PB 191

h-Speed Ground Transportation
stems Engineering Study

SERVICE ANALYSIS OF TUBE VEHICLE SYSTEMS

Prepared for the U.S. DEPARTMENT OF TRANSPORTATION

Under Contract No. C-353-66 (Neg)

December 1969

28

HSGT

TRW
SYSTEMS GROUP

11-Advanced Systems

TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No. FRA-RT-70-33	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Service Analysis of Tube Vehicle Systems.		5. Report Date Dec. 1969
		6. Performing Organization Code
7. Author(s)		8. Performing Organization Report No. 06818-W006-RO-00
9. Performing Organization Name and Address TRW Systems Group, Redondo Beach, California		10. Work Unit No.
		11. Contract or Grant No. C-353-66
12. Sponsoring Agency Name and Address Office of High Speed Ground Transportation Dept. of Transportation 7th & D Sts. S.W. Washington D.C. 20591		13. Type of Report and Period Covered Final
		14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

This report describes an analysis of the service characteristics, cost and performance of Tube Vehicle Systems operating within the Northeast Corridor of the United States in the 1975 to 1985 time frame. The basis of this study is the TRANSOP computer program which, as described herein, searches for optimal service policies for high speed ground transportation modes in competition with automobile, bus, conventional air and new technology air modes. Included in the report is a description of the TVS model used in the program, the mathematical basis for the optimization, and the results of the applications of the program to the TVS service design. The results indicate that, with the assumptions and approximations employed in the model, the improved travel opportunities attendant with the introduction of the TVS technology in the Northeast Corridor do not provide sufficient revenue to cover the costs of implementing TVS.

17. Key Words Tube Vehicle Systems, Northeast Corridor, Transportation, Transop.	18. Distribution Statement Clearinghouse for Federal Scientific & Technical Information

19. Security Classif. (of this report) UNCL.	20. Security Classif. (of this page) UNCL.	21. No. of Pages 73	22. Price

Form DOT F 1700.7 (8-69)

ABSTRACT

This report describes an analysis of the service characteristics, cost and performance of Tube Vehicle Systems operating within the Northeast Corridor of the United States in the 1975 to 1985 time frame. The basis of this study is the TRANSOP computer program which, as described herein, searches for optimal service policies for high speed ground transportation modes in competition with automobile, bus, conventional air and new technology air modes. Included in the report is a description of the TVS model used in the program, the mathematical basis for the optimization, and the results of the applications of the program to the TVS service design. The results indicate that, with the assumptions and approximations employed in the model, the improved travel opportunities attendant with the introduction of the TVS technology in the Northeast Corridor do not provide sufficient revenue to cover the costs of implementing TVS.

TABLE OF CONTENTS

ILLUSTRATIONS

TABLES

1.0 INTRODUCTION

Under the sponsorship of the Office of High Speed Ground Transportation the TRW System engineering studies have included in their objectives the investigation of the service characteristics of ground mode systems whose features were identified as being promising for future service in the Northeast Corridor (NEC).

This report addresses the design and analysis of the service characteristics of a representative tube vehicle system (TVS) operating in the corridor.

The methodology utilized in the TVS analysis is similar to that under which high speed rail (HSR) and tracked air cushion vehicles (TACV) systems have been investigated.*

The objectives of this study included a determination of a nominal system in terms of economic viability and passenger service levels.

These objectives can be achieved only with an appreciation for the interrelationship between the demand for transportation services and the inherent capacity of systems of transportation technologies to efficiently supply such services in a competitive transportation market. The purpose of this report is to summarize that portion of the study which has dealt with the analyses of these interrelationships for the Tube Vehicle System (TVS) in the Northeast Corridor.

Included in the analysis are a number of transportation modes, including currently available as well as configurations of new and innovative technologies, competing in the NEC for traveler patronage at some defined, future planning date. The analysis assumes that each competing transportation facility will be configured to operate in an efficient manner and that, in the long term, the adjustments made to each facility will lead to an equilibrium between all of the competing modes. The attractiveness of alternative investment strategies for

---

*TRW Systems Group Final Report 06818-W007-R0-00, "HSGT Mode Service Analysis in NEC," NECTP-214, December 1969, Prepared for the Office of High Speed Ground Transportation under Contract C-353-66(Neg).

improved transportation facilities within the NEC is then dependent upon the economic posture of the competing modes at the point of competitive equilibrium. The equilibrium search between interacting modes focuses principally on the adjustment of routes and service levels.

