of existing railroad right of way. This value likewise reflects current local costs (the MBTA paid this amount to acquire railroad right-of-way for the Quincy extension of the Red Line).

For annualization purposes, all land acquired was assumed to have a 200-year (essentially infinite) life.

5.3 HIGHWAY CAPITAL COSTS

Traditionally, highway costs have been estimated for planning purposes by state highway departments. The departments usually make estimates of future project costs based on detailed designs using sub-element unit costs from current contract data. This method results in accurate cost estimates because the road design is known in detail, because costs on recent, similar facilities are known and because costing is done on detailed sub-elements (e.g., each overpass by type, etc.).

For general economic analysis and planning purposes, the detailed cost estimating methods used by highway departments are not appropriate since detailed facility designs are usually not available. Very little methodology is available for estimation of road construction costs for economic analysis purposes. Most regional transportation studies have used highway department personnel who have adapted their standard estimating methods to regional study needs. A single exception is the work of Hyman Joseph for the Chicago Area Transportation Study.[42]

Ideally one would like a road capital cost estimating equation which is a function of the following independent variables:

1. Demand
2. Land Use
3. Topography

4. Climate

5. Highway Standards

Little work has been done to develop such cost estimating equations. Most work of this type has been done in recent years and has been directed primarily toward developing countries applications (e.g., the World Bank model developed by MIT and the work of Vance at the University of California). The developing countries work is concerned with low-volume, rural roads and is thus inapplicable to urban problems although the general methology is the same.

5.3.1 FHWA and Related Methods

The most logical agency to develop cost estimating relationships for roads and highways would appear to be the Federal Highway Administration. FHWA has assembled gross highway cost statistics and cost indexes from state highway data. The highway finance section of the annual FHWA publication Highway Statistics contains data on unit prices for highway labor and materials. Total revenue and expenditures are given as well as a composite construction cost index. Use of this data plus data on road mileage construction in a given year from another section of Highway Statistics provides a very crude average construction cost figure for various type facilities. However, this calculation is not made here since better data is available.

Recently FHWA developed a limited construction cost estimation procedure as a part of its TRANS model for estimating future U.S. highway needs. The TRANS model provides an estimating method for establishing the costs of freeway and arterial facilities in urban areas. Freeway costs are estimated as a function of city size. A single, average cost figure (cost per mile of facility) is used for each of 173 U.S. cities (including Boston). The freeway costs are based on a limited sample of Interstate freeway costs from 11 large U.S. cities. Costs per lane mile are obtained for each of the 11 cities for CBD and suburban areas. A national, weighted average cost is derived for lane-mile cost in CBD areas and another for suburban areas. Data on the distribution of freeway widths (i.e., number of lanes) over the total freeway mileage as a function of city size is used to determine the weighted average freeway costs as a function of city size (population). Arbitrary assumptions about the distribution of freeway mileage in CBD and in suburban areas are made. The average freeway costs for each of the 173 cities are then taken from the cost vs. city size relationship. The TRANS freeway construction costs were expanded to account for ROW (30%), inflation (1966-1969, 15%), increased costs of safety and beautification (10%), and engineering and design (5%). The 1969 base year freeway construction cost for Boston, excluding ROW and averaged for all freeway widths is $5,540,000 per mile. Arterial road construction costs are also tabulated by city for use in TRANS. The arterial costs are simply the reported average arterial construction costs per mile for urban areas as reported to FHWA by the states. All cities within each state have the same unit cost. The reported cost is for new construction only; repairing and widening projects are excluded. The arterial cost per mile for Boston (excluding 30% ROW and engineering allowance, and averaged for all widths) is $1,120,000.

Another source of road construction cost data is a recent book by Winfrey.[113] Costs are tabulated by region and are broken down by highway type and cost category (pavement, structures, etc.). The average urban highway cost data for New England, exclusive of ROW and escalated from 1964 to 1969 levels using the FHWA composite construction cost index, are shown below:

Interstate Freeway Average Construction Cost per Centerline Mile in Urban Areas	Federal Aid Primary Highway Construction Costs Per Centerline Mile in Urban Areas	Federal Aid Secondary Highway Construction Costs Per Centerline Mile in Urban Areas
$3,980,000	$943,000	$292,000

Comparison of the TRANS and Winfrey figures indicates the effect of including data for all urban areas in the region as compared to data for a major city - the regional average cost is significantly lower.

5.3.2 Construction Cost Estimating Methods

For the Chicago Area Transportation Study, Hyman Joseph developed the following construction cost estimation equation:[42]

$$Y = \$999,000 + \$70,800X$$

where:

Y = Freeway construction cost in \$/mile for an 8-lane facility

X = Net residential density.

Meyer, Kain and Wohl[57] used Josephs' general formulation but expanded it to consider other than 8-lane facilities. They also checked the relationship against freeway construction cost data from several cities. The Meyer, Kain and Wohl cost relationship is:

$$Y_k = W_c\ (\$311,000 + \$70,800X) + \$86,000k$$

where:

Y_k = Construction cost in \$/mile

W_c = Width of right of way for k lanes divided by the right of way width for an 8-lane facility

X = Net residential density - thousands of persons per square mile of residential land

k = Number of lanes.

Meyer, Kain and Wohl also derived a cost equation for estimating the construction cost of exclusive busways:

$$Y_k = W\ (\$288,000 + \$65,500X) + \$84,200K$$

General Research Corporation in their report to HUD[31] intended to use the Meyer, Kain and Wohl methods for estimation of highway construction costs with updated data for their cities. Because of difficulties in obtaining net residential density data they used only three construction cost figures typical of central, urban and suburban locations within the metropolitan area. The GRC cost data for Boston, in 1966 dollars, is shown below:

Region	Number Of Lanes	Construction Cost $/Mile
Suburban	4	$ 1,870,000
Urban	6	5,000,000
Central	8	15,300,000

General Motors in a study prepared for HUD[29] used the following unit costs for expressways:

Region	Expressway Construction Cost $/Lane Mile		
Rural	$250,000	-	440,000
Suburban	350,000	-	590,000
Urban - Low Density	470,000	-	2,000,000
Urban - High Density	400,000*	-	3,200,000

GM assumed the following unit costs as appropriate:

Bridges - $7 to $20 per square foot (60 to 80 foot span)

Elevated ROW - $10 to $15 per square foot (80 foot span)

Overpasses - $200,000 - $700,000 each (2 to 8 lanes).

*This value appears questionable, since it is lower than the corresponding figure for low-density urban locations.

5.3.3 Adopted Procedure

The cost estimation methods generally used by state highway departments are too detailed for use in this analysis. On the other hand, the gross statistics assembled by FHWA lead to very crude estimates of urban highway costs for specific cities. Thus, the Meyer, Kain and Wohl approach, modified to reflect recent construction costs in the Boston area, was used to generate the following costs per route mile for the 1990 plan analysis:

Type of Highway	At Grade	Elevated	Tunnelled
Freeway	$4,000,000	$5,000,000	$25,000,000
Surface Arterial	$ 400,000	2,500,000	15,000,000

5.4 HIGHWAY MAINTENANCE COSTS

There has been relatively little analysis of highway maintenance costs. This is probably because maintenance expenditures are generally less than half of total construction expenditures so that a larger error can be tolerated. Like highway construction costs, highway maintenance costs are readily available to highway departments performing economic analysis so there is little incentive for them to develop maintenance cost estimating equations.

Estimates of maintenance costs differ widely among various sources. For example, according to an FHWA publication,[96] the average annual road maintenance cost for all U.S. roads in 1968 was $1,022 per mile. The TRANS model[100] uses the following annual maintenance costs for urban facilities: 5-lane Interstate - $16,795 per mile; 4-lane arterial - $5,600 per mile (1968 dollars). Meyer, Kain and Wohl[57] assume $9,000 per lane-mile per year for maintenance and administration of freeways. The same figure is used for exclusive busways. General Research Corporation[29] uses the MK&W approach but a figure of $9,800 per lane mile per year. JPL[39] assumes $5,000 per lane mile per year.

Of the few studies of highway maintenance costs which have been conducted, the Ohio study[65], based on experience in that state, appears to be the most comprehensive. The following table presents 1969 data from this study on the cost of urban highway maintenance.

Type of Work	Freeway Cost Per Lane Mile	Surface Concrete Cost Per Lane Mile	Arterial Bituminous Cost Per Lane Mile
Pavement Maintenance	$268.09	$359.14	$181.95
Roadside Maintenance	512.73	216.22	239.25
Snow and Ice Control	491.94	296.40	320.41
Vegetation Control	475.22	84.49	42.03
Signs, Signals	81.41	127.45	220.90
Pavement Marking	86.10	55.86	75.64
Bridge & Culvert Maint.	159.26	53.88	53.88
Lighting	1804.45	437.00	437.00
Test Mileage		70.08	232.76
Weighted Total Per Lane	$3879.20	$1584.80	

Because of its level of detail, this data formed the basis for the highway maintenance and operating costs used in the Dual Mode analysis. The figures, modified to reflect Boston conditions and stratified to fit the structure of the cost/benefit model, are shown below:

Type of Highway	Lighting and Other Power Consumption $/Route Mile/Year	Manpower $/Manyear	Maintenance $/Route Mile/ Year
Freeway	$1,400	$20,000	$1,600
Surface Arterial	400	20,000	900

5.5 HIGHWAY USER COSTS

Of the several areas of highway cost analysis, highway user costs are the most throughly studied and reported. (There is a shortage of data on private automobile operating costs since most private owners do not keep detailed records. This shortage has been met by a number of detailed studies which have developed adequate estimates of the operating costs of private vehicles.) There are two general methods of estimating road user costs. The "micro" approach is to calculate resource consumption values for various vehicle types and terrain features, etc., and then to convert them to costs using appropriate cost coefficients. The resource consumption method is widely used for economic analysis of specific highway improvements. The basic reference used by highway departments for this purpose is the AASHO "Red Book".[6] The Red Book data is tabulated directly in cost form using typical 1959 U.S. costs and thus must be updated for a considerable time span. A further limitation of this data is that truck user costs are not considered directly, but rather are calculated as a multiple of passenger automobile costs.

Another data source for the micro approach is the "World Bank" report EC-140a.[34] This report is preferable to the Red Book because trucks are considered explicitly and because the data presented is in the form of resource consumption rather than cost, thus allowing use of current cost coefficients.

The second method of user cost estimation (the macro approach) is to estimate user cost for average use conditions. A good source of data is FHWA's periodic publication, "Cost of Operating an Automobile",[97] which reports the operating costs for an average passenger car in Baltimore (10.5 cents per mile, excluding taxes, as of January 1970). Other organizations make similar user cost estimates which differ little from the FHWA figures.

The macro approach is generally considered satisfactory where a large mileage of roadway with substantial traffic is evaluated in a single study. The micro method, on the other hand, is desirable for analysis of detailed highway alternatives. Since the

Dual Mode analysis considered the Boston highway system in terms of aggregate mileage and travel, the former approach was selected for automobile user costs. The actual costs (in cents per vehicle mile) employed in the Boston analysis are shown below:

Depreciation	Maintenance	Fuel	Insurance	Parking
3.2¢	1.9¢	1.9¢	1.7¢	1.8¢

Due to lack of macro-type data on trucks, figures from World Bank report were aggregated and updated to obtain a cost of 54.5¢ per vehicle mile.

5.6 TRANSIT CAPITAL COSTS

5.6.1 Way-Related Capital Costs

A. Rapid Rail

Way-related capital costs for rail transit include:

1. Basic way construction
    a. Elevated structures
    b. At-grade - sub-grade preparation
    c. Tunneling, cut and cover (including tunnel lining and cut and cover box)
2. Track construction
3. Electrification (3rd rail or overhead wire with attendant power distribution facilities)
4. Way located command and control equipment (including switch machines).

Meyer, Kain and Wohl[57] used the following estimates of rail transit construction costs:

Rail Construction Costs Per Mile

Type of Construction	Without right-of-way and without allowances for engineering and contingencies — Double track	Single track	Without right-of way but with allowances for engineering and contingencies — Double track	Single track
Tunnel	$15,300,000		$19,125,000	
Cut and cover	14,000,000		17,500,000	
Elevated	3,168,000	$1,584,000	3,960,000	$1,980,000
Open cut (or fill)	2,640,000	1,320,000	3,300,000	1,650,000

In addition they assumed:

Electrification - $250,000 to $350,000/single track mile

Signals and Train Control - $50,000 to $175,000/single track mile for conventional signals and automatic control, respectively

Stations - 2 track, underground with mezzanine - $7,200/ lineal foot. (This would result in a cost of $5,400,000 for a typical, 2 track, cut and cover BART station, a slight underestimate.) 2 track, at grade $1,100/lineal foot. (This would correspond to $825,000 for a BART station, again an understimate.)

Crossovers - $50,000 each

General Research Corp.[29] used the Meyer, Kain and Wohl costs as is except for adjustments for inflation.

Perhaps the best sources of way construction costs are recently constructed facilities. The 6.2 mile Quincy Extension of the MBTA in Boston was completed in September 1971. The unit costs for this line, which was upgraded from an existing rail facility, are as follows:

- Roadbed and Structures - $3,000,000/double track mile which includes:

  2 1/2 miles of highway relocation
  5 short span highway overpasses

2 long span aerial structures including the
1,200 foot Neponset river bridge
1 track separation structure
2.3 miles of retaining wall

- Signals and Communication - $600,000/double track mile (the total control contract with General Railway Signal was $5,613,000 which includes a control center for the full Harvard-Quincy Line)
- Power Transmission & Substations - $700,000/double track mile (5 substations, does not include 3rd rail)
- Track and 3rd rail - $600,000/double track mile (includes switches and ties)

A preliminary review of BART cost information[82] indicates the following unit costs:

1. The overall, average construction cost for BART is estimated to be $16,300,000/route mile (2 tracks, excludes car procurement)
2. The basic route construction costs are:
   a. Elevated - $2,550,000/double track mile
   b. Cut and Cover - $4,860,000-$8,680,000/double track mile
   c. Tunnel - $10,600,000-$57,200,000 with most work costing $14,000,000-$18,000,000/double track mile
3. Track procurement and installation - $478,000 double track mile (Hayward-Oak) (based on second pour on elevated structures with about 10% of track at-grade with concrete tie); $522,000 (Oak to Daly City). Kaiser engineers' original estimate of the cost of at-grade track with concrete ties was $353,068/double track mile, installed. The total track cost for BART including ties and alignment is, on the average, $495,000/double track mile.
4. Third rail procurement and installation - $313,000/double track mile. Substations and switch gear are an additional $123,000/double track mile.

5. Automatic train control - The basic contract for automatic train control with Westinghouse Electric Corp. is $26,000,000, or $346,700/double track route mile.

On the basis of MBTA and BART experience, the following unit costs were derived to reflect Boston conditions:

Cost per Mile - Rapid Rail

At-grade	Elevated	Tunneled
$3,000,000	$3,000,000	$15,000,000

B. Surface Rail (Streetcars)

The major way construction costs are track laying and overhead trolley wire construction. Based on MBTA cost estimates for new construction of at-grade streetcar lines, a figure of $1,000,000 per route mile was used in this analysis.

5.6.2 Station Capital Costs

A. Rapid Rail

The cost of stations for the Quincy Extension was $1,200,000 for a station with a single lobby and center platform and $800,000 each for additional lobbies. Average BART system station costs are given below:

1. Elevated - $1,800,000 - complete
2. At-grade - $1,800,000 - complete
3. Cut and Cover

   Shell - $4,000,000-$6,000,000 (2 track)
   $15,000,000-$20,000,000 (4 track)

   Finish- $2,000,000-$4,000,000 (excluding extra plazas)
4. Ticketing, turnstiles and related equipment - $250,000 per station
5. Station communications equipment - $8,800/station
6. Station drinking fountains - $910/station

7. Elevators and escalators - $260,000/station

8. Customer parking at suburban stations - $468/stall (construction only)

The TEAM model calculated station construction costs on a square foot basis. The corresponding per station costs are as follows:

Typical rapid transit station - $2,030,000
Major downtown underground terminus - $9,310,000

B. Bus and Streetcar

The majority of bus and street railway passenger stops are at street corners with minimal improvements. The basic costs are for signing, pedestrian islands and, occasionally, benches. The average costs are in the range of $200-$1,000. Occasionally, such stops are provided with simple shelters, which probably cost on the order of $2,000 each.

Downtown bus and streetcar terminals, where a number of routes converge, are generally larger and more elaborate than curbside stations (e.g., they are off-street, sheltered). Their costs tend to approach that of a typical rapid rail station.

The cost figures used in the analysis were:

Typical curbside station - $1,000
Downtown station - $1,450,000

C. Parking Facilities at Outlying Transit Stations

Some of the outlying transit stations (all modes) were assumed to have at-grade park'n'ride facilities. The construction cost of these lots was calculated on the basis of $600 per automobile (Quincy Extension figure).

5.6.3 Storage and Maintenance Facility Capital Costs

The following unit construction costs were used for storage and maintenance facilities.

	Cost per vehicle space	
	Storage	Maintenance
Bus	$ 550	$ 8,000
Rapid Rail	1,000	14,000
Streetcar	920	12,000

5.6.4 Vehicle Capital Costs

The BART cars are 70 ft. long and seat 72 passengers. The contract cost was $339,000 each for an order of 250 cars (includes design and contract administration). The vehicles for the Quincy Line seat 64 passengers and are capable of traveling 70 mph. The contract cost was $171,000 each for an order of 76 cars (1966). The unit cost used in this study was $250,000, representing an average of these two values. Buses were assumed to cost $45,000 each, and streetcars were assumed to cost $200,000 apiece.

5.7 TRANSIT OPERATING COSTS

5.7.1 Operating Costs

The Institute for Defense Analyses (IDA) has prepared cost statistics for American and Canadian rapid rail properties from the American Transit Association (ATA) and other sources for DOT-TPI.[35] Their statistics include the average, annual operating cost per passenger car mile (excludes depreciation). 1970 annual operating costs for major properties are shown in Table 5.1. Note that the operating costs include supervisory and maintenance operating costs.

TABLE 5-1. ANNUAL OPERATING COSTS FOR VARIOUS URBAN RAIL TRANSIT PROPERTIES (BASED ON ATA STATISTICS)

City & Property	1970 Annual Operating Cost per Car Mile (Depreciation Excluded)
NYC Transit Authority	$1.24
Chicago (CTA)	1.06
Boston (MBTA)	2.87
Toronto (TTC)	.75
Philadelphia (SEPTA)	1.39
Montreal (MUCTC)	.84
NYC (PATH)	2.04
Philadelphia(Lindenwold)	1.18
Cleveland	.98

Lang and Soberman[45] indicate the following distribution of total operating and maintenance costs (Table 5.2):

TABLE 5-2. DISTRIBUTION OF RAIL TRANSIT OPERATING COST (AVERAGE OF 5 PROPERTIES, 1960)

Cost Category	% of Total Operating Cost	Labor Cost as % of Cost Category
Way & Structures	15	79
Maintenance of Equipment	14	74
Conducting Transportation	44	97
Power	15	17
Other Operating Expenses	12	22
	100	

Using the Lang and Soberman breakdown applied to an average car mile operating cost of $1.63 (based on Table 5.1 excluding the Canadian operations) the following cost breakdown per car mile was obtained (Table 5.3):

TABLE 5-3. AVERAGE OPERATING COST PER CAR MILE BY EXPENSE CATEGORY FOR URBAN RAIL TRANSIT SYSTEMS - 1970

Cost Category	Average 1970 Cost $/car mile
Way & Structures	$.24
Maintenance of Equipment	.23
Conducting Transportation	.72
Power	.24
Other Operating Expenses	.20

Lang and Soberman report that the cost of motormen is about 20% of the cost of conducting transportation, or $.14/car mile based on Table 5.3.

Lang and Soberman report the 1960 maintenance of way and structures costs for the New York City Transit Authority as $55,600 per track mile. Escalated to 1970 dollars this is then $63,000 per track mile. This appears to be a reasonable average value. (Lang and Soberman report a range of $8,900 to $120,200 per track mile in 1960.) As indicated in Table 5.2, about 79% of the maintenance cost is for labor (i.e., $49,800).

The average operating cost (excluding depreciation and amortization) for buses operated by firms having revenues over $10 million per year was 79.5 cents per mile in 1969, according to IDA.[36] Operating cost per bus mile declines with firm revenue. Firms with revenues from $5-10 million per year had an average operating cost of 75.7 cents per mile in 1969.

The distribution of expenses by account is as follows (based on 1968 ATA statistics)[7] :

	% of Total Operating Cost Less Depreciation	Cents Per Mile (based on a total of 76¢ per mile)
Equipment Maintenance & Garage	18	13.7
Transportation	57	43.3
Drivers' & Helpers' Wages	45	34.2
Fuel & Oil	3	2.3
Administration	12	9.1
Station Expense	2	1.5
Other (including insurance & safety)	11	8.1
	100%	76.0¢

The data above is based on the five largest transit operators in the United States (on the basis of operating revenue).

Table 5.4 shows transit operating costs used in this analysis. Streetcar vehicle and way costs were assumed to be identical to rapid transit costs.

5.7.2 Depreciation

The annual depreciation for each rapid rail car on a per car mile basis can be calculated as follows:

TABLE 5-4. BOSTON 1990 TRANSIT OPERATING COSTS

	Transit System		
	Bus	Rapid Rail	Streetcar
Way power, \$/VMT	0	0.24	0.24
Way manpower,\$/rt.mi./yr.	0	49,800	49,800
Way maint.,\$/rt.mi./yr.	0	13,200	13,200
Veh. misc. costs,\$/VMT	0.50	0.85	0.85
Veh. manpower,\$/VMT	0.50	0.70	0.70
Veh. storage,\$/veh.sp./yr.	20	60	60
Veh. maint.,\$/veh.sp./yr.	100	300	300
Terminal operating cost, \$/term./yr.			
Curbside terminals	10	0	10
Major term. facility (underground or surface)	20,000	50,000	40,000
Station automobile parking, \$/veh.sp./yr.	20	20	20

5.7.2 Depreciation (Continued)

Average Car Capital Cost - \$200,000

Life - 30 years

Annual Miles - 50,000 miles/year (range 25,000-70,000)

Interest Rate	Annual Cost	Cost/Car-Mile
6%	\$14,530	\$.29
8	17,766	.35
10	21,216	.42

The annual depreciation cost for buses on a bus-mile basis can be calculated as follows:

Average Capital Cost	-	$35,000
Life	-	12 years
Annual Miles	-	30,000 (range 25,000-30,000)

Interest Rate	Annual Cost	Cost/Bus-Mile
6%	$3,800	$.127
8	4,650	.155
10	5,140	.171

A 10% interest rate was used in this analysis, with 30-, 12-, and 25-year life spans assumed for rapid rail cars, buses, and street cars, respectively (depreciation calculations were done on a life-interest basis, rather than a cost per vehicle mile basis).

5.8 SUMMARY OF EXISTING DUAL MODE COST ESTIMATES

A survey was made of all known, published Dual Mode cost estimates. In addition, a selected group of PRT cost estimates were reviewed for its applicability to Dual Mode costing.

The Dual Mode estimates are summarized in Figures 5-1 to 5-4. Each table summarizes the published costs for a system concept. More detailed costs are given in Figures 5-5 to 5-20.

The cost data can only be crudely compared since each estimating agency used different assumptions in estimating costs. The data clearly indicate, however, a considerable difficulty in estimating Dual Mode costs by the range of costs for similar items. For instance, there is a capital cost difference of a factor of two in pallets, all designed to carry one automobile. Cost estimating difficulties are understandable with the present level of design definition of Dual Mode systems. Because of the uncertainty in Dual Mode costs it is important that the range of uncertainty be defined in addition to a best engineering estimate.

The data presented in this report are based on references 5, 19,20,21,26,30,31,39,41,65,86,102, and 104.

Cost	General Motors	Estimating Organization TRW	Cornell Aero Lab	JPL
Guideway - Capital	$1,200,000	$1,350,000	$9,000,000 (All Tunnel)	$3,360,000 (Includes Terminals, C&C, Elect.)
Terminal - Capital Average $ each	$4,400,000	$7,730,000 to $34,760,000	$3,620,000	Included in Guideway
Control Center-Cap Average $ each	$32,000,000 (Total Control Cost)	$1,333,000	$360,000	Included in Guideway
Vehicle - Capital Average $ each	$31,000	$17,800	$30,000	$15,000
Vehicle Operating Cost ¢/veh-mi	13.18¢	6.00¢	-	-
Average Vehicles Per Mile	19-190		70	94
Total Capital $/lane-mi	$3,680,000 - $13,200,000	No example given	$13,500,000	$4,710,000
Total Operating $/lane-mi-yr	$830,000 - $8,250,000	No example given	$735,000	$1,120,000

Figure 5-1. Dual Mode Cost Estimates-Pallet Concept

	Estimating Organization			
Cost	General Motors	TRW	Cornell Aero Lab	North Amer. Rockwell
Guideway - Capital Average $/Lane-Mi.	$750,000 + Inter-changes & Overpasses	$111,000 + Merge & Demerge	$2,317,000	
Terminal - Capital Average $ each		$2,000,000 (ramps only)		
Control Center-Cap Average $ each				
Vehicle - Capital Average $ each	$3,445	$3,162	$3,000	
Vehicle Operating Cost ¢/veh-mi	13.6¢	5.37¢		
Comments				Detailed Cost Breakdown not given
Average Vehicles Per Mile	Not included in total costs		206	18
Total Capital $/Lane - Mi	$3,660,000		$7,260,000	$1,460,000
Total Operating $/lane-mi-yr	$1,500,000		$274,000	Not Given

Figure 5-2. Dual Mode Cost Estimates-Automated Highway Vehicle Concept

Cost	General Research Corp.	Stanford Research Inst.	General Motors (PRT)	APL (PRT)
	Estimating Organization			
Guideway - Capital Average $/lane-mi				
Terminal - Capital Average $ each	$665,000		$153,000	$3,200,000 Subway $1,200,000 Elevated
Control Center-Cap Average $ each				
Vehicle - Capital Average $ each	$2,000		$1,835	
Vehicle Operating Cost ¢/veh-mi				
Comments		Detailed Cost Breakdown not given		
Average Vehicles Per Mile	Not included in total costs	Number unknown	149	100
Total Capital $/lane-mi	$1,880,000	$5,100,000 - $6,270,000	$4,300,000	$6,500,000 Subway $4,000,000 Elevated
Total Operating $/lane-mi-yr		$92,000 - $203,000	$321,000	$140,000

Figure 5-3. Dual Mode Cost Estimates-Small Personal Vehicle Concept

Cost	Estimating Organization		
	General Motors	Milwaukee	North Amer. Rockwell
Guideway - Capital Average $/lane-mi	$1,000,000	$1,983,000	
Terminal - Capital Average $ each	384,000 (includes land)	$735,000	
Control Center-Cap Average $ each	$3,000,000	-	
Vehicle - Capital Average $ each	$42,000	$41,000	
Vehicle Operating Cost ¢/veh-mi	100¢		
Comments			Detailed cost breakdown not given
Average Vehicles Per Mile	12.7	11.8	
Total Capital $/lane-mi	$2,520,000	$3,430,000	$2,600,000
Total Operating $/lane-mi-yr	$312,000	$264,000	

Figure 5-4. Dual Mode Cost Estimates-Dual Mode Bus Concept

COST CATEGORY		COSTS IN MILLIONS OF DOLLARS (except as noted)	
ROW	$/lane-mi	.306	
Guideway	$/lane-mi		
Elevated		1.645	
At Grade		.553	
Below Grade			
Electrification			
Way Controls			
Total Average		1.22	
Terminals	(ea)		
Controls			
Structures			
Total Average		4.4 (Range 2. - 20.)	
Control Center	(ea)	32. (Total control cost)	
Yards & Shops	(ea)		
Vehicle			
Controls			
Shell & Power			
Total		.031 (Enclosed pallet)	
Operation & Maintenance			
Way		8.62/pass-mi	
Control			
Terminals			
Vehicle Operating Cost		13.18¢/veh-mi (Pallet)	
FARE			
R&D		2.	
		190 veh/mi	19 veh/mi
Total Capital	$/lane-mi	13.2	3.68
Total Operating	$/lane-mi-yr	8.25	.830

Figure 5-5. General Motors Pallet Concept

COST CATEGORY		COSTS IN MILLIONS OF DOLLARS (except as noted)
ROW	$/lane-mi	
Guideway	$/lane-mi	
Elevated		.635 - .988
At Grade		
Below Grade		
Electrification		.416
Way Controls		.160
Total Average		1.211 - 1.564
Terminals	(ea)	
Controls		1.2
Structures		
Total Average		34.76 (2600 vph) - 7.73 (960 vph)
Control Center	(ea)	1.333
Yards & Shops	(ea)	12.7 (1000 veh)
Vehicle		
Controls		
Shell & Power		
Total		.0178 (75 mph)
Operation & Maintenance		
Way		.003/mi/year
Control		.133 + .0048/mi/year
Terminals		.0413/year
Vehicle Operating Cost		6¢/veh-mi (Pallet)
Fare		
R&D		26.5
Total Capital	$/lane-mi	No Example Given
Total Operating	$/lane-mi-yr	No Example Given

Figure 5-6. TRW Pallet Concept

COST CATEGORY		COSTS IN MILLIONS OF DOLLARS (except as noted)
ROW	$/lane-mi	
Guideway	$/lane-mi	
Elevated		
At Grade		
Below Grade		11.9 (Poor Rock Tunnel)-7.3(Tunnel)
Electrification		Not Costed
Way Controls		
Total Average		
Terminals	(ea)	
Controls		
Structures		
Total average		3.62
Control Center	(ea)	.360
Yards & Shops	(ea)	7.445 (Included admin. offices)
Vehicle		
Controls		
Shell & Power		
Total		.02965 (bus pallet) .0309 (auto pallet)
Operation & Maintenance		
Way		
Control		
Terminals		
Vehicle Operating Cost		
Fare		
R&D		
Total Capital	$/lane-mi	13.5 (69.5 pallets/mi)
Total Operating	$/lane-mi-yr	.735

Figure 5-7. Cornell Aeronautical Lab Pallet Concept

COST CATEGORY		COSTS IN MILLIONS OF DOLLARS (except as noted)
ROW	$/lane-mi	
Guideway	$/lane-mi	
Elevated		.635 - .988
At Grade		
Below Grade		
Electrification		.416
Way Controls		.160
Total Average		1.211 - 1, 564
Terminals	(ea)	
Controls		1.2
Structures		
Total Average		34.76 (2600 vph) - 7.73 (960 vph)
Control Center	(ea)	1.333
Yards & Shops	(ea)	12.7 (1000 veh)
Vehicle		
Controls		
Shell & Power		
Total		.0178 (75 mph)
Operation & Maintenance		
Way		.003/mi/year
Control		.133 + .0048/mi/year
Terminals		.0413/year
Vehicle Operating Cost		6¢/veh-mi (Pallet)
Fare		
R&D		26.5
Total Capital	$/lane-mi	No Example Given
Total Operating	$/lane-mi-yr	No Example Given

Figure 5-8. JPL Pallet Concept

COST CATEGORY		COSTS IN MILLIONS OF DOLLARS (except as noted)
ROW	$/lane-mi	1.27
Guideway	$/lane-mi	
Elevated		
At Grade		
Below Grade		
Electrification		
Way Controls		.250
Total Average		.725 + {Bridges & Grade Sep. $.654/mi.; Interchanges 1.320/mi} (17 mi. at grade, 5 mi. elevated)
Terminals	(ea)	
Controls		
Structures		
Total Average		
Control Center	(ea)	
Yards & Shops	(ea)	.500 (includes central office)
Vehicle		
Controls		.000345
Shell & Power		.003100 (standard auto)
Total		.003445
Operation & Maintenance		
Way		.1/veh.-mi (includes way controls)
Control		
Terminals		
Vehicle Operating Cost		13.6¢/veh-mi (total veh. op cost)
Fare		
R&D		
Total Capital	$/lane-mi	3.66 (Vehicle controls only)
Total Operating	$/lane-mi-yr	1.15

Figure 5-9. General Motors Automated Highway Vehicle Concept

COST CATEGORY		COSTS IN MILLIONS OF DOLLARS (except as noted)
ROW	\$/lane-mi	
Guideway	\$/lane-mi	.051 (paving only)
Elevated		
At Grade		
Electrification		
Way Controls		.060 + .013 merge .007 diverge
Total Average		
Terminals	(ea)	
Controls		
Structures		
Total Average		.829 (entrance), .285 (exit)
Control Center	(ea)	3.575
Yards & Shops	(ea)	
Vehicle		
Controls		.000095
Shell & Power		
Total		.003162
Operation & Maintenance		
Way		.002187 + .000324(merge) .000222 (diverge) + .041 (merge op) + .005(diverge op)
Control		.486(control center op) + \$0.75/ month-mi (leased lines) + \$13/ month-terminal
Terminals		10% of capital investment in command & control + 3% capital interest in guideway-related equipment
Vehicle Operating Cost		5.37¢/veh-mi (75 mph)
Fare		
R&D		
Total Capital	\$/lane-mi	
Total Operating	\$/lane-mi-yr	

Figure 5-10. TRW Automated Highway Vehicle Concept

COST CATEGORY		COSTS IN MILLIONS OF DOLLARS (except as noted)
ROW	$/lane-mi	None Considered
Guideway	$/lane-mi	
Elevated		.741
At Grade		.152
Below Grade		1.148 (depressed), 4.025 (cut & cover)
Electrification		.250
Way Controls		.0264 (detectors & wiring)
Total Average		
Terminals	(ea)	(From Transit Expressway)
Controls		.07 ea
Structures		
Total Average		$50/ft^2 (at grade & elevated) $82/ft^2 (underground) + .041 ea for escalators
Control Center	(ea)	.500 each computer
Yards & Shops	(ea)	.150
Vehicle		
Controls		
Shell & Power		
Total		.003 (4 pass.)
Operation & Maintenance		
Way		
Control		
Terminals		
Vehicle Operating Cost		
Fare		
R&D		
Total Capital	$/lane-mi	7.26 (206 Vehicles per mi)
Total Operating	$/lane-mi-yr	.274

Figure 5-11. Cornell Aeronautical Automated Highway Vehicle Concept

COST CATEGORY		COSTS IN MILLIONS OF DOLLARS (except as noted)
ROW	$/lane-mi	
Guideway	$/lane-mi	
Elevated		
At Grade		
Below Grade		
Electrification		
Way Controls		
Total Average		
Terminals	(ea)	
Controls		
Structures		
Total Average		
Control Center	(ea)	
Yards & Shops	(ea)	
Vehicle		
Controls		
Shell & Power		
Total		
Operation & Maintenance		
Way		
Control		
Terminals		
Vehicle Operating Cost		
Fare		
R&D		
Total Capital	$/lane-mi	1.46 (Includes 18 vehicles)
Total Operating	$/lane-mi-yr	

Figure 5-12. North American Rockwell Automated Highway Vehicle Concept

COST CATEGORY		COSTS IN MILLIONS OF DOLLARS (except as noted)
ROW	\$/lane-mi	
Guideway	\$/lane-mi	
Elevated		1.00
At Grade		1.00
Below Grade		4.000 (subway)
Electrification		
Way Controls		
Total Average		
Terminals	(ea)	
Controls		
Structures		
Total Average		2.0(elev.& at grade),4.0(subway)
Control Center	(ea)	
Yards & Shops	(ea)	
Vehicle		
Controls		
Shell & Power		
Total		.003
Operation & Maintenance		
Way		
Control		
Terminals		
Vehicle Operating Cost		
Fare		15-20¢/mi (breakeven)
R&D		
Total Capital	\$/lane-mi	2.57 (no veh. included)
Total Operating	\$/lane-mi-yr	.374

Figure 5-13. Fichter-Rochester Automated Highway Vehicle Concept

COST CATEGORY		COSTS IN MILLIONS OF DOLLARS (except as noted)
ROW	$/lane-mi	Depends on land use & city
Guideway	$/lane-mi	
Elevated		.665
At Grade		.53
Below Grade		5.0 (10' dia. tunnel)
Electrification		.38
Way Controls		.015 + .0075 ea merge/demerge
Total Average		
Terminals	(ea)	
Controls		
Structures		
Total Average		.665
Control Center	(ea)	
Yards & Shops	(ea)	$600/veh. space
Vehicle		
Controls		
Shell & Power		
Total		.002 (12 year life!)
Operation & Maintenance		
Way		0.5% of investment/year
Control		
Terminals		2% of structural investment + 3% of equipment investment
Vehicle Operating Cost		
Fare		
R&D		
Total Capital	$/lane-mi	1.88 (Boston 400 rt. mi - vehicles omitted)
Total Operating	$/lane-mi-yr	

Figure 5-14. General Research Corp. Small Personal Vehicle Concept

COST CATEGORY		COSTS IN MILLIONS OF DOLLARS (except as noted)
ROW	$/lane-mi	.1 - .25
Guideway	$/lane-mi	
Elevated		
At Grade		
Below Grade		
Electrification		
Way Controls		
Total Average		
Terminals	(ea)	
Controls		
Structures		
Total Average		$25/ft^2 (elevated)
Control Center	(ea)	
Yards & Ships	(ea)	$20/ft^2 (shops),$3/ft^2 (yards)
Vehicle		
Controls		
Shell & Power		
Total		
Operation & Maintenance		
Way		
Control		
Terminals		
Vehicle Operating Cost		
Fare		
R&D		
Total Capital	$/lane-mi	5.1 - 6.27 (number of veh. included unknown)
Total Operating	$/lane-mi-yr	.092 - .203

Figure 5-15. Stanford Research Inst. Small Personal Vehicle Concept

COST CATEGORY		COSTS IN MILLIONS OF DOLLARS (except as noted)
ROW	$/lane-mi	.595 - .89
Guideway	$/lane-mi	
Elevated		
At Grade		
Below Grade		
Electrification		
Way Controls		
Total Average		1.47
Terminals	(ea)	
Controls		
Structures		
Total Average		.153
Control Center	(ea)	
Yards & Shops	(ea)	4.7 (includes office)
Vehicle		
Controls		
Shell & Power		
Total		.001835 (passive vehicle)
Operation & Maintenance		
Way		.054
Control		
Terminals		
Vehicle Operating Cost		
Fare		
R&D		1. - 2.
Total Capital	$/lane-mi	4.30 (includes 149 veh/mi)
Total Operating	$/lane-mi-yr	.321

Figure 5-16. GM (PRT) Small Personal Vehicle Concept

COST CATEGORY		COSTS IN MILLIONS OF DOLLARS (except as noted)
ROW	$/lane-mi	
Guideway	$/lane-mi	
Elevated		1.3
At Grade		
Below Grade		5.2 (subway)
Electrification		
Way Controls		
Total Average		
Terminals	(ea)	
Controls		
Structures		
Total Average		3.2 (subway), 1.2 (elevated) (60 mph)
Control Center	(ea)	
Yards & Shops	(ea)	
Vehicle		
Controls		
Shell & Power		
Total		
Operation & Maintenance		
Way		
Control		
Terminals		
Vehicle Operating Cost		
Fare		
R&D		
Total Capital	$/lane-mi	6.5 (subway), 4.0(elevated) (includes 100 veh/mi)
Total Operating	$/lane-mi-yr	.140

Figure 5-17. APL (PRT) Small Personal Vehicle Concept

COST CATEGORY		COSTS IN MILLIONS OF DOLLARS
ROW	$/lane-mi	.262
Guideway	$/lane-mi	
Elevated		1.2 + bridge $.5/lane-mi
Below Grade		.625 + bridge $.5/lane-mi
Electrification		
Way Controls		.100
Total Average		
Terminals	(ea)	
Controls		
Structures		
Total Average		.384 (Includes land)
Control Center	(ea)	3.0
Yards & Shops	(ea)	
Vehicle		
Controls		.005
Shell & Power		.037
Total		.042
Operation & Maintenance		
Way		$.005/pass-mi
Control		
Terminals		
Vehicle Operating Cost		$1.00/veh. mi. ($.001/pass-mi Maint.)
Fare		
R&D		1.5 + (12.68 Demo)
Total Capital	$/lane-mi	2.52 (Includes 12.7 veh/mi)
Total Operating	$/lane-mi-yr	.312

Figure 5-18. General Motors Dual Mode Bus Concept

COST CATEGORY		COSTS IN MILLIONS OF DOLLARS (except as noted)
ROW	$/lane-mi	
Guideway	$/lane-mi	
Elevated		
At Grade		
Below Grade		
Electrification		
Way Controls		
Total Average		1.983
Terminals	(ea)	
Controls		
Structures		
Total Average		.735
Control Center	(ea)	1.0 - 2.5 (Equipment Only)
Yards & Shops	(ea)	
Vehicle		
Controls		
Shell & Power		
Total		.041 to .0493
Operation & Maintenance		
Way		
Control		
Terminals		
Vehicle Operating Cost		
Fare		
R&D		
Total Capital	$/lane-mi	3.43 (Includes 11.8 veh/mi)
Total Operating	$/lane-mi-yr	.264

Figure 5-19. Milwaukee Dual Mode Bus Concept

COST CATEGORY		COSTS IN MILLIONS OF DOLLARS (except as noted)
ROW	\$/lane-mi	
Guideway	\$/lane-mi	
Elevated		
At Grade		
Below Grade		
Electrification		
Way Controls		
Total Average		
Terminals	(ea)	
Controls		
Structures		
Total Average		
Control Center	(ea)	
Yards & Shops	(ea)	
Vehicle		
Controls		
Shell & Power		
Total		
Operation & Maintenance		
Way		
Control		
Terminals		
Vehicle Operating Cost		
Fare		
R&D		35.
Total Capital	\$/lane-mi	2.6
Total Operating	\$/lane-mi-yr	

Figure 5-20. North American Rockwell Dual Mode Bus Concept

5.9 DUAL MODE GUIDEWAY AND TERMINAL COSTS

Unless otherwise noted, all structures were assumed in this analysis to have a 50-year lifetime.