Such an openly competitive situation is not truly representative of the market for services in an industry which is as highly regulated as is transportation. In order to partially account for the influence of regulatory agencies on the transportation industry, the fare policies for each mode were determined externally to the computer program. The air mode fares were adjusted to allow the operator to achieve the normal returns which are experienced by commercial air carriers.

In recognition of the uncertainties in the various input data, a series of parametric, sensitivity analyses were performed. Section 2 of this report summarizes the methodology employed to design the service on the TVS modes. It describes the mathematical algorithm, which was utilized to assure the efficiency of the HSGT configuration, and the TRANSOP computer program. Section 3 describes the analysis assumptions and input data and presents the results of the analysis of the baseline HSGT configurations. The parametric analyses performed to assess the relative importance of the uncertainties in the input data are reviewed in Section 4.

2.0 TVS SERVICE ANALYSIS APPROACH

There are two fundamental aspects of the service design of the TVS system within the NEC. The first is the assumption of long term equilibrium which implies that the service level of each competitive mode is adjusted until it matches the portion of total travel demand attracted to that mode. Secondly, this adjustment should be based upon criteria which lead to an efficient use of each transportation resource. Consideration of these two aspects of the service design has prompted the development and application of computerized procedures for assuring efficiency of operation in the competitive HSGT and air modes. The service design for the air modes, composed of conventional, short take-off and landing (STOL), and vertical take-off and landing (VTOL) technologies, is accomplished utilizing an algorithm which determines plane routings on the basis of economical load factors. This algorithm has been prepared by the MITRE Corporation. The service design of the TVS system was accomplished with the transportation system optimization program (TRANSOP) which is written in a proprietary master program called SLANG and which was initially developed by TRW Systems. The built-in optimization capability of TRANSOP was utilized to assure an operationally efficient TVS system. The TRANSOP procedure and the air mode service design algorithm were utilized in the study iteratively to converge upon the equilibrium service between the HSGT and new air technologies.

Although the methodology is built around an "optimization" program, it is important to note that the optimization was utilized in the stricter sense of assuming an economically "efficient" operation of the HSGT system rather than providing an absolute "optimal" mix of transportation services. By a process of manipulating the TRANSOP and other models and their input data, it has been possible to describe the effects of policy variation, data uncertainties, temporal changes in demand levels and other critical factors on the economic viability of the HSGT systems.

2.1 OPTIMIZATION FRAMEWORK

Optimization pertains to the process of selection, from a range of possibilities, those hardware and service parameters which satisfy certain specified criteria. In the HSGT service design this criteria has been formulated in terms of mathematical statements of the design objectives and sets of mathematical restrictions, which the service design must satisfy. It has then been possible to reduce the service design problem to one of finding the external values of an objective function subject to a set of constraints. The objective functions and constraints which comprise the HSGT service design problem cannot, as a rule, be satisfactorily represented by linear relationships. Consequently, a computerized procedure, based upon LaGrange's formulation of the constrained optimization problem has been adapted toward its solution.

2.1.1 Mathematical Basis

In general, the TRANSOP model structure is composed of several sets of non-linear, transitional equations which relate p dependent variables (Y_j) to n independent variables (X_i):

$$\begin{aligned} Y_1 &= Y_1 \ (X_1, X_2, \ldots X_n) \\ Y_2 &= Y_2 \ (X_1, X_2, \ldots X_n) \\ Y_p &= Y_p \ (X_1, X_1, \ldots X_n) \end{aligned} \tag{1}$$

We wish to find the set of values of X_i at which $F = F(Y_1, Y_2, \ldots Y_p)$ (2) is at an extremal point, and for which a set of m constraints are satisfied, i.e.,

$$\begin{aligned} G_1 \ (Y_1, Y_2, \ldots Y_p) &= 0 \\ G_2 \ (Y_1, Y_2, \ldots Y_p) &= 0 \\ G_m \ (Y_1, Y_2, \ldots Y_p) &= 0 \end{aligned} \tag{3}$$

In LaGrange's classical formulation, if a set of X_i are found for which

$$U = F + \sum_{k=1}^{m} \lambda_k G_k \tag{4}$$

is at an extremal point--then F is also at an extremal point, and the constraints of Equation 3 are also satisfied.

The necessary conditions for an extremal point of the function U in Equation (4) are:

$$\frac{\partial U}{\partial X_i} = 0; \; i = 1, 2, \ldots n$$
$$\frac{\partial U}{\partial \lambda_k} = 0; \; k = 1, 2, \ldots m \tag{5}$$

The method used to solve for the sets (X_i) and (λ_k) is the Newton-Raphson iterative procedure. This procedure is based upon the multi-variate Taylor expansion of a function $H(z_1, z_2, \ldots z_n)$ about the point$(z_{10}, z_{20}, \ldots z_{n0})$:

$$H\Big|_{z_i} = \sum_{h=o}^{\infty} \left[\sum_{i=1}^{n} (z_i - z_{i_o}) \frac{\partial}{\partial z_i}\Big|_{z_{i_o}} \right]^h \frac{H}{h!} \tag{6}$$

Truncating this to the linear terms yields, in matrix form:

$$H\Big|_{z_i} = H\Big|_{z_{1_o}} + \left\lfloor \frac{\partial H}{\partial z_i}\Big|_{z_{io}} \right\rfloor \left\{ z_i - z_{io} \right\} \tag{7}$$

Expandings Equations (5) in accordance with the rule in Equation (7) yields for $\{U^1 (n + 1)\} = 0$.

$$\{Z_{n+1}\} = \{Z_n\} - [V_n]^{-1} \{U^1_n\} \tag{8}$$

where $\{Z_{n+1}\}$ is the solution vector at the n + 1 iteration, $\{Z_n\}$ is the solution vector at the <u>nth</u> iteration, $\{U^1_n\}$ is the vector of first order partials evaluated at the point $\{Z_n\}$ and $[V_n]$ is the matrix of second order partials evaluated at the point $\{Z_n\}$. The matrix [V], which must be nonsingular, can be partitioned into:

$$[V] = \left[\begin{array}{c|c} A & B \\ \hline B^T & C \end{array}\right]$$

where [A] is an n x n matrix

$$[A] = \left\langle \left\lfloor \frac{\partial Y_\ell}{\partial x_i} \right\rfloor \left[\frac{\partial^2 F}{\partial Y_\ell \, \partial Y_q} + \lfloor \lambda_k \rfloor \left\{ \frac{\partial^2 G_k}{\partial Y_\ell \, \partial Y_q} \right\} \right] \left\{ \frac{\partial Y_q}{\partial X_j} \right\} + \left\lfloor \frac{\partial^2 Y_\ell}{\partial x_i \, \partial x_j} \right\rfloor \left| \frac{\partial F}{\partial Y_\ell} + \lfloor \lambda_k \rfloor \left\{ \frac{\partial G_k}{\partial Y_\ell} \right\} \right| \right\rangle \tag{9}$$

[B] is an n x m matrix

$$[B] = \left[\left\lfloor \frac{\partial Y}{\partial x_i} \right\rfloor \left\{ \frac{\partial G_q}{\partial Y_\ell} \right\} \right] \tag{10}$$

and [C] is an m x m null matrix

$$[C] = 0 \tag{11}$$

and $[B^T]$ is the transpose of [B]. The optimization process begins with a trial solution vector $\{Z_o\}$. The values of $\{Z_1\}$ are computed according to Equation 8 and compared with $\{Z_o\}$. This is continued until the differences on successive iterations falls within the allowable covergence bounds.

2.1.1.1 Inequality Constraints

The computational procedure outlined above considers only equality constraints. TRANSOP must accommodate inequalities as well. This practical difficulty can be resolved by the use of penalty functions in a manner which imposes a large penalty on the objective function when the inequalities are violated, and no penalty when they are satisfied. In accordance with the restrictions on the functional relationships outlined above, the form of the penalty function must be selected such that it, along with its first and second derivatives, is continuous everywhere. A form of penalty function which satisfies these conditions is defined by

$$Q_s = \begin{cases} 0; & r_s \leq r_{sc} \\ \alpha_s (r_s - r_{sc})^{\beta_s}; & r_s > r_{sc} \end{cases} \tag{12}$$

as long as $\beta_s > 2$, where $r_s = r_s (Y_1, Y_2, \ldots Y_p)$ is restricted to be less than, or equal to, a value r_{sc}. The revised objective function for n_p inequalities is

$$U = F + \sum_{k=1}^{m} \lambda_k G_k \pm \sum_{s=1}^{n_p} Q_s \tag{13}$$

The selection of the signs of Q_s and α_s is dependent on whether a minimum or maximum value of F is sought. Their magnitude is selected such that the penalty of violating the constraints falls within the desired convergence accuracy of the objective function when the violation of the constraint falls within its allowable tolerances.

Penalty functions have been used in TRANSOP to design the service when the train lengths and service frequencies are restricted to be within certain ranges defined by station design, motive power restrictions, and vehicular control system characteristics.