5.9.1 Dual Mode Guideway Costs

In general, the following cost sub-elements are considered a part of the total guideway capital cost:

1. Site preparation (clearing, utility relocation, etc.)
2. Guideway structure
    a) at grade (roadbed preparation)
    b) elevated (elevated structure)
    c) depressed (excavation and roadbed preparation)
    d) tunneled (excavation and tunnel liner)
    e) cut & cover (similar to tunnel)
3. Track, paving or other horizontal and vertical running surfaces
4. Electrification (3rd rail and power supply) or other systems used in guideway power sources (e.g., compressed air)
5. Control and communication (guideway-located equipment only)
6. Grade crossings (overpasses, underpasses, etc.)
7. Major bridges
8. Switches and other special trackwork
9. Design and planning
10. Construction overhead and profit

In this analysis the number of cost categories was reduced by combining several of the categories above into:

1. Guideway structure
    a) at grade
    b) elevated
    c) depressed
    d) tunneled

2. Track

3. Electrification

4. Control and communication

Design and planning costs as well as construction overhead and profit were distributed among the four categories above in approximate proportion to their dollar cost. Guideway structural costs include site preparation costs, grade crossing costs and switches (except those which are a part of an intersection). Intersections were costed separately from line-haul guideway and are discussed below.

A. Guideway Structural Costs

At grade guideway structural costs include subgrade preparation, sub-grade base (or ballast) and miscellaneous drainage structures. Elevated structural costs include the basic elevated structure (columns, footings and trackway beams) and drainage structures as required. Depressed way costs are the same as at grade with the addition of required excavation costs. Tunnel structural costs include excavation costs, tunnel lining costs, ventilation, and drainage costs. All structural types include utility relocation costs and average grade separation costs where required.

For this economic analysis project only the most basic design definition for each baseline system was provided. As a result the guideway design was only defined as to grade location (above, at grade, below) and vehicle loading. It was assumed that all vehicles, including pallets, would be equipped with rubber tires. The lateral control type was not defined, but it was assumed that even if it were electronic, a positive mechanical lateral guidance would be required as a backup.

At-grade guideway structural costs have been estimated by several organizations. For guideway with electronic lateral control TRW estimates the marginal structural cost of upgrading an existing freeway lane for automatic control to be $51,387 per mile (pavement overlay only). General Motors Research estimates the average structural cost of an electronic highway for one example project at $725,000 per lane mile (one-quarter elevated, no breakdown published). General Research Corporation estimates that the cost of at grade structure would be $640,000 per lane mile for Dual Mode and $600,000 per lane mile for PRT (includes track). For pallet systems at grade structure costs have been estimated by GMRC ($1,960,000 per track mile, one-half elevated, track included) and by TRW ($72,500 per track mile, rural location, no grade crossings). Cornell Aeronautical Laboratory estimates at grade costs to be $152,328 per lane mile (includes track).

The Westinghouse Expressway concept is estimated to cost $365,000/track mile (includes track, 1966 dollars). Morgantown experience indicates a cost for at grade structure of about $300,000/track mile (includes track, 1971 dollars). Estimates of at grade structure for conventional rail transit range from $586,000 to $3,485,000 (1969 prices).

With highway costs ranging from $250,000 to at least $3,000,000 per lane mile for freeway facilities in urban regions, it seemed unreasonable to expect an automated facility to be built for substantially less. Although some savings may result from the slightly decreased lane widths of Dual Mode this is unlikely to have a significant effect on utility relocation costs, grade separation structure costs or temporary traffic relocation costs on a per lane basis.

For the Dual Mode analysis, the cost of at-grade structure was assumed to be $500,000 per lane mile for the new small vehicle baseline and $700,000 per lane mile for the pallet and automated highway vehicle systems. The higher cost of the latter two baselines reflects the more substantial guideway structures required to support the larger, heavier vehicles. The figures selected appear to be reasonable as systemwide average values. The minimum cost for at grade structure in urban areas is about $250,000 per lane mile, the maximum is on the order of $1,000,000 per lane mile. The maximum cost used in this analysis is considerably less than that observed for some freeways, owing to the decision to tunnel or elevate sections of Dual Mode guideway in the more densely settled areas of Boston (where at grade location would require extensive community disruption and/or extensive grade separation structures).

Costs for elevated guideway structure have been estimated by many of the organizations noted in connection with at-grade structures. Since elevated guideways are inherently grade separated, estimates[103] for elevated structure cost are considerably more consistent. Elevated guideway costs are primarily a function of vehicle loads, guideway height above ground, and guideway span. Most elevated structures provide 18 feet of clearance above ground and have spans in the range of 40 to 80 feet (excluding long span bridges).

Most promoters of small vehicle systems have asserted that their elevated structures can be much lighter as a result of the smaller vehicle load they carry. Although lighter vehicle loads can result in a somewhat lighter elevated structure the effect is not so great as is often presented. There are several reasons for this. First, total vehicle weight is not the actual loading on the structure since the loading criteria is always the load per unit length along the beam assuming bumper-to-bumper vehicles. Thus, a 4-passenger vehicle which weighed as much as a transit car on a weight per foot basis would require the same elevated structure even though its total weight was less than the transit car's weight. However, small vehicles are usually narrower than larger vehicles such as transit cars so that they are lighter on a per unit length basis.

A second major reason that smaller vehicles may not yield a lighter structure is that the structure weight is a function of several other design criteria, any one of which may govern the design. These criteria include: static and dynamic deflection, wind loading, earthquake loading, and static loading due to the structure's own weight. A third reason is the conservative factors of safety used for civil structures.

The estimates for Dual Mode elevated structure range from $454,000 (TRW - Pallet) to $1,645,000/lane mile (GM - PRT). Other estimates per lane mile include $740,520 (Cornell Aero Lab), $800,000 (GRC), $807,000 (TRW-Pallet, upper limit), $1,200,000 (GM busway), and $1,300,000 (APL-PRT).

BART elevated structures cost $1,275,000 per single track mile. The Morgantown experience indicates elevated costs on the order of $1,500,000 per single track mile (includes track). The Westinghouse Transit Expressway costs were estimated to be $975,000 per single track mile in 1966. DOT-TPI uses a value of $2,000,000 per single track mile for estimating costs of elevated rapid transit structure (structural cost only).

For this analysis elevated structure was assumed to cost $1,100,000 per lane mile for the new small vehicle baseline and $1,300,000 per lane mile for the pallet and automated highway vehicle baselines. These "best engineering estimate" costs assume that the elevated structure has a standardized design and is produced in significant quantities (on the order of 1,000 track beams, for example). The probable range of elevated structural costs is $800,000 - $2,000,000 per lane mile (excludes special long span structures).

Tunnel costs are highly variable depending on construction method (cut and cover or tunneling), the ground through which the tunnel is run (hard rock and soft, non-supporting ground are more costly than soft rock or self-supporting earth), the tunnel cross-sectional area, and the ground water inflow rates. The recent BART tunneling projects varied in cost from $2,430,000 to $26,600,000 per track mile (excavation and lining cost), an order of magnitude range.

Three organizations have made estimates of tunneling costs for small vehicle systems. Cornell Aeronautical Lab estimates that the tunneling cost for a pallet system would be $7,310,000 (soft rock) to $11,973,000 (hard rock) per single track mile (includes track). The Applied Physics Lab estimates the tunneling cost for PRT to be $5,200,000 per track mile. General Research Corporation used a figure of $5,000,000 per track mile in its study for HUD (includes track).

In this study only general alignments for Dual Mode have been established and no sub-surface geology has been investigated. Thus, only generalized costs for tunnel can be established. (If detailed routes and sub-surface geology were known detailed tunneling costs could be estimated using references 32 and 79). Unit costs for tunnel structure (including excavation) were assumed to be $5,000,000 per track mile for the new small vehicle system and $7,000,000 per track mile for the other two baselines. Because of the very limited extent of tunneling for the pallet and automated highway vehicle baselines, there was no need to adjust the automated highway vehicle system tunnel structure cost upward to $8-10,000,000 per lane mile (to account for the ventilation equipment and increase in tunnel diameter necessitated by internal combustion engines).

The costs above are averages over both cut and cover and traditional tunneling methods and are consistent with BART experience. On the BART system, cut and cover construction was only used in favorable ground where minimal traffic relocation and utility relocation problems were encountered. Thus, the lowest tunnel construction costs were for cut and cover. Cut and cover construction costs ranged from $2,430,000 to $4,340,000 per track mile. Tunnel construction costs using traditional construction methods averaged $7,000,000 to $9,000,000 per track mile. The highest tunnel construction cost was for a section where it was necessary to use compressed air to prevent tunnel collapse during excavation. This section cost $28,600,000 per track mile.

B. Track and Electrification

All baselines were assumed to have either electronic guidance with mechanical backup or mechanical guidance. Since no track configuration was designed for this analysis, track was costed on the basis of generalized experience.

There are two basic approaches to track design. The first is exemplified by the railroad track, which has a long life, great wear resistance and, as a result, is designed for ease of repair and realignment. The ordinary road is an example of the other extreme in track design, the road having a rather short life, less wear resistance and no capability for realignment of the surface structure except by reconstruction.

Like conventional systems, Dual Mode can be constructed with either a long lived, adjustable set of running surfaces or a shorter lived track which requires reconstruction to correct mis-alignment. The Westinghouse Transit Expressway is one example of the latter type of track.

In this analysis of Dual Mode systems a long-lived track (20-year life) with adjustable running surfaces* was assumed for all baselines. Track and electrification cost for new small vehicle baseline was assumed to be $400,000 per track mile ($200,000 each for track and electrification); the cost for the pallet was assumed to be $500,000 per track mile ($250,000 each for track and electrification). The automated highway vehicle system, which is not electrified, was assumed to cost $200,000 per track mile for track. The reason the automated highway track is less costly than the pallet track is that mechanical lateral guidance is a backup only and can be built to lower standards. The new small vehicle baseline was assumed to have lower track and electrification costs than the pallet system because of lower axle loadings and lower total power requirements.

The track costs were based on several sources. BART track procurement and installation costs average $250,000 per track mile. TRW estimates the conventional railroad track for its pallet Dual Mode system would cost $67,200 per single track mile for a 60 mph system. This appears to be an underestimate since

*Roadway can be adjusted mechanically to ease construction and compensate for eventual settling and wear.

Kaiser Engineers estimates conventional railroad track for BART would cost about $170,000 per single track mile (1964 estimate). The Westinghouse Transit Expressway track was estimated to cost $175,000 per single track mile in 1966. If an exotic beam structure is used under conventional rails, track cost would increase to above $500,000 per track mile (based on Kaiser Engineers estimates for BART).

Electrification costs on BART average $313,000 per track mile (1,000 volts, DC, third rail). GRC used an estimate of $380,000 per track mile for electrification in its study of Dual Mode. TRW estimates electrification costs for its pallet system to be about $625,000 per track mile (1,000 volts DC). Cornell Aeronautical Lab used an estimate of $250,000 per track mile in its analysis. Allis Chalmers, in its Milwaukee analysis, determined the electrification cost as a function of vehicle density on the system (i.e., peak power requirement) and found that electrification costs could range from $100,000 to $1,000,000 per track mile. AC power systems were found to be slightly cheaper than DC, particularly for higher power requirements. The range of electrification costs determined by Allis Chalmers appeared to be a reasonable range for this analysis. The baseline cost used of $250,000 per track mile is on the low side of the figures cited above because a single phase AC system with slightly lower costs than DC was assumed.

C. Command and Control Equipment

By far the largest uncertainty in Dual Mode capital costs is in command and control equipment. There is little experience with highly automated transportation concepts of this type. The highest degree of automation in urban transportation is found in automated transit systems (e.g., BART, MBTA Quincy Line, Westinghouse Transit Expressway). Costs for the systems cited are known. BART command and control equipment (including the central control equipment) cost an average of $173,350 per track mile. The Quincy Line cost $300,000 per track mile (higher in part because the control center cost is allocated to a considerably shorter track section than it is capable of controlling - 6.2 route miles, 12 track miles). The 1967 estimate of the Westinghouse Transit Expressway control cost was $77,000 per track mile. This estimate is surprisingly low considering Westinghouse Electric also supplied the BART control system which performs the same functions yet costs over twice as much.

Several organizations have made estimates of command and control costs for Dual Mode systems as follows:

1) General Motors Research

Automated Highway - $250,000/lane mile

Bi Modal Bus - $100,000/track mile + $3,000,000/control center (one)

Pallet - $760,000/track mile (high density traffic)
$340,000/track mile (low density traffic)

2) TRW

Pallet - $160,750/track mile + $1,200,000/station + $1,333,000/control center (one)

Automated Highway - $60,398/lane mile + $12,900/merge + $7,400/demerge + $3,269,000/control center (one) + $306,000/communications

3) GRC

$15,000/lane mile + $7,500/exit or entrance ramp + $7,500/station + $1,500/station ramp

4) Cornell Aero Lab

$26,400/track mile + $70,000/terminal + $500,000/central computer

5) Allis Chalmers (Milwaukee)

Approximately $165,000/track mile

A rough median value for command and control systems is $200,000 per track mile based on the various figures above. This figure was used as a best engineering estimate for guideway installed equipment. In addition $2,000,000 of central control equipment was assumed. From the various cost estimates cited above it is clear that there is a large discrepancy between the various estimates. It seems unlikely that any estimate less than $100,000/track mile is credible in view of transit experience. In view of the GM pallet figure of $760,000 per track mile it is conceivable that command and control costs could approach $1,000,000 per track mile. Hopefully, future cost analysis from Morgantown and similar projects will reduce the considerable uncertainty in command and control costs.

D. Intersections

Intersections were costed on the basis of the unit costs developed above for the guideway. Because of the computational logic contained in the economic analysis computer program (TEAM) the intersection costs were developed as follows: the model first calculated guideway costs through an intersection as if the intersection did not exist. Then it added to the basic costs of the guideway the cost of turning ramps and the additional costs necessary for grade separation of the mainline guideway and turning ramps (no grade separation cost for tunnels). The incremental costs assumed are shown below.

Dual Mode Interchange Costs (Additional)

Type I (4-way)	15 mph	30 mph	60 mph
Pallet & Automated Highway Vehicle System (At Grade & Elevated)	$ 750,000	$1,800,000	$5,000,000
New Small Vehicle System (Except Underground)	580,000	1,200,000	3,800,000
New Small Vehicle System (Underground)	2,800,000	6,500,000	19,000,000

Type II ("T" type)	15 mph	30 mph	60 mph
Pallet & Automated Highway Vehicle System (At Grade & Elevated)	$ 500,000	$1,000,000	$2,000,000
New Small Vehicle System (Except Underground)	300,000	700,000	1,400,000
New Small Vehicle System (Underground)	1,500,000	3,300,000	9,550,000

E. Acceleration and Deceleration Lanes

Acceleration and deceleration lanes at stations were itemized separately by the economic analysis computer program. They were costed using the same unit costs developed for line-haul guideway above.

5.9.2 Dual Mode Terminal Costs

Terminal costs can be estimated reasonably accurately given a detailed design (except perhaps for special control equipment associated with terminal operations). For this project detailed terminal designs were not developed; some conceptual terminal layouts were established, but these were insufficient for costing purposes. Thus, costs were estimated on the basis of very general considerations.

A number of agencies have estimated costs for Dual Mode stations. It appears that most estimates are based on the cost of rail rapid transit facilities. Typical of transit facilities are BART costs: elevated and at-grade stations average $1,800,000 each, and cut and cover stations cost $6,000,000 to $25,000,000 each. BART station costs include an average of $250,000 each for communication and fare collection equipment and $260,000 for escalators and elevators. MBTA Quincy Line stations cost $1,200,000 (one lobby, at grade). Additional lobbies are $800,000 each. Estimates for the Westinghouse Transit Expressway stations are: underground, $2,207,000 each; at grade, $727,000 each; and elevated, $677,280 each. The elevated station costs are lower than at-grade because the supporting structure for the elevated station is costed as part of the guideway.

Dual Mode station estimates are as follows:

1) TRW

Automated Highway (no terminal building)
Entrance - $829,340 each
Exit - $244,910 each

2) GRC

Average cost - $665,000 each

3) GM

PRT - $153,000 each
Pallet - average $4,400,000 each
range $2,000,000 to $20,000,000
Bi Modal Bus - average $384,000 each

4) APL

Subway (PRT - 60 mph) - $3,500,000 each
Elevated $1,200,000 each

5) Fichter (Rochester)

Subway - $4,000,000 each
Elevated and at-grade - $2,000,000 each

It appears the major independent variables in station cost are passenger and vehicle throughput and station location (i.e., at grade, elevated or subway), given a basic design concept. For the Boston network most stations are at-grade except for the downtown small personal vehicle network which is underground. Any elevated stations were assumed to have the same cost as at-grade stations. All station costs were estimated as a function of passenger flow through the station in the design peak hour. Note that the stations were designed to serve traffic in both flow directions although the passenger demand parameter used in the analysis was peak direction flow (i.e, slightly more than one-half of the total station demand in the peak hour).

At grade new small vehicle stations were assigned the following costs:

Peak Hour Peak Direction Passenger Flow through Station (persons per hour)		At Grade Station Cost (Two direction station)
1500<0<2700		1,500,000
2700	3900	2,000,000
3900	5100	2,500,000
5100	6300	3,000,000
6300	7500	3,500,000
7500	8700	4,000,000
8700	9900	4,500,000

The station cost for the pallet baseline is given by the following set of equations:

$$\text{Cost per station} = \$1,500,000 + \$535 \cdot D \qquad 0 \leq D \leq 2800$$

$$= \$3,000,000 + \$811 \cdot D \qquad D > 2800$$

Where: D = peak hour, peak direction passenger flow through station

Stations for the automated highway vehicle baseline require vehicle checkout stations for entering automobiles and waiting facilities for bus drivers. Vehicle exit facilities are minimal. The ratio of number of vehicles to number of passengers should be the same as that for pallet. The Dual Mode auto requires vehicle checkout equipment of a more complex nature than that required for autos riding on pallets, thus increasing station cost. Offsetting this cost increase is the elimination of the pallet loading equipment required in all pallet stations. Since little is known about the design of any of this equipment it was assumed that automated highway vehicle system station costs would be the same as those for the pallet system.

The station costs above are admittedly arbitrary. They are reasonable approximations of the station costs given the present state of Dual Mode system definition. It is clear, however, that the costs above should be varied in a range between one-half to two times the selected baseline cost in the sensitivity analysis. The variation of cost with demand is also arbitrary and should be reexamined when better design data is available (station size as a function of demand can best be estimated by use of simulation of the system operation, lacking data from real systems).

Station storage (for temporary storage of system-owned vehicles) and parking (for private automobiles) costs were calculated separately in the economic analysis model. For this analysis of the Dual Mode baselines in Boston it was assumed that all system vehicle storage would be on low cost land located away from stations. Thus, the station storage cost calculation routine was not used.

Parking for private automobiles is provided in the pallet and automated highway vehicle baselines at selected stations. Manual parking of the vehicle by the user was assumed for all parking facilities. It was assumed that 300 square feet of space would be required per car. All garages were assumed to be 5-story structures costing $2,500 per parking place ($18,100,000 per acre of ground area). This figure is based on construction of a two-story parking garage on the MBTA's Quincy Line. Other unit costs for multi-story parking garages indicate that unit costs could be as high as $4,000 per parking space. If at-grade parking facility costs are needed in the future a reasonable construction cost is $600 per vehicle space.

5.9.3 Dual Mode Maintenance, Storage, and Command and Control Facilities

A. Maintenance Facilities

It was assumed that two acres of land and $3,000,000 worth of equipment would be required for maintenance facilities for the pallet and automated highway vehicle baselines. Corresponding figures used for the new small vehicle system were five acres and $5,000,000. These estimates reflected the cost of only the most basic maintenance facility (building and major equipment) to be used for repairing system-owned vehicles. Maintenance facilities were assumed to have a 30-year life.

B. Storage Facilities

All Dual Mode baselines having system-owned vehicles require storage yards. All storage yards were assumed to be at grade. A basic cost of $34,800 per acre was assumed for site and subgrade preparation. In addition, the guideway track necessary for automatic storage and retrieval was costed at the unit values for at-grade, line-haul facilities. The storage area and track mileage required for each vehicle type are shown below:

	Acres per 100 vehicles	Miles of track per 100 vehicles
Small personal vehicle	1.2	0.6
Pallet	1.2	1.0
Minibus	1.2	0.6
Large bus	3.0	1.0

For the large fleets (pallet and small personal vehicle) it was not necessary to provide offline storage for all vehicles. A substantial number of pallets were assumed to be on the system at any given time and likewise a large portion of the small personal vehicle fleet was assumed to be in use on or off the guideway or stored by the user off the guideway. The cost of storage facilities for the pallet, automated highway vehicle, and new small vehicle system worked out to be $107 million, $7.8 million, and $223 million, respectively. Storage yards, like maintenance facilities, were assumed to have a 30-year life.

C. Command and Control Facilities

All baselines were assumed to have a control center costing $12.1 million. The detailed capital cost breakdown is as follows: structure, $10,000,000; computers, $2,000,000; and land (two acres), $145,000.

5.10 DUAL MODE VEHICLE COSTS

No Dual Mode vehicle as envisioned in this study has been built. Thus, any cost estimate is conjectural at best. The cost estimates for this study were based on the following general sources:

1. Previous estimates of Dual Mode vehicle costs
2. Costs of present land transportation vehicles
3. Estimates of PRT vehicle costs

5.10.1 Dual Mode Buses

General Motors [29] estimates that a full-size (36-seat) Dual Mode bus would cost $42,000 (including $5,000 for the control package). JPL [39] estimates the cost of a 12-seat Dual Mode bus to be $15,000. Allis Chalmers Corporation [5] has produced the most detailed cost estimate for Dual Mode buses to date. They estimate a 20-passenger minibus would cost from $40,801 (electronic guidance) to $49,330 (mechanical guidance) in production quantities. Vehicle costs of $121,088 - $138,303 each are estimated for a 100-vehicle prototype production run.

The two buses analyzed in the Dual Mode study were originally considered to have seated passenger capacities of 50 and 12 persons. The 50-passenger bus was later replaced by a 20-passenger vehicle (owing to demand considerations), but the following discussion deals with the 50-passenger large bus and the 12-passenger minibus.

One method of estimating vehicle cost is to add the cost of accessories and Dual Mode control equipment to the base cost of standard buses. Conventional, air-conditioned buses with 50 and 12 passenger capacities cost about $39,000 and $16,000, respectively, in 1970 dollars. In addition to the basic bus prices above, the following accessory prices [3] are indicative of the additional costs to be expected on Dual Mode vehicles:

	Cost Per Item
Two-way Mobile Radio	$800 - 1,500
P.A. System	$700
Power Steering	$500
Fare Box (Registering)	$800 - 1,000
Side Destination Signs	$200

Clearly, the normal equipment on a bus can add $2,700 to $4,100 to the base cost of the vehicle. Thus, JPL's estimate for the minibus of $15,000 appears unrealistic. On the basis of General Motors' estimate of $5,000 for the Dual Mode electronic control package, the minibus cost would range from $23,700 to $25,100.

An alternate method of estimating vehicle cost is on the basis of total cost per pound of resources consumed. Typical unit costs for existing ground transportation vehicles are given in the following table:

Vehicle	Unit Cost $/Pound	Type of Control
Basic Passenger Automobile	1.0	Manual
Standard Bus	2.0	Manual
Minibus	2.6	Manual
Standard Rail Transit Car	2.0	Manual
MBTA Quincy Rail Transit Car	2.8	Manual/Automatic
NYC (1971) Rail Transit Car	2.6	Manual/Automatic
Penn-Central Metroliner Coach	2.8	Manual(with electronic speed control)
Bay Area Rapid Transit Car	6.0	Automatic
Westinghouse Transit Expressway Car	4.4	Automatic
Morgantown Transit Car	10.0	Automatic

Clearly, all transit vehicles cost at least twice what a typical automobile costs on a unit weight basis. The higher cost of transit vehicles is attributable to two major factors: production quantities and design. Less than 10,000 transit buses are produced annually in this country and less than 1,000 transit cars, compared to nearly 10,000,000 passenger vehicles. Several design factors contribute to the higher unit cost of transit vehicles:

a. design for longer vehicle life
b. design for ease of maintenance
c. design for high reliability
d. use of light weight and/or high cost materials (e.g., aluminum and stainless steel)

The low production volume of transit vehicles probably accounts for the largest portion of the cost difference between transit and passenger vehicles.

It is evident from the above table that automatically controlled vehicles have higher costs than more conventional transit vehicles. The most highly automated cars built to date are the last three in the table: i.e., BART, Transit Expressway and Morgantown.

If transit unit costs are appropriate for the Dual Mode minibus the latter's cost could range from $16,000 to $36,000. Since a single large urban application of the Dual Mode minibus would require between 10,000 and 100,000 vehicles some cost savings could be gained from economies of scale in production. However, the increased complexity of a Dual Mode vehicle would probably increase its unit cost above that of a single mode automated vehicle, offsetting to some extent the economies obtained in large scale production.

Since detailed design information was not available for the Dual Mode minibus, its cost could not be estimated on a component basis. After reviewing the cost information above it was concluded that $30,000 would be an appropriate baseline cost for the Dual Mode minibus, with a range of $18,000 to $50,000. The costs above assume a vehicle with a dry weight between 6,000 and 6,500 pounds and a 12-year life.

The large (50-passenger) Dual Mode bus cost was estimated on the same basis as the minibus. A standard 50-passenger bus costs about $40,000. On a unit cost basis, costs for the automated, large Dual Mode bus might range from $40,000 to $120,000. Automation of the large bus requires essentially the same equipment as the minibus.

The large bus requires more massive lateral control hardware to handle its 20,000 pound weight, resulting in higher costs than those required by the minibus. On the order of 10,000 buses would be required by a large scale urban application of the Dual Mode busway concept. Since this approximates current U.S. production of urban buses, little economy of scale in production is likely for a single city application. (Note that many major bus components are common to truck production and are thus produced in much larger quantities than the U.S. bus production numbers would indicate.)

On the basis of all the above factors, $55,000 was selected as the capital cost for the 50-passenger bus having a 12-year life. The cost of the 20-person bus was afterwards determined to be $35,500 by interpolating between the 12- and 50-passenger bus characteristics.

5.10.2 Pallet

The pallet vehicle is a fully automated, single mode vehicle used to carry automobiles on the guideway. It is required to have automatic tie down equipment, a communication console and probably an air-conditioning unit for attachment to any automobile riding on it. The pallet is a substantial vehicle since it must have a payload capability of at least 5,000 pounds in order to provide service for the full range of automobiles.

The pallet is estimated to weigh at least 6,000 pounds and have a 12-year life. A large urban application would require on the order of 20,000 pallets. Since the pallet is an intensively utilized vehicle its costs are likely to be similar to transit rather than automobile costs.

The pallet is similar to the minibus in weight and equipment. Although the pallet does not have the passenger cabin of the minibus or the manual control features of other Dual Mode vehicles it does require additional equipment for automobile tie down and control and for air-conditioning interfaces with the automobile. Thus, the pallet would probably have a cost similar to that of the minibus-$30,000, with a cost range of $18,000 to $50,000, a figure which is consistent with other estimates of pallet costs: General Motors estimates the capital cost of the pallet to be $31,000; Cornell Aeronautical Lab estimates $29,650 to $30,900; TRW estimates $17,800; and JPL, $15,000.

5.10.3 Small Personal Vehicle and Dual Mode Automobile

The small personal vehicle and Dual Mode auto are genereerally similar. Both vehicles have Dual Mode capability and both are assumed to have a 6-year life in fully operational condition. The small personal vehicle is smaller than the automated highway vehicle (3,000 pounds gross weight for the SPV vs. 4,500 pounds for the automated highway vehicle). The SPV is all electrically powered, whereas the Dual Mode auto is powered by a conventional internal combustion engine.

The minimum possible cost for the two vehicles would be on the order of $2,500 for the SPV and $3,300 for the automated highway vehicle based on net vehicle weights of 2,500 pounds and 3,300 pounds, respectively. These values assume zero cost for Dual Mode capability.

According to JPL,[84] the cost of adding Dual Mode capability to an automobile has been estimated to range from $600 to $3,000. With current estimates[13] for anti-pollution and safety add-ons for automobiles reaching $873 by 1976 it is difficult to believe complete Dual Mode capability can be built into an automobile for $600.

It appears that many estimates of Dual Mode automobile costs are based on marketing considerations rather than the cost of the equipment necessary for conversion to Dual Mode. The market argument for Dual Mode cost says that few Dual Mode highway vehicles will be sold unless the marginal cost is small, because the Dual Mode auto will be sold in a competitive marketplace with conventional autos. Thus, the Dual Mode package is generally estimated to cost between $200 and $600, the price range of the larger, presently available options such as air-conditioning.

Market criteria for Dual Mode costs is one method for cost estimation. It assumes that a Dual Mode vehicle must be sold in 1990 under market conditions typical of 1970. It is possible the market conditions of 1990 will be the same as 1970 but an equally plausible argument can be made for radically different conditions in 1990. For instance, the "conventional" automobile of 1990 may be designed for long life, high reliability, ease of repair and maximum safety for occupants, resulting in a much higher initial cost (although a similar annual capital cost).

An alternate method of estimating the Dual Mode vehicle cost is to estimate the cost of all sub-elements of the vehicle, given a specific design for the vehicle. Although a specific design for each vehicle is not available, the equipment required for Dual Mode capability would probably include:

1. Two way communication
2. Automatic steering
3. Automatic control
4. Vehicle identification transponder
5. Console for indicating change of route instructions to central control.

In addition, the vehicles would require all highway safety equipment.

The electrically powered personal vehicle would probably have a slightly higher initial cost than an otherwise similar but internal combustion engined vehicle. The increased cost is primarily a result of higher cost materials in batteries, motors, and controllers in the electric vehicle.

Both vehicles must be produced in large quantities for any reasonable urban market. For Boston, for instance, a demand for at least 420,000 vehicles was projected, a significant model run by auto manufacturing standards.

As noted above, the basic cost of the vehicles would be $2,500 and $3,300. If the vehicles cost as much as automated transit vehicles on a per pound basis, the cost for the vehicles could be as high as $15,000 (SPV) and $19,800 (auto). The preliminary estimate is that the Dual Mode capability will cost on the order of

$2,000. Thus, the baseline cost for the small personal vehicle is $4,500 with a range of $2,500 to $15,000. The automated highway vehicle was assumed to have the lowest possible cost for Dual Mode capability. For this baseline, $1,700 was assumed for the Dual Mode equipment, for a total vehicle cost of $5,000 (with a range from $3,300 to $19,800).

5.11 DUAL MODE OPERATING COSTS

5.11.1 Vehicle Operating Costs

Vehicle operating costs for the various baselines were estimated on a vehicle mile basis. The figures used were based on 1970 costs for existing vehicles. On- and off-guideway costs were separate inputs. Slightly higher on-guideway operation and maintenance costs were estimated for Dual Mode vehicles to partially account for the increased reliability presumed necessary for Dual Mode operation (increased capital costs also help to account for the cost of the high reliability required for Dual Mode operation).

On-guideway operating maintenance and power costs were charged for all vehicles. Off guideway the SPV and private vehicles (i.e., auto on pallet and Dual Mode auto) incur a parking and garage cost in addition to power, operation and maintenance costs. The buses off guideway were charged for the cost of drivers in addition to power, operation, and maintenance costs. Taxes, depreciation while on the guideway, and parking costs were not included as operating costs because they were either costed elsewhere or, in the case of taxes, are not economic costs (highway user taxes are simply a means of transferring road construction and maintenance costs to the user). For the Dual Mode analysis the following vehicle operating cost "(Dollars per vehicle mile)" were assumed:

	On-Guideway			Off-Guideway				
Vehicle Type	Maint.	Power	Depr.	Maint.	Power	Depr.	Parking Garage	Driver
SPV	.03	.02	-[1]	.03	.02	-[1]	-	-
Dual Mode Auto	.04	.02	.04	.04	.02	.04	.02	-
Pallet	.07	.025	-[1]	-	-	-	-	-
Pallet-Auto[2]	-	-	-	.04	.02	.03	.02	-
Minibus	.10	.02	-[1]	.10	.02	-[1]	-	.60
Ray Dual Mode Bus	.10	.025	[1]	.10	.025	[1]	-	.60

[1]Depreciation accounted for under capital costs
[2]Conventional auto which rides on pallet

The figures on the previous page are based on ATA statistics for buses and FHWA data for small vehicles.