2.1.1.2 Discrete Variables

One difficulty is encountered due to the restriction of the formulation to continuous variables, As long as the variable is large, no significant argument ensues since the relative difference between a variable's continuous value and the adjacent whole numbers is small. The costs of operation and fleet acquisition are, however, influenced by the differences between the continuous and adjacent whole number values of the number and sizes of trains. If the optimal continuous value of the number of vehicles per train and the number of trains are always rounded up to the next higher whole number value, the satisfaction of all demand attracted to the HSGT mode is assured. With this ground rule a slight reduction in the utilization of capacity is incurred. This is partially offset, however, by the slight increase in effective service frequency.

The rounding-up rule is incorporated into TRANSOP by adding a second pass after optimization convergence. The optimization is performed on the first pass where all variables are considered continuous. After successful convergence those variables which must be restricted to whole numbers are rounded according to the above rules and the resulting set of simultaneous non-linear equations are solved.

2.1.2 Slang Computer Code

TRANSOP is programmed in a proprietary computer code called SLANG. In this code, the objective function and constraints are specified in formats similar to those used in FORTRAN. The utility of SLANG in the TRANSOP application lies in the fact that it is not necessary to reduce the problem formulation to the point where the objectives function and constraints contain only the independent variables, and secondly in the fact that the code provides two key command statements: OPTIMIZE and SOLVE. The OPTIMIZE command causes the computer to follow the logical and numerical steps outlined in Section 2.1.1. The SOLVE command causes the computer to determine the roots of the set of simultaneous, nonlinear equations comprising the model structure. The optimization process will customarily converge only if the objective function, constraints and transitional equations are continuous and have continuous first and second partial derivatives. The representation must also be stationary, i.e., the functional relationships between any variables must remain unchanged during the convergence process.

2.2 TRANSOP STRUCTURE

TRANSOP has been prepared especially for the analysis and design of the hardware and service characteristics of the HSGT modes. Applications of this program to the Northeast Corridor Project have been oriented toward the determination of optimal service policies for High Speed Rail (HSR) and Tracked Air Cushion Vehicle (TACV) configurations.

The system of equations which comprise the TRANSOP model can be divided for convenience, into the following submodels:

- Demand and modal split model
- Network operation rules
- Cost/performance relationships

Each of these submodels is discussed in the following paragraphs.

2.2.1 Demand and Modal Split

In the NEC study estimation of the patronage attracted to each mode has been approached in two steps. First, the total demand for transportation service between each origin-destination (O-D) pair is estimated from demographic characteristics, e.g., population and income measures, and measures of the availability of transportation services. This is then distributed over the available competing modes through the use of modal split relationship. Customarily the latter is dependent on the attributes of the service perceived by the aggregation of travelers: travel times, service frequencies and fares. The procedure in deriving these relationships is to first postulate an equation form whose properties mirror patterns of travel characteristics of the situation to be investigated. The parameters or degrees of freedom of the equation form are then determined from observed travel patterns in such a manner that the sum of the squares of the deviations of the resulting predictions from the actual observations is minimized. This least squares, or multiple regression, analysis can be applied to a variety of trial equation forms, leading eventually to a set which closely fit the observed travel patterns and also exhibit certain desirable qualities when extrapolated beyond the observations.

The application of the TRANSOP program has included both demand and modal split relationships in equation form as part of the model structure. One version of demand and modal split has been incorporated into most of the applications to date. This formulation of the demand model utilized is code named CN25 and was provided to TRW by the Technical Analysis Division of the National Bureau of Standards. This particular model is mode specific, i.e., the set of calibration parameters may be different for each transportation mode. Its computation is one of annual demand for transportation service between all O-D pairs of the linear network. In this model the total annual demand for transportation services is related to the demographic parameter N_i where

N_i = the number of family units with annual incomes in excess of $10,000 within market region (node) i,

and the modal attributes:

T_{ijk} - the travel time in minutes (including access and egress) on mode k for O-D pair (i, j)

C_{ijk} - the travel cost in cents (including access and egress) on mode k for O-D pair (i, j).

f_{ijk} - the number of daily departures from node i to node j on mode k

These attributes are reflected in the value of W_{ijk} of the form

$$W_{ijk} = e^{a_{1k}}(T_{ijk})^{-a_{2k}}(C_{ijk})^{-a_{3k}}(F_{ijk})^{a_{4k}} \quad (14)$$

where a_{1k}, a_{2k}, a_{3k}, and a_{4k} are calibration parameters determined from regression analysis of data and where

$$F_{ijk} = 1 - e^{-\ell_k f_{ijk}} \quad (15)$$

The term ℓ_k is called the frequency damping factor which is introduced to account for the decreasing marginal returns with increasing service frequency.