For comparison TRW estimates operating and maintenance costs for an automated highway vehicle would be \$.0537/vehicle-mile and the energy cost for operating pallets would be \$.009/vehicle-mile. GRC assumes vehicle operating costs of \$.02/vehicle-mile for the small personal vehicle and \$.025/vehicle-mile for the bus (on guideway). GM assumes \$.059/vehicle-mile for pallet maintenance, \$.136/vehicle-mile for automated guideway vehicle operating and maintenance cost and \$1.10/vehicle-mile for the operating and maintenance cost of the Bi-modal bus (off guideway). JPL assumes a maintenance cost of pallets of \$.02/vehicle mile or \$7,592/pallet-year for its assumed 397,690 miles per year per pallet. JPL calculates power costs on a per guideway mile rather than per vehicle-mile basis. It appears this cost is about \$.006/vehicle-mile. Both Cornell Aero. Lab. in its studies and Allis Chalmers in the Milwaukee study estimated total system operating and maintenance costs per guideway mile - no vehicle operating costs were isolated.

5.11.2 Terminal Maintenance Costs

For this analysis each terminal was assumed to require an average of \$15,000 per year for maintenance. In addition, terminals were assumed to have annual operating costs between \$30,000 and \$40,000, depending on size.

By comparison TRW assumed annual terminal operating and maintenance costs of 3% of structural capital cost plus 10% of the capital investment in station equipment for its automated highway system. For its pallet system TRW assumed an annual operating and maintenance cost of \$41,000 per terminal. GRC used a percent of investment approach assuming 2% of structural cost and 3% of equipment cost. JPL assumed pallet stations would have annual maintenance and operating costs of \$193,490. This estimate was for a system with one two way station every 10 route miles assuming two lanes of traffic.

The station operating and maintenance costs in this analysis average about 1.5% of average station capital investment (except for the new small vehicle baseline which has a number of high cost underground stations, thus raising the average station cost and lowering the percent for maintenance and operation). The maintenance and operating costs used are probably a lower bound on such costs and any further analysis should examine the effects of higher costs. A high capital cost-low maintenance and operating cost approach to terminals was taken in this study.

5.11.3 Guideway Operating and Maintenance Costs

The procedure used here was that there are three cost elements to guideway annual "operating" costs: the actual operation cost (which includes such items as power for lighting and overhead), maintenance costs for the guideway proper, and guideway command and control operation and maintenance cost. Values of $5,000/lane-mile per year for guideway operation, $10,000/lane-mile per year for guideway maintenance, and $5,000/lane-mile per year for guideway command and control operating and maintenance cost were assumed.

For comparison TRW assumed operation and maintenance cost for the automated highway vehicle system would be about $2,000/lane-mile/year and about $2,925/lane-mile/year for a pallet system. GRC assumed the annual guideway maintenance cost would be about 0.5% of the capital investment in the guideways (less than $9,000 per mile per year). JPL assumed $20,000/lane-mile/year for guideway operating and maintenance costs.

5.11.4 Maintenance Facility, Yard and Control Center Operating Costs

The maintenance facilities in all the baselines were assumed to have a fixed overhead cost of $100,000 per year, in addition to the vehicle operating maintenance costs. The storage yards in all baselines were assumed to incur a $6,000/year/acre operating and maintenance cost, alloted primarily to maintenance and based on guideway maintenance costs. Operating costs of the control centers for all baselines were set at $800,000/year, including costs of office staff and central control equipment. Considerable uncertainty exists in this figure since staff sizes are unknown and no such control system has ever been developed, so a conservative value was deliberately chosen. By way of comparison, TRW assumed an annual control center cost of $485,000 for an automated highway vehicle system and $133,000 for a pallet system.

5.11.5 Fares and Parking Costs

For each baseline, a specific fare and parking cost structure (in 1963 dollars) was used in the demand analysis. These fares and costs were combined with the patronage in the TEAM model to determine system revenues (for this the 1963 dollars were inflated to the base year of 1970). The specific fares and parking charges used in this analysis can be found in Chapter 3 of this volume.

5.12 VEHICLE DEPRECIATION

Dual Mode vehicle depreciation was accounted for under capital or operating costs, depending on vehicle type and/or ownership. The basic rule of thumb was as follows: if the vehicle was purchased by the system, depreciation was calculated in the capital cost section of the TEAM model (using life and interest tables); if the vehicle was purchased by the individual, depreciation was calculated in the operating cost section (on the basis of cost per vehicle mile).

Applying this rule, all buses and pallets were depreciated in the capital cost section. Depreciation for personal vehicles was handled as shown in the table below:

	Pallet System Auto	Dual Mode Auto	New Small Vehicle
On-guideway	0	operating cost	capital cost
Off-guideway	operating cost	operating cost	capital cost

6. IMPACTS

6.1 AIR POLLUTION

The amount of air pollution emitted by the highway, transit and Dual Mode systems was calculated by applying to the various types of power plants and propulsion systems involved the presently published EPA standards scheduled to go into effect closest to 1990.[23,24] All systems are assumed to emit pollutants at the levels allowed by the standards.

For gasoline engines the 1976 pollution standards were applied for the output of carbon monoxide, hydrocarbons and nitrous oxides on a vehicle mile basis. A General Motors study[83] on propulsion system emissions, reflecting the currently envisioned standards, were used as a source of levels of carbon monoxide, hydrocarbon and nitrous oxide emission for diesel engines. This data also was on a vehicle mile basis.

For electrically powered vehicles the 1971 stationary source standards were used, governing the output of nitrous oxides, sulfur dioxide and particulates for coal fired steam generating plants. The assumption was made that the electricity will be produced by steam driven turbine-generators and that coal will be the fuel used. The pollution emission data is on a heat input basis, so it was necessary to use an efficiency factor to account for generating and distribution losses in the conversion of power required by the vehicles from heat input into the generating plant. An overall efficiency of 36% for these processes was assumed, representing the near-maximum possible generating efficiency of 40%[88] and a 90% distribution efficiency. If oil or gas had been chosen as the fuel instead of coal the pollution levels would have been somewhat lower, but this also would have had little effect on the relative standings of the various systems. A choice of nuclear power would, on the other hand, significantly alter the pollution results, since the basic pollutants from a nuclear generating station are radioactive and heat.

The costs associated with the emission of the various pollutants were estimated from a Mitre study[58] wherein was listed a calculated nationwide annual cost of the pollutants emitted by internal combustion engines and electric power plants in 1968 and also the total quantities of these pollutants produced in that year. The costs, based on health expenses and lost earnings due to premature deaths, and property and vegetation damage, were calculated to be as follows:

Pollutant	Cost (dollars/ton
Carbon Monoxide	1.65
Particulates	205.17
Sulfur Dioxide	250.30
Hydrocarbons	129.93
Nitrous Oxides	50.89

Sulfur dioxide and particulates, which are emitted by electric power plants, are by far the worst pollutants in terms of their costs, and this fact significantly influenced the relative standing of the various baselines. As discussed in Vol. II, Chapter 4, the baselines with electrically powered Dual Mode vehicles emitted a smaller quantity of pollutants than those without, but their pollutant cost was considerably higher.

It should be noted that any projection into the future such as this is founded on a number of assumptions, and the greater their number or the more their uncertainty, the more fragile are the results. The key assumptions involved in the pollution analysis are that gasoline and diesel engines would still be the primary internal combusiton power plants, that coal would be used to generate electricity, that these sources would emit pollutants at the level now postulated and that the pollution damage costs are appropriate. Any significant changes in these assumptions could significantly affect the nature of the results.

6.2 ENERGY CONSUMPTION

The energy consumed by the highway, transit and various Dual Mode vehicles was calculated from considerations of aerodynamic drag, wheel rolling friction, cruising speeds and time spent traveling. Aerodynamic drag increases with the frontal area of the vehicle and the square of the velocity while drag due to wheel rolling friction increases with the weight of the vehicle. The power required to propel a vehicle is given by the product of the forces necessary to overcome these drags and the velocity of the vehicle, and the energy consumed is given by the product of the rate of power consumption and the time spent traveling. The energy consumption equation takes the following form:

$$\text{Energy consumed} = \left[Wk + \frac{C_D V^2 A\rho}{2}\right] Vt = \left[Wk + \frac{C_D V^2 A\rho}{2}\right] d$$

where

W = vehicle weight

k = wheel friction coefficient

C_D = aerodynamic drag coefficient

A = vehicle frontal area

V = vehicle velocity

ρ = atmospheric density

t = time spent traveling

d = distance traveled

For purposes of energy consumption calculations, vehicles were assumed to travel on level grade with no head or tail wind and with no deceleration or acceleration. The rationale for this is that to a large degree grades, winds and velocity changes will individually average out. The pertinent characteristics for the vehicles are as follows:

Vehicle	Weight, lbs.	Frontal aera, ft^2	Aerodynamic drag coefficient	Wheel rolling friction coefficient
20-passenger dual mode bus	15,000	72	0.6	0.015
12-passenger dual mode bus(minibus)	10,000	56	0.6	0.015
Pallet carrying auto	10,000	48	0.6	0.015

Vehicle	Weight, lbs.	Frontal area, ft^2	Aerodynamic drag coefficient	Wheel rolling friction coefficient
Small personal vehicle	3,000	24	0.4	0.015
Automobile (Dual Mode and highway)	4,000	33	0.5	0.015
Transit bus	26,000	72	0.6	0.015
Truck	40,000	100	0.6	0.015
Rail rapid transit car	94,000	120	0.6	0.001
Trolley car	65,000	93.5	0.6	0.001

For the various Dual Mode vehicles operating on the guideway the power consumption was calculated on a link-by-link basis, taking into account the speeds and lengths of the links and the numbers of vehicles on them. For Dual Mode vehicles operating off the guideway on surface streets, the energy consumption was calculated from the average speed, distances and numbers of Dual Mode vehicles on the off-guideway portions of the trips. For energy consumption by trucks and automobiles operating on streets and freeways, the average speeds on the streets and freeways during peak and off-peak hours, and the respective vehicle miles generated in these four combinations by trucks and autos, were considered. Transit vehicle energy consumption was calculated by considering the vehicle miles generated by the different transit vehicles and their average speeds.

The energy values calculated by the above means are those required to overcome the external forces on the vehicles. The actual energy consumed by the vehicles is greater than this, since the engines, motors and drive lines incur losses. Internal combustion-powered vehicles were assumed to have an efficiency of 80% for transmission of energy from engine to wheels, and were assumed to consume fuel at a rate 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. For electrically powered vehicles, the energy value of interest is not just that consumed by the vehicles themselves, but the amount consumed by the powerplant that generates the electricity, since that is the real energy cost paid by the system. Therefore, the energy consumption values for the electrically powered vehicles reflect a 36% efficiency in power generation and transmission, consisting of an assumed near-maximum possible efficiency of 40% in generation (4x) and an efficiency of 90% in distribution. By presenting the power plant energy consumption, the energy values of the electric and internal combustion powered vehicles are made comparable, since the same thermodynamic losses are being considered for both systems.

6.3 NOISE EFFECTS

In view of the increasing concern for the quality of the urban environment, it is highly appropriate to compare the 1990 plan and Dual Mode alternatives with respect to their noise impact. Recent studies of transportation systems and reference sources on noise have used or suggested several methods of analyzing the effects of noise. The following sections review the various methods available and examine their applicability to the Dual Mode study.

6.3.1 The Northeast Corridor Study Approach

The Northeast Corridor Transportation Project[88] evaluated noise effects of alternative transportation systems by estimating the costs imposed by noise on non-users. In particular, the noise cost arising from each system, expressed as decreases in the value of adjacent residential land, was calculated as follows:

$$\begin{matrix}\text{Total Decrease}\\ \text{in Residential}\\ \text{Property Values}\end{matrix} = \begin{pmatrix}\text{Proportion}\\ \text{Increase in}\\ \text{Noise}\end{pmatrix}\begin{pmatrix}\text{Elasticity}\\ \text{Impact of}\\ \text{Noise on}\\ \text{Residential}\\ \text{Property}\\ \text{Values}\end{pmatrix}\begin{pmatrix}\text{Acreage}\\ \text{Subject}\\ \text{to Noise}\end{pmatrix}\begin{pmatrix}\text{Average}\\ \text{Property}\\ \text{Value/}\\ \text{Acre}\end{pmatrix}$$

The Northeast Corridor approach seemed inappropriate for the Dual Mode noise analysis for a number of reasons. In the first place, "there are two types of effects of transportation facilities on property and land values:

- an accessibility effect, which makes the area surrounding the transportation facility more productive, and is sometimes reflected in changes in land uses in the affected areas; and
- a neighborhood disturbance effect, which is characterized by increases in noise, air pollution, and aesthetic and safety effects on the adjacent area." (94 pp. 37-38)

Since the Northeast Corridor study was dealing with intercity systems having widely spaced stations, the residential land along a high-speed ground mode right of way could be assumed to undergo changes primarily in neighborhood quality, as opposed to accessibility. Thus, any changes in that land's value could reasonably be attributed to changes in the level of neighborhood disturbance and, conversely, a particular neighborhood disturbance (in this case noise) could be quantified in terms of property value changes. The Dual Mode analysis, however, involves intra-city systems with close station spacing; in such a setting, transportation-related changes in land value are a function of accessibility as well as neighborhood disturbances. Therefore, even assuming that a new transportation system is the only force influencing land values over the period in question (a less reasonable assumption for a dense urban area, with a multitude of continually changing land uses, than for a less densely settled interurban corridor), and assuming that noise is the only neighborhood disturbance arising from the system, it is incorrect to attribute the change in nearby property values just to additional noise from the system or, conversely, to measure noise impact in terms of the entire amount of change in value. Moreover, since increases in accessibility and in neighborhood disturbances have opposite effects on land values, the actual <u>net</u> amount of change is likely to be rather insignificant, thereby disguising or understating the true magnitude of benefits from the former and disbenefits from the latter transportation-induced factor.

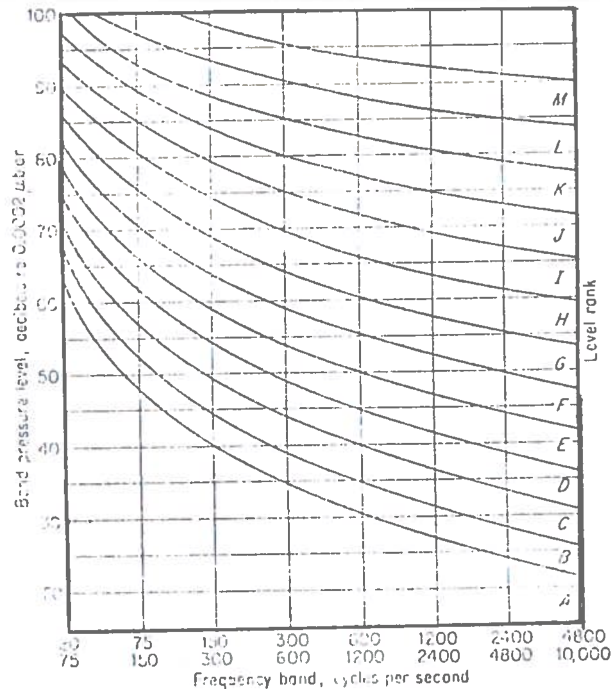
Still another shortcoming of the Northeast Corridor Study method as a potential Dual Mode study method concerns the derivation of the second term in the equation, "elasticity impact of noise on residential property value". The Resource Management Corporation (under contract to DOT for the External Costs and Benefits Analysis) used regression analysis techniques on property along existing railroad right of way to determine the elasticity value -- an acceptable procedure in view of the relative ease of singling out transportation-induced changes in land value having no accessibility component.* However, because new transportation systems in urban areas affect land values in two directions simultaneously, regression analysis would undoubtedly yield a lower-than-actual elasticity value.

Perhaps the most significant disadvantage of the Northeast Corridor approach is its failure to examine the community impact of noise -- viz., the types of land uses affected, the number and socio-economic background of people adversely impacted, and their probable reaction to the noise. In translating noise impact into a monetary cost and studying it with respect to the impersonal market mechanism, the Northeast Corridor method seemed to overlook the far more important, social ramifications of noise.

6.3.2 Noise Rating Procedure

The noise rating procedure described in McCormick's Human Factors Engineering (61, pp. 479-83) and Rosenblith and Stevens' Handbook of Acoustic Noise Control[80] does consider the community impact of noise in that it predicts the nature of the expected response from people exposed to noise. This method works as follows: an octave-band noise spectrum of the environment (an average spectrum based on numerous measurements) is superimposed on the following set of curves corresponding to alphabetically labeled "level ranks" or residential noise, and the highest level rank zone into which any part of the spectrum protrudes is identified.

*All adjacent areas except for property near stations probably satisfied this condition.

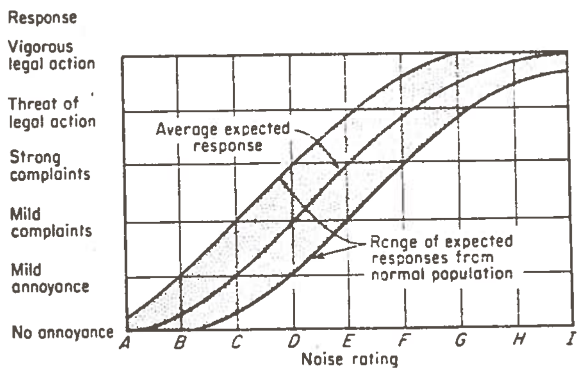


This level rank is corrected by adding or subtracting the appropriate correction values obtained from the table below:

Influencing factor	*Possible conditions*	*Correction number*
Noise-spectrum character	Pure-tone components	+1
	Wide-band noise	0
Peak factor	Impulsive	+1
	Not impulsive	0
Repetitive character (about ½-min noise duration assumed)	Continuous exposures	
	0 to 1 per min	0
	10–60 exposures per hr	−1
	1–10 exposures per hr	−2
	4–20 exposures per day	−3
	1–4 exposures per day	−4
	1 exposure per day	−5
Background noise	Very quiet suburban	+1
	Suburban	0
	Residential urban	−1
	Urban, near some industry	−2
	Area of heavy industry	−3
Time of day	Nighttime	0
	Daytime only	−1
Adjustment to exposure	No previous conditioning	0
	Considerable previous conditioning	−1
	Extreme conditioning	−2

SOURCE: Rosenblith and Stevens [53], as adapted by Peterson and Gross [47].

If the original level rank is E and the net correction is -2, the corrected level rank is C. Finally, the expected neighborhood response is determined from the following graph:



This approach has the appeal of simplicity: with either an actual or estimated noise spectrum, one can predict how a community will react to the noise level of an existing or future environment. However, the noise rating method has several disadvantages: first of all, in the case of a new transportation system to be installed 10 to 20 years hence (such as Dual Mode), it would be much easier and more accurate to estimate the noise output of the system itself than to predict the composite noise level of a community having this system. Second, the absolute and relative values of the correction numbers are somewhat open to question: for instance, one might conceivably reject the assumption that the background noise in an area of heavy industry has the same effect (-3) on the initial level rank as 4-20 exposures per day. Likewise, the range of expected response depicted in the graph above is of questionable validity, especially if the community under consideration is atypical from the standpoint of sensitivity to noise and propensity to vocalize complaints. The final shortcoming of this method is that by skipping from environmental noise measurements to residents' reaction it ignores the intermediate issue of what kinds of people are affected.

6.3.3 TSC Noise Model

The TSC Noise Exposure Model (MOD 4)[107] is a refinement and expansion of the MOD 0 Noise Exposure Model developed by Serendipity, Inc. to rate aircraft noise perceived by individuals on the ground near airports. This model has the capability of calculating Noise Exposure (NE) using flight statistics for a 24-hour day, Noise Exposure Forecast (NEF) using flight data for two separate periods during the day (7 A.M. to 10 P.M. and 10 P.M. to 7 A.M.), or the Weighted Equivalent Continuous Perceived Noise Level (WECPNL) using three time periods (daytime, evening -- 7 P.M. to 10 P.M., nighttime) and then presenting the calculated results as a grid array (maximum size of 20 points in the X-direction by 25 points in the Y-direction). The model also has the option for automatic CALCOMP plotting of one to three contours of selected value plus automatic calculation of the area within each contour.

In the calculation of noise exposure values, aircraft noise output is expressed in terms of Effective Perceived Noise Level (EPNL) in units of EPNdB. This value represents the loudness sensation (Perceived Noise Level in PNdB, which reflects sound intensity and frequency spectrum generated by aircraft), plus corrections for tonal content in the noise spectrum and time duration of the aircraft's flyby. The total noise exposure for an airport consists of the sum of the effective perceived noise levels produced at each point on the ground by the different classes of aircraft flying along simulated flight paths. The various noise measurement values can be related schematically as follows:

Noise level	PNdB			
Frequency spectrum				
Tonal content				
Time duration		EPNdB		
Aircraft types				
Number of operations				
Runway utilization			NE	NEF and WECPNL
Flight paths				
Operating procedures				
Time of day				

The TSC Model is a very sophisticated means of measuring the impact of airport noise, since it uses specific information about aircraft types and operations to generate contours which in turn can be evaluated with respect to people affected. However, this model was deemed unsuitable for the Dual Mode analysis for the following reasons: (1) it is designed especially to handle noise from aircraft, whereas the Dual Mode study deals exclusively with ground modes; (2) the three noise exposure measures are insensitive to the existing ambient noise level (an acceptable characteristic in the case of airports, where background noise is insignificant relative to aircraft noise, but not in the case of ground mode settings, where the difference between transportation-related and ambient noise may be small); (3) the model allows very loud noise levels for low numbers of occurrences, so that it would tend to undervalue the impact of noisy buses operating infrequently during off-peak periods.

6.3.4 Noise Pollution Envelope Approach

The next noise evaluation method is applicable to ground modes and does consider background noise. It involves two steps: the generation of one or more noise pollution contours corresponding to specific noise levels and the calculation of the number and type of people, households, or businesses contained within these contours. This calculation can either be done in a very aggregate manner -- e.g., by multiplying the area within the contour (called the noise pollution envelope) less the right of way area times the population density of the land surrounding the noise source - or in a more detailed fashion, using Census block or tract data to count the actual number of people residing within the envelope and to determine their socio-economic characteristics.

6.3.5 Rand STAR Study Approach

The Rand STAR Study[76] expanded upon the noise pollution envelope approach by using a two-pronged criterion of community noise annoyance: the Perceived Noise Level (PNL) for single loud occurrences and the Noise Pollution Level (NPL) for recurring noise.* A household was considered excessively annoyed if it was located in an area where the PNL exceeded 98 PNdB or the NPL exceeded 87 PNdB. In the case of a transportation alternative producing fewer than 10 noise occurrences per day, a contour was drawn corresponding to 98 PNdB; where the number of occurrences exceeded 20, an 87-PNdB contour was generated; and for the in-between case, both contours were drawn, and the one farthest from the noise source was used as the boundary of the noise pollution envelope.

The specific methodology used by Rand to evaluate the noise impact of high speed ground transportation alternatives (TACV and Autotrain) consisted of the following steps:

1. The exact HSGT route was laid out on large base maps.
2. Approximate linear segments were defined according to guideway type (elevated vs. at-grade), vehicle speed, lane use, and right of way required.
3. The noise output of each alternative was calculated at designated distances from the noise source based on characteristics of the noise source and the ambient noise level.
4. Noise contours were generated corresponding to the PNL and/or NPL threshold levels.

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*The noise pollution level, developed by Robinson, is defined as:

$$L_{NP} = L_{eq} + 2.56\sigma$$

where L_{eq} is the mean value of the noise level over a specified period and σ is the standard deviation of level fluctuation over the same period. (28,p.3) The advantage of this noise impact measurement over the noise exposure forecast is that it considers the background noise level and treats duration in a general manner (not specific to a mode) and thus is applicable to the entire mix of transportation noises to which a community and individuals are exposed. Both the NPL and NEF measurements suffer from the disadvantage of allowing very loud noise levels for low numbers of occurrences; hence the need for the second criterion of annoyance, the PNL.

5. Meanwhile, envelope polygons 1/2 mile or one mile wide were drawn straddling the HSGT route and then superimposed by a CALCOMP plotter on maps showing Census block groups. First-count Census data for the block groups included within each polygon was summed, and the resulting number divided by the total area of the polygon to yield segment density tapes. The particular Census items analyzed were the number and type (income/ethnic categories) of households; the income distribution for each block group was derived from the value of housing occupied (since first-count Census files, the only ones available at the time of the STAR Study, do not contain income data).

6. The area within noise contours was multiplied by the appropriate segment density of households by type to produce a table of output similar to the following:

NUMBER OF HOUSEHOLDS IMPACTED BY HSGT SYSTEM A*

	Criterion		
Households Impacted	NPL	PNL	Dual
Total	X	X	X
White	X	X	X
Black	X	X	X
Other	X	X	X
Residential Property Value($$10^6$)			
Low Income	X	X	X
Middle Income	X	X	X
High Income	X	X	X

6.3.6 Dual Mode Study Approach

Rand's basic methodology appeared to be quite appropriate for the Dual Mode noise analysis because it used two acceptable measures of noise annoyance and provided for a socio-economic evaluation of

*Number which were not already adversely impacted by the base systems (highway and conventional take-off and landing air systems).

the noise impact. However, certain modifications were necessary in order to substitute projected 1990 demographic data for 1970 Census data. Below is a description of the procedure used to analyze noise impacts for Dual Mode systems operating singly or in combination with conventional transportation modes (freeways, railways, rapid transit lines):

1. The exact Dual Mode network was laid out on large-scale U.S. Geological Survey maps.

2. Individual guideway segments were defined according to construction type (elevated/at-grade/below-grade), land use type, number of lanes, vehicle speed, guideway location (by itself, along freeway, etc.), and width of existing right of way.*

3. Meanwhile, various possible combinations of vehicle, roadway, and noise receiver characteristics for conventional and Dual Mode alternatives (engine type, vehicle speed and headway, guideway width, barrier height and location, guideway location with respect to conventional modes, receiver height) were fed into the TSC Highway Noise Prediction Model[108], or the train noise model, which then generated the noise output of each system configuration in dBA at various distances from the noise source.

4. Residential noise annoyance criteria were established for assessing the comparative intrusiveness of Dual Mode alternatives: for both the single event and cumulative impact criteria the threshold values selected were 80 dBA for daytime and 70 dBA for nighttime operation.

*See Volume IV, Chapter 3.2.4, for a complete list of subcategories within each classification code and a description of how the TEAM model calculates noise impacts.

5. These criteria were superimposed on plots of the data generated in Step 3 to obtain the daytime and nighttime gross impact distances (GID) for each system variant (the distance outward from the centerline of guideway in which a noise impact exists).

6. For system configurations where the Dual Mode guideway was in the median strip of or elevated above a surface arterial, freeway, railway, or rapid transit system, the gross impact distance for the conventional mode was subtracted from the gross impact distance for the Dual Mode system to obtain the net noise impact distance due to Dual Mode.

7. Using the right of way characteristics, land categories, construction types, and speeds defined for the Dual Mode network, a daytime and nighttime noise pollution envelope was generated for each non-tunneled segment located on developed land.

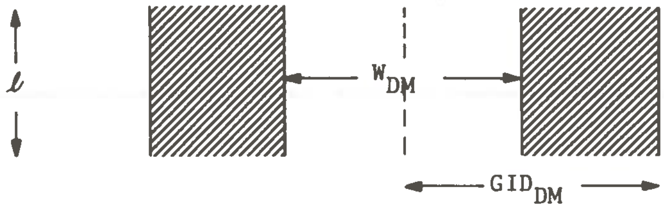
8. The net impacted area (NIA) was determined by taking the total area of the noise pollution envelope minus the area of transportation right of way. Figure 6-1 on the following page shows the procedure for calculating the net impacted area for various possible Dual Mode guideway locations.

9. The net impacted area associated with each segment was multiplied by the appropriate category of 1990 net residential density to yield the number of noise impacted households. Per-segment household impacts were then summed to obtain Dual Mode network totals.

A more complete discussion of Steps 3 to 5 is presented in Appendix F, "Development of Input Data for Noise Impact Calculations." Tables showing the gross impact distance for Dual Mode and conventional system configurations are also contained in this appendix.

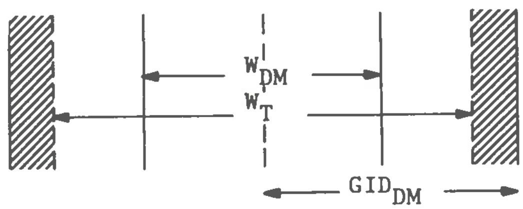
The procedure for determining the number of households which would be impacted by noise from the highway and transit additions planned by 1990 was basically the same as the methodology used for

DUAL MODE GUIDEWAY ON NEW RIGHT-OF-WAY



$$NIA = (2\ GID_{DM} - W_{DM})\ (\ell)$$

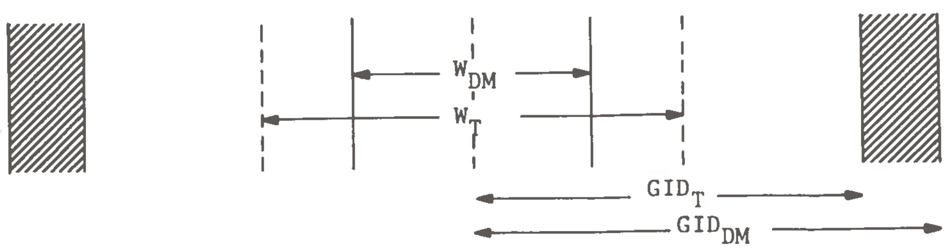
DUAL MODE GUIDEWAY ON ABANDONED RAIL RIGHT-OF-WAY



$$NIA = (2\ GID_{DM} - W_T)\ (\ell)$$

$$\text{IF } 2\ GID_{DM} \le W_T,\ NIA = 0$$

DUAL MODE GUIDEWAY ON HIGHWAY, OPERATING RAIL, OR TRANSIT RIGHT-OF-WAY



$$NIA = 2\ell\ (GID_{DM} - GID_T)$$

$$\text{IF } GID_{DM} = GID_T,\ NIA = 0$$

LEGEND

ℓ	= SEGMENT LENGTH
W_{DM}	= WIDTH OF DUAL MODE RIGHT-OF-WAY
W_T	= WIDTH OF EXISTING TRANSPORTATION RIGHT-OF-WAY
GID_{DM}	= GROSS NOISE IMPACT DISTANCE FOR DUAL MODE
GID_T	= GROSS NOISE IMPACT DISTANCE FOR EXISTING TRANSPORTATION FACILITY
NIA	= NET IMPACTED AREA

Figure 6-1. Procedure for Determining Net Impacted Areas

Dual Mode baselines (first example in Figure 6-1), except that calculations were based on the combined mileage of sections having similar characteristics rather than on individual segments. Using available information on planned locations,[11,61] the total freeway and transit mileage was subdivided by land use type and construction type; surface arterials were assumed to be at-grade and to have the same land use breakdown as freeways. Arbitrary right of way widths were assigned for each system.

Since the noise analysis for Dual Mode alternatives and the 1990 plan considered only the noise emanating from newly constructed facilities,* it was not possible to come up with systemwide comparisons. Instead, the noise results were used to determine how many fewer households would be impacted by building Dual Mode vs. going ahead with the 1990 highway and transit plan.

6.4 ACCIDENTS

The relative safety of the Dual Mode baselines and the 1990 plan was measured in terms of the annual number of traffic accidents and fatalities for the region. The basic procedure for calculating accidents and fatalities for each Dual Mode system was to multiply the annual travel on highway, transit, and Dual Mode (expressed in vehicle miles or person trips) by the respective accident and fatality rates. Highway computations and results were stratified by freeways vs. surface arterials; transit calculations were classified by type of transit system; and accidents and fatalities on Dual Mode were computed for on- vs. off-guideway travel.

*Moreover, it should be noted that no noise impacts were calculated for the off-guideway portion of the Dual Mode network. Considering the personal vehicle components of the Dual Mode baselines, the net effect of Dual Mode traffic on local street noise levels would be zero, since Dual Mode trips would be substituting for auto trips. The only situation which might give rise to additional noise impacted households would be off-guideway bus operations in an area which formerly had only automobile traffic.

The highway and transit components of the 1990 plan were handled in the same manner as the highway and transit portions of the Dual Mode systems.*

Accident and fatality data for highways was derived from the Interstate System Accident Research Study-1 by Julie Fee et al. of FHWA[25], which in turn was based on 1969 data from 40 states. This report contains tables showing accidents, injuries, and fatalities per 100 million vehicle miles of travel (VMT) by area type, type of section (Interstate/non-Interstate) type of highway (number of lanes, divided/undivided), and average daily traffic grouping (ADT), for a normal mix of autos, trucks, and buses. First, fatality and injury rates from the table were adjusted to fatal accident and injury accident rates using conversion ratios for Massachusetts taken from Table III of Reference[101]. Then the rate of property damage accidents per 100 million VMT was calculated by subtracting fatal and injury accident rates from total accidents per 100 million VMT. The next step was to condense the rates for each type of section and highway into two rates for surface arterials and freeways by means of weighted averages. Data from Tables FM-110 and INT-110 of Highway Statistics/1969[96], showing surface mileage by number of lanes and ADT for the traveled way of the Federal-Aid Primary System and the Interstate System, respectively, were manipulated to develop weighting factors (in the form of daily VMT values) for this purpose.

Figure 6-2 presents Massachusetts highway accident rates and weighting factors for 9 ADT classes; by keeping these rates and factors intact for each ADT class, it was possible to obtain peak/off-peak rates corresponding to traffic conditions on each type of road. The rates actually used in the Boston analysis are given on the following page.

*See Volume IV, Chapter 3.4.6 for a complete description of how the TEAM model calculates accidents and fatalities for highway, transit, and Dual Mode.

Freeways	Peak Period	Off-Peak Period
Fatal accidents per 100M VMT	2.00	2.00
Injury accidents per 100M VMT	100.00	67.00
Property-damage-only accidents per 100M VMT	192.00	129.00
Fatalities per 100M VMT	2.70	2.60
Injuries per 100M VMT	157.00	104.00

Surface Arterials	Peak Period	Off-Peak Period
Fatal accidents per 100M VMT	2.00	3.00
Injury accidents per 100M VMT	175.00	198.00
Property-damage-only accidents per 100M VMT	411.00	458.00
Fatalities per 100M VMT	2.40	2.90
Injuries per 100M VMT	278.00	314.00

These rates were applied to the peak and off-peak freeway and surface arterial VMT to obtain the total number of accidents (by type), fatalaties, and injury cases by peak, off-peak, daily, and annual period.

Transit accident rates were developed from information contained in the American Transit Association publication Comparative Operating Accident Rates for First Six Months 1971-1970.[9] The A.T.A. data provided two types of accidents rates by mode -- traffic accidents per million miles operated and passenger accidents per million passengers carried--as well as the number of vehicle miles operated and the number of passengers carried for 81 transit companies representing one or more of the following modes--bus, trolley coach, street car, and rapid transit.

To obtain traffic and passenger accident rates for each mode representative of both half-year periods and all companies having operations in that particular modal category, a weighted average was computed of each company's rates for 1971 and 1970 and then

Type of Highway	1-19	20-39	40-79	80-159	160-239	240-359	360-519	520-759	760+
	ADT (in hundreds of vehicles)								
Freeways -- all cities									
Accidents per 100 m.v.m.	-	141	134	202	189	158	198	294	239
Fatalities per 100 m.v.m.	-	7.7	4.1	3.5	3.2	2.6	2.6	2.7	1.0
Injuries per 100 m.v.m.	-	80	68	95	104	79	104	157	134
Surface arterials -- all cities									
Accidents per 100 m.v.m.	342	524	552	646	659	588	-	-	-
Fatalities per 100 m.v.m.	0	6.8	4.6	3.9	2.9	2.4	-	-	-
Injuries per 100 m.v.m.	161	280	233	281	314	278	-	-	-
Massachusetts									
Freeways									
Fatal accidents per 100 m.v.m.	-	7	4	3	3	2	2	2	1
Injury accidents per 100 m.v.m.	-	51	43	61	67	51	67	100	86
PDO accidents per 100 m.v.m.	-	83	87	138	119	105	129	192	152
Surface arterials									
Fatal accidents per 100 m.v.m.	0	6	4	3	3	2	-	-	-
Injury accidents per 100 m.v.m.	101	176	147	177	198	175	-	-	-
PDO accidents per 100 m.v.m.	241	342	401	466	458	411	-	-	-
Weighting factors (estimated daily VMT in hundreds)									
Freeways	-	5,030	36,040	163,375	231,640	358,560		1,181,520	
Surface arterials	5,734	62,630	325,680	905,725	640,440	558,030			

Figure 6-2. Highway Accident, Fatality, and Injury Rates (1969)

a weighted average of all companies' combined 1970/71 rates within a mode was calculated. In the case of traffic accident rates, vehicle miles operated were used as a weighting factor, and for passenger accidents, passengers carried were used as a weighting factor.

Figure 6-3 shows the results of these computations as well as the weighting factors. It will be noted that the bus traffic accident rate is rather high compared to the surface arterial accident rate of 342-659 accidents per 100 million vehicle miles, or about five accidents per million vehicle miles. This more than tenfold difference can be attributed to a number of factors: (1) according to the ATA Statistical Department, the transit traffic accident rate actually reflects involvements rather than accidents (i.e., a two-bus collision would be reported as two traffic accidents, whereas in the case of the highway data, a two-car or a car-bus collision would be counted as one accident); (2) transit vehicle operators are required to report every mishap, no matter how minor, so that the company will have something on record in the event of litigation; in contrast, the bulk of minor highway accidents go unreported, due to rather lenient legal reporting requirements (only accidents involving death, injury, or property damage over some specified amount have to be reported) and people's reluctance to report even the more serious accidents (involving larger amounts of property damage) for fear of insurance increases; and (3) buses tend to run along the most congested routes within a city and to require the most difficult maneuvers (pulling in and out of the moving lane of traffic), whereas the vehicles comprising the highway surface arterial rates are fairly evenly distributed throughout the city and stay in the moving lane of traffic.

Transit fatality rates were taken from a background memo prepared for the TRANS Study,[37] which in turn obtained these rates from ATA bus, trolley, and street car data[8] and data on the subway systems of New York, Boston, and Philadelphia. Figure 6-4 shows transit fatality rates by mode which were used in the TEAM model.

Accident Rates and Weighting Factors	Bus	Trolley Coach	Street Car	Rapid Transit
Traffic accidents per million miles operated (m.v.m)	68.80	117.68	92.48	0.67
Vehicle miles operated (000)	664,169	24,700	22,606	442,998
Passenger accident per million passengers carried	6.47	5.55	2.66	5.75
On-vehicle accident rate	6.47	5.55	2.66	1.83
Station accident rate	-	-	-	3.92
Passengers carried (000)	2,533,239	165,071	150,343	1,838,379

Figure 6-3. Transit Accident Rates (1970/71)

Fatality Rates and Weighting Factors	Bus, Trolley Coach, Street Car*	Rapid Transit**
Total fatalities per million passenger trips	0.026	0.15
Passenger fatality rate	0.003	0.15
Non-passenger fatality rate	0.023	-
Passengers carried (000)	5,981,000	1,626,000

*Includes trolley coach and street car, but predominantly motor bus. Based on data from American Transit Association, Estimates of Fatalities...Transit Industry, Calendar Year 1968, Washington, D.C., April 24, 1969.[8]

**Based on data for New York, Boston, and Philadelphia subway systems.

Figure 6-4. Transit Fatality Rates (1968)

It should be noted that the majority of the 240 passenger deaths occurring on the three subway systems in 1968 were attributed to a category called "fall or jumped to tracks" -- in other words, most deaths occurred in the station rather than on the train.

The procedure for calculating transit accidents and fatalities was to multiply the VMT for each mode by the respective accident and fatality rates. Even though the rates were not differentiated by peak/off-peak period, the computations and results were stratified by the same four temporal periods as the highway results by using VMT stratifications.

For Dual Mode systems, accidents and fatalities were computed separately for on- vs. off-guideway travel. Off-guideway calculations were based on either highway (automobile) or transit (bus) rates, depending on the nature of the Dual Mode vehicle. In the case of accident calculations, the highway and bus rates were applied to the total off-guideway VMT (of loaded and empty vehicles) for the respective vehicle types.* In the case of fatality calculations for automobile-like vehicles, the highway rate was multiplied by the loaded vehicle VMT, reflecting the fact that personal mishaps would occur only on vehicles carrying passengers. Since Dual Mode bus fatality calculations were based on rates per person-trip, there was no need to apply a loaded/total VMT factor; however, it was necessary to adjust the total number of person-trips downward to reflect just the off-guideway portion of the person-trip.

Since the guideway portion of a Dual Mode trip encompasses some very novel transportation features--e.g., close vehicle headways; automatic command and control of speeds, merging and demerging; elimination of the "human element" in driving -- it did not seem appropriate to apply accident and fatality rates based on one or more existing transportation modes. Yet at the same time it would have been impossible to develop realistic rates without detailed knowledge of the operating characteristics of the system, specifically of the command and control system. Thus, a decision was made to analyze on-guideway accidents and fatalities parametri-

*Small vehicle off-guideway VMT was stratified by freeways vs. surface arterials.

cally, varying rates through a range that included those of air carriers, rapid transit, highway, and bus systems and the idealized accident-free (zero rate) case.

Figure 6-5 shows the accident and fatality rates per million VMT used in the sensitivity analysis. Airline rates were derived from National Transportation Safety Board data on certified route air carriers for the period 1965-70; transit rates were based on ATA data for 1968, and highway rates were derived from FHWA data for 1969. Since accidents are a function of vehicle travel, a single rate for each conventional mode could be used for all three types of Dual Mode vehicles (small vehicle, minibus, 20-passenger bus); however, since fatalities are related to the passenger occupancy factor as well as vehicle travel, it was necessary to adjust the fatality rates according to the ratio of average occupancy of the Dual Mode vehicle in question to that of the conventional mode. The following occupancy factors were used:

Mode	Average Occupancy (Passengers)
Air Carrier	56
Rapid Transit	22
Bus, Trolley, Street Car	9.8
Small Vehicle	1.45
Minibus	9
20-Passenger Bus	12.5

On-guideway accidents and fatalities were then calculated as a function of on-guideway VMT. As in the case of off-guideway calculations, the VMT of loaded plus empty vehicles was used for computing accidents, whereas only the loaded vehicle VMT was used to compute fatalaties.

In addition to accident and fatality calculations for on- and off-guideway Dual Mode travel, the number of station accidents was determined as a function of Dual Mode person trips. As shown in Figure 6-3, rapid transit systems experience 3.92 passenger accidents in stations per million passengers carried. It seemed

Mode	Traffic Accidents Per Million VMT	Passenger Fatalities Per Million VMT	Adjusted Fatality Rate for Small Vehicles	Adjusted Fatality Rate for Minibus	Adjusted Fatality Rate for 20-Passenger Bus
Zero Accident Rate Case	0	0	0	0	0
Air Carrier (Certified Route)	0.0265	0.0819	0.00212	0.01316	0.01828
Rapid Transit	0.67	0.6	0.0355	0.24545	0.34091
Bus, Trolley Coach, Street Car	71.36*	0.098	0.01451	0.09009	0.12513
Highway	4.2	0.025	0.025	0.15517	0.21352

*The traffic accident rate for buses was far out of line with the rates for the other modes and therefore was not included in the sensitivity analysis.

Figure 6-5. Accident and Fatality Rates Used in On-Guideway Sensitivity Analysis reasonable to use a rate for Dual Mode half that for rapid transit, because in general passengers are in stations only on the CBD end of their trip.

6.5 ACCESSIBILITY

Perhaps the initial question which arises concerning accessibility is its suitability as a criterion for evaluating alternative transportation systems. Since the primary function of an urban transportation system is to move people and goods efficiently and easily throughout the metropolitan area -- and, moreover, since one of the four goals of the Department of Transportation is "economic efficiency in transportation"[92] -- it would seem highly appropriate to compare alternative proposals in terms of the degree to which they serve the mobility needs of the urban population.* Furthermore, it is useful to disaggregate the population according to socio-economic characteristics such as income, age, employment status, car ownership, and residential location and to distinguish mobility requirements by trip purpose so as to judge the performance of the transportation system from the standpoint of special interest groups (e.g., ghetto residents, the elderly). Rather than evaluating alternative systems on the basis of their impact on overall mobility (that is, cohesiveness at the metropolitan level), the analyst can compare them in terms of how well they link particular groups of people to employment, educational, commercial, recreational, and social opportunities.

Among the recent studies on new transportation systems, only two made an attempt to quantify accessibility. Rand's study on short haul transportation in California[76] did not examine mobility per se but did contain a tabulation of the number and percentage

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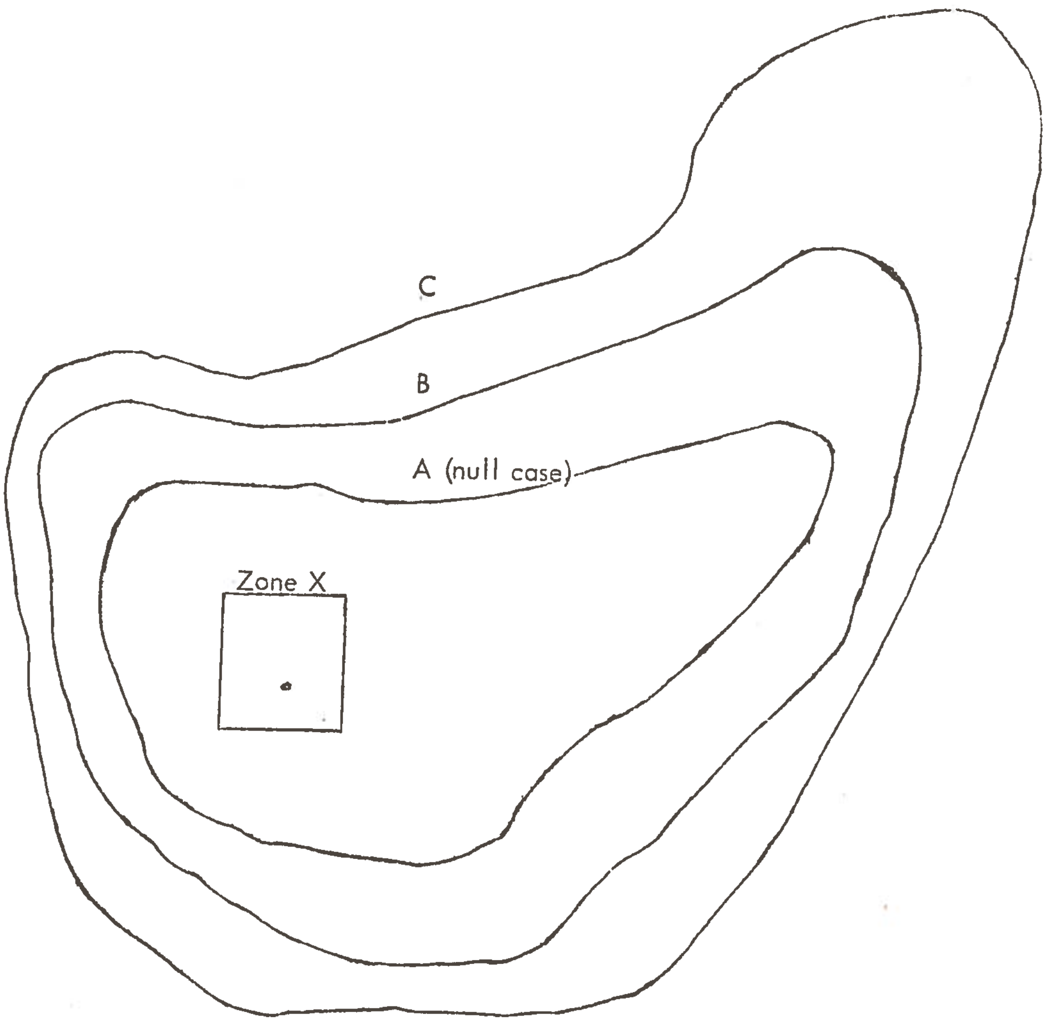
*It should be noted that the terms accessibility and mobility both refer to the impact of a transportation system on the ease, efficiency, or possibility of travel from one point to another within the area served. There is, however, a semantic difference between them -- accessibility being an attribute of a location, mobility being an attribute of a person or population group -- which dictates which term should be used in a particular context.

distribution of travelers by trip purpose and income which could be considered a proxy measurement of mobility in the sense of showing which groups of the population would use the proposed transportation systems.

Continuing along the lines of Rand's methodology, one could envision using a number of other surrogate measures of mobility -- for example, number of trips, vehicle or passenger miles of travel, and vehicle or passenger hours of travel, each stratified by trip purpose and peak/off-peak period. The analysis of the above variables, while permitting a rank ordering of alternative systems, would be of too broad a nature to indicate the specific service - related merits or shortcomings of alternative proposals.

The approach used in the General Research Corporation (GRC) study[31] specifically addresses the problem of accessibility and, moreover, can be applied to particular subsegments of the population and sub-areas of the city. This approach consists of generating accessibility indexes -- constant dollar cost and/or constant travel time contours (both measures of user cost) -- for each alternative and relating the area between any two contours to the number of specific activities, trip ends, or people. In other words, the incremental benefit of a particular alternative is specified in terms of incremental accessibility to certain desirable facets of urban living. GRC's approach can be illustrated with the following diagram on the next page, which contains hypothetical "iso-user cost" contours for three alternatives (one of which is the null case).

If the zone in question contained a major activity center (e.g., a university complex or office buildings), the procedure would be to count the number of people residing within contours A, B, and C, respectively, and then use the differences B-A and C-A to compare Alternatives B and C. The same procedure would apply if Zone X were inhabited primarily by low-income or elderly people, except that the area between contours would be translated



into the number of jobs or other opportunities rather than people. The above type of analysis could employ peak or off-peak iso-user cost contours, depending on the nature of the population origin or activity destination (e.g., peak period contours for evaluating ghetto residents' access to employment opportunities).

The GRC study uses isochrones (constant travel time contours) of 30 minutes to generate the following accessibility data for each system:

Group/Area	Criterion	Total	Results (actual numbers) Central	Urban	Suburban
Service to Disadvantaged					
Poor	# nearby jobs*	X	X	X	X
Aged	# other destinations**	X	X	X	X
Zone 27 (ghetto area)	# nearby jobs*	X	X	X	X
	# other destinations**	X	X	X	X
Zone 65 (ghetto area)	# nearby jobs*	X	X	X	X
	# other destinaations**	X	X	X	X

Accessibility to Special Zones		Peak Hour Public	Peak Hour Private	Off-Peak Hour Public	Off-Peak Hour Private
CBD Zone 38	# people	X	X	X	X
University 68	# people	X	X	X	X
Airport 1	# people	X	X	X	X
Hospital 10	# people	X	X	X	X

*Number of jobs which can be reached via public transit in 30 minutes during peak hour.

**Number of other destinations which can be reached via public transit in 30 minutes during off-peak hours.

GRC's basic two-pronged approach of counting jobs and other destinations accessible from disadvantaged zones and of counting the number of people living within a specified range of major activity centers seemed quite satisfactory for the Dual Mode accessibility analysis in that it could provide a meaningful and effective method of quantifying mobility using only a limited number of cost contour centroids. (Time and/or budgetary constraints generally preclude the generation of isochrones for each zone in the metropolitan area.)

The two-part methodology employed in the Dual Mode study involved a slight modification and expansion of the GRC approach.

A. Accessibility to Major Activity Centers

The analysis of major activity centers were designed to yield the same type of output as in the table above, but involved a larger number of activity centers: for the Boston study four sets of travel time contours* (peak vs. off-peak by public vs. combined public and private mode) were generated around a superzone in the approximate center of the CBD and around superzones containing Logan Airport, Northeastern University, Massachusetts General Hospital, Natick Mall (a large suburban shopping center) and Boston Garden (a sports arena). The area between contours was related to resident population, stratified by ethnic group (white, black, other non-white) and income level (low, medium, and high, corresponding to annual family incomes of less than $5,000, $5,000-14,999, and $15,000 or more, respectively).** In order to detect possible sensitivity of baseline ranking to trip length, the analysis was conducted for two values of travel time -- 20 and 40 minutes -- yielding a total of eight sets of isochrones.

*A set of contours consists of one isochrone for each alternative.

**Owing to the lack of projected per capita income data, the percentage breakdown by income level is based on the family unit. For an area where family size is unrelated to income, a percentage brekdown based on the family unit and family income is virtually identical to one based on per capita income (family income divided by number of family members); however, an area with large, low-income families and small, high-income families appears wealthier according to the family-based than the individual-based breakdown, and an area with the reverse correlation between family size and income appears poorer by the family-based breakdown.

B. Service to Transportation Disadvantaged Groups

The analysis of service to disadvantaged groups likewise expanded upon the GRC approach in dealing not only with the poor, the elderly, and hard-core ghetto residents but also with teenagers. Since these four groups tend to lack private transportation, the analysis was limited to public modes of transportation -- that is, the bus components of the baselines studied.

With regard to poor people, the most relevant criterion of accessibility is employment opportunities contained within peak-hour isochrones. However, since poor individuals tend to be ineligible for white-collar positions (largely because of educational and/or training deficiencies), the tally of jobs contained within the area included only blue collar positions.

The ghetto area analysis was in two parts: an employment accessibility analysis similar to the one used for the poor and a study of off-peak accessibility to other destinations. The index chosen to represent "other destinations" was nonwork trip attractions (the sum of personal business/shopping, social/recreactional, school, and non-home-based trips beginning in the travel time contour centroid -- the ghetto superzone -- and ending in the superzones comprising the area between isochrones).*

The mobility analysis for the young and the aged employed the same methodology as the study of ghetto residents' off-peak access to nonwork destinations; however, in the case of elderly people, the sum of nonwork trip attractions excluded school trips (the presumption being that people over 65 are generally not involved in formal education).

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*The use of non-work trip actions (also GRC's approach) has one serious shortcoming: since the distribution of trip ends throughout a city reflects travel times of conventional transportation systems, the potential benefits of a faster new alternative system tend to be understated. The ideal method of evaluating accessibility to other destinations would probably have been to use a detailed land use map to identify specific destinations (e.g., college, movie theater, zoo, department store) and then calculate a weighted sum of places (using total person capacity or gross retail sales as a weighting factor). However, this method would have required considerably more time and a greater level of detail than available for or warranted by this study.

The study areas for the Boston analysis of service to special groups, as well as the area selection criteria, are presented below:

Group	Criterion	Study Area
Poor	Cluster of suburban traffic analysis zones with lowest 1990 median worker income	Section of Quincy
Ghetto residents	Traffic analysis zone with highest percentage of population non-white and in the lowest quartile of income and education (as of 1960)	Section of Roxbury*
Elderly	Central/suburban traffic analysis zones containing Census tracts with highest percentage of people over 62 years of age (as of 1970)	1. Section of Brookline 2. Section of Lynn
Teen-agers	Central/suburban traffic analysis zones containing Census tracts with highest percentage of people under 18 years of age (as of 1970)**	1. Section of Dorchester 2. Section of Burlington

C. Data Sources and Detailed Methodology

The two major sources of secondary data for the Boston accessibility analysis were 1970 Census publications and transportation planning studies containing projected 1990 travel and socio-economic data at the traffic analysis zone level. The variables used to evaluate the area between contours were 1990 population (with racial breakdown based on the 1970 Census); the number of high-, medium-, and low-income families in 1990; 1990 "manufacturing and

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*This area of Roxbury was also analyzed in the GRC study.

**It would have been preferable to choose these study areas on the basis of the 12- to 18-year age group, since it is strictly teen-agers who constitute the transportation disadvantaged. However, data about this specific age bracket at the Census tract level was not available in printed form.

other" employment (total employment less retail, service, finance, insurance, and real estate employment)*; and 1990 trip attractions by trip purpose. These data were aggregated to the superzone level to correspond to the format of the travel time skim trees** used to generate isochrones.

Skim trees for the various Dual Mode baselines were created as part of the demand analysis and provided superzone-to-superzone total travel times for peak and off-peak periods. Comparable 1990 highway and transit skim trees were obtained from the ongoing Boston transportation planning study. In the case of major activity centers, the relevant consideration was peak or off-peak travel time from each outlying area to the superzone containing the activity center (only off-peak time for the sports arena), whereas the analysis of service to special groups was based on the travel time from the study area superzone to all surrounding superzones.

The procedure for quantifying accessibility for a particular baseline and activity center/special area consisted of these steps: (1) to determine from the appropriate skim tree(s) which superzones were within 20 to 40 minutes of the superzone in question (for peak and/or off-peak period, depending on the superzone); (2) to compare this list of superzones with the list corresponding to the 1990 highway and transit plan; and (3) to sum the population, employment, or nonwork trip ends associated with the incrmentally accessible superzones. This incremental, as opposed to total, approach reflected the fact that a Dual Mode system would be operating in conjunction with, not instead of, conventional transportation systems.

*It should be noted that "manufacturing and other" employment does not correspond exactly to what is commonly considered blue collar positions. To obtain the latter category would have required an occupational, as opposed to industry, breakdown of employment, which was not available for the 1990 time period at the traffic analysis zone level.

** A skim tree is a table of minimum time paths between various origin-destination pairs.

From the superzone classification list for each baseline, it was possible to generate various sets of travel time contours, which demonstrated the geographic difference in service levels among the alternatives studied.

D. Summary

Figure 6-6 summarizes the salient features of the Dual Mode accessibility analysis. Figures 6-7 and 6-8 show the location of the 12 travel time contour centroids used in the Boston analysis.

6.6 DISPLACEMENTS

The analysis of displacements was designed to serve two functions: first, to provide a rather general understanding of how the various Dual Mode alternatives compare in terms of land consumption, which in turn is related to the number of dislocations and disruptions; and second, to permit a specific ranking of alternatives from the standpoint of households and businesses displaced.

Both the generalized and detailed portions of the displacement analysis were based on coding of the guideway segments and corresponding facilities (including interchanges, terminals, maintenance and storage yards) for each Dual Mode alternative by geographic area, construction type, projected 1990 land use, and width of existing transportation right-of-way. For the Boston analysis, Metropolitan Area Planning Council maps as well as large-scale U.S.Geological Survey maps were used to classify Dual Mode right of way according to the following ten land use categories:

Land Use 1 - High density residential -- 15 dwelling units per net residential acre (d.u./n.r.a)*

2 - High density residential, on existing transportation facility (i.e., Dual Mode right-of-way is on, above, or under an existing highway

*Expressing density in terms of net residential acreage means that street and open space right-of-way has been excluded from the acreage of residentially zoned areas.

	Analysis of Accessibility To Major Activity Centers	Analysis of Service to Special Groups
Types of Origins/Destinations Considered	CBD Airport Suburban Shopping Center University Hospital Sports Arena	Central City Ghetto Poor Suburban Area Area with Large Teen-Age Population Area with Large Over-65 Population
Types of Contours Generated	20/40 Minute Peak/Off-Peak Travel Time Contours For All Baselines	20/40 Minute Peak/Off-Peak Contours for Public Vehicle Baselines
Criteria for Evaluating Baselines	Number and Socio-Economic Background of People Living Within Contours	Number of Jobs and Index Of Educational, Recreational, and Commercial Opportunities Contained Within Contours

Figure 6-6. Features of Accessibility Analysis

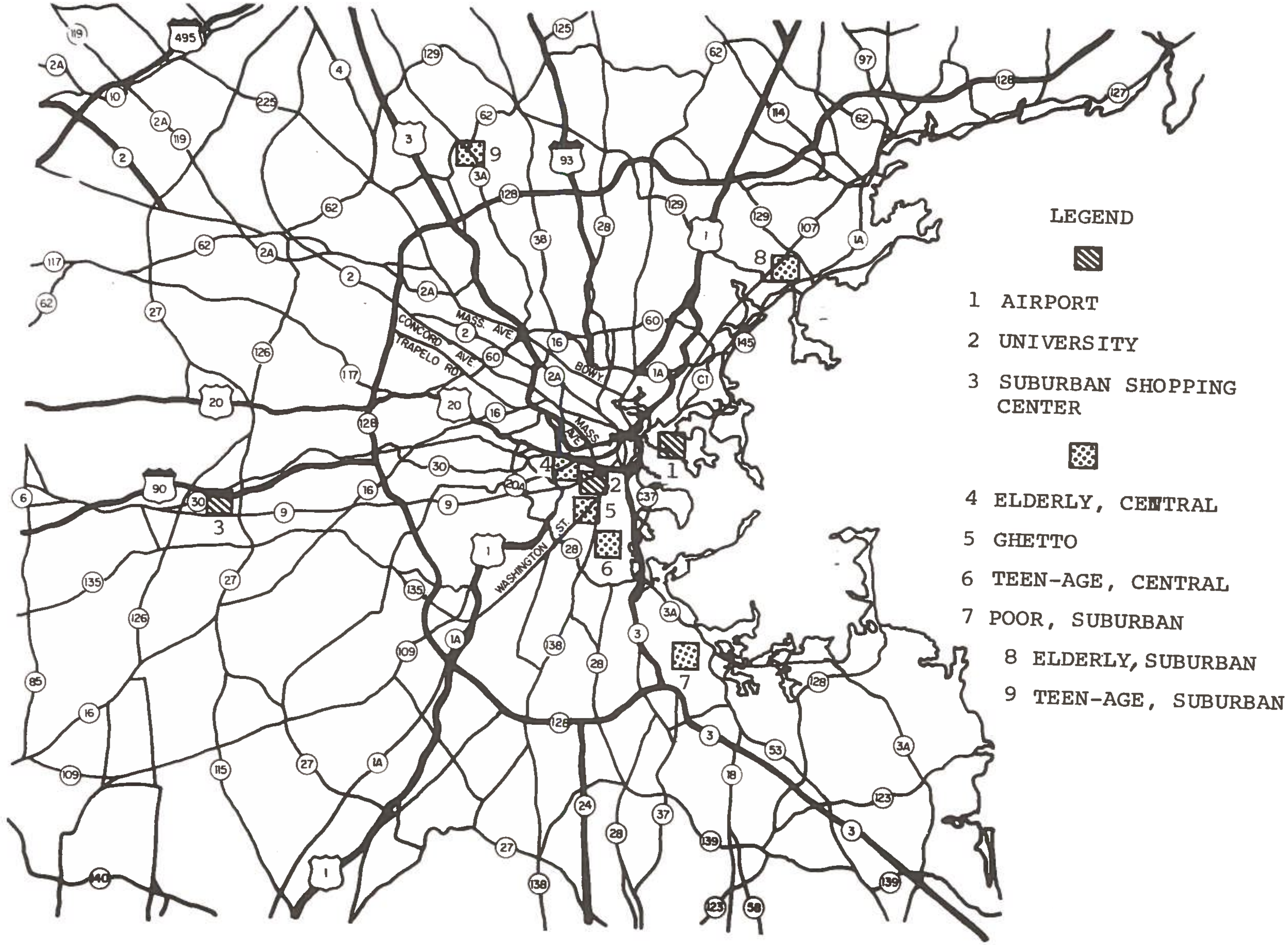

Figure 6-7 Study Areas for Boston Accessibility Analysis

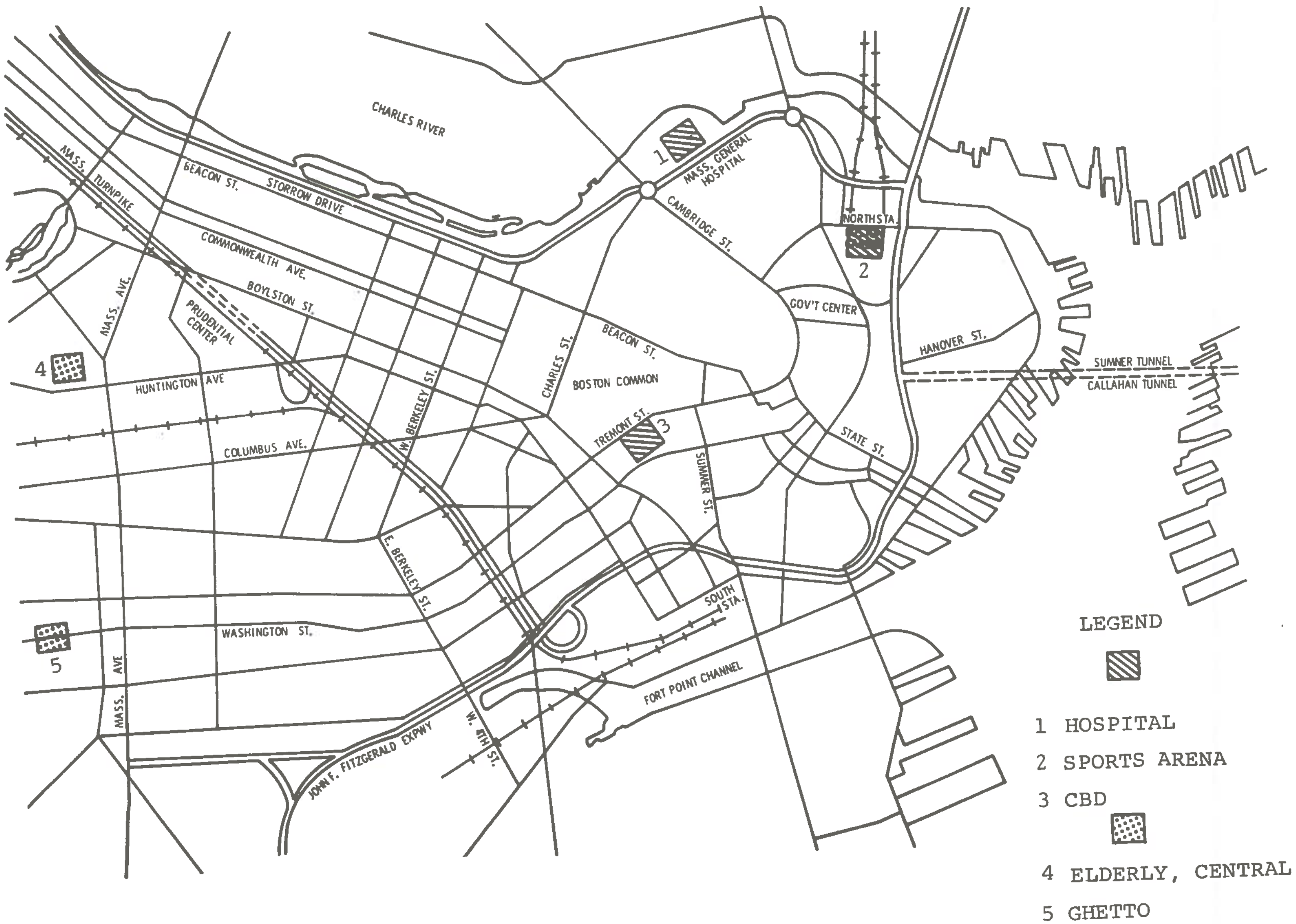

Figure 6-8 Study Areas for Boston Accessibility Analysis

or railroad line but is surrounded by high density residential land)

3 - Moderately high density residential -- 4.5 d.u./n.r.a.

4 - Moderately high density residential, on existing transportation facility

5 - Medium density residential -- 2.1 d.u./n.r.a.

6 - Medium density residential, on existing transportation facility

7 - Low density residential -- 1.2 d.u./n.r.a.

8 - Low density residential, on existing transportation facility

9 - Existing and proposed recreation, conservation, and open space (e.g, public or private parkland, bodies of water)

10 - Dual Mode right-of-way is on existing transportation facility, but surrounded by open space (Note: large railroad yards are classified as open space, because of nonresidential nature)

In the case of highway and transit additions included in the 1990 plan, coding was not performed on a segment-by-segment basis. Instead, the procedure was to classify freeway, surface arterial, and fixed-rail transit route mileage by geographic area, construction type, land use, and right-of-way width, and to calculate as well as classify right-of-way acreage for highway interchanges and transit parking facilities, terminals, and storage/maintenance yards.

The generalized land consumption analysis then consisted of comparing alternatives with respect to total route mileage, lane mileage and right-of-way acreage as well as mileage/acreage breakdowns. These numbers provided a good indication of the visual and spatial intrusiveness of alternative systems and thus could be used in the qualitative analysis of neighborhood appearance and character.

The second part of the displacement analysis provided a more detailed account of the impact of alternative systems by calculating the number of households and businesses displaced. The usual method of estimating displacements is to apply a rate for dislocations per mile of proposed construction. Displacement data on highways is rather abundant, because of the extensive mileage which has been built and the detailed records which have been kept.* However, a decision was made against using even a modified form of these displacement rates, and an alternative approach, involvoing average density figures corresponding to the land use categories listed above, was devised for calculating household displacements. There were two main reasons for not using per-mile displacement rates based on highway data: first, modifying the highway rates to reflect 1990 population densities, narrower Dual Mode way widths, and the additional acreage needed for Dual Mode terminals and yards would have involved as much work as devising and implementing a new technique; and second, even adjusted rates would have tended to overstate dislocations due to the Dual Mode network, which is located wherever possible on existing right-of-way.

The procedure for determining the number of households displaced by the Dual Mode guideway was: (1) to calculate the net displaced area of each non-tunneled segment on developed land by multiplying the segment length by the difference, if any, between the widths of the guideway and existing right-of-way; (2) to

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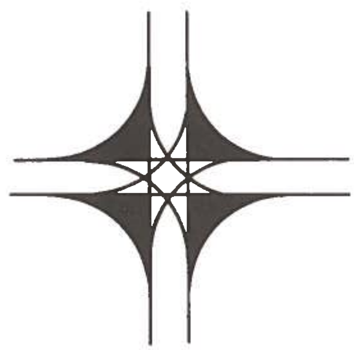
*The TRANS-Urban model[27] used FHWA records to urban Interstate dislocations for the two-year period up to October 1970 and average mileage figures for urban Interstate construction in a comparable period to obtain a nationwide average of 146 persons and 8 businesses displaced for each mile of urban freeway constructed. Another study done in FHWA[60] used PR-37 data (project status reports describing all phases of every highway project, including displacements and road miles) as well as anticipated Interstate displacement data for the period 1964-72 to come up with displacement rates for urban freeway and urban non-freeway facilities.

multiply the net displaced area associated with each segment by the appropriate category of 1990 net residential density to obtain the number of displaced households; and (3) to sum per-segment displacement figures to yield network totals.*

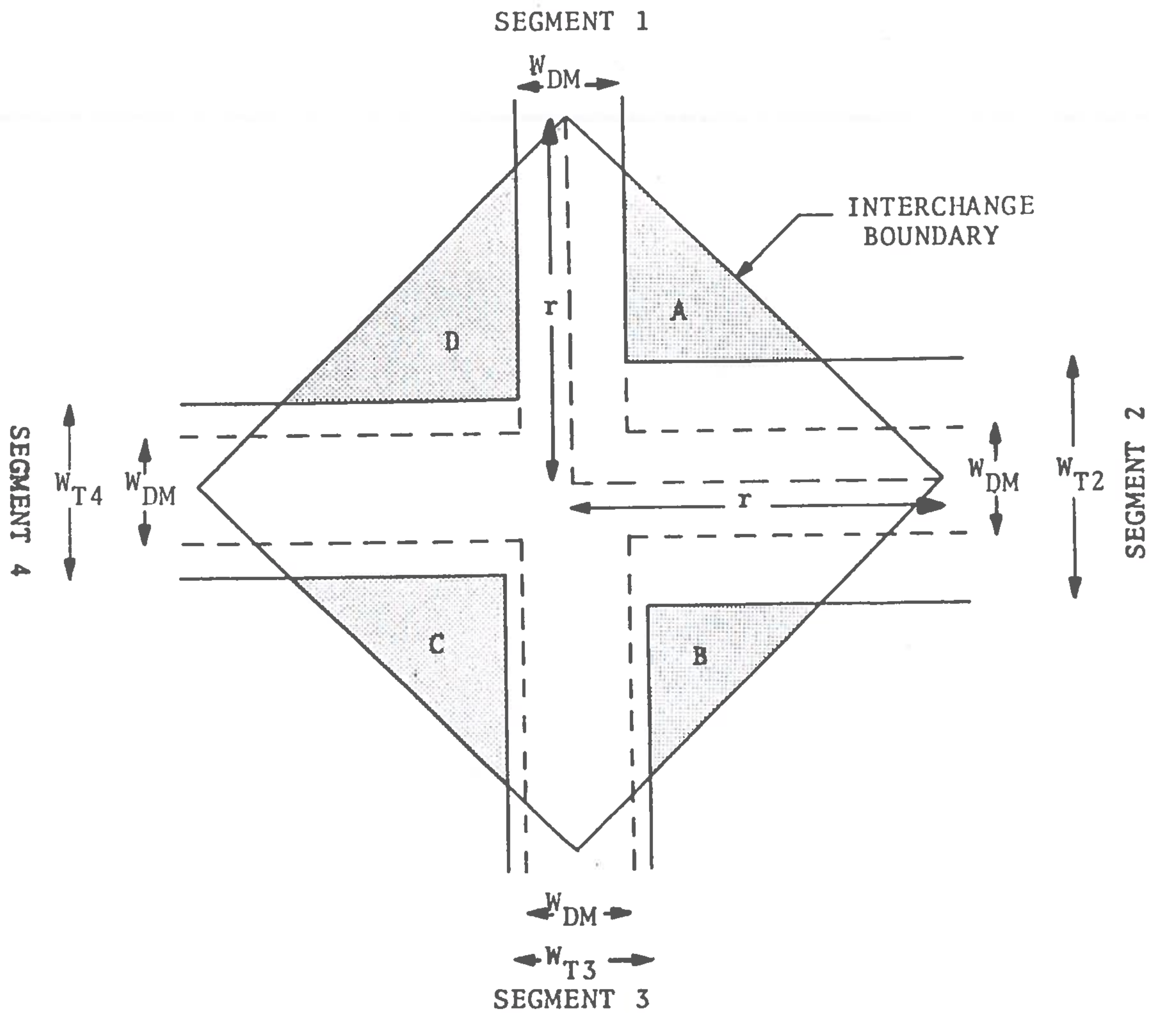
In the case of interchanges, it was necessary to calculate displacements in two stages: those attributable to the guideway itself and those attributable to the peripheral land needed for ramps. The figure below shows a four-way configuration of a Dual Mode interchange ("iron cross" design).