The total annual demand between nodes i and j is then computed as:

$$D_{ij} = b_o \ (N_i N_j)^{b_1} \ S_{ij}^{b_2} \ R_{ij}^{b_3} \quad (16)$$

where b_o, b_1, b_2, and b_3 are also calibration parameters determined from the regression analysis of data, and s_{ij} and R_{ij} are measures of the availability of service. The values of S_{ij} and R_{ij} are computed from:

$$S_{ij} = \sum_{k=1}^{n-1} W_{ijk}$$

$$R_{ij} = \alpha \sum_{k=1}^{n} W_{ijk} \tag{17}$$

where α is a parameter introduced to measure the sensitivity of demand to uncertainties in model attributes and n is the number of modes. Finally, the demand for services attracted to mode k is given by

$$D_{ijk} = \frac{W_{ijk}}{\sum_{k=1}^{n} W_{ijk}} D_{ij} \tag{18}$$

The specific values of the calibration parameters used in the analyses are presented in Table 2-1.

TABLE 2-1

DEMAND MODEL PARAMETERS

(Courtesy National Bureau of Standards)

Mode	a_1	a_2	a_3	a_4	ℓ
Air	0.108	1.91	0.96	.325	0.12
HSGT	0.108	1.91	0.96	.325	0.12
Bus	0.108	1.91	0.96	.325	0.12
Auto	0	1.93	0	0	0

The values of b (for all modes) are:

$$b_o = 6.272 \times 10^6$$
$$b_1 = 0.8254$$
$$b_2 = 0.6655$$
$$b_3 = 0.1$$

Legend: + Parameters for air are used for VTOL and STOL, as well conventional air modes.

Finer grain representation is required to adequately investigate system operation qualities. Annual demand is consequently divided into an average daily level and this is distributed over the day according to a diurnal variation profile. The analyses to date have approximated this profile by dividing the average daily travel demand into three demand rates representing peak, off-peak daily and night time levels. The assumption is then made that the diurnal demands are uniformly distributed within each diurnal period. The hourly percentage of daily demands for the peak, off-peak and right period is 8 percent, 5 percent, and 0.675 percent, respectively. The duration of these corresponding periods is 5 hours, 11 hours, and 8 hours thus 40 percent of the total daily demand occurs during the five peak hours, 55 percent occurs during the off-peak eleven hours and the remaining 5 percent occurs during the 8 hour night period.

Inputs to the demand and modal split model consist of demographic parameters such as population and income levels for each node, the attributes of competing services, i.e., travel times, fares and service frequencies and the calibration parameters derived in the multiple regression analysis.

2.2.2 Network and Operation Rules

A linear nine code network extending from Washington, D. C., on the south to Boston, Massachusetts, on the north was selected for the analysis of the HSGT modes. The specific nodal market regions serviced by the HSGT modes are Washington, D. C.; Lanham, Maryland; Baltimore, Maryland; Philadelphia, Pennsylvania; Trenton, New Jersey, North Jersey Terminal; New York, New York; Milford, Connecticut; Providence, Rhode Island; Route 128 Terminal; and Boston, Massachusetts. The close proximity of Lanham, Maryland to Washington and Route 128 to Boston eliminated the possibility of using the demand estimated procedures on these links. Therefore, the two end terminal in the HSGT network are composite representations of the individual Lanham and Washington stations on the south and Route 128 and Boston stations on the north. All terminals are city center with the exception of Lanham and Route 128.

The routing of trains over the linear network is modeled via sets of trains which cycle between selected O-D pairs. The policy for the make-up and disbursement of trains is established to allow the nodes and times at which trains originate or train size variations occur to be selected externally as is the mix of local and thru service. Both of these items relate to the satisfaction of estimated patronage in consequence of the relationship between these estimates and the modal attributes.

Investigations into the behavior of the models, thus, led to the selection of certain operating ground rules:

- Trains are specified as to type, implying the nodes at which they turn about, and time of day in reference to diurnal demand periods.

- Each of the train types has a corresponding order associated with its turnabout nodes. The longest-cycle train types are assigned the lowest order. Their set of nodes completely encompasses the sets of turnabout nodes of higher order train types.

- Capacities to be provided and corresponding train lengths are computed from the peak link loading where no other train types of a higher order operate or from the residual capacity remaining after any lower order trains types have been loaded to capacity.

- Cycle times (i.e., the time for a train type to complete a round trip at any node including the station stops and turnabout delays) and the service frequencies dictate the number of trains required in the first pass* during an optimization analysis. On the second pass* the number of trains are rounded up to the next integer and the corresponding frequencies are computed from the cycle times for each train type.