The unshaded area represents the two sections of intersecting guideway, and the shaded areas represent the additional land for ramps. The guideway-related displacements are computed by the TEAM model according to the method described in the preceding paragraph.

Figure 6-9 shows the method for calculating displacements associated with the ramp areas (which for computational purposes are assumed to have a triangular shape). The hypothetical interchange depicted is formed by the intersection of four segments, one of which is on new right-of-way and three of which are on existing

*See Volume IV, Chapter 3.2.3 for a description of how the TEAM model calculates guideway-related displacements. Displacements due to interchanges, terminals, and other facilities are not calculated by the model.



r = RADIUS OF CURVATURE FOR INTERCHANGE

W_{DM} = WIDTH OF DUAL MODE SEGMENT RIGHT-OF-WAY

W_{Ti} = WIDTH OF EXISTING TRANSPORTATION RIGHT-OF-WAY FOR SEGMENT i

AREA OF SHADED TRIANGLE A = $1/2 \left(r - \frac{W_{DM}}{2} - \frac{W_{T2}}{2} \right)^2$

AREA OF SHADED TRIANGLE B = $1/2 \left(r - \frac{W_{T2}}{2} - \frac{W_{T3}}{2} \right)^2$

NET DISPLACED AREA FOR INTERCHANGE (EXCLUDING DISPLACED AREA DUE TO FOUR GUIDEWAY SEGMENTS) = $\Delta A + \Delta B + \Delta C + \Delta D$

FOR T-TYPE INTERCHANGE, NET DISPLACED AREA = $\Delta A + \Delta B$

Figure 6-9. Interchange Displacement Calculation transportation right-of-way. Since the majority of the guideway and even part of the ramp acreage is located on existing right-of-way (which, of course, contains no residences), the net displaced area attributable to the ramp portion of the interchange is simply the sum of the four shaded triangles.

For terminals, acceleration-deceleration lanes, maintenance facilities, yards, and the control center, it was assumed that a facility was either on new right-of-way or totally contained within existing right-of-way (i.e., not straddling existing right-of-way). The total area of each facility was multiplied by the appropriate 1990 density to yield household displacements.

The procedure for calculating the number of household displacements due to the 1990 highway and transit plan was to multiply the combined route mileage of sections having similar construction type and land use codes by the appropriate right-of-way width and then to multiply the resultant area as well as the acreage for highway interchanges and transit-related facilities by the appropriate residential density.

The calculation of business displacements for the 1990 plan and Dual Mode alternatives included only roadway (guideway) displacements, because the available data was in the form of a displacement rate per mile rather than a density rate of businesses per acre. The basic displacement rates for an at-grade, elevated, and tunneled 6- to 8- lane freeway in the central city (from Reference 27) were converted to suburban rates by means of a 1960 population density-index, and then all values were adjusted according to the ratio of planned highway, transit, or Dual Mode right-of-way width to the assumed freeway width.

6.7 TAX REVENUE CHANGES

In light of the ever expanding financial requirements of urban areas, it is extremely relevant to examine the effects of Dual Mode vs. the 1990 plan on the community tax base and tax revenues. In the short term at least, "...the removal of private property from the tax rolls for right-of-way purposes reduces the taxable base of a community.... In essence, the loss of a portion of the taxable base of a community entails a short-run cost which must be borne by the community in the form of either higher taxes [a higher tax rate] or reductions in the level of community services."[106] On the other hand, any increase in the value of taxable land expands the tax base, resulting in either better (and/or more) services or a lower tax rate.

For the Dual Mode analysis, two categories of tax revenue changes were calculated: tax revenue losses associated with right-of-way acquisition and tax revenue changes related to land value changes (which in turn are determined by accessibility and noise characteristics of the various alternatives). The basic procedure for determining tax revenue increases or decreases was to multiply the change in the property tax base (expressed in terms of full market value, 1970 dollars) by the 1970 tax rate. Tax data for the Boston region was derived from several sources (12, 14, 49, 50, 54) containing the 1970 assessment, full value property tax rate, MBTA deficit, and Metropolitan Distirct Commission (MDC) deficit by city or town in the Boston region. The 152 communities were classified into three geographic area categories -- CBD, urban, and suburban -- according to the boundaries established for the Boston analysis, and then an average composite tax rate (reflecting contributions to the transit system and the MDC as well as to the general treasury) was computed for each geographic area. These tax rates and the number of communities in each class are given below:

	Composite Tax Rate (per $1,000 of full market value)
CBD 1	125.63
Urban 23	64.52
Suburban 128	45.91

The calculation of tax revenue losses due to Dual Mode right-of-way acquisition was based on the coding of guideway segments and related facilities by geographic area, construction type, projected 1990 land use, and land cost. The ten possible land cost codes fell into two categories, the first five applying to nontaxable land and the last five applying to taxable land. The following codes were used for the Boston analysis:

	Cost per Acre
1 - Public property (e.g., highway, open space)	$ 0
6 - Railraod R.O.W.	11,100
7 - Low-cost area (geographic area 3, suburban)	32,200
8 - Medium-cost area (geographic area 2, urban)	72,500
9 - High-cost area (geographic area 1, CBD)	428,000

The procedure for computing tax losses due to the guideway was (1) to calculate the taxable acreage of each non-tunneled segment having a land cost code between 6 and 9 by multiplying segment length by width; (2) to calculate the market value of land acquired on the basis of taxable acreage and land cost per acre; (3) to multiply the market value of land acquired by the tax rate corresponding to the segment's geographic area code; and (4) to sum per-segment tax loss figures to obtain network totals.*

The methodology for interchanges, terminals, maintenance yards, and other facilities was basically the same, except that calculations were done on the basis of individual facilities, rather than segments. In the case of the ramp area for interchanges (i.e., the diamonds comprising the area over and above that needed for the guideway component of the interchange), a distinction was made

*See Volume IV, Chapter 3.2.9 for a description of how the TEAM model calculates Dual Mode tax losses.

between portions of the diamonds on existing transportation right-of-way (which could be tax-yielding, such as railroad property, or non-tax-yielding) and portions located on new right-of-way (which could be tax-yielding, such as developed residential land, or not).

Tax losses associated with the 1990 plan were calculated as follows: first, the route mileage of non-tunneled highway and transit sections located on tax-yielding land was multiplied by the appropriate right-of-way width; next, the taxable acreage for highway interchanges and transit-related facilities as well as the taxable area associated with any were multiplied by the appropriate land cost category; finally, the total market value of land acquired in each geographic area was multiplied by the corresponding tax rate.

The procedure for determining tax revenue changes related to land value changes consisted of multiplying the incremental change in land value due to Dual Mode (relative to the 1990 plan) for each geographic area type by the appropriate tax rate. As is explained in Chapter 6.8 of this volume, land value changes are assumed to come about because of either accessibility improvements or noise impact reductions.

6.8 MONETARY EVALUATION OF IMPACTS

In order to calculate a meaningful benefit-to-cost ratio for each Dual Mode alternative it was necessary to convert several of the quantitative impacts into monetary terms. The process of deriving the monetary benefits/disbenefits of Dual Mode alternatives involved a number of assumptions regarding which impact items to monetize and what unit dollar values to use. For this reason, charts have been included in the "Costs and Benefits" section of each baseline discussion in Volume II, Chapter 3 showing the quantitative units of each type of impact, the assigned cost per unit, and the resultant total dollar benefit. The costed items included changes in travel time (including a special factor for driver relief), accidents, air pollution, household/business displacements, and land values (as well as tax revenue changes, described in the preceding section). The unit dollar values were either based on those used in previous studies (by the Federal Highway Administration, the Mitre Corporation, and the University of Toledo) or developed specifically for the Dual Mode analysis.

The dollar value of annual travel time savings was computed by multiplying the difference in regionwide passenger hours traveled for Dual Mode vs. the 1990 plan by $3.00 per hour and multiplying the truck driver time savings by $6.00 per hour. The value of time saved for automobile passengers is highly variable -- $0-14 according to the Stanford Research Institute [85] -- depending on such factors as the driver's income, the number of minutes saved, and the type of trip. However, the above values were selected because they were used by the Federal Highway Administration for the 1972 Needs Study, and they represented average values for all trip purposes, driver income levels, and time savings per trip.

Driver relief benefits were arrived at by valuing the vehicle driver hours traveled on the guideway at $1.50 per hour. Although there is a clear social gain when a driver is relieved from his piloting chores, the value of this "free time" is even more subjective than that assigned to travel time savings, since no Dual Mode system has operated so that such a value could be experimentally measured. The vaule was arbitrarily fixed at half the value of travel time savings, on the grounds that the time available to the driver when the car is operating under automatic control has the restriction that the driver cannot leave the car, whereas trip time saved can be used at the passenger's discretion.

Accident cost savings were calculated using an average cost for all accident types of $1,108 per accident. This figure was derived from 1965 highway accident cost data for the Washington, D.C. metropolitan area (as presented in Reference 33); the average cost of an involvement (which included loss of future earnings for injured or deceased persons) was converted into an average cost per accident by means of a ratio of involvements to accidents, and then the accident cost figure was escalated to 1970 price levels.

The annual cost to society of air pollution (in the form of damage to property, vegetation, health, and decrease in human lifespan), was computed on the basis of the following rates per ton for the various constituents:

Constituent	Cost per Ton
Carbon monoxide	$ 1.65
Particulates	205.17
Sulfur dioxide	250.30
Hydrocarbons	129.93
Nitrous oxides	50.89

These pollution costs were derived from data in a Mitre study[58] on 1968 national pollution output by type and total estimated costs corresponding to each type of pollutant. Although there is some uncertainty regarding the cost estimates (in particular, whether they fully reflect the adverse effects of pollution), the far more significant feature of these values is the relatively high cost associated with sulfur dioxide. For purposes of the Dual Mode analysis, it was assumed that all electric power would be supplied by coal-fired generating plants. On the basis of the above cost figures, the two baselines with electrically powered vehicles resulted in a higher pollution cost than the automated highway system whose vehicles have internal combustion engines; thus, the penalty for coal-fired plants tended to offset the potential benefits of electrical power (greater efficiency, localization of pollution, noise reduction, etc.). If the analysis had assumed an alternate source of electrical power in 1990 (e.g., nuclear fission), the relative ranking of the baselines would have changed depending on the values associated with nuclear waste and heat. The relatively high cost assigned to sulfur compounds therefore has the effect of making the power source assumption a very crucial determinant of total pollution costs. However, in view of the small proportion of total annual Dual Mode costs and benefits accounted for by pollution costs, the Mitre data appears adequate for this analysis.

Household and business displacement savings for Dual Mode vs. the 1990 plan consisted of relocation costs not incurred by the system owner ($1,604 per dwelling unit, $3,076 per business) as well as "aggravation" costs not borne by the displacees ($20,000 per dwelling unit). Relocation cost values were obtained from FHWA data on relocation assistance payments* to businesses and dwelling units in urban areas over the period of October 1, 1970 to June 30, 1971.[95] 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. Since this component of displacement cost savings accounts for only 10 to 16% of total incremental benefits due to Dual Mode, the cost-benefit results for the various baselines are not terribly sensitive to the value chosen. Total displacement cost savings relative to the 1990 plan were annalized at 10% assuming an infinite lifetime.

The increase in land values due to Dual Mode reflected two factors: improved accessibility to the CBD and a reduction in the number of noise impacted households. The accessibility-related change in land value was computed as follows. First, the communities comprising six radial corridors in the Boston region were identified, and the 1970 full market value per acre of developed

*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.

**Actually, 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?"

land was calculated for each community. Next, each community's value per acre was plotted against its distance (in miles) from the CBD, and a curve was fitted through the points. Using this graph it was possible to determine the percentage increase in land value per acre in response to a given, baseline-specific increase in a regionwide travel speed (which effectively reduces distance from the CBD) for various distance intervals relative to the CBD. The percent increase in value applicable to each ring was then applied to the full market value of all land within that ring, and the total increase in value for each ring was summed.

The noise-related change in land value actually consisted of savings in land value losses. This benefit was calculated by multiplying the savings in noise impacted households (realized by building Dual Mode instead of the 1990 plan) by 20% of the average value of a dwelling unit.* The 20% figure was based on a University of Toledo study of highway traffic noise[105] which reported that professional realtors expect one-family residences abutting an expressway to decline 20 to 30% in value. Since the tally of noise impacted households for Dual Mode and the 1990 plan included nonabutting households, the lower end of the range was selected.

The total increase in land value for each baseline relative to the 1990 plan was annualized on the basis of a 10% interest rate and an infinite lifetime.

*Based on data from Reference 11, the average value of a dwelling unit, by ring, is: $6,700 (CBD); $21,200 (urban); and $27,100 (suburban).

7. TRANSPORTATION ECONOMIC ANALYSIS MODEL

7.1 INTRODUCTION

7.1.1 Model Definition

The Transportation Economic Analysis Model (TEAM) is a cost accounting model that can be used to quantify the direct costs and impacts of all ground passenger transportation systems in an urban environment. Using as input system ridership data, quantitative units of subsystem and system elements, and corresponding unit-costs and unit-impact data, the model computes for output capital and operating costs and impacts for each transportation system under analysis. To a limited extent, it also sizes some system elements based upon input system descriptiors and operating characteristics. All cost and impact data generated by the model are accumulated, organized, and displayed in numerous output forms for subsystem, system and regional analysis.

7.1.2 Background and Objectives

Once the study objectives of the Dual Mode analysis were identified, a survey of existing transportation cost analysis models was undertaken to determine their applicability to this analysis. The need for a computerized model to aid in the analysis became apparent because of the rather high level of detail planned for the study, the number of Dual Mode baselines to be studied, and the anticipation of performing parametric analyses of input data. To conduct the analysis using manual computation would have been a horrendous task prone to innumerable errors.

The survey identified two models that most closely approximated the study requirements - the General Research Corporation (GRC) Model developed for the HUD Study, and the Federal Highway Administration TRANS-Urban Model. These models were investigated in depth and it was found that in both cases extensive program modifications would be required to increase the level of analysis detail. The GRC model costed transportation systems only at a high level of aggregation; the TRANS model was even more aggregate. The use of either of these models in this analysis was also ruled out for the following reasons in addition to their insufficient analytical detail.

- The TRANS model, available at the time, only considered highway transportation alternatives. A transit portion of this model was being developed but would not be available in the time frame required for the analysis.
- Documentation for both models was highly inadequate. Documentation of the program code and the model assumptions were not available.
- For both models, too many major changes, additions, and modifications were required. To perform these without a complete understanding of the models would have been a most difficult task.

As a result of the examination of these models, it was decided that a new model - the Transportation Economic Analysis Model - should be developed. To meet the objectives of the Dual Mode analysis and to be adaptable for future transportation cost analyses, the model was designed with the following characteristics:

- Capable of performing detailed cost analyses of new and existing ground passenger transportation systems at the regional level.
- Capable of analyzing and distinguishing between vehicle baselines of the same transportation system.
- Capable of automatically performing repeated analysis runs on parametric input data.
- Capable of performing base and parametric runs at low cost by using small amounts of core and low execution times.

7.1.3 Model Overview

The structure of the TEAM model parallels the structure of the Dual Mode analysis procedure. The analysis procedure called for comparing the costs and impacts of each Dual Mode baseline against corresponding costs and impacts of a base alternative (the 1990 plan). The incremental costs and benefits of each baseline relative to the 1990 plan were then used as the measures of comparison of one Dual Mode baseline against another. Thus for this analysis procedure, two independently executable cost programs were developed: the New System Cost Program, which computes and outputs costs and impacts related to each Dual Mode transportation system and the complementary highway and transit systems; and the Highway-Transit Cost Program, which calculates costs and impacts for the 1990 plan.

The costs and impacts quantified within each of these programs are:

A. Highway-Transit Cost Program

- All capital investment costs of highway and transit systems increased between 1970 and 1990.
- All costs associated with the operation and maintenance of the highway and transit facilities.
- Several impacts (i.e., accidents, pollution, and energy consumption) resulting from the operation of the highway and transit systems.*

B. New System Cost Program

- All costs of capital investments of the new transportation system.
- All costs associated with the operation and maintenance of the new transportation system and the facilities of this system.

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*Noise impacted households, displacement, land value changes, and tax losses were tabulated manually. The assignment of dollar values to some of the impacts was also done manually.

- Several impacts (i.e., air pollution, noise impacted households, displacement, accidents, energy consumption, and tax losses) associated with the new transportation system.*
- All costs associated with the operation and maintenance of existing highway and transit facilities.
- Several impacts (i.e., accidents, air pollution, and energy consumption) associated with existing highway and transit systems.

A more detailed description of the structure of these programs is presented in paragraph 7.3 and within Volume IV - Program Documentation of the TEAM Model.

7.1.4 Other Model Applications

Although the TEAM model was developed primarily as a tool to aid in the analysis of Dual Mode transportation systems, it was structured such that it could be used (or easily modified for use) in the analysis of other ground transportation systems.

The TEAM model can also be applied to transportation cost analyses at more aggregate levels of detail. Basically, the model's level of analysis detail is determined by the level of input data detail. To understand the extremes, consider the following example. Within the model, a network may be described in a very detailed manner by segmenting the network into links such that each link is uniquely different from any other according to the characteristics a_1, a_2, a_3, and a_4. On the other hand, the same network may be described in a more aggregate manner. The entire network could be conceived as one link; the a_1, a_2, a_3 and a_4 characteristics of this link would be the average characteristics of all possible links of the network.

*Land value changes were calculated manually. The assignment of dollar values to some of the impacts was also done manually.

7.2 MODEL CHARACTERISTICS

The computer, core storage, and execution time requirements of the New System Cost and the Highway-Transit Cost programs are described in the following paragraphs.

7.2.1 Computer Requirements

All programs of the TEAM model are written in the Fortran IV programming language for execution on a CDC-6600 digital computer. The CDC-6600 is one of the CDC-6000 series computers. It has two highspeed central processors and ten peripheral processors. Each peripheral processor has its own memory and is capable of executing programs independent of the other processors. Under the control of its operating system, the CDC-6600 can process up to seven independent jobs concurrently such that each job is sharing the central processor in a multiprogramming manner. The main core storage of the CDC-6600 is 300000_8 60-bit words. It has a memory access time of 100 nanoseconds.

The operating system of the CDC-6600 is called SCOPE (Supervisory Control of Program Execution). It performs the following functions:

- Controls all phases of program compilation, assembly and execution.
- Assigns storage and performs program segmentation and overlay loading.
- Controls all the input/output functions.
- Maintains the system library routines and the system day file records.

The New System Cost Program and the Highway-Transit Cost Program are executed independently of each other. They can be submitted for execution in either the "batch" or the "remote-job-entry" mode. Listed below are the CDC-6600 peripheral hardware devices that are required for the execution of these two programs.

A. New System Cost Program

- Card Reader
- Card Punch (only if punched data output is desired)
- Disk Storage
- Tape Drives (only if program is to be loaded from tape)
- Printer
- Plotter (only if plotted data output is desired).

B. Highway-Transit Cost Program

- Card Reader
- Disk Storage
- Tape Drives (only if program is to be loaded from tape)
- Printer.

7.2.2 Core Storage Requirements

Since the overall size of the New System Cost Program exceeded the main core storage of the CDC-6600, it was necessary to structure the program into four executable sections called overlays. An overlay program structure is more efficient in core management since it allows designated overlays, wherever in execution, to occupy a common sub-region of core. Thus under this type of program structure, only the main overlay and one other overlay is resident in core at any given time during the execution of the program.

The New System Cost Program was divided into four overlays - a main overlay, named PRMY, and three additional overlays - DMCP, NTWK, and OTHR. The main overlay resides in core throughout the execution of the program and is never destroyed by the loading of any of the other overlays. The DMCP, NTWK and OTHR overlays are dynamically loaded by the SCOPE operating system whenever they are to be executed. These overlays share a common region of core immediately following the storage area of the main overlay. The core size (in octal 60-bit words) of each of these overlays is presented below:

Overlay	Core Size
(0.0) - PRMY	122, 245
(1.0) - DMCP	120, 761
(2.0) - NTWK	34, 402
(3.0) - OTHR	30, 066

For programs having an overlay structure, the size of the main overlay plus the size of the largest overlay, that would reside in core with the main overlay, determines primarily the amount of core required for program execution. Thus, a field length of approximately $246,000_8$ words (122, 245 + 120, 761 + system routines + loader) is recommended for the execution of the New System Cost Program.

The Highway-Transit Cost Program is relatively small compared to the size of the New System Cost Program. Since its overall size is well within the available core requirements of the CDC-6600, there was no need to segment this program into overlays. The recommended field length for execution of the Highway-Transit Cost Program is $125,000_8$ sixty-bit words.

7.2.3 Execution Time Requirement

There are a number of factors that directly affect the amount of time required to execute each of the TEAM model programs. For example, the execution time of the New System Cost Program is influenced by the number of executions (or loops) of the program, the amount of data processing required to be performed, and the amount and the types of data to be output. Obviously, parametric runs, involving multiple loops of this program, add to the execution time. The size of the network being analyzed (i.e., the number of guideway links, terminals, interchanges, etc.) contributes heavily to the amount of data processing required to be performed. As the data processing increases so will the program execution time. The amount of printed data output also influences the execution time of the program; a lower execution time can be realized by suppressing a number of the detailed output tables.

Whenever punched card or plotted data output is desired, a larger program execution time can be expected.

It is for these reasons that one execution time cannot be identified for this program. Presented below are representative execution times of program runs conducted for the Boston Dual Mode analysis. No times were available, however, for runs conducted with punched card or plotted data output.

	Central Processor (CP) Seconds	Input/Output (I/O) Seconds	System Seconds
Base Program Run (Full printout)	21. - 22.	30. - 31.	44. - 45.
Base Program Run (Suppressed printout)	10. - 11.	26. - 27.	30. - 31.
Base Run + Four Parametric Runs with Suppressed printout	47. - 48.	41. - 42.	78. - 79.

The program execution time of the Highway-Transit Cost Program is affected primarily by the amount of data output that is to be printed. This program normally executes within the following time limits:

	CP Seconds	I/O Seconds	System Seconds
Base Run (Full printout)	6. - 7.	6. - 7.	9. - 10.
Base Run (Suppressed printout)	4. - 5.	5. - 6.	7. - 8.

It should be noted that the system second is time upon which computer charges are determined. The system second is computed as follows:

Total system seconds = Central processor time + I/O channel time x Fraction of core utilized

7.3 MODEL STRUCTURE

7.3.1 New System Cost Program

In each run of the New System Cost Program, capital and operating costs and impacts of one new transportation system along with operating costs and impacts of the co-existing highway and transit systems are quantified.

A. Capital Costs

Figure 7-1 illustrates the capital costs computed within the program. For the new system guideway, capital costs for land acquisition, track, and construction are quantified. The width of the guideway and the number of lanes required are computed based upon the peak hour directional flow of vehicles. Land acquisition costs, for various land cost and land use areas, are computed in relation to the amount of guideway area required. Track and construction costs are computed based upon the number of lane miles of guideway.

Interchange land acquisition, structure, and track costs are computed for each identified interchange in the network. Terminal capital costs for land, track, and structures are computed for each network terminal according to one of ten terminal design types. The design type of each terminal is determined by the program based upon the number of persons required to be serviced. Land, track, and construction costs for acceleration/deceleration lanes associated with each terminal are also quantified.

Capital costs for maintenance facilities, yards, and a control center are computed as a combination of costs for land acquisition, construction, and equipment. Way command and control costs for wayside equipment and detectors are computed based upon the number of guideway route miles. Vehicle capital costs are computed as a function of the number of vehicles required.

All capital costs are annualized by the program by means of capital recovery factors computed for each capital element described above.

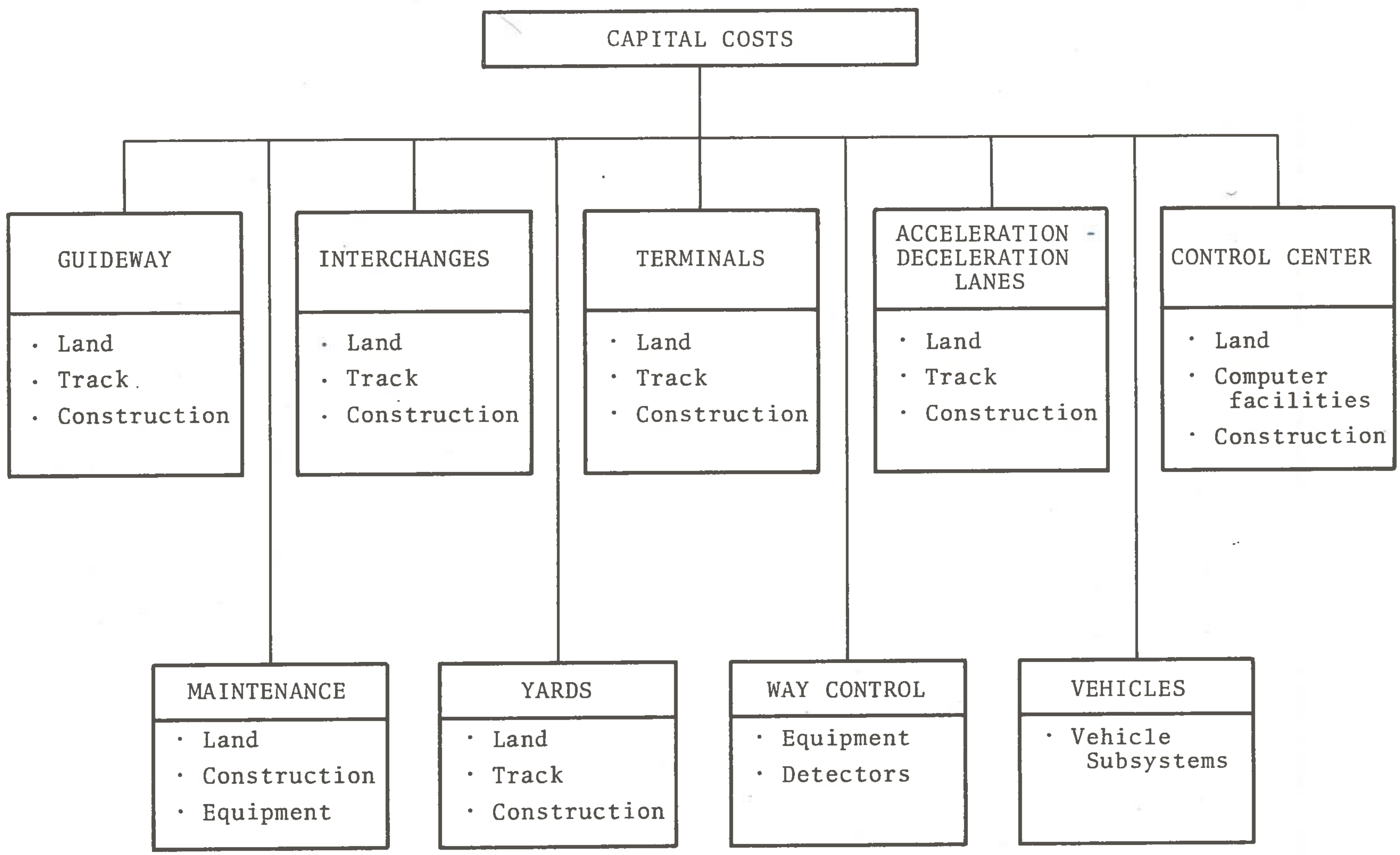


Figure 7-1. Capital Costs Computed by the New System Cost Program

B. Operating Costs

As shown in Figure 7-2, the New System Cost Program computes operating costs for a new transportation system and for the complementary highway and transit systems.

For highways, annual way maintenance and operation costs are computed for freeways and surface arterials based upon the annual vehicle miles traveled (VMT). Vehicle operating costs for depreciation, fuel, insurance, parking, etc. are also computed for autos and trucks as a function of the annual VMT.

Similarly, for each transit system, the following annual operating costs are computed:

- Way
- Vehicle
- Manpower
- Maintenance
- Storage
- Parking
- Terminals.

Transit way power operating costs are computed as a function of the annual vehicle miles traveled; way manpower and maintenance costs are computed as a function of the number of route (or track) miles that exists for each transit system. Vehicle operating costs, for vehicle depreciation and maintenance, and transit manpower costs are calculated based upon the annual VMT of the respective transit systems. Transit maintenance, storage, and parking costs are quantified based upon the required number of vehicle spaces; transit terminal operating costs are computed according to the number of terminals required.

For the new transportation systems, annual operating costs are quantified for way, vehicles, terminals, yards, maintenance facilities, and a control center. Annual costs for guideway maintenance and operation are computed based upon the number of

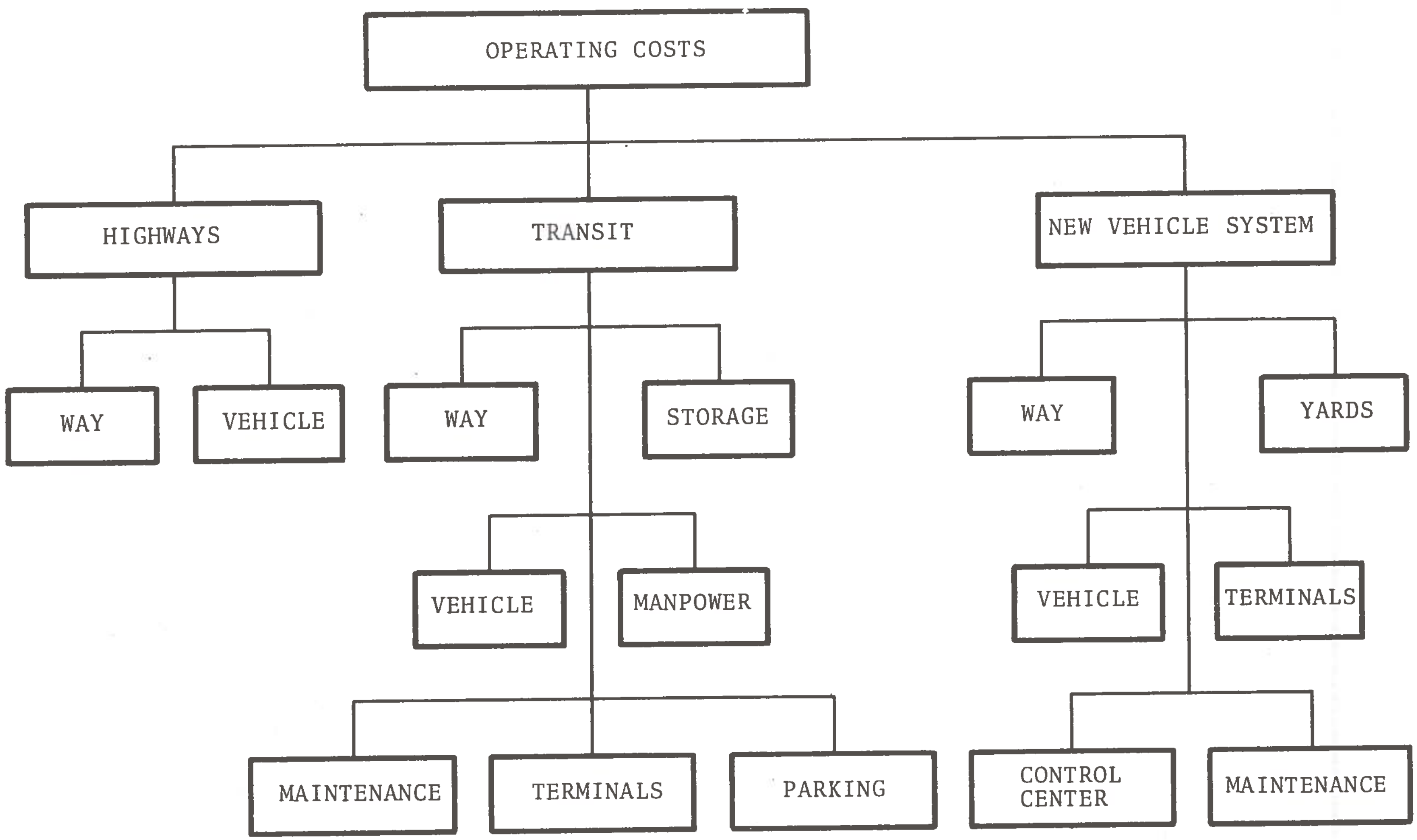


Figure 7-2. Operating Costs Computed by the New System Cost Program

lane miles of guideway. Operating costs for vehicle depreciation, maintenance, power, parking, and drivers are computed as a function of the annual vehicle miles traveled on and off the guideway. Annual terminal operating costs are computed according to the number of terminals required. Operating costs of yards, maintenance facilities, and control center are also quantified within the program.

C. Impacts, Network Analysis Data, and Profit/Loss Data

The impact, network analysis, and profit/loss data identified in Figure 7-3 are computed for a new transportation system and for its complementary highway and transit systems.

Network analysis data such as person miles traveled, vehicle miles traveled, average trip lengths, and average trip times are computed with respect to four temporal periods (peak, off-peak, daily, and annual) and, in the case of the new systems, for operations on and off the guideway. Highway travel data is analyzed separately for freeways and surface arterials.

Power consumption data for each of these transportation systems is computed based upon the type of vehicle propulsion and the amount of vehicle travel (VMT). This data is also stratified with respect to the four temporal periods identified above.

Air pollution emissions from each of these systems are calculated with respect to five pollutant types (CO, HC, NOX, SO_2, and particulates). For internal combustion engine vehicles, the amount of air pollution emitted is computed based on the vehicle miles traveled; for electric vehicles air pollution data is computed based upon the amount of power consumed.

Traffic accidents, fatalities, and injuries are computed by the program based upon the amount of travel (expressed in terms of VMT and person trips). Accident data is stratified by temporal period (peak, off-peak, daily and annual), by freeways and surface arterials, by transit system type, and, for the new systems, by operations on and off the guideway.

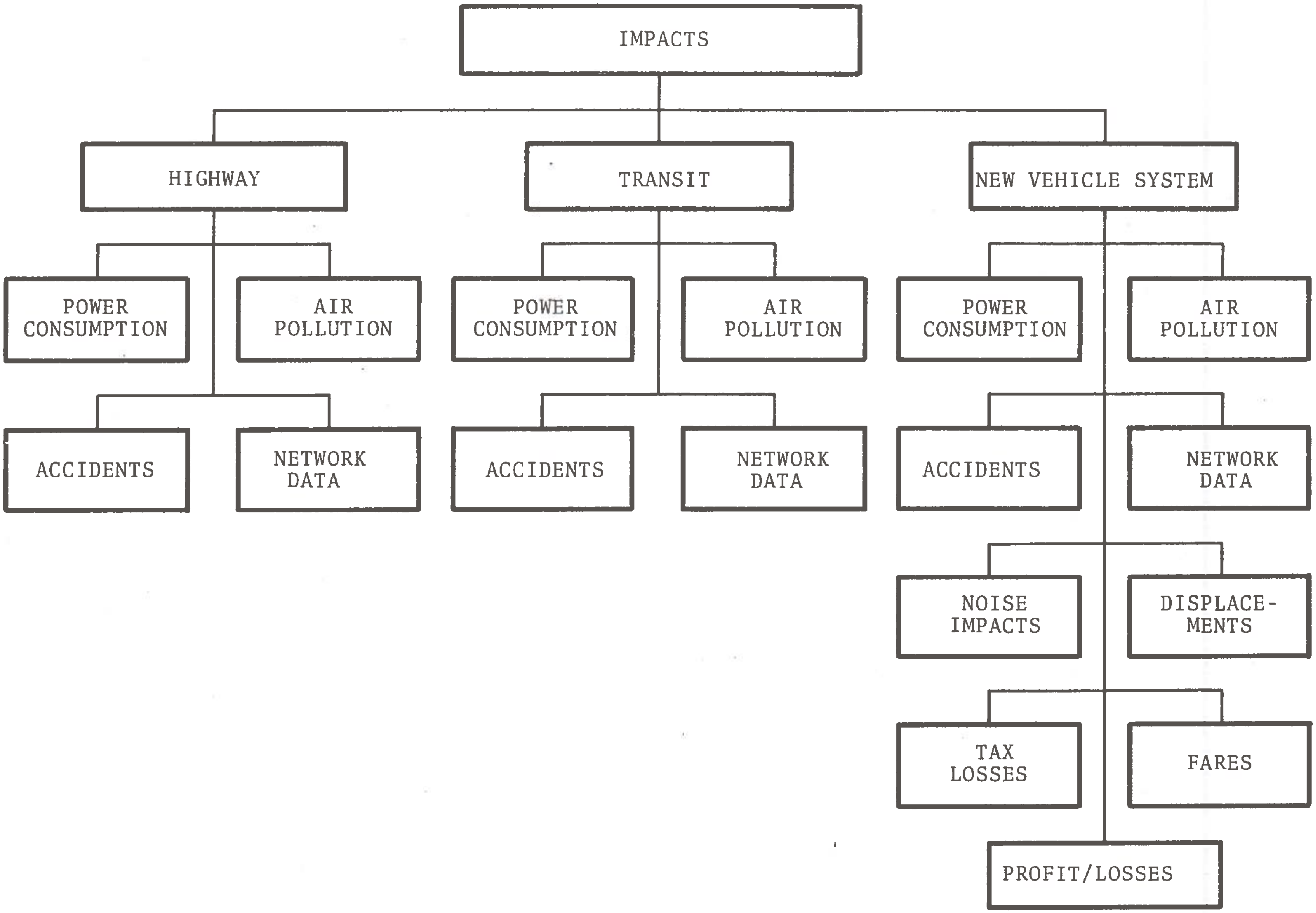


Figure 7-3. Impacts Computed by the New System Cost Program

The number of dwellings displaced as a result of the constru-tion of each new system's guideway and the number of dwellings that are impacted by noise from the guideway are quantified within this program. Utilizing noise contour areas, construction acreage, and residential densities, these data are generated for each identified land use and land cost area. The types of dwellings displaced or impacted by noise are also identified by various ethnic and income groups.