- In the computation of service frequencies; trains are assumed to be uniformly distributed over each cycle including the superimposed cycle. Thus, during any diurnal period the headway times are equal.

The preceding description summarized the general rules. Terminal locations vary between HSRA, HSRC, TVS, and TACV configurations at the north Jersey station. Due to the short link distances between this terminal and the one at New York, the demand between this O-D pair was zeroed out for the TVS service design.

*First and second pass refer to the process of rounding the continuous values of the numbers of trains and train length computed either the optimization loop into discreet values as described in Section 2.1.1.2.

Travel times over each link are computed externally from velocity profiles determined on the basis of cruise speed, operating accelerations and decelerations, and any identified speed restriction zones associated with bridges, tunnels, stations, etc. Time delays at the ends of cycles are included to account for minor maintenance and cosmetic requirements. Individual station delays are also included to account for passenger enboarding and deboarding.

A degree of flexibility in the establishment of cycles is built into the program. The applications to date have all used the same operating rules. Trains of type 1 cycle between Washington, D. C. and Boston during all three diurnal periods. Trains of type 2 cycle between Philadelphia and Milford during the peak and off-peak daily periods. No separate service between Baltimore and Philadelphia during the peak and off-peak daily periods. During the night period these are sized by the peak loaded link in the Philadelphia - New York section as are trains of type two during the peak and off-peak daily periods.

Operational constraints are incorporated to reflect the limitations on minimum headway (and consequently on maximum service frequency) imposed by the operational policy employed, the characteristics of the vehicular control system and the operational profiles in the stations. Additional constraints are employed to reflect the limitations on train size due to siding lengths in terminals and the motive power limitations. These constraints are included using the inequality/penalty function approach defined in Section 2.1.1.1.

2.2.3 Cost/Performance Relationships

The external specification of the hardware configuration simplifies the formulation of the cost and performance submodel. In essence, the equations in this section relate the investment and operational cost to the parameters which reflect the network design and the level of service to be provided. The accounting of these costs follow the standard format. The investment items as guideways, vehicles, and stations, are separately costed and aggregated into three investment categories: fixed plant, rolling stock and land acquisition. To each of these investments is applied a factor which converts each to an equivalent annual cost of of capital recovery and return.* These three separate capital recovery factors are used to accommodate different interest rates and depreciation periods for each of the investment categories. The nominal interest rates used for the HSGT modes is 10 percent for fixed plant and rolling stock and 8 percent for land. Vehicle and fixed plant investments are amortized to zero salvage value at 14 years and 35 years, respectively. Land is assumed to have 100 percent salvage value and the land investments were treated as perpetual loans. The three equivalent annual costs of capital recovery and return of the investment are combined to yield the annual costs of capital recovery and return for each HSGT system.

The investments are subdivided into the following categories:

Guideway Construction and Routeway Preparation

Guideway Electrification

Command Control and Communication

Passenger Terminals

Yards and Shops

Research and Development

Land Acquisition

Fleet Acquisition

The guideway and routeway preparation costs were derived externally. They include estimates for at-grade and elevated construction requirements as well as bridges and tunneling costs. The costs of Electrification of guideways was estimated to be sufficient to provide the required power under peak usage. Terminals were costed with a fixed value and a cost proportional to the peak level of passenger throughput. Land for guideway yards and shops were specified in consideration of the portion of current

---

*The capital recovery factor = $\dfrac{i(1+i)^n}{(1+i)^n-1}$

where i = annual interest rate and n is the number of years of amoritization.

rail facility which could be utilized. Vehicles costs were estimated taking into consideration the economics of mass productions.*

The Direct Operating Cost (DOC) is computed from the sum of the costs of energy and fuel consumption, crew, and maintenance of vehicles and guideways. In general each of these is related to one or more of the parameters which define the level of service, e.g., total train miles/year, vehicular miles per year, fleet size, peak service frequency, etc.

The Indirect Operating Costs (IOC) are customarily selected to reflect the operational experience on comparable travel modes. They are, in general, also a function of the functional service parameters.

All of the specific inputs to the TRANSOP program are listed in Section 3 of this report.

2.3 ANALYSIS PROCEDURE

Two objectives have received considerable attention in the NECTP: (1) maximization of patronage on the HSGT mode and (2) minimization of subsidy if required. The first represents a principal of choice which would hopefully alleviate conjestion on the air and auto modes. The second is oriented toward achieving a practical level of economic viability while providing an attractive service. With regards to the maximization of patronage it is recalled that the modal split relationships are functions of travel times, service frequencies and fares. Travel times are dictated by the external specification of the hardware configuration in the NECTP applications. Consequently, the degrees of freedom for optimization of HSGT service are the service frequencies and ticket prices. The fare policy consists of a fixed charge and mileage related charge as an approximation of observed pricing policies.