Tax losses to the urban area are quantified by this program based upon the amount of land area assumed by the new transportation system. This data is computed utilizing input property assessment ratios and tax rates.

Fares, revenues, subsidies, and resulting profits or losses are also quantified for the new transportation system. Breakeven fares, for two fare structures, are computed to cover all operat-ing costs and all non-subsidized capital costs. Revenues and the relative profits (or losses) realized by the system are computed based upon user-input fare rates.

D. Program Structure

The New System Cost Program is comprised of four control programs (DULMODE, DMCAPC, NTWORK, and ALLOTH) and thirty-five subroutines.

By design, the program was structured into modules corres-ponding to functions that were required to be performed. It is felt that this type of assemblage facilitates program modification, learning, and use. Other features of the program include:

- The capability of multiple program executions (or loops) per run.
- The capability to suppress the printing of all inter-mediate output data tables.
- The capability to plot summary data output through the use of CDC-6600 library plot routines and a CALCOMP plotter.

Since the overall size of the program (approximately 330,000 sixty-bit words of core storage) exceeded the main storage capacity of the CDC-6600 computer, it was necessary to divide the program into smaller executable units - called overlays. Four overlays were created with each overlay being controlled by a main program designated below:

Overlay	Main Program	Function
OV.0.0 (PRMY)	DULMODE	Acts as the primary overlay - controls the functions performed by overlays 1.0, 2.0, and 3.0.
OV.1.0 (DMCP)	DMCAPC	Computes all capital costs associated with the new transportation system.
OV.2.0 (NTWK)	NTWORK	Computes all network data for the new system.
OV.3.0 (OTHR)	ALLOTH	Computes network data for the highway and transit systems along with operating costs, impacts, and profit/loss data for the highway, transit, and new systems.

A general flow diagram of the New System Cost Program is presented in Figure 7-4 followed by a description of the functions performed by each of its subroutines in Table 7-1.

7.3.2 Highway-Transit Cost Program

As described earlier, this program performs all cost and impact calculations for highways and transit systems. In the Dual Mode analysis, this program was used to quantify all capital and operating costs and impacts of the null alternative (the 1990 transportation plan).

A. Capital Costs

Figure 7-5 identifies all capital costs computed within this program. For highways, the program quantified capital costs for way land acquisition and way construction. Cost data for freeways and surface arterials are generated and identified with respect to three land cost areas and four types of construction.

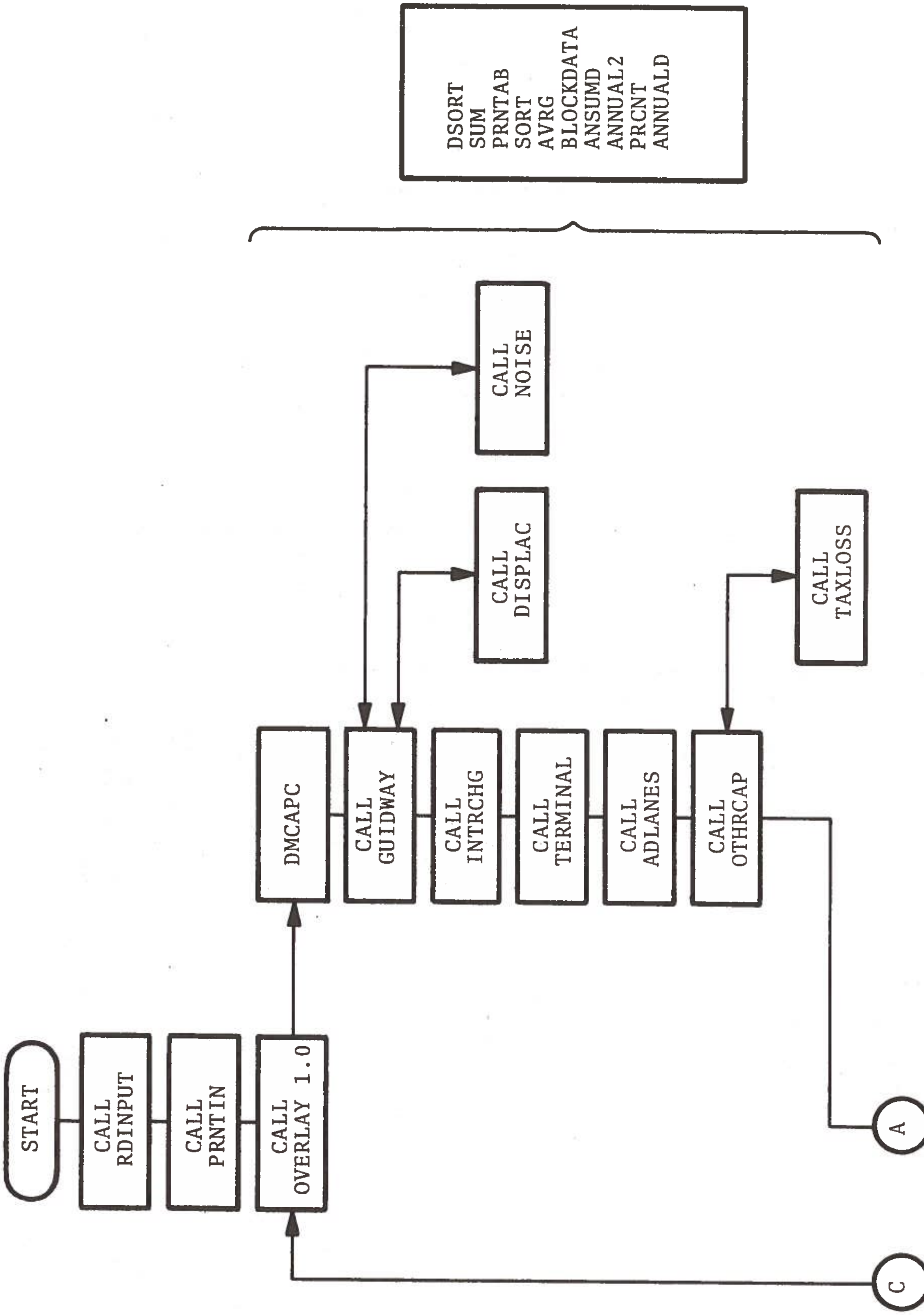
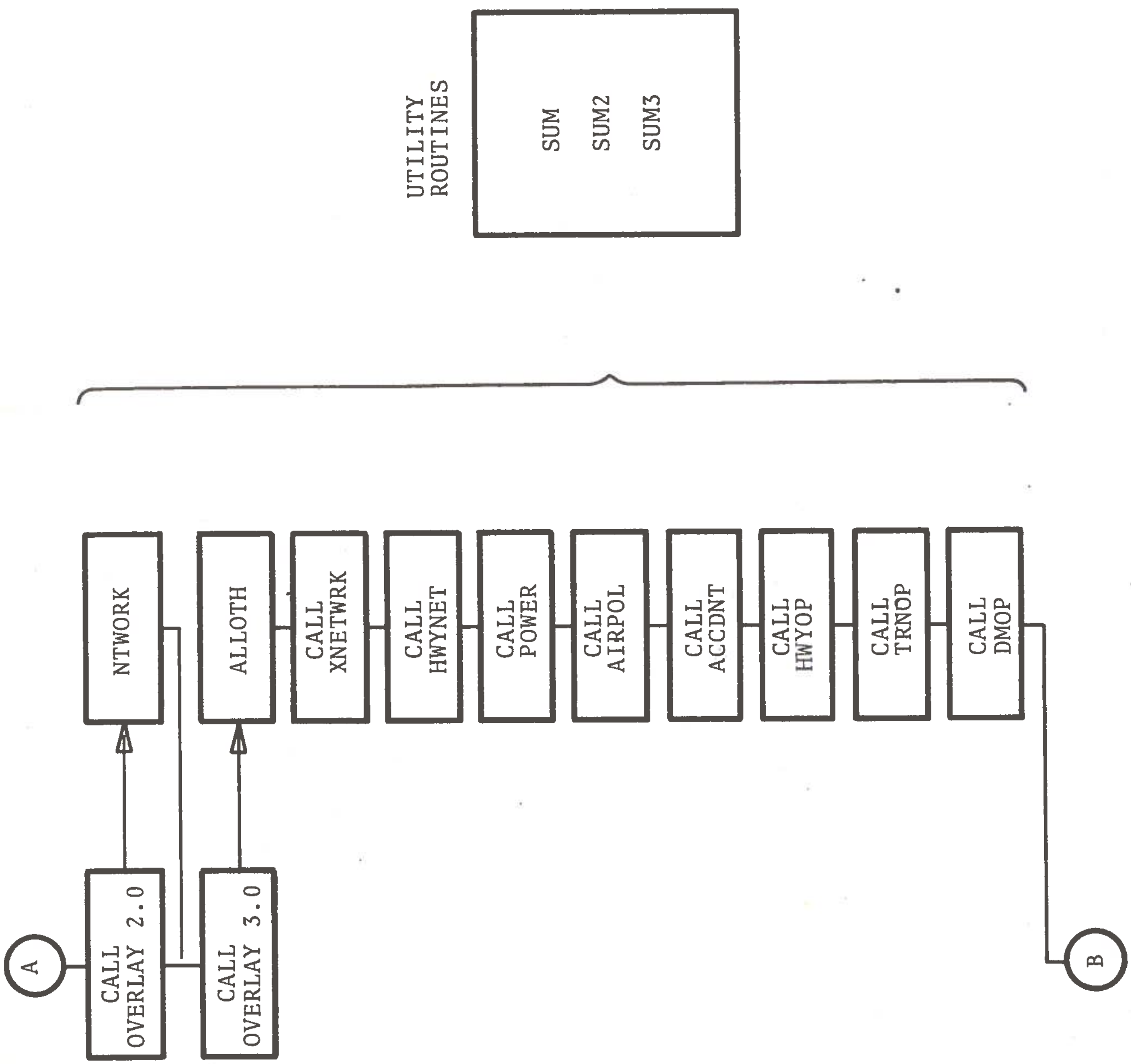


Figure 7-4. New System Cost Program


UTILITY ROUTINES
SUM
SUM2
SUM3
A
CALL OVERLAY 2.0
NTWORK
CALL OVERLAY 3.0
ALLOTH
CALL XNETWRK
CALL HWYNET
CALL POWER
CALL AIRPOL
CALL ACCDNT
CALL HWYOP
CALL TRNOP
CALL DMOP
B

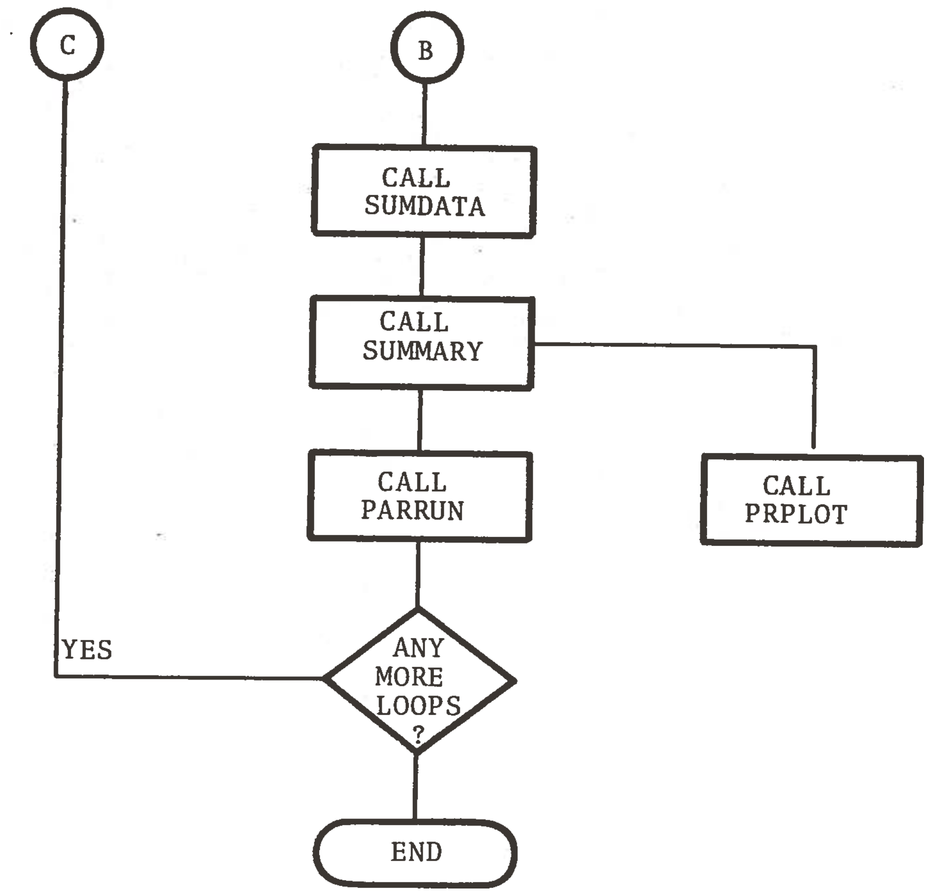


Figure 7-4. New System Cost Program (Cont'd)

TABLE 7-1. NEW SYSTEM COST PROGRAM

Program/Subroutine	Function
<u>OV-0.0</u>	
DULMODE	Control program - controls all overlays and all computational subroutines within overlay 0.0.
RDINPUT	Reads all card input data for the entire program.
PRNTIN	Prints all card input data.
SUMDATA	Stores summary data in summary data array.
SUMMARY	Prints and punches summary data output.
PRPLOT	Reads plot input data and calls system plotting routines.
PARRUN	Reads parametric run input data and conditions program for the performance of such runs.
<u>OV-1.0</u>	
DMCAPC	Controls all computational subroutines within Overlay 1.0.
GUIDWAY	Computes all way capital costs associated with the new system vehicle.
INTRCHG	Calculates all interchange capital costs.
TERMNAL	Computes capital costs of terminals.
ADLANES	Calculates all capital costs of the acceleration/deceleration lanes.
OTHRCAP	Computes capital costs of yards, maintenance facilities, control center, etc.

TABLE 7-1. NEW SYSTEM COST PROGRAM (CONT'D)

Program/Subroutine	Function
DSORT	Sorts capital costs and various units of the new vehicle system into total system grouped tables.
TAXLOSS	Calculates tax loss data.
SUM	Sums all row, column, and depth elements of a three dimensional array that is dimensional (5,6,12).
DISPLAC	Computes the number and the types of dwellings displaced due to the construction of the new system guideway.
PRNTAB	Prints grouped tables of sub-system capital costs and sub-system units.
NOISE	Calculates the number and the types of dwellings impacted by noise from the new system guide-way.
SORT	Sorts individual capital costs and units of the new system into grouped tables by subsystem.
AVRG	Computes average cost per unit for each capital cost element of the new system.
BLOCKDATA	Stores new system capital cost data names for output tables.
ANSUMD	Computes and prints annual cost summary data.
ANNUAL2	Computes and prints annual cost data for those output tables that do not contain unit or cost/unit data.
PRCNT	Computes percentages of new system capital costs.

TABLE 7-1. NEW SYSTEM COST PROGRAM (CONT'D)

Program/Subroutine	Function
ANNUALD	Calculates and prints annual cost data for those output tables that contain unit and cost/unit data.
OV-2.0	
NTWORK	Computes all "on-guideway" and "off-guideway" network data for the new system vehicles.
OV-3.0	
ALLOTH	Controls all computational subroutines within Overlay 3.0.
XNETWRK	Calculates all network data for the various transit systems.
HWYNET	Computes all highway vehicle network data.
POWER	Computes power consumption data for the new system vehicles, highway vehicles, and transit systems.
AIRPOL	Calculates amounts of air pollution emitted by the new system vehicles, highway vehicles, and transit systems.
ACCDNT	Computes number of accidents attributed to the new system vehicles, highway vehicles, and transit systems.
HWYOP	Computes all highway operating costs.
TRNOP	Computes all operating costs of transit systems.
DMOP	Calculates new system operating costs, fares, revenues, and profit/loss data.

TABLE 7-1. NEW SYSTEM COST PROGRAM (CONT'D)

Program/Subroutine	Function
SUM	Sums all row, column and depth elements of a three dimensional array dimensioned (5,6,12).
SUM2	Sums all row, column, and depth elements of a three dimensional array dimensioned (6,9,4).
SUM3	Sums all row, column, and depth elements of a three dimensional array dimensioned (5,8,5).

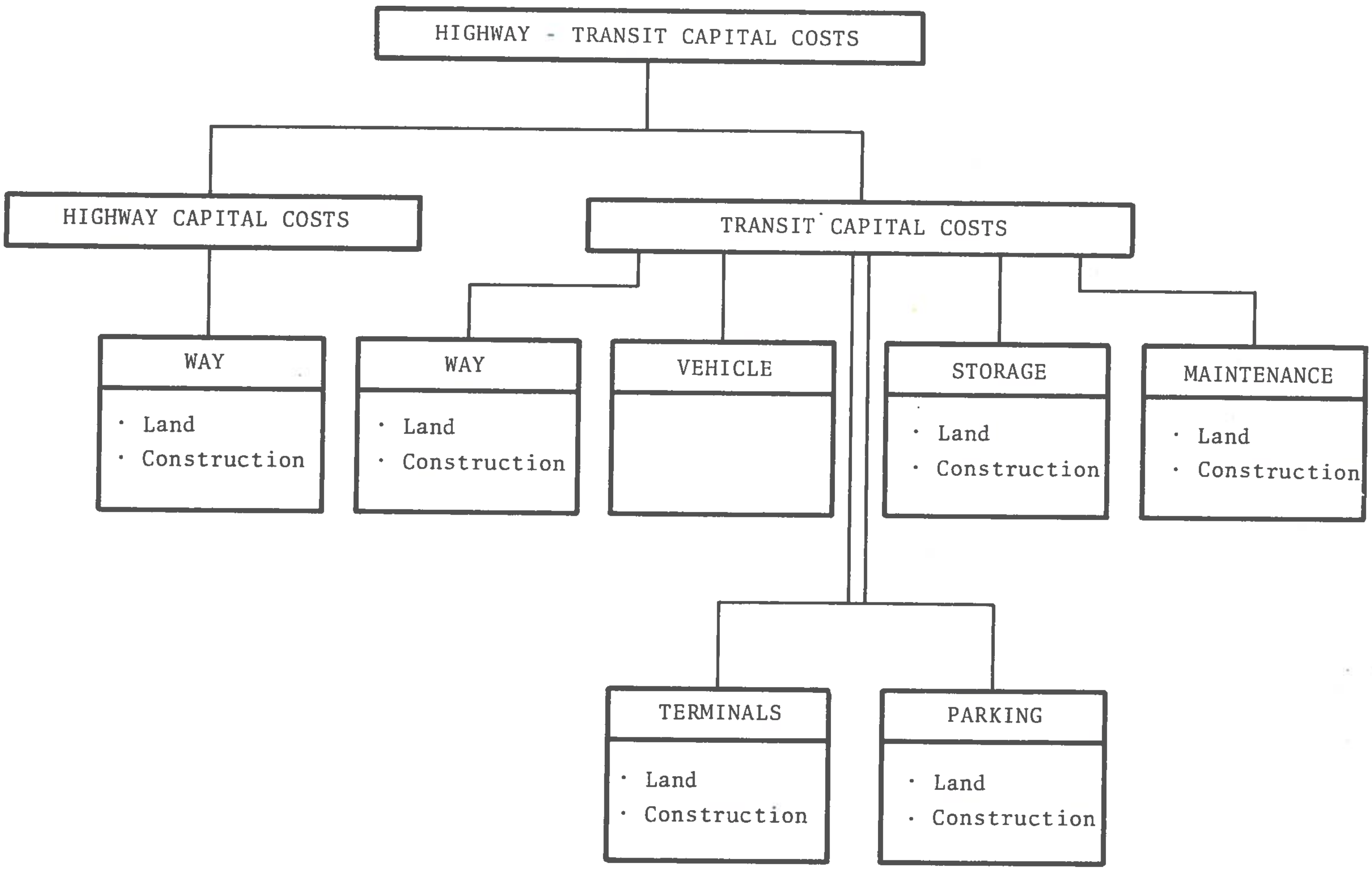


Figure 7-5. Capital Costs Computed by the Highway-Transit Cost Program

These costs are computed using as input units of land and construction and corresponding unit cost data.

Transit capital costs are calculated and reported with respect to individual transit systems (a maximum of four) being analyzed. Cost for way, vehicles, terminals, storage, and maintenance facilities are quantified by this program. Land acquisition costs are computed using as input units of land area required and land unit cost data. Construction costs are calculated based upon the number of facilities required and the type of facility construction.

Each of the highway and transit capital costs identified above are annualized by the program. Annual costs are determined utilizing capital recovery factors computed for each highway and transit capital element.

B. Operating Costs

All operating costs computed by this program are identifed in Figure 7-6.

For freeways and surface arterials, the program calculates way operating costs for power, manpower, and maintenance as a function of the annual vehicle miles traveled. Auto and truck vehicle operating costs are also computed based upon the amount of vehicle travel.

For transit systems, annual operating costs are computed for:

- o Way
- o Vehicles
- o Storage facilities
- o Maintenance facilities
- o Terminals
- o Parking facilities

Operating costs for way power are computed based upon the annual transit VMT; way manpower and maintenance costs are determined based upon the number of route (or track) miles that exist for each transit system. Vehicle operating costs and

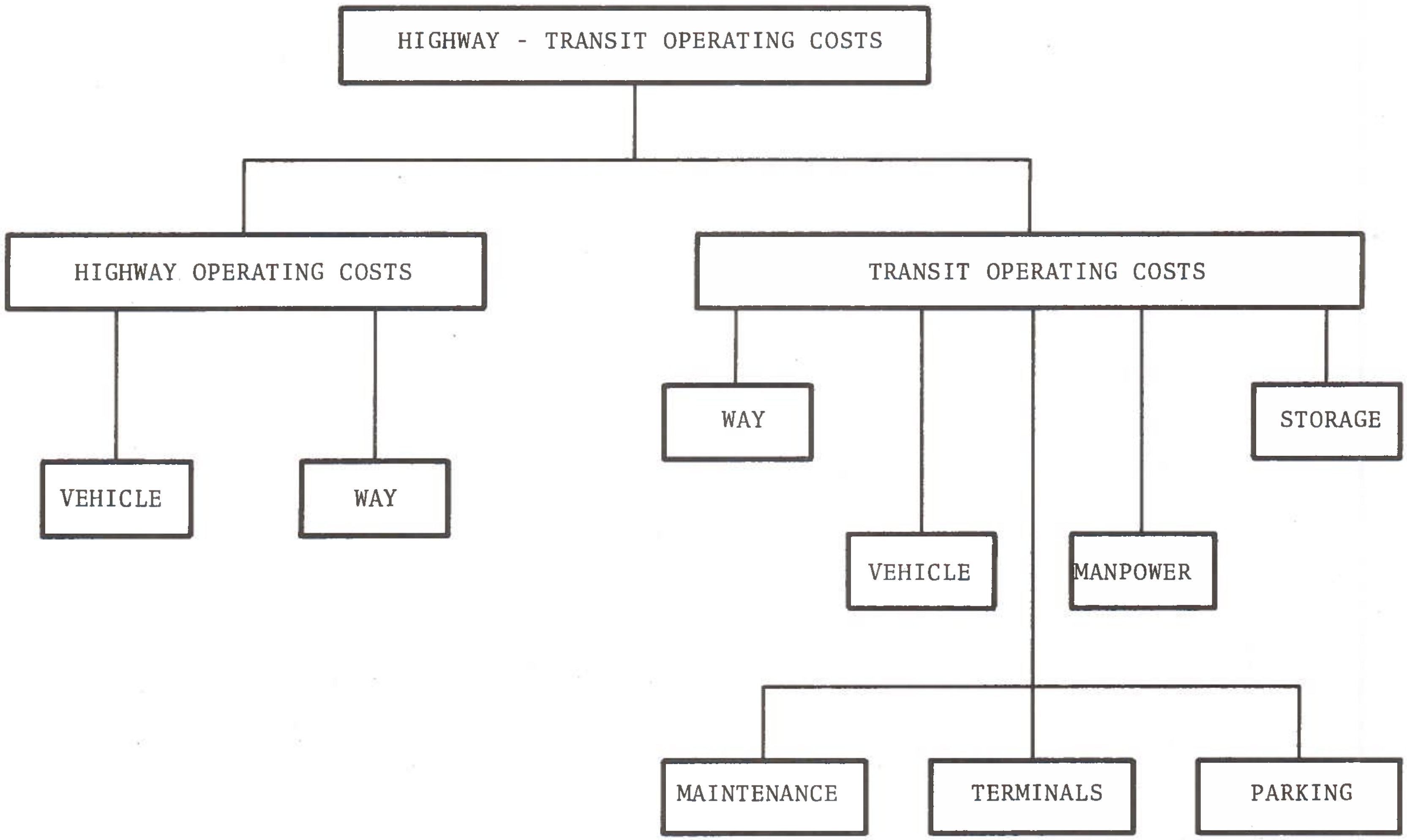


Figure 7-6. Operating Costs Computed by Highway-Transit Cost Program

transit manpower costs are calculated based upon the annual vehicle miles traveled by each system. Annual operating costs for transit storage, maintenance, and parking facilities are computed on the basis of the number of vehicle spaces required. Terminal operating costs are calculated as a function of the number of terminals that exist for each transit system.

C. Impacts and Network Analysis Data

Figure 7-7 shows that in addition to network analysis data, the following impacts are quantified by this program:

- Power consumption
- Air pollution
- Accidents

For highway and transit vehicle systems, network analysis data, i.e., person-miles traveled, vehicle miles traveled, average speeds, average trip lengths and trip times, etc. are computed and reported with respect to four temporal periods (peak, off-peak, daily and annual).

The program quantifies power consumption and air pollution levels for highway and transit vehicle systems. This data is generated as a function of the vehicle miles traveled by each of these systems. Data is stratified with respect to four temporal periods and, for air pollution, with respect to five pollutant types.

Highway and transit traffic accidents, fatalities, and injuries are calculated for four temporal periods and stratified by freeways and surface arterials and by transit system type. Using as input accident rate data, the program computes the number of accidents as a function of the amount of system travel (VMT and person trips).

D. Program Structure

The Highway-Transit Cost Program is comprised of a main control program, NULCASE, and twenty-two subroutines.

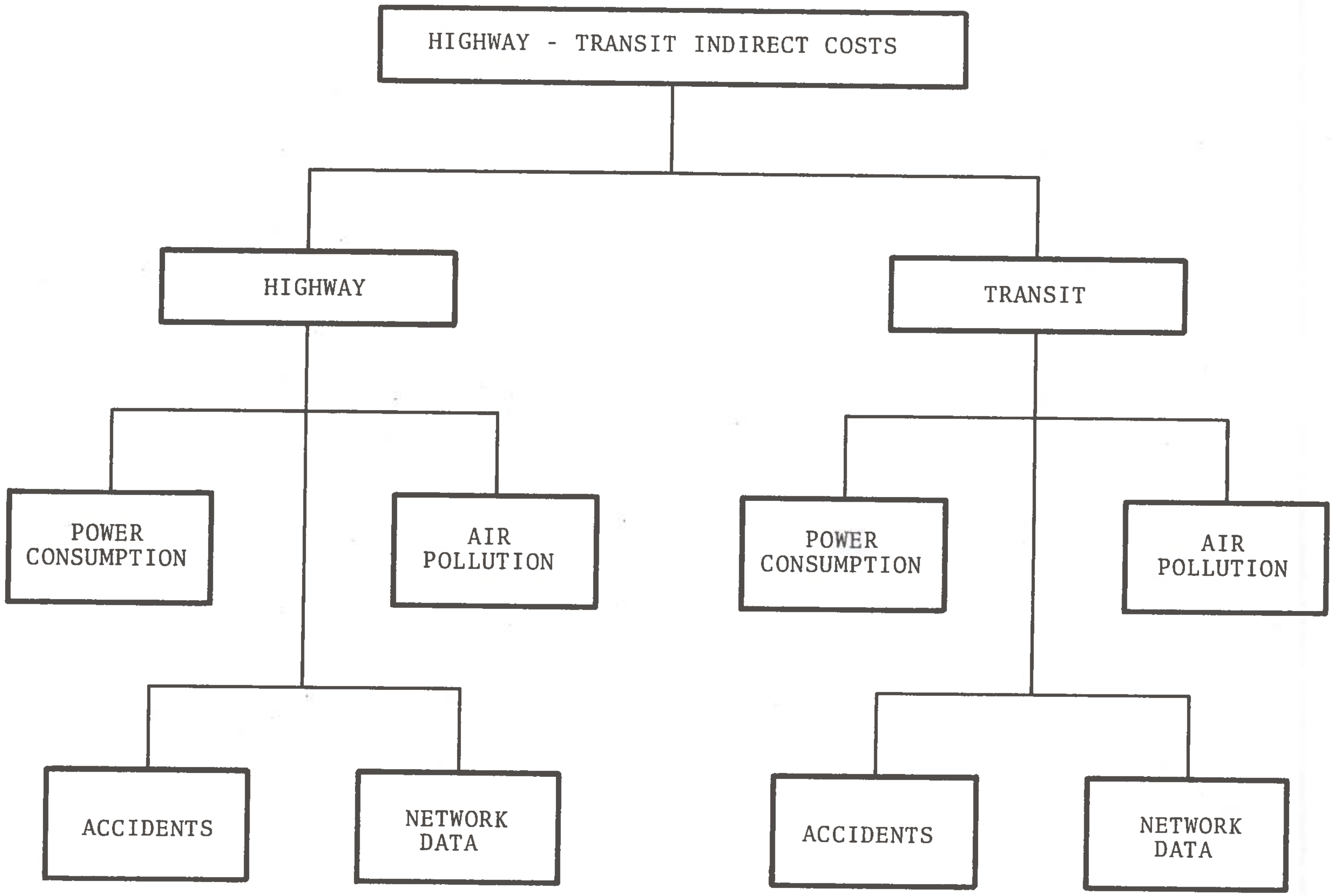


Figure 7-7. Impacts Computed by Highway-Transit Cost Program

The program was structured such that the highway capital cost, the transit capital cost, and the operating cost-impact sections of the program are independent of each other. Because of this type of program structure, each or any combination of these three cost sections can be independently executed. The user controls the execution of each of these three sections by means of three input parameters.

Another feature of the program is the ability to control the printing of all intermediate output data tables. Through input parameters, the program can be controlled by the user to print only summary data output tables.

Figure 7-8 describes the overall structure of the Highway-Transit Cost Program. A definition of the functions performed by each of the subroutines of this program is presented in Table 7-2.

7.4 Model Documentation and Availability

The Transportation Economic Analysis Model is fully documented in Volume IV of the Dual Mode report. This documentation includes a descriptive text of the structure and assumptions of each program and subroutine, general and detailed flowcharts, compiled listings of all routines, input data formats, typical input data listings, and typical output printouts. Examples are presented on how to use the model including a detailed explanation on how to use it in conjunction with the CDC 6600 computer.

The TEAM programs are available in source and binary form on 9-track, 800-BPI magnetic tapes.

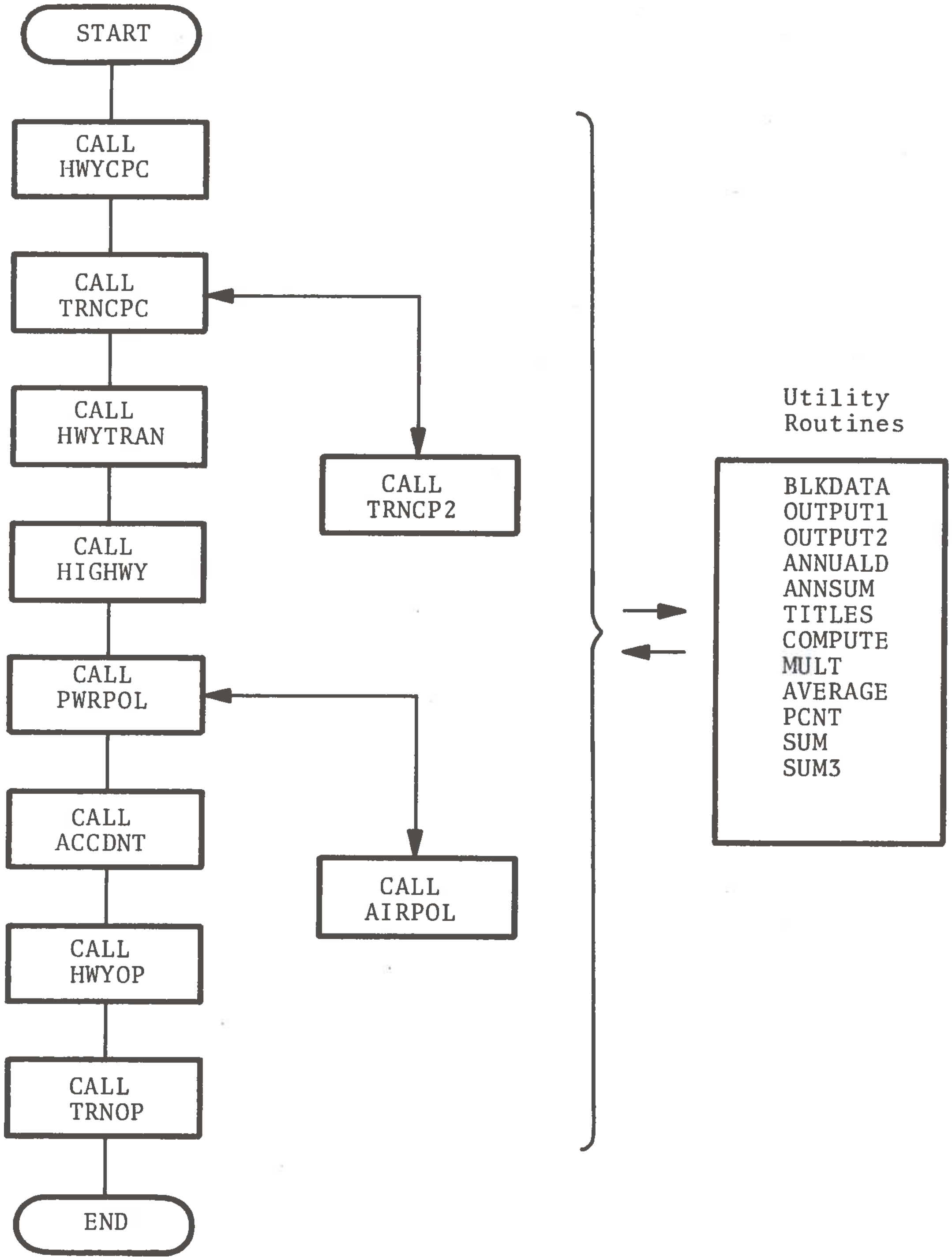


Figure 7-8. Highway-Transit Cost Program (NULCASE)

TABLE 7-2. HIGHWAY-TRANSIT COST PROGRAM

Program/Subroutine	Function
NULCASE	Control program - calls all computational subroutines
HWYCPC	Computes all highway capital costs
TRNCPC	Computes all transit capital costs for way, vehicles and storage facilities
TRNCP2	Computes all transit capital costs for maintenance, terminals, and parking facilities
BLKDATA	Stores highway and transit capital cost data names for output tables
OUTPUT1	Prints highway and transit capital cost output data
OUTPUT2	Prints highway and transit capital cost output data
ANNUALD	Computes and prints highway and transit annual cost data
ANNSUM	Computes and prints highway and transit annual cost summary data
TITLES	Prints titles of highway and transit capital cost output tables
COMPUTE	Computes highway and transit capital costs, average cost per unit, and cost percentages through the use of the MULT,SUM,AVERAGE, and PCNT subroutines
MULT	Multiplies a three-dimensional unit and a three-dimensional unit cost array to produce a cost product array
AVERAGE	Computes an average cost per unit for each highway and transit capital cost element

TABLE 7-2. HIGHWAY-TRANSIT COST PROGRAM (CONTINUED)

Program/Subroutine	Function
PCNT	Computes percentages of highway and transit capital costs
SUM	Sums all row, column and depth elements of an array that is dimensioned (5,6,12)
HWYTRAN	Computes all network data for the various transit systems
HIGHWY	Computes all highway vehicle network data
PWRPOL	Computes power consumption data for the highway and transit systems
AIRPOL	Computes highway and transit air pollution data
ACCDNT	Calculates highway and transit accident data
HWYOP	Computes all highway operating costs
TRNOP	Computes all transit operating costs
SUM3	Sums all row, column, and depth elements of an array that is dimensioned (5,87).

REFERENCES

1. A.B. Young and Co., Passenger Demand and Modal Split Models, J.M. McLynn and T. Woronka, NECTP 230, December 1959.

2. Abt Associates, Inc., Qualitative Aspects of Urban Personal Travel Demand, Cambridge, Mass., August 1968.

3. Agarwal, Paul D. and Levy, I.M., "A High Performance AC Electric Drive System," Society of Automotive Engineers, Paper No. 670178, January 1967.

4. Alan M. Voorhees and Associates, Inc., A System Sensitive Approach for Forecasting Urbanized Area Travel Demands, Technical Memorandum No. 4, McLean, Virginia, May 1971.

5. Allis-Chalmers Corp., Milwaukee County Dual Mode Systems Study, Volumes I-IV, Paul S. Gurski, Advanced Technology Center, for UMTA, December 1971.

6. American Association of State of Highway Officials, Road User Benefit Analyses for Highway Improvements, Washington, D.C., 1960.

7. American Transit Association, "Transit Operating Reports - 1968, Part II - Motor Bus Operations," Bulletin No. 926, Washington, D.C., May 1969.

8. American Transit Association, Estimates of Fatalities... Transit Industry, Calendar Year 1968, Washington, D.C., April 24, 1969.

9. American Transit Association, Comparative Operating Accident Rates for First Six Months 1971-1970, Report No. 63, ATA Accident Data Exchange, Washington, D.C., September 1971.

10. Block, F.C., "Factors Influencing Modal Trip Assignment," Highway Research Bulletin No. 57, 1968.

11. Boston Redevelopment Authority, Transportation Facts for the Boston Region, 1968.

REFERENCES (CONT.)

12. Boston Safe Deposit and Trust Company, Financial Statistics of Massachusetts, Sixty-Third Edition, Boston, 1971.

13. Business Week, "A Backlash Against New Car Standards," (Report of estimate by the President's Office of Science and Technology), March 25, 1972, p. 23.

14. Cabot, Cabot & Forbes, 1971 Greater Boston Cities and Towns; Population and Tax Rates, Boston, Mass., 1972 (Pamphlet).

15. Commerce, U.S. Dept. of, Census of Governments, Volume 2, Taxable Property Values, Bureau of the Census, Washington, D.C., 1967.

16. Commerce, U.S. Dept. of, Statistical Abstract of the United States 1969, 90th Annual Ed., Bureau of the Census, Washington, D.C., 1969.

17. Commerce, U.S. Dept. of, Modal Split, Documentation of Nine Methods for Estimating Transit Usage, Bureau of Public Roads, Office of Planning, December 1966.

18. Consad Research Corp., Transit Usage Forecasting Techniques: A Review and New Directions, T.R. Lakshmanan, Pittsburgh, Pa., April 1968.

19. Cornell Aeronautical Lab., Bi-Modal Urban Transportation System Study - Vol. I: Study in New Systems of Urban Transportation, March 1968.

20. Cornell Aeronautical Lab., Bi-Modal Urban Transportation System Study - Vol. II: Technical Appendices, May 1968.

21. Cornell Aeronautical Lab., Bi-Modal Urban Transportation System Study - Vol. III: Addendum - Technical Appendices, May 1968.

22. Donaldson, J., National Bureau of Standards Modeling for the NECTP, NECTP-213 DOT/OHSGT, December 1969.

23. Federal Register, Vol. 36, No. 228, pp. 22452-3, November 25, 1971.

24. Federal Register, Vol. 36, No. 247, pp. 24878-9, December 23, 1971.

25. Fee, Julie et al., Interstate System Accident Research Study - 1, FHWA, Office of Research and Development, Traffic Systems Division, October 1970.

26. Fichter, Donn, An Analysis of Dual Mode Transport (Urbmobile), New York State Dept. of Transportation, Albany, New York, December 1970 (Rochester, New York Study).

27. Fleischman, E., TRANS Technical Report Dislocations, FHWA, March 1971.

28. Franklin, P. and Bender, E., "Environmental Effects of Transportation Noise," Bolt, Beranek and Newman, Inc., Cambridge, ASME Paper 70-TRANS-52, July 1970.

29. General Motors Research Laboratories, New Systems Implementation Study, for U.S. Dept. of Housing and Urban Development (3 Volumes), Warren, Michigan, February 1968: Volume I - Summary and Conclusions; Volume II - Planning and Evaluation Methods; Volume III - Case Studies.

30. General Motors Research Laboratories, Future Transportation Systems Study, Eugene T. Canty, Warren, Michigan, January 1968.

31. General Research Corporation, Systems Analysis of Urban Transportation, for U.S. Dept. of Housing and Urban Development, (4 Volumes), January 1968: Volume I - Summary; Volume II - Cases for Study; Volume III - Network Flow Analyses; Volume IV - Supporting Analyses.

32. Harza Engineering Co., High Speed Ground Transportation Tunnel Design and Cost Data, PB-178201, Chicago, Ill., March 1968.

33. Heaton, Carla J., A Comparison of Motor Vehicle Accident Cost Data, Highway Planning Technical Report No. 21, FHWA, Washington, D.C., May 1971.

34. International Bank for Reconstruction and Development, Quantification of Road User Savings, Report EC-140a, Washington, D.C., 1965.

35. Institute for Defense Analyses, Economic Characteristics of the Urban Public Transportation Industry, for DOT/TPI, February 1972.

36. Institute for Defense Analyses, Summary of Work to Date, John D. Wells, Memorandum to Edward Weiner, DOT/TPI, Arlington, Va., January 12, 1972.

37. Institute for Defense Analyses, Some Air Pollution, Accident and Noise Factors Due to Mass Transit Systems, Murry Kamrass, Study Memorandum to DOT, March 1971.

38. Institute for Defense Analyses, Fare and Service Elasticities of Urban Bus Transit: A Time Series Analysis of Demand, J. Hayden Boyd and Gary R. Nelson, May 1972.

39. Jet Propulsion Laboratory, Technical and Cost Considerations for Urban Applications of Dual-Mode Transportation, for DOT/TST, California Institute of Technology, Pasadena, Calif., May 23, 1972.

40. Johns Hopkins University, Applied Physics Laboratory, Acceleration and Comfort in Public Ground Transportation, J.W. Gebhard, Transportation Programs Report TPR 002, February 1970.

41. Johns Hopkins University, Applied Physics Laboratory, Parametric Analysis of Generic Urban Transit Systems, B.M. Ford, W.J. Roesler, and M.C. Waddell, Silver Spring, Maryland, December 1969.

REFERENCES (CONT.)

42. Joseph, Hyman, "Construction Cost of Urban Expressways," CATS Research News, Vol. 4, No. 1, December 19, 1960.

43. Kangas, Ronald, Alternative Dual Mode Network Control Strategies, Report No. DOT-TSC-OST-72-10, Transportation Systems Center, Cambridge, Mass., March 1972.

44. Kennedy, Norman, "San Francisco Bay Area Rapid Transit; Promises, Problems, Prospects," Paper presented to SAE, Melbourne, Australia, 1971.

45. Lang, A. Scheffer and Soberman, Richard M., Urban Rail Transit: Its Economics and Technology, MIT Press, Cambridge, Mass., 1964.

46. Lave, C.A., "A Behavioral Approach to Modal Split Forecasting," Transportation Research, Vol. 3, pp. 463-480, 1969.

47. Manheim, M.L. and Ruiter, E.R., "Dodotrans I: A Decision Oriented Computer Language for Analysis of Multi-Mode Transportation Systems," Highway Research Record No. 314, 1970.

48. Mason, F.J. and Mumford, J.R., "Computer Models for Designing Dial-A-Ride Systems," SAE Congress, January 1972.

49. Massachusetts Bay Transportation Authority, "Comparative Analysis of the Net Cost of Service, Interest Charged by State Treasurer and Boston Metropolitan District Expenses for Fiscal Periods Since August 4, 1964," (Unpublished table).

50. Massachusetts, Commonwealth of, 1970 Assessment for Interest, Serial Bonds and Maintenance of the Metropolitan Districts, Public Document No. 92, 1970.

51. Massachusetts Department of Public Works, Recommended Highway and Transit Plan, Eastern Massachusetts Regional Planning Project, 1968.

REFERENCES (CONT.)

52. Massachusetts Institute of Technology, A Survey of the New York City Airport Limousine Service: A Demand Analysis, R. DeNeufville, R. Skinner, and F. Koller, an unpublished paper by Dept. of Civil Engineering, 1970.

53. Massachusetts Institute of Technology, Modal Split Models for Airport Access, F. Koller and R. Skinner, R70-47, Vol. 7 of a series on Airport Location and Planning, Dept. of Civil Engineering, August 1970.

54. Massachusetts Taxpayers Foundation, Inc., 1970 Tax Rates; Actual and Full Value, November 1970.

55. Mathematica, Studies in Travel Demand, Vols. I-V, for North-east Corridor Project, U.S. Dept. of Commerce.

56. Metropolitan Area Planning Council, Economic Base and Population Study, Vol. II: Prospects for Economic Growth, Boston, Mass., March 1967.

57. Meyer, J.R., Kain, J.F., and Wohl, M., The Urban Transportation Problem, Harvard University Press, Cambridge, Mass., 1965.

58. Mitre Corporation, A Technology Assessment Methodology, Automotive Emissions, W.E. Jacobsen et al., MTR 6009, Vol. 2, June 1971.

59. Mohring, Herbert, "Urban Highway Investments," in Measuring Benefits of Government Investments, Robert Dorfman, Ed., The Brookings Institution, Washington, D.C., 1965.

60. Mungenast, James A., A Preliminary Study on the Magnitude of Federal Aid Highway Displacements, on a Per-Mile Basis, and of Some Related Cost-Benefit Factors Concerning the Displaced Families, Individuals, and Businessmen, (unpublished), a working paper prepared as background for the 1972 National Highway Needs Report, FHWA, Office of Policy Planning, November 1970.

REFERENCES (CONT.)

61. McCormick, Ernest J., Human Factors Engineering, McGraw-Hill, New York, 1964.

62. McGillioray, Robert G., "Demand and Choice Models of Modal Split," Journal of Transport Economics and Policy, May 1970.

63. National Analysts, The Needs and Desires of Travelers in the Northeast Corridor: A Survey of the Dynamics of Mode Choice Decisions, for DOT/OHSGT, January 1970.

64. North American Rockwell Corporation, Frontiers of Technology Study, Vol. III: Implementation Requirements Studies, 1968.

65. North American Rockwell Corporation, Transportation System Technology, Implementation Requirements for Four Advanced Urban Transportation Systems, Phase II Final Report NA-68-807, for U.S. Dept. of Housing and Urban Development, Los Angeles, Calif., October 18, 1968.

66. Ohio Department of Highways, Maintenance Cost Study, Columbus, 1966 Report and Interim Report, Parts I and II (July 1968).

67. Oi, Walter Y. and Shuldiner, Paul W., An Analysis of Urban Travel Demands, Northwestern University Press, 1962.

68. Pasternack, Sam, Modern Control Aspects of Automatically Steered Vehicles, Report No. DOT-TSC-OST-72-3, Transportation Systems Center, Cambridge, Mass., December 1971.

69. Peat, Marwick, Mitchell and Co., Sensitivity Analysis of the Evaluation of a Bus Transit System in a Selected Urban Area, for FHWA, May 1970.

70. Peat, Marwick, Mitchell and Co., The N-Dimensional Logit Model: Development and Application, P.R. Hassam, R.H. Ellis, J.C. Bennett, 1970.

71. Peat, Marwick, Mitchell and Co., Vehicle Access Penalty Validation Program VEAMP (Vehicle Access Modifier Program), Donald E. Ward et al., (International Memorandum),July 14, 1971.

72. Peat, Marwick, Mitchell and Co., An Analysis of Urban Area Travel by Time of Day, L.H. Tittemore et al., Boston, Mass., January 1972.

73. Pulver, H.E., Construction Estimates and Costs, Third Ed., McGraw-Hill, New York, 1960.

74. Rand Corporation, A Model and Computer Code for Studying Alternate Air Passenger Processing Strategies, Memo D.M. Landi and A.V. Rolfe, RM-5818-PA, August 1969.

75. Rand Corporation, New Directions for Passenger Demand Analysis and Forecasting, G. Kraft and M. Wohl, Rand P-3877, AD 672 150, June 1968.

76. Rand Corporation, The STAR Study: Impacts of Alternative Intercity Short-Haul Transportation Systems on the California Corridor, B.F. Goeller et al., prepared for DOT, Santa Monica, Calif., September 1971.

77. Regional Planning Commission, Modal Split Analysis, Cuyahoga County, Ohio, May 1970.

78. Resource Management Corp., Cost Analysis for NECTP, Vol. I, High Speed Ground Modes, Bethesda, Md., December 1969.

79. Robert S. Mayo and Associates, Tunneling-the State of the Art: A Review and Evaluation of Current Tunneling Techniques and Costs with Emphasis on Their Application to Urban Rapid Transit Systems in the U.S.A., Robert S. Mayo, Lancaster, Pa., January 1968.

80. Rosenblith, W.A., and Stevens, K.N., Handbook of Acoustic Noise Control, Vol. II, Noise and Man, U.S.A.F., WADC, Technical Report 52-204,U.S. Dept. of Commerce, Office of Technical Services, Report PB-111 274, June 1953.

81. Rothenberg, M.J. and Prokopy, J., Access and Demand Data Used in the Development and Calibration of Northeast Corridor Transportation Models, NECTP-217, DOT/OHGST, January 1970.

REFERENCES (CONT.)

82. San Francisco Bay Area Rapid Transit District, "Comparative Data Report," San Francisco, Calif., October 1, 1971, (Quarterly).

83. Scheel, Jerold W., "A Method for Estimating and Graphically Comparing the Amounts of Air Pollution Emissions Attributable to Automobiles, Buses, Commuter Trains, and Rail Transit," SAE Congress, January 1972.

84. Society of Automotive Engineers, "Future Electirc Cars," 1969.

85. Stanford Research Institute, <u>The Value of Time Saved by Trip Purpose</u>, Thomas C. Thomas and Gordon I. Thompson, Menlo Park, Calif., October 1970.

86. Stanford Research Institute, <u>Future Urban Transportation Systems: Descriptions, Evaluations, and Programs</u>, (Final Report I), Clark Henderson et al., 1968.

87. Stopher, P.R. and Lisco, T.E., "Modeling Travel Demand: A Disaggregate Behavioral Approach - Issues and Applications," Paper presented at 11th Annual Transportation Research Forum, October 1970.

88. Summers, Claude M., "The Conversion of Energy," <u>Scientific American</u>, September 1971.

89. Toye, Charles R., <u>Automated Guideway Network Traffic Modeling</u>, Report No-DOT-TSC-OST-72-7, Transportation Systems Center, Cambridge, Mass., February 1972.

90. Toye, Charles R., <u>Accumulative Probability Model for Automated Network Traffic Analyses</u>, Report No. DOT-TSC-OST-72-30, Transportation Systems Center, Cambridge, Mass., October 1972.

91. Traffic Research Corporation, <u>Calibration of a Discriminant Function Model of Interurban Modal Split Errata</u>, Arrigo P. Mongini, New York, N.Y., March 1966.

REFERENCES (CONT.)

92. Transportation, U.S. Dept. of, Goals and Objectives, Washington, D.C., May 1968.

93. Transportation, U.S. Dept. of, 1972 National Transportation Needs Study - Cost Estimates for Urban Public Transportation, Office of Systems Analysis and Information, Washington, D.C., July 28, 1971.

94. Transportation, U.S. Dept. of, External Costs and Benefits Analysis, OHSGT, Northeast Corridor Transportation Project, NECTP-224, Washington, D.C., 1969.

95. Transportation, U.S. Dept. of, News, FHWA-31-72, Washington, D.C., February 19, 1972.

96. Transportation, U.S. Dept. of, Highway Statistics, (Annual), FHWA, Washington, D.C., 1969.

97. Transportation, U.S. Dept. of, Cost of Operating an Automobile, FHWA, Office of Highway Planning, Highway Statistics Division, Washington, D.C., February 1970.

98. Transportation, U.S. Dept. of, Urban Transportation Planning - General Information and Introduction to System 360, FHWA, June 1970.

99. Transportation, U.S. Dept. of, Program Documentation - Urban Transportation Planning, FHWA, March 1972.

100. Transportation, U.S. Dept. of, TRANS Maintenance Costs, FHWA, November 1970, (Preliminary).

101. Transportation, U.S. Dept. of, The Highway User Investment Study: Model to Determine Highway Accidents, (unpublished), a working document prepared for the 1972 Highway Needs Report, FHWA, Statewide Planning Division, 1971.

102. TRW Systems Group, Automated Highway Systems, (High-Speed Ground Transportation Systems Engineering Study, Report 06818-W006), December 1968.

REFERENCES (CONT.)

103. TRW Systems Group, Elevated Guideway Structures, (High-Speed Ground Transportation Systems Engineering Study, Report No. 06818-W005-RO-00), December 1969.

104. TRW Systems Group, Multimodal Systems, (High-Speed Ground Transportation Systems Engineering Study, Report No. 06818-6040-RO-00), February 1970.

105. University of Toledo, "Expressway Traffic Noise and Residential Properties," 1967. Abstracted in Guide for Highway Impact Studies, U.S. Dept. of Transportation, FHWA, Washington, D.C., 1971.

106. Varhus, Alan, Highways' Effect on Land Value, (unpublished), a working paper prepared as background for the 1972 National Highway Needs Report, FHWA, Office of Policy Planning, November 1971.

107 Wesler, J.E., The Noise Exposure Model (MOD 4), Report No. DOT-TSC-OST-71-14, Transportation Systems Center, Cambridge, Mass., August 1971.

108. Wesler, J.E., Manual for Highway Noise Prediction, Report No. DOT-TSC-FHWA-72-1 and -2, Transportation Systems Center, Cambridge, Mass., March 1972.

109. Wesler, John E., Noise Impact Comparisons for Dual Mode Transportation Concepts, (Unpublished), Transportation Systems Center, Electromagnetics Technology Division, April 1972.

110. Wiggers, G.F., Airport Access Modal Choice - Analysis Alternatives, A Working Paper, U.S. Dept. of Transportation, Office of Systems Analysis and Information, May 1970.

111. Wilbur Smith and Associates, Comprehensive Traffic and Transportation Inventory, September 1965.

112. Wilson, E.E., "Deceleration Distances for High Speed Vehicles," Proceedings of the Highway Research Board, Washington, D.C., 1940.

113. Winfrey, Robley, Economic Analysis for Highways, International Textbook Company, Scranton, Pa., 1969.

DUAL MODE SYSTEMS ANALYSIS BIBLIOGRAPHY

BOOKS

Bierman, Harold, Jr. and Smidt, Seymour. The Capital Budgeting Decision. New York: Macmillan, Second Edition, 1966.

DeNeufville, Richard and Stafford, J.H. Systems Analysis for Engineers and Managers. New York: NcGraw Hill, 1971.

Fisher, Gene H. Cost Considerations in Systems Analysis. Rand Corp. New York: American Elsevier Pub. Co., Inc., 1971.

Godfrey, R.S., Ed. Building Construction Cost Data. Duxbury, Mass.: Means, 25th Edition, 1967.

Harper and James. The Law of Torts. 1956 Edition.

Hay, William W. An Introduction to Transportation Engineering. New York: John Wiley, Inc., 1961.

Hiller, F.S. and Lieberman, G.J. Introduction to Operations Research, Chapter 10-Queueing Theory. San Francisco: Holden-Day, Inc., 1967.

Hoel, Paul G. Introdution to Mathematical Statistics. New York: John Wiley and Sons, Inc., 1947.

Jaffe, A.J. Handbook of Statistical Methods for Demographers. Washington, D.C.: Bureau of Census, 1951.

Johnston, John. Econometric Methods. New York: McGraw-Hill, 1963.

Lang, A. Scheffer and Soberman, Richard M. Urban Rail Transit: Its Economics and Technology. Cambridge, Mass.: MIT Press, 1964.

McCormick, Ernest J. Human Factors Engineering. New York: McGraw-Hill, 1964.

Meyer, J.R., Kain J.F. and Wohl, M. The Urban Transportation Problem. Cambridge, Mass.: Harvard University Press, 1965.

BOOKS (CONT.)

Mohring, Herbert. "Urban Highway Investments," in Measuring of Benefits of Government Investments. Robert Dorfman, Ed. Washington, D.C.: The Brookings Institution, 1965.

Oi, Walter Y. and Shuldiner, Paul W. An Analysis of Urban Travel Demands. Northwestern University Press, 1962.

Page, J.S. Estimators General Construction Man-hour Manual. Houston, Texas: Gulf Publishing Co., 1959.

Peurifoy, R.L. Construction Planning, Equipment, and Methods. New York: McGraw-Hill, Second Edition, 1970.

Prosser. The Law of Torts. 4th Edition, 1971.

Pulver, H.E. Construction Estimates and Costs. New York: McGraw-Hill, Third Edition, 1960.

Smith, Philip. Exhaust and Intake Systems. Robert Bentley, Inc., 1970.

Thompson, Wilbur R. A Preface to Urban Economics. Baltimore: The Johns Hopkins Press, 1969.

Winfrey, Robley. Economic Analysis for Highways. Scranton, Pa.: International Textbook Company, 1969.

Wohl, Martin and Martin, Brian V. Traffic System Analysis for Engineers and Planners. New York: McGraw-Hill, 1967.

PERIODICALS

Agarwal, Paul D. and Levy, I.M. "A High Performance AC Electric Drive System," Society of Automotive Engineers, Paper No. 670178, January 1967.

Aldrich, Brian C. "Neighborhood Improvement Associations and Innovations in Urban Transportation Systems," Paper prepared for presentation at the National Conference on Personal Rapid Transit, Minneapolis, Minnesota, November 1-3, 1971.

American Transit Association. <u>Comparative Operating Accident Rates for First Six Months 1971-1970</u>, Report No. 63, ATA Accident Data Exchange, Washington, D.C., September 1971.

American Transit Association. <u>Estimates of Fatalities ... Transit Industry, Calendar Year 1968</u>, Washington, D.C., April 24, 1969.

American Transit Association. <u>1971 Transit Operating Report</u>, Washington, D.C., 1972.

American Transit Association. "Transit Operating Reports - 1968, Part II - Motor Bus Operations," Bulletin No. 926, Washington, D.C., May 1969.

Ayres, Robert U. "Technology and Urban Transportation," Resources for the Future, Inc., Paper prepared for the Brookings Institution Seminar on Science, Technology and Public Policy, March 12, 1968.

Bauer, Herbert J. "User Attitude Surveys and Transportation System Development," SAE Congress, January 1972.

Baumann, Dwight M. "Commucar - An Intra-Urban Transportation System." National Transportation Symposium, ASME, San Francisco, May 1966.

Beller, William S. "Megalopolis Transportation: Attacking the Systems Problem," <u>Space/Aeronautics</u>, 1967.

Bellomo, S.L. et al. "Factors, Trends, and Guidelines Related to Trip Length," Highway Research Bulletin No. 89, 1970.

PERIODICALS (CONT.)

Bender, J.G. and Fenton, R.E. "A Study of Automatic Car Following," IEEE Transactions on Vehicular Technology, November 1969.

Block, F.C. "Factors Influencing Modal Trip Assignment," Highway Research Bulletin No. 57, 1968.

Brigham, Georges. "Transportation Tomorrow," Science and Technology, February 1969.

Business Week, "A Backlash Against New Car Standards," (Report of Estimate by the President's Office of Science and Technology), March 25, 1972, p. 23.

DeWeille, Jan. "Quantification of Road User Savings," International Bank for Reconstruction and Development (World Bank), World Bank Staff Occasional Papers Number Two, Johns Hopkins Press, Baltimore, Maryland, 1966.

Favout, R. "Improving Urban Highway Transportation Through Electronic Route Guidance," ASCE, Urban Transportation Innovation, July 1970.

Fenton, R.E. and Olson, K.W. "The Electronic Highway," IEEE Spectrum, July 1969.

Franklin, P. and Bender, E. "Environment Effects of Transportation Noise," Bolt, Beranek and Newman, Inc., Cambridge, Mass., ASME Paper 70-TRANS-52, July 1970.

Funaya, Y. et al. "Demand Bus System for New Residential Area in Japan," SAE Congress, January 1972.

Gurski, Paul S. and Stuart, Darwin G. "Dual Mode Transportation: A Case Study of Milwaukee," Paper prepared for presentation at HRB Annual Meeting, January 1972.

Hamilton, William. "Balance and Innovation in Urban Transportation," HRB Paper, August, 1970.

PERIODICALS (CONT.)

Herman, Robert, Lam, Tenny and Rothrey, Richard. "Further Studies on Single Lane Bus Flow: Transient Characteristics," Transportation Science, Vol. IV, No. 2, May 1970.

Janzow, L.S. "New Transportation System Concept for Urban Industrial and Bulk-Material Applications," Dashaveyer Co. ASME Paper, March 1969.

Joseph, Hyman. "Construction Cost of Urban Expressways," CATS Research News, Vol. 4, No. 1, December 19, 1960.

Kennedy, Norman. "San Francisco Bay Area Rapid Transit: Promises, Problems, Prospects," Paper presented to SAE, Melbourne, Australia, 1971.

Lave, C.A., "A Behavioral Approach to Modal Split Forecasting," Transportation Research, Vol. 3, pp. 463-480, 1969.

Leary, Frank. "Megalopolis Transportation: High-Speed Ground Transportation," Space/Aeronautics, 1967.

Manheim, M.L. and Ruiter, E.R. "Dodotrans I: A Decision Oriented Computer Language for Analysis of Multi-Mode Transportation Systems," Highway Research Record No. 314, 1970.

Mason, F.J. and Mumford, J.R. "Computer Models for Designing Dial-A-Ride Systems," SAE Congress, January 1972.

McGillioray, Robert G. "Demand and Choice Models of Modal Split," Journal of Transportation Economics and Policy, May 1970.

McMillan, R.K. and Assael, H. "National Survey of Transportation: Attitudes and Behavior - Phase I Summary Report," Highway Research Bulletin No. 49, 1968.

McMillan, R.K. and Assael, H. "National Survey of Transportation: Attitudes and Behavior - Phase II Analysis Report," Highway Research Bulletin No. 82, 1969.

PERIODICALS (CONT.)

Meyers, Edward. "Exclusive: Transit '72 - City-by-City Directory of Urban Rail Systems," Modern Railways, May 1972.

Overgaard, K. Rask. "Traffic Estimation in Urban Transportation Planning," Acta Ploytechnic Scandinavia, C.E. and Building Construction Series No. 37.

Pendleton, William C. "Relation of Highway Accessibility to Urban Real Estate Values," Highway Research Record No. 16, 1963, pp. 14-23.

Pratt, R.H. "A Utilization Theory of Travel Mode Choice," Highway Research Record No. 322, 1970.

Ross, Howard R. "The Future of the Automobile," Science and Technology.

Rothery, R., Silver, R., Herman R. and Torner, C. "Analysis of Experiments on Single Lane Bus Flow," Operations Reserach, Vol. 12, No. 6, Nov. - Dec., 1964.

San Francisco Bay Area Rapid Transit District. "Comparative Data Report," San Francisco, California, October 1, 1971 (Quarterly).

Scheel, Jerold W. "A Method for Estimating and Graphically Comparing the Amounts of Air Pollution Emissions Attributable to Automobiles, Buses, Commuter Trains, and Rail Transit," SAE Congress, January 1972.

Skinner, R. and Koller, Frank. "A Survey of Airport Limousine Passengers," Vol. 6 of a series of Airport Location and Planning (R70-46), August 1970.

Society of Automotive Engineers. "A Hybrid Battery System for Electric Vehicle Propulsion," 1969.

Society of Automotive Engineers. "Future Electric Cars," 1969.

Society of Automotive Engineers. "Review of Battery Systems for Electric Vehicles," 1969.

PERIODICALS (CONT.)

Stefanek, R.G. and Keselwick, S.J. "Evaluation of the Operating Conditions on a Detroit Dual-Mode Vehicle Network," SAE Congress, January 1972.

Stopher, P.R. and Lisco, T.E. "Modeling Travel Demand: A Disaggregate Behavioral Approach - Issues and Applications," Paper presented at 11th Annual Transportation Research Forum, October 1970.

Summers, Claude M. "The Conversion of Energy," Scientific American, September 1971.

Wanttaja, Glen J. "Automated Roadway Transportation System Configurations," SAE Congress, January 1972.

Wilson, E.E. "Deceleration Distances for High Speed Vehicles," Proceedings of the Highway Research Board, Washington, D.C., 1940.

Wolf, Robert A. "Elements of a Future Integrated Highway Concept," Paper presented to Transportation Research Seminar, U.S. Department of Commerce, March 17-18, 1965.

Zraket, C.A. and Nutter, R.D. "Multi-Modal Transportation Systems Planning," Mitre Corp., AIAA Paper No. 70-1265, October 1970.

REPORTS

A.B. Young and Co., Passenger Demand and Modal Split Models, J.M. McLynn, and T. Woronka, NECTP 230, December 1959.

Abt Associates, Inc., Qualitative Aspects of Urban Personal Travel Demand, Cambridge, Mass., August 1968.

Abt Associates, Inc., System for Surveying Regional Travel, Volume II: Proposed Sample Design and Survey Procedures for a Coordinated Air, Auto, Bus and Rail Traveler Survey in the Northeast Corridor, Cambrige, Mass., April 1968.

Abt Associates, Inc., Travel Barriers: Transportation Needs of the Handicapped, PB 187-327, Cambridge, Mass., August 1969.

Abt Associates, Inc., Washington-Baltimore Airport Access Surveys, Vols. I-IV, OHSGT, FRA, 1968.

Aerospace Corporation, A Simulation Apporach to Transportation Modal Split Analysis, W.K. Clarkson and J.R. Buyan, December 1970.

Aerospace Corporation, Technical Proposal for a Personal Transit Systems Program, prepared by Transportation Systems Directorate Corporate Planning Office for UMTA, August 11, 1969.

Alan M. Voorhees and Associates, Inc., A System Sensitive Approach for Forecasting Urbanized Area Travel Demands, Technical Memorandum No. 4, McLean, Virginia, May 1971.

Alan M. Voorhees and Associates, Inc., Factors and Trends in Trip Lengths, Highway Research Bulletin No. 48, 1968.

Alan M. Voorhees and Associates, Inc., The Northeast Corridor Intercity Travel Survey, Air, Auto and Bus Modes, March 1971.

Alan M. Voorhees and Associates, Inc., Urban Mass Transit Planning Project, Volumes I and II, for U.S. Dept. of Housing and Urban Development, January 1968.

Alden Self-Transit Systems, Tomorrow's Transportation Today, Bedford, Mass., June 1969.

REPORTS (CONT.)

Allis-Chalmers Corp., Conceptual Hardware Design Description for a Dual Mode Urban Transit System, for UMTA, 1971.

Allis-Chalmers Corp., Milwaukee County Dual Mode Project, Paul S. Gurski, June 1971.

Allis-Chalmers Corp., Milwaukee County Dual Mode Systems Study, Volume I - Summary Report, Paul S. Gurski, Advanced Technology Center, for UMTA, December 1971.

Allis-Chalmers Corp., Milwaukee County Dual Mode Systems Study, Volume II - Technical Evaluation, Paul S. Gurski, Advanced Technology Center, for UMTA, December 1971.

Allis-Chalmers Corp., Milwaukee County Dual Mode Systems Study, Volume III - Socio-Economic Evaluation, Paul S. Gurski, Advanced Technology Center, for UMTA, December 1971.

Allis-Chalmers Corp., Milwaukee County Dual Mode Systems Study, Volume IV - Implementation Plan, Paul S. Gurski, Advanced Technology Center, for UMTA, December 1971.

Barton-Aschman Associates, An Evaluation of Alternative Transitway Equipment Systems for Milwaukee County, Chicago, Illinois, 1969.

Barton-Aschman Associates, General Criteria for Transitway Design-Milwaukee Co. Transitway, Chicago, Illinois, 1968.

Barton-Aschman Associates, Study Design for the Mass Transit Technical Planning Study in Milwaukee County, Chicago, Illinois, 1968.

Barton-Aschman Associates, Transit System Development Objectives, Principles and Standards, Chicago, Illinois, 1969.

Battelle Memorial Institute, Automatic Fare Collection Systems, (Papers-8th Annual Meeting, Transportation Research Forum), Battelle Technical Review, 1967.

Battelle Memorial Institute, High Speed Ground Transportation Journal, Vol. IV, No. 1, Battelle Technical Review, 1970.

REPORTS (CONT.)

Battelle Memorial Institute, Mathematical Research in Traffic Flow, Battelle Technical Review, 1967.

Battelle Memorial Institute, Transit in Columbus, Vol. 1, Display of Alternative Public Transportation Systems to Advisory Committee on Transit, Research Report, 1968.

Battelle Memorial Institute, Trends in Urban Transportation Research, Battelle Technical Review, 1968.

Bendix Research Laboratories, Factors Influencing Evolution of the Automobile for the Era 1970-1985, Southfield, (Internal Memorandum), February 12, 1970.

Boeing Vertol Division, Methodology for Evaluation of an Intra-urban and Interurban V/STOL Transportation System, October 1970.

Boston Safe Deposit and Trust Company, Financial Statistics of Massachusetts Sixty-Third Edition, Boston, MA, 1971.

Cabot, Cabot and Forbes Co., 1971 Greater Boston Cities and Towns; Population and Tax Rates, Boston, MA, 1972 (Pamphlet).

Charles River Associates, Inc., Prospects for Urban Transit, Cambridge, Mass., 1970.

Consad Research Corp., Transit Usage Forecasting Techniques: A Review and New Directions, T.R. Lakshmanan, Pittsburgh, Pa., April 1968.

Cornell Aeronautical Lab., Bi-Modal Urban Transportation System Study - Vol. I: Study in New Systems of Urban Transportation, March 1968.

Cornell Aeronautical Lab., Bi-Modal Urban Transportation System Study - Vol. II: Technical Appendices, May 1968.

Cornell Aeronautical Lab., Bi-Modal Urban Transportation System Study - Vol. III: Addendum - Technical Appendices, May 1968.

REPORTS (CONT.)

Cornell Aeronautical Lba., Requirements Aspects of the Urbmobile System Concept, B. Noress, Buffalo, NY, February 1958.

Daniel, Mann, Johnson and Mendenhall/Kaiser Engineers, Baltimore Region Rapid Transit System, Baltimore, MD, June 1971.

Development Research Associates, Benefits to the Washington Area from the Adopted Regional Metro System, prepared for the WMATA, Ocotber 25, 1968.

Electronic Systems Lab., The Metropolitan-Boston Transportation Problem, Mark E. Connelly, 1969.

Favout, R. and Haefner, L. Simulation of an Airport-CBD (Personal Rapid) Transit Line, unpublished working paper, June 1968.

Favout, R. Generalized Model for Estimating Way-Construction Quantities and Costs for Transportation Systems, unpublished working paper, November 1966.

Ford Motor Company, Automatic Headway Control - An Automatic Vehicle Spacing System, 1970.

Ford Motor Company, The Courier: A Prototype Vehicle for Dial-A-Ride Service, 1970.

General Electric Company, A Study of Command and Control Systems for Urban Transportation, 1968.

General Electric Company, Analysis and Requirements of Electronic Command and Control Systems, 1967.

General Electric Company, Communications and Control for Transportation, 1968.

General Electric Company, Study in New Systems of Urban Transportation - A Study of Command and Control Systems for Urban Transportation, 1968.

General Electric Company, Survey of Electronic Command and Control Systems, 1967.

REPORTS (CONT.)

General Motors Corporation, Metro-Mode, A New Approach to Rapid Transit, prepared in collaboration with the Southeastern Wisconsin Regional Planning Commission, (undated).

General Motors Research Laboratories, New Systems Implementation Study, for U.S. Dept. of Housing and Urban Development (3 Volumes), Warren, Michigan, February 1968: Volume I, Summary and Conclusions; Volume II, Planning and Evaluation Methods; Volume III, Case Studies.

General Motors Research Laboratories, Stir-Lee I, A Stirling Electric Hybrid Car, Paul D. Agarwal, Warren, Michigan, 1969.