Adjustment of the relative values of the fixed and mileage related portions influences the distribution of travel over the network. A relatively large fixed charge will attract longer distance patronage and discourage short distance commuter travel. Conversely a relative small fixed

*Individual vehicle costs were computed for:

cost of vehicle = AQ^{-B} where A and B are constants and Q is the total fleet size.

charge will have the reverse effect. The selection of the relative values is therefore, a policy question. In the NECTP applications the HSGT patronage maximization analysis were performed with the fixed charge held constant and the optimal value of the mileage related charge and the service frequencies over the day computed. Such analyses will result in infinite patronage and economic loses only if the economics of the system operation are constrained. Thus, the patronage maximization cases were analyzed under financial breakeven conditions. This unfortunately, due to the nature of the demand model, results in ticket prices for which the demand and modal split relationships are of suspect appropriateness. In order to reduce these prices to regions of model validity a system loss must be considered. This loss would no doubt require governmental subsidy of one form or another.

The second objective of minimization of the required subsidy was thus considered. The constraints which must be imposed in this case is the specification of ticket price. This is true because the price elasticity of demand in the model is less than unity.* In this case the revenue will monotonically increase with increasing price. Since demand also decreases with prices, the operation profit is monotonically increasing with price. Minimum subsidy analyses were therefore, performed with input values of fixed charge and mileage related charge. The independent variables in this case are the service frequencies of the train types discussed previously.

---

*Price elasticity of demand for the HSGT mode is computed as

$$E_{ijk} = \frac{-\partial D_{ijk}}{\partial P_{ijk}} \frac{P_{ijk}}{D_{ijk}}$$

Where D_{ijk} and P_{ijk} are the demands and fares between nodes i and j and mode k.

If the $W_{ijk} << \sum_{k=1}^{n} W_{ijk}$, which is customarily true for the HSGT modes, then from equations 14, 16, and 18.

$E_{ijk} \simeq a_3 = 0.96$ thus the demand for HSGT service is slightly inelastic i.e., $E_{ijk} < 1$.

3.0 BASELINE SERVICE DESIGN

3.1 INTRODUCTION

The extensive analysis carried out in 1967 and 1968 identified the principal design characteristics of the TVS system and synthesized a representative configuration of these systems for inclusion as a major alternative in the NEC program. Each of the major subsystems was investigated in sufficient depth to determine the most significant details of its performance. Significant effort was devoted to establishing the interactions among principal subsystems such as suspension, propulsion and guideway. Once the interactions were established, it was possible to proceed to the design of a typical system which could serve the needs of the NEC.

While these interactions were recognized in 1967 and 1968, the scope of the TRW study did not make it possible to examine their consequences in any great detail. Instead, TVS was designed to yield an approximation of minimum cost for investment and operation. The nature of the approximation can be better understood through the following argument. Since the design was essentially separated from service considerations, it was deemed reasonable to generate a whole set of designs, each destined to provide travel at many speeds and frequencies and capacities. It remained for the NEC analysis to select for each link of its networks the type of service it deemed best or more attractive. Once this was done, the TRW data provided the necessary system definition including cost, performance and so on. So, if on link "ij" the TVS were to be required to operate at 300 mph, the TRW data could supply a description of the system which would be somewhat different from that required over link "pq" where only 250 mph could be felt to be sufficient.

Obviously, this is but the first step of a more involved design analysis from which complete hardware configurations would evolve. Nevertheless, the data yielded a system description which, although somewhat coarse insofar as very specific design detail was concerned, still provided a satisfactory, but nonetheless approximate, picture of basic performance and costs. Basic operational costs due to the requirement to operate a coherent service over some form of network were not addressed.

In order to compare and evaluate alternative transportation investment strategies for the TVS mode in the Northeast Corridor, a representative set of baseline or nominal mixes of transportation services have been established. The TRANSOP procedure was utilized to establish efficient operation of the TVS mode in two of these nominal mixes.