General Motors Research Laboratories, A Case Study of a Demand Responsive Transportation System, Herbert J. Bauer, GMR-1034, Warren, Michigan, September 10, 1970.

General Motors Research Laboratories, Evaluation of User Benefits Arising from Changes in Transportation Systems, Martin J. Beckmann and Hames P. Wallace, III, Warren, Michigan, November 1969.

General Motors Research Laboratories, Electronic Highways, Joseph B. Bidwell, Eugene A. Hanysz and Albert F. Welch, GMR-245, Warren, Michigan, January 12, 1960.

General Motors Research Laboratories, Case Studies of New Systems of Urban Transportation, Eugene T. Canty and Albert J. Sobey, GMR-845, Warren, Michigan, January 7, 1969.

General Motors Research Laboratories, Future Transportation Systems Study, Eugene T. Canty, Warren, Michigan, January 1968.

General Motors Research Laboratories, Transportation and Urban Scale, Eugene T. Canty, GMR-843, Warren, Michigan, January 1969.

REPORTS (CONT.)

General Motors Research Laboratories, Automatic Car Controls for Electronic Highways, Keith Gardels, GMR-276, Warren, Michigan, June 1960.

General Motors Research Laboratories, A Utility Model for Travel Forecasting, Thomas F. Golob and Martin J. Beckmann, GMR-1006, Warren, Michigan, September 14, 1970.

General Motors Research Laboratories, Economic Analysis of a Demand Responsive Public Transportation System, Thomas F. Golob and Richard L. Gustafson, GMR-1046, Warren, Michigan, January 1971.

General Motors Research Laboratories, Toward the Stratification and Clustering of Metropolitan Areas, Thomas F. Golob, Eugene T. Canty and Richard L. Gustafson, GMR-1093, Warren, Michigan, May 6, 1971.

General Motors Research Laboratories, Metropolitan Areas and Arterial Transportation Needs, Thomas F. Golob, Eugene T. Canty and Richard L. Gustafson, GMR-1225, Warren, Michigan, 1972.

General Motors Research Laboratories, An Analysis of Consumer Preferences for a Public Transportation System, Thomas F. Golob, Eugene T. Canty and Richard Gustafson and Joseph Vitt, GMR-1037, Warren, Michigan, October 26, 1970.

General Motors Research Laboratories, The Survey of User Choice of Alternate Transportation Modes, Thomas F. Golob, GMR-950, Warren, Michigan, January 1970.

General Motors Research Laboratories, Special Purpose Urban Cars, James J. Gumbleton, Daniel L. Frank, Stanley Genslak and Albert G. Lucas, Warren, Michigan, May 23, 1965.

General Motors Research Laboratories, Survey Data: Measurement of User Preferences for a Demand Responsive Transportation System, GMR-1057, Warren, Michigan, January 1971.

General Motors Research Laboratories, User Preferences for a Demand Responsive Transportation System: A Case Study Report, Richard L. Gustafson, Harriet N. Curd and Thomas F. Golob, GMR-1047, Warren, Michigan, January 1971.

General Motors Research Laboratories, Vehicular Traffic Flow, Robert Herman and Keith Gardels, Warren, Michigan, December 1963.

General Motors Research Laboratories, The Starting Characteristics of Automobile Platoons, Robert Herman, Tenny Lam and Richard Rothery, Warren, Michigan, (undated).

General Motors Research Laboratories, Traffic Dynamics: Analysis of Stability in Car Following, Robert Herman, Elliott W. Montroll, Refrey B. Potts, and Richard W. Rothery, Warren, Michigan, (undated).

General Motors Research Laboratories, Algorithms for Routing and Scheduling in Demand Responsive Transportation Systems, Larry L. Howson and Kenneth W. Heathington, GMR-944, Warren, Michigan, January 14, 1970.

General Motors Research Laboratories, Mathematical Methods of Optimization for Multi Objective Transportation Systems, Kailash C. Kapur, GMR-965, Warren, Michigan, April 22, 1970.

General Motors Research Laboratories, Reservation Systems for Synchronous Automated Highway Networks, Louis T. Klauder, Jr., GMR-1094, Warren, Michigan, October 1971.

General Motors Research Laboratories, Automatic Highway and Driver Aid Developments, H.M. Morrison, A.F. Welch and E.A. Hanysz, GMR-252, Warren, Michigan, March 17, 1960.

REPORTS (CONT.)

General Motors Research Laboratories, Bus Operation in Single Lane Platoons and Their Ventilation Needs for Operation in Tunnels, Jerold W. Scheel and James E. Foote, GMR-808, Warren, Michigan, October 1968.

General Motors Research Laboratories, Comparison of Experimental Results with Estimated Single Lane Bus Flow Through a Series of Stations Along a Private Busway, Jerold W. Scheel and James E. Foote, GMR-888, Warren, Michigan, June 1969.

General Motors Research Laboratories, Urban Mobility - Why, How, When and Where? William M. Spreitzer, GMR-1056, Warren, Michigan, October 10, 1970.

General Motors Research Laboratories, Determining the Importance of User Related Attributes for a Demand Responsive Transportation System, J.E. Vitt, H.J. Bauer, E.T. Canty, T.F. Golob and K.W. Heathington, GMR-941, Warren, Michigan, December 1, 1969.

General Motors Research Laboratories, A Mechanically Rechargeable 1-KW Zinc-Air Battery, Romeo R. Witherspoon, Warren, Michigan, 1969.

General Research Corporation, Systems Analysis of Urban Transportation, for U.S. Department of Housing and Urban Development, (4 Volumes), January 1968: Volume I, Summary; Volume II, Cases for Study; Volume III, Network Flow Analyses; Volume IV, Supporting Analyses.

General Research Corporation, A Systems Approach to Surface Transporation, Ben Alexander, prepared for Hearings Before the Senate Commerce Committee Chairman and Technical Director, February 27, 1970.

General Research Corporation, Dual Mode: The Overdue Innovation in Urban Transportation, Ben Alexander, January 1970.

General Research Corporation, Prospect for a New Balance Among The Transportation Modes, Ben Alexander, Technical Memorandum 1573, November 1971.

General Research Corporation, Supplemental Studies of Urban Transportation Systems Analysis, J.A. Boys, E.N. Dodson, W.F. Hamilton and A.R. Sjovold, September 1968.

General Research Corporation, Alternative Paths to Guideway Transportation, William Hamilton, Technical Memorandum 1357, July 1970.

General Research Corporation, Developing Dual Mode Transportation, William Hamilton, May 1971.

Grimble and Associates Ltd., Description of a Guided Automated Individual Transportation System, Consulting Engineers, Edmonton, Alberta, for the Canadian Council on Urban and Regional Research sponsored by the City of Regina, February 1, 1968.

Harza Engineering Co., High Speed Ground Transportation Tunnel Design and Cost Data, PB-178201, Chicago, Ill., March 1968.

Institute for Defense Analyses, Economic Characteristics of the Urban Public Transportation Industry, for DOT-TPI, February 1972.

Institute for Defense Analyses, Summary of Work to Date, John D. Wells, Memorandum to Edward Weiner, DOT-TPI, Arlington, Va., January 12, 1972.

Institute for Defense Analyses, Some Air Pollution, Accident and Noise Factors Due to Mass Transit Systems, Murray Kamrass, Study Memorandum to DOT, March 1971.

Institute for Defense Analyses, Fare and Service Elasticities of Urban Bus Transit: A Time Series Analysis of Demand, J. Hayden Boyd and Gary R. Nelson, May 1972.

REPORTS (CONT.)

Institute for Defense Analyses, The ACT System, W.H. Avery, for Urban Mass Transportation Workshop, Arlington, Va., 1969.

International Bank for Reconstruction and Development, Quantification of Road User Savings, Report EC-140a, Washington D.C., 1965.

Jacobs, Justin, Presentation to the Bay Area Transportation Study Commission, 1970.

Jet Propulsion Laboratory, Technical and Cost Considerations for Urban Applications of Dual Mode Transportation, for DOT-TST, California Institute of Technology, Pasadena, California, May 23, 1972.

Johns Hopkins University, Applied Physics Laboratory, Alden Capsule Transit System Control Subsystem and Baseline Definition, Silver Spring, Maryland, 1970.

Johns Hopkins University, Applied Physics Laboratory, Practical Requirements for Advanced Public Transportation Systems, W.H. Avery, January 1972.

Johns Hopkins University, Applied Physics Laboratory, Acceleration and Comfort in Public Ground Transportation, J.W. Gebhard, Transportation Programs Report TPR 002, February 1970.

Johns Hopkins University, Applied Physics Laboratory, Parametric Analysis of Generic Urban Transit Systems, B.M. Ford, W.J. Roesler and M.C. Waddell, Silver Spring, Maryland, December 1969.

Louis T. Klauder and Assoc., Preliminary Engineering Report on Possible Improvements to Railroad Passenger Service Between New York and Boston, PB-169907, November 15, 1965.

Massachusetts Institute of Technology, Summary of Research at MIT on High Speed Ground Transportation.

REPORTS (CONT.)

Massachusetts Institute of Technology, Roles for Public and Private Enterprise in Transportation.

Massachusetts Institute of Technology, A Survey of the New York City Airport Limousine Service: A Demand Analysis, R. DeNeufville, R. Skinner, and F. Koller, unpublished paper by Dept. of Civil Engineering, 1970.

Massachusetts Institute of Technology, Emerging Patterns of Urban Growth and Travel, 1968.

Massachusetts Institute of Technology, Headway and Switching Strategies for Automated Vehicular Ground Transportation Systems, 1966.

Massachusetts Institute of Technology, On the Optimal and Sub-optimal Position and Velocity Control of a String of High-Speed Moving Trains, 1966.

Massachusetts Institute of Technology, Pallet Systems for Integrating and Automating Urban Transportation, 1970.

Massachusetts Institute of Technology, Program in Urban Transportation Dual Transportation Systems; Analysis of Demands and Benefits in Urban Areas; and Development of Performance Requirements, 1970.

Massachusetts Institute of Technology, Project Metran, (MIT Report #8), 1966.

Massachusetts Institute of Technology, Project Romulus, (MIT Report #12), 1967.

Massachusetts Institute of Technology, Simulation-Analysis of a High Speed Ground Transportation System, 1968.

Massachusetts Institute of Technology, Simulation of a Computer Aided Routing System (CARS).

Massachusetts Institute of Technology, Survey of Technology for High Speed Ground Transport, 1965.

REPORTS (CONT.)

Massachusetts Institute of Technology, The Guideway System for Automated Transportation, 1969.

Massachusetts Institute of Technology, An Adaptable Transportation System for a Subcity of the Future, School of Engineering, by Students of subject 1.214 Transport Systems Design-Spring, 1967, July 1968.

Massachusetts Institute of Technology, Development of a Behavioral Model of Travel Mode Choice, R.P. Plourde, Dept. of Civil Engineering, Thesis Working Paper, April 1970.

Massachusetts Institute of Technology, Automated Guideway Transportation Between and Within Cities: A Report on the Demand for, Control of, and Station and Guideway Design for Dual Mode Transportation, David Gordon Wilson, Ed., Urban Systems Laboratory, for Office of High-Speed Ground Transportation, February 1971.

Massachusetts Institute of Technology, Dual-Mode Vehicle Terminal, and Network Alternatives for Automated Guideway Transportation, David G. Wilson, Michael B. Godfrey and Henry H. Fuller, Jr., MIT Industrial Liaison Program Report, May 12, 1971.

Massachusetts Institute of Technology, Program in Urban Transportation, Dual Mode Transportation Systems, D. Brand, Urban Systems Laboratory, 1970.

Massachusetts Institute of Technology, Modal Split Models for Airport Access, F. Koller and R. Skinner, (R70-47), Vol. 7 of a series of Airport Location and Planning, Dept. of Civil Engineering, August 1970.

Massachusetts Institute of Technology, Optimal Location of Transportation Terminals, B. Genest, R70-54, Vol. 3 of a series, Dept. of Civil Engineering, August 1970.

Massachusetts Taxpayers Foundation, Inc., 1970 Tax Rates; Actual and Full Value, November 1970.

REPORTS (CONT.)

Mathematica, Studies in Travel Demand, Vol. I-V, for Northeast Corridor Project, U.S. Dept. of Commerce.

Mitre Corporation, Cost Analysis for NECTP, Volume II, Air and Highway Modes, McLean, Va., December 1969.

—Mitre Corporation, Urban Transportation - Strategies and Alternatives for the Future, C.A. Zraket and R.H. Winslow, MTP-366, February 1972.

Mitre Corporation, A Technology Assessment Methodology, Automotive Emissions, W.E. Jacobsen et al., MTR 6009, Vol. 2, June 1971.

National Academy of Engineering, Urban Transportation Research and Development, Committee on Transportation, 1972.

National Analysts, The Needs and Desires of Travelers in the Northeast Corridor: A Survey of the Dynamics of Mode Choice Decisions, for DOT/OHGST, January 1970.

National Research Council, Design and Performance Criteria for Improved Nonrail Urban Mass Transit Vehicles and Related Urban Transportation Systems, 1963.

North American Rockwell Corporation, Frontiers of Technology Study, Vol. I: Summary, 1968.

North American Rockwell Corporation, Frontiers of Technology Study, Vol. II: Survey Report, 1968.

North American Rockwell Corporation, Frontiers of Technology Study, Vol. III: Implementation Requirements Studies, 1968.

North American Rockwell Corporation, Transportation System Technology, Implementation Requirements for Four Advanced Urban Transportation Systems, Phase II, Final Report NA-68-807, for U.S. Dept. of Housing and Urban Development, Los Angeles, Calif., October 18, 1968.

REPORTS (CONT.)

Ohio State University, Multiple Rear-End Collisions in Freeway Traffic, Their Causes and Their Avoidance, 1970.

Parsons Brinckerhoff-Tudor-Bechtel, Metropolitan Atlanta Rapid Transit Plan, Report PBTB A-71-1 prepared for Metropolitan Atlanta Rapid Transit Authority, September 1971.

Peat, Marwick, Mitchell and Co., Evaluation of a Bus Transit System in a Selected Urban Area - Final Report, for FHWA, June 1969.

Peat, Marwick, Mitchell and Co., Sensitivity Analysis of the Evaluation of a Bus Transit System in a Selected Urban Area, for FHWA, May 1970.

Peat, Marwick, Mitchell and Co., System for Surveying Regional Travel, Volume I, Proposed Method for Selection of Survey Sites for a Coordinated Air, Auto, Bus and Rail Traveler Survey in the Northeast Corridor, Washington, D.C., June 1967.

Peat, Marwick, Mitchell and Co., The N-Dimensional Logit Model: Development and Application, P.R. Rassam, R.H. Ellis, J.C. Bennett, 1970.

Peat Marwick, Mitchell and Co., An Analysis of Urban Area Travel by Time of Day, L.M. Tittemore et al., Boston, Mass., January 1972.

Peat, Marwick, Mitchell and Co., Vehicle Access Penalty Validation Program VEAMP (Vehicle Access Modifier Program), Donald E. Ward et al., (Internal Memorandum), July 14, 1971.

Peat, Marwick, Mitchell and Co., Dual Mode Calibration Variable Correlations, Donald E. Ward, (Task Memorandum), January 21, 1972.

Peat, Marwick, Mitchell and Co., Notes on Logit Model Calibration, Donal E. Ward, (Task Memorandum), February 3, 1972.

Peat, Marwick, Mitchell and Co., Modal Split Factors, Donald E. Ward, (Task Memorandum) March 7, 1972.

Peat, Marwick, Mitchell and Co., Final Notes on Logit Model Calibration, Donald E. Ward, (Task Memorandum), May 5, 1972.

Princeton Universtiy, A First Approximation Satellite Terminal System Evaluation Model, FAA-AV-71-1, Department of Civil Engineering, March, 1971.

Rand Corporation, A Model and Computer Code for Studying Alternate Air Passenger Processing Strategies, D.M. Landi and A.V. Rolfe, Memo RM-5818-PA, August 1969.

Rand Corporation, New Directions for Passenger Demand Analysis and Forecasting, G. Kraft and M. Wohl, Rand P-3877, AD 672 150, June 1968.

Rand Corporation, The STAR Study: Impacts of Alternative Inter-city Short-Haul Transportation Systems on the California Corridor, B.F. Goeller et al., for DOT, Santa Monica, California, September 1971.

Resource Management Corp., Cost Analysis for NECTP, Vol. 1, High Speed Ground Modes, Bethesda, Md., December 1969.

Robert S. Mayo and Associates, Tunneling-the State of the Art: A Review and Evaluation of Current Tunneling Techniques and Costs with Emphasis on Their Application to Urban Rapid Transit Systems in the USA, Robert S. Mayo, Lancaster, Pennsylvania, January 1968.

Simpson and Curtin, Inc.; Midwest Planning and Research, Inc.; Daniel, Mann, Johnson and Mendenhall; Honeywell, Inc., Development of Vehicle Performance Specifications, Prepared for the Twin Cities Area Metropolitan Transit Commission, September 22, 1972 (Draft).

REPORTS (CONT.)

Stanford Research Institute, The Value of Time Saved by Trip Purpose, Thomas C. Thomas and Gordon I. Thompson, Menlo Park, Calif., October 1970.

Stanford Research Institute, Future Urban Transportation Systems: Desired Characteristics, MR-1, May 1967.

Stanford Research Institute, Future Urban Transportation Systems: Tehcnological Assessment, Ernest G. Chilton, MR-2, prepared for U.S. Dept. of Housing and Urban Development, May 1967.

Stanford Research Institute, Future Urban Transportation Systems: Descriptions, Evaluations, and Programs, (Final Report I), Clark Henderson et al., 1968.

Stanford Research Institute, Future Urban Transportation Systems: Impacts on Urban Life and Form, (Final Report II), Robert A. Burco and David A. Curry, March 1968.

Stanford Research Institute, SRI Network Analysis Programs (SNAP), 1968.

Syracuse University, Measuring Accessibility, Thomas J. Wilbanks, October 1970.

Traffic Research Corporation, Calibration of a Discriminant Function Model of Interurban Modal Split Errata, Arrigo P. Mongini, New York, New York, March 1966.

TRW Systems Group, Transportation System Optimization Program Demonstration Problem, (High-Speed Ground Transportation Systems Engineering Study, Program Report No. 06818-W917-RO-00), June 1, 1968.

TRW Systems Group, A Computer-Assisted Method for Optimizing Route Profiles, (High-Speed Ground Transportation Systems Engineering Study, Report No. 06818-W004-RO-00), December 1969.

TRW Systems Group, Automated Highway Systems, (High-Speed Ground Transportation Systems Engineering Study, Report 06818-W006), December 1969.

REPORTS (CONT.)

TRW Systems Group, A Study of Synchronous Longitudinal Guidance as Applied to Intercity Automated Highway Networks, September 1969.

TRW Systems Group, Elevated Guideway Structures, (High-Speed Ground Transportation Systems Engineering Study, Report No. 06818-W005-RO-00), December 1969.

TRW Systems Group, High Speed Rail Systems, (High-Speed Ground Transportation Systems Engineering Study, Report No. 06818-6037-RO-00), PB-192506, February 1970.

TRW Systems Group, Multimodal Systems, (High-Speed Ground Transportation Systems Engineering Study, Report No. 06818-6040-RO-00), February 1970.

TRW Systems Group, Network-Control Study, (High Speed Ground Transportation Systems Engineering Study, Report No. 06818-W019-RO-00), July 1970.

TRW Systems Group, System Effectiveness Studies, (High-Speed Ground Transportation Systems Engineering Study, Report No. 06818-W002-RO-00), November 1969.

TRW Systems Group, Train Elevated Guideway Interactions, (High-Speed Ground Transportation Systems Engineering Study - Report No. 06818-6036-RO-00), February 1970.

TRW Systems Group, Train/Elevated Guideway Parametric Investigation, (High-Speed Ground Transportation Systems Engineering Study, Report No. 06818-W018-RO-00), July 1970.

Uniflo Systems Company, Uniflo Transportation System, Minn., 1970.

University of California, Cost Functions for Comparison of Low Cost Transportation Technologies, Dissertation Series, Lawrence L. Vance, Jr., Institute of Transportation and Traffic Engineering, April 1971.

REPORTS (CONT.)

University of California, Tables for Investment Analysis, P.F. Wendt and Alan R. Cerf, Center for Real Estate and Urban Economics, Institute of Urban and Regional Development, (Special Report No. 3), Berkeley, 1966.

University of Toledo, "Expressway Traffic Noise and Residential Properties," 1967. Abstracted in Guide for Highway Impact Studies, U.S. Dept. of Transportation, FHWA, Washington, D.C., 1971.

The Urban Institute, An Analysis and Evaluation of the Rapid Transit Extension to Clevand's Airport, Martin Wohl, Washington, D.C., August 1971.

W.C. Gilman & Co., Inc. and Alan M. Voorhees & Associates, Inc. Traffic Reveune, and Operating Costs, Revised version prepared for the Washington Metropolitan Area Transit Authority, McLean, Virginia, February 1971.

Westinghouse Air Brake Company, Evolutionary Improvements in Urban Transportation Systems, Vol. 1, 1968.

Westinghouse Air Brade Company, Study in New Systems of Urban Transportation - Study of Evolutionary Urban Transportation, Vol. I, Appendices 1, 2, and 3, 1968.

Westinghouse Air Brake Company, Study in New Systems of Urban Transportation - Study of Evolutionary Urban Transportation, Vol. III, App. 4, 1968.

Westinghouse Electric Corporation, Computer Program Simulates Proposed Transit Systems and Evaluates Them Economically, 1968.

Westinghouse Electric Corporation, Transit Expressway Report, 1967.

Westinghouse Electric Corporation, Systems Modeling and Simulation Help Develop and Test the Logic for BART Train Control Strategies.

REPORTS (CONT.)

Wilbur Smith and Associates, Comprehensive Traffic and Transportation Inventory, September 1965.

Wilbur Smith and Associates, Parking in the City Center, New Haven, Conn., 1965.

GOVERNMENT PUBLICATIONS

American Association of State Highway Officials, A Policy on Arterial Highways in Urban Areas, 1957.

American Association of State Highway Officials, Road User Benefit Analyses for Highway Improvements, Washington, D.C., 1960.

BART Office of Research, BART Interstation Fare Schedule Report, San Francisco, California, May 18, 1971.

Bay Area Transportation Study Commission, Bay Area Transportation Report, Berkeley, California, May 1969.

Boston Redevelopment Authority, Transportation Facts for the Boston Region, 1968.

Cantilli, Edmund J. and June L. Shmelzer, Ed., Transportation and Aging: Selected Issues, Based on proceedings of the Interdisciplinary Workshop on Transportation and Aging, Washington, D.C., May 24-26, 1970.

Cole, L.M., Editor, Tomorrow's Transportation, New Systems for the Urban Future, HUD, 1968.

Commerce, U.S. Dept. of, A System to Facilitate Bus Rapid Transit on Urban Freeways., Vol. I, PB 183 390, 1968.

Commerce, U.S. Dept. of, A System to Facilitate Bus Rapid Transit on Urban Freeways, Vol. II, PB 183 391, 1968.

Commerce, U.S. Dept. of, Bureau of the Census, 1970 Census of Population and Housing: General Demographic Trends for Metropolitan Areas, 1960 to 1970, PHC (2)-23, Massachusetts, June 1971.

Commerce, U.S. Dept. of, Census of Governments, Volume 2, Taxable Property Values, Bureau of the Census, Washington, D.C., 1967.

GOVERNMENT PUBLICATIONS (CONT.)

Commerce, U.S. Secretary of, Science and Technology in the Railroad Industry, National Academy of Sciences - National Research Council, PB 166 882, 1963.

Commerce, U.S. Dept. of, High-Speed Ground Transportation Research and Development: A Preliminary Appraisal, PB 168 782, 1965.

Commerce, U.S. Dept. of, Long Term Economic Growth, Bureau of the Census, 1966.

Commerce, U.S. Dept. of, Statistical Abstract of the United States 1969, 90th Annual Ed., Bureau of the Census, Washington, D.C., 1969.

Commerce, U.S. Dept. of, Survey of Current Business, Bureau of the Census, (monthly).

Commerce, U.S. Dept. of, Business Conditions Digest, Bureau of the Census, (weekly).

Commerce, U.S. Dept. of, The Automobile and Air Pollution, Parts I and 2, 1967.

Commerce, U.S. Dept. of, The Mass Transportation Demonstration Project, July 1964.

Commerce U.S. Dept. of, Traffic Assignment Manual, Bureau of Public Roads, Washington, D.C., June 1969.

Commerce, U.S. Dept. of, Modal Split, Documentation of Nine Methods for Estimating Transit Usage, Bureau of Public Roads, Office of Planning, December 1966.

Commerce, U.S. Dept. of, Highways and Economic and Social Changes, Bureau of Public Roads, Washington, D.C., 1964.

Donaldson, J., National Bureau of Standards Modeling for the NECTP, NECTP-213, DOT/OHSGT, December 1969.

Endriss, J.R., Calibration of the Multimode Assignment Model: Choice of the Base Mode, TAD/National Bureau of Standards, U.S. Dept. of Commerce, October 1967.

GOVERNMENT PUBLICATIONS (CONT.)

Federal Register, Vol. 36, No. 228, pp. 22452-3, Novermber 25, 1971.

Federal Register, Vol. 36, No. 247, pp. 24878-9, December 23, 1971.

Fee, Julie et al., Interstate System Accident Research Study - 1, FHWA, Office of Research and Development, Traffic Systems Division, October 1970.

Fitcher, Donn, An Analysis of Dual Mode Transport (Urbmobile), New York State Dept. of Transportation, Albany, New York, December 1970 (Rochester, New York study).

Fleischman, E., TRANS Technical Report: Dislocations, FHWA, March, 1971.

Foote, Robert S., Technology for Upgrading Urban Highway Traffic, Port of New York Authority, April 1968.

Freck, P.G., Intra-Airport Transportation Systems: An Examination of Technology and Evaluation Methodology, Study S-351, IDS for UMTA, Dec., 1969.

Hall, G. and Breuer, R., User and Community Benefits in Intercity Freeway Corridor Evaluation, Planning Division, New York State Department of Transportation, Albany, N.Y., December 1971.

Health, Education and Welfare, U.S. Dept. of, Air Quality Criteria for Carbon Monoxide, March 1970.

Health, Education and Welfare, U.S. Dept. of, Kanawha Valley Air Pollution Study.

Heaton, Carla J., A Comparison of Motor Vehicle Accident Cost Data, Highway Planning Technical Report No. 21, FHWA, Washington, D.C., May 1971.

GOVERNMENT PUBLICATIONS (CONT.)

Housing and Urban Development, U.S. Dept. of, Further Analyses of the Passenger Flow Improvement (PFI) and Dart Concepts as Evolutionary Improvements in Urban Transportation Systems, Participating Organizations: Westinghouse Air Brake Co., Melpar, Inc., and the Institute for Public Administration, Washington, D.C., June 1968.

Housing and Urban Development, U.S. Dept. of, Study of Evolutionary Urban Transportation, Volume 1, Participating Organizations: Westinghouse Air Brake Co., Melpar, Inc., Wilbur Smith and Associates and the Institute for Public Administration, February 1968.

Josephs, J.A., Approaches to the Modal Split: Intercity Transportation, Technical Paper No. 7, U.S. Dept. of Commerce, February 1967.

Kangas, Ronald, Alternative Dual Mode Network Control Strategies, Report No. DOT-TSC-OST-72-10, Transportation Systems Center, Cambridge, Mass., March 1972.

Kassoff, H. and Gendell, D., An Approach to Multiregional Urban Transportation Policy Planning, FHWA, January 1971.

Kovatch, George and Zames, George, Modeling Transportation Systems: An Overview, TSC Preliminary Memorandum, June 1971.

Kovatch, George and Zames, George, Personalized Rapid Transit Systems: A First Analysis, Report No. DOT-TSC-OST-71-11, Transportation Systems Center, Cambridge, Mass., August 1, 1971.

Kovatch, George, Barber, John B., Casey, Robert F., and Zames, George, Transportation Systems Technology: A Twenty-Year Outlook, Report No. DOT-TSC-OST-71-10, Transportation Systems Center, Cambridge, Mass., August 1, 1971.

GOVERNMENT PUBLICATIONS (CONT.)

Massachusetts Bay Transportation Authority, "Comparative Analysis of the Net Cost of Service, Interest Charged by State Treasurer and Boston Metropolitan District Expenses for Fiscal Periods Since August 4, 1964." (Unpublished table).

Massachusetts, Commonwealth of, Mass Transportation in Massachusetts, Commission of Mass Transportation, July 1964.

Massachusetts, Commonwealth of, 1970 Assessments for Interest, Serial Bonds and Maintenance of the Metropolitan Districts, Public Document No. 92, 1970.

Massachusetts Department of Public Works, Recommended Highway and Transit Plan, Eastern Massachusetts Regional Planning Project, 1968.

Metropolitan Area Planning Council, Economic Base and Population Study, Vol. II: Prospects for Economic Growth, Boston, Mass., March 1967.

Metropolitan Atlanta Rapid Transit Authority, Rapid Transit for Metro Atlanta, Atlanta, Georgia, September 1971.

Morgan, Gwenn, Joint Development: The Key to a More Compatible Urban Freeway, (unpublished), a working paper prepared as background for the 1972 National Highway Needs Report, FHWA, Office of Policy Planning, May 26, 1971.

Morgan, Gwenn, The Social Impact of Highway Improvements on Urban Neighborhoods, (unpublished), a working paper prepared as background for the 1972 National Highway Needs Report, FHWA, Office of Policy Planning, May 24, 1971.

Moser, Patricia, Aesthetic and Ecological Disharmonies of Highways, (unpublished), a working paper prepared as background for the 1972 National Highway Needs Report, FHWA, Office of Policy Planning, May 1971.

GOVERNMENT PUBLICATIONS (CONT.)

Moser, Patricia, The Benefits of Highway Improvement to Health and Education, (unpublished), a working paper prepared as background for the 1972 National Highway Needs Report, FHWA, Office of Policy Planning, June -, 1971.

Moser, Patricia, The Influence of Highways on Recreational and Cultural Opportunities, (unpublished), a working paper prepared as background for the 1972 National Highway Needs Report, FHWA, Office of Policy Planning, May 20, 1971.

Mungenast, James A., A Preliminary Study on the Magnitude of Federal Aid Highway Displacements, on a Per-Mile Basis, and of Some Related Cost-Benefit Factors Concerning the Displaced Families, Individuals, and Businessman, (unpublished), a working paper prepared as background for the 1972 National Highway Needs Report, FHWA, Office of Policy Planning, November 1970.

Ohio Department of Highways, Maintenance Cost Study, Columbus, 1966 Report and Interim Report, Parts I and II (July 1968).

Pasternack, Sam, Modern Control Aspects of Automatically Steered Vehicles, Report No. DOT-TSC-OST-72-3, Transportation Systems Center, Cambridge, Mass., December 1971.

Regional Planning Commission, Cleveland Hopkins Airport Access Study, Cuyahoga County, Ohio, Special Surveys, Inc. of Cleveland, Ohio, June 1970.

Regional Planning Commission, Modal Split Analysis, Cuyahoga County, Ohio, May 1970.

Rhode Island Statewide Comprehensive Transportation and Land Use Planning Program, Rhode Island Transit Plan: Future Mass Transit Services and Facilities - Report Number 9, June 1969.

Rosenblith, W.A. and Stevens, K.N., Handbook of Acoustic Noise Control, Vol. II, Noise and Man, U.S.A.F., WADC, Technical Report 52-204, Report PB 111 274, U.S. Dept. of Commerce, Office of Technical Services, June 1953.

Rothenberg, M.J. and Prokopy, J., Access and Demand Data Used in the Development and Calibration of Northeast Corridor Transportation Models, NECTP-217, DOT/OHGST, January 1970.

Symmes, Donald, Air Pollution, (unpublished), a working paper prepared as background for the 1972 National Highway Needs Report, FHWA, Office of Policy Planning, November 1971.

Toye, Charles, Automated Guideway Network Traffic Modeling, Report No. DOT-TSC-OST-72-7, Transportation Systems Center, Cambridge, Mass., February 1972.

Toye, Charles, Accumulative Probability Model for Automated Network Traffic Analysis, Report No. DOT-TSC-OST-72-30, Transportation Systems Center, Cambridge, Mass., October 1972.

Transportation, U.S. Dept. of, Goals and Objectives, Washington, D.C., May 1968.

Transportation, U.S. Dept. of, Travel Barriers, Notes of the Secretary, May 1970.

Transportation, U.S. Dept. of, 1972 National Transportation Needs Study - Cost Estimates for Urban Public Transportation, Office of Systems Analysis and Information, Washington, D.C., July 28, 1971.

Transportation, U.S. Dept. of, Recommendations for Northeast Corridor Transportation Final Report - Summary Report, Vol. I of III, Office of Systems Analysis and Information, May 1971.

Transportation, U.S. Dept. of, Published Reports by the Office of High Speed Ground Transportation, Federal Rail Administration, November 1970.

GOVERNMENTS PUBLICATIONS (CONT.)

Transportation, U.S. Dept. of, Northeast Corridor Transportation Project Report, OHSGT, Northeast Corridor Transportation Project, NECTP-209, Washington, D.C., April 1970.

Transportation, U.S. Dept. of, External Costs and Benefits Analysis, OHSGT Northeast Corridor Transportation Project, NECTP-224, Washington, D.C., 1969.

Transportation, U.S. Dept. of, Urban Mass Transportation Act of 1964 and Related Laws.

Transportation, U.S. Dept. of, Directory of Research, Development and Demonstration Projects, UMTA, 1970.

Transportation, U.S. Dept. of, An Analysis of Urban Public Transportation Requirements for the Handicapped and Elderly, Interim Report prepared for UMTA, Transportation Systems Center, Cambridge, Mass., September 6, 1972.

Transportation, U.S. Dept. of, The Minicar Transit System, 1970.

Transportation, U.S. Dept. of, News, FHWA-31-72, Washington, D.C., February 19, 1972.

Transportation, U.S. Dept. of, Highway Statistics, FHWA, Washington, D.C., 1969, (annual).

Transportation, U.S. Dept. of, Cost of Operating an Automobile, FHWA, Office of Highway Planning, Highway Statistics Division, Washington, D.C., February 1970.

Transportation, U.S. Dept. of, National Highway Functional Classification and Needs Study Manual (1970-1990), FHWA, February 1970.

Transportation, U.S. Dept. of, 1968 National Highway Functional Classification Study Manual, FHWA, April 1969.

Transportation, U.S. Dept. of, 1970 National Highway Needs Report with Supplement, FHWA, September 1970.

Transportation, U.S. Dept. of, Urban Transportation Planning Data, FHWA, Office of Planning, Urban Planning Division, August 1969.

Transportation, U.S. Dept. of, Urban Transportation Planning - General Information and Introduction to System 360, FHWA, June 1970.

Transportation, U.S. Dept. of, Program Documentation - Urban Transportation Planning - System 360, FHWA, June 1970.

Transportation, U.S. Dept. of, Program Documentation - Urban Transportation Planning, FHWA, March 1972.

Transportation, U.S. Dept. of, TRANS Maintenance Costs, FHWA, November 1970, (Preliminary).

Transportation, U.S. Dept. of, TRANS-URBAN Model Documentation, FHWA, Office of Planning, 1971.

Transportation, U.S. Dept, of, The Highway User Investment Study: Model to Determine Highway Accidents, (unpublished), a working document prepared for the 1972 National Highway Needs Report, FHWA, Statewide Highway Planning Division, 1971.

Transportation, U.S. Dept. of, Fatal and Injury Accident Rates on Federal Aid and Other Highway Systems/1969, FHWA, Office of Research and Development.

Transportation, U.S. Dept. of, ERGS Benefit Cost Model Working Papers, Computer Program, and Computer Outputs, FHWA, Office of Research and Development, Traffic Systems Division, 1970.

Varhus, Alan, Highways' Effect on Land Value, (unpublished), a working paper prepared as background for the 1972 National Highway Needs Report, FHWA, Office of Policy Planning, November 1971.

GOVERNMENT PUBLICATIONS (CONT.)

Washington Metropolitan Area Transit Authority, METRO: A Rapid Rail Transit System for the National Capital Region, 1969.

Wesler, J.E., The Noise Exposure Model (MOD 4), Report No. DOT-TSC-OST-71-14, Transportation Systems Center, Cambridge, Mass., August 1971.

Wesler, J.E., Manual for Highway Noise Prediction, Report No. DOT-TSC-FHWA-72-1 and -2, Transportation Systems Center, Cambridge, Mass., March 1972.

Wesler, J.E., Noise Impact Comparisons for Dual Mode Transportation Concepts, (unpublished), Transportation Systems Center, Electromagnetics Technology Division, April 1972.

Wiggers, G.F., Airport Access Modal Choice - Analysis Alternatives, A Working Paper, U.S. Department of Transportation, Office of Systems Analysis and Information, May 1970.

Zuckerberg, H. and Royal, J., Bus Transit System - Overview, Transportation Systems Center, September 1971.