Iterations were performed between TRANSOP and the MITRE air service design program to converge on an equilibrium service level for the HSGT and new air modes (STOL and VTOL). For the TVS mode, converged air mode characteristics for the TACV mode were utilized due to the simularities in the service characteristics of these two systems. This iteration was performed by allowing the HSGT mode service attributes and vice versa. Due to the fact that the travel times were exogenously determined from the baseline HSGT configurations and in recognition of the inelastic quality of the demand, the only explicit service parameter adjustment in the HSGT mode was the service frequency. At each stage in the iteration process the TRANSOP program determined the value of service frequencies which minimized the operational deficit or subsidy on the HSGT mode. STOL and VTOL, on the other hand, were allowed to adjust travel times, by changing the mix of direct and intermediate-stop flights, and consequently fares as well as the service frequency. The auto and bus modes were assumed to remain unresponsive to the air and HSGT competition.

In performing the analyses on the baseline system configurations operating in a specified network it was necessary to establish baseline values for several important parameters in addition to the vehicle performance characteristics and cost estimating relationships. Specifically, the following policy items were included in the baseline descriptions of the system.

- Fare policy
- Interest rates applicable to capital expenditures
- Baseline time frame for analysis
- Operating rules

In the baseline analyses the TVS fare was set at $1.50 plus 7.5¢ per passenger mile.

Interest rates for TVS investments were set at 10 percent for fixed plant and rolling stock and land costs were assumed to be based on perpetual, interest-only loan at 8 percent. Fixed plant and rolling stock were amortized to zero salvage value at 35 years and 14 years, respectively.

The baseline time frame was set at 1980 and all annual TVS costs were computed for the first year of operation. The establishment of this time base implied certain inputs to the demand model namely the demographic data and access/egress times.

The TVS mode was modeled to provide all-stop service between Washington and Boston. A superimposed train service was provided between Philadelphia and Milford during peak and off-peak diurnal periods.

The following sections of this report summarize the TVS mode baseline configurations, define the baseline inputs and present the results of the iterative equilibrium search analysis.

3.2 SUMMARY OF TVS TECHNOLOGY

The tube vehicle system is made up of trains of 48 passenger cars, running on steel rails, driven by a linear electric motor operating in a steel tube at a pressure between .001 and .01 atmospheres. The trains may be up to 10 cars long. The cars are 85 feet long which is somewhat longer than 48 passenger cars normally, but the cars have an underslung carriage between cars which takes up 22 feet of each car. This underslung carriage permits the design of a tube with a small cross section. The passengers sit two abreast in two rows with an aisle separating the rows.

The tube is contained within a concrete lined tunnel which is located deep underground, perhaps as deep as 3000 feet. The vehicle gains considerable advantage in acceleration and deceleration by the use of gravity. It accelerates down the hill as it leaves the terminal and decelerates as it goes up the hill to the next terminal resulting in time, power and energy savings. Another important reason for building the tunnels deep is to locate them in self-supporting rock which reduces tunnel construction costs in comparison with near surface tunnels.

The propulsion system consists of a linear electric motor, a variable frequency and variable voltage power conditioning unit, and a power pickup. The braking system uses the output of an alternator directly connected to the wheels to provide an excitation field to the linear electric motor which is then operated as a linear electric alternator. The braking energy is dissipated through resistor banks which cool themselves by radiation.

The system design speed ranges from 300 mph to 450 mph with the only limitation being the maximum design capability of the power pickup and wheel rail safety.

The cabin air and vehicle equipment cooled by evaporative coolers which exhaust low pressure, low temperature water vapor into the tube where the vapor is eventually removed by the vacuum pumps.

3.3 FIXED DEMAND INPUTS

The demand model CN25 described in Section 2.2.1 requires the specification of the calibration parameters as presented in Section (2.2.1), the demographic constant (the number of family units within each market area whose annual income exceeds $10,000) and the modal attributes of travel times, costs and service frequencies. The baseline year is 1980. Table 3-1 presents the estimates of the demographic constants for this year.

As mentioned in the beginning of Section 3 the auto and bus modes were described as unresponsive to changes in other modal attributes. Consequently, a fixed set of travel times, cost and service frequencies (bus only) were derived. These are presented in Tables 3-2 and 3-3 for the auto and bus modes, respectively.

3.4 BASELINE TVS INPUT DATA

This section describes the input data, including the basic cost estimating relationships utilized, TVS service characteristics, competing mode service characteristics and other parameters input to TRANSOP to determine resulting levels of service provided by an operational TVS system in the baseline year, 1980. Also presented in a completed summary of the TVS mode operation, both with and without VTOL competition, including system patronage, fleet operating statistics, investment costs, and operating statistics such as costs, revenues, and profits.

TABLE 3-1

1980 BASELINE DEMOGRAPHIC DATA

Market Region	Number of Family Units with Income over $10,000/year (1980)
Washington	321,000
Baltimore	99,100
Philadelphia	274,900
Trenton	22,220
North Jersey	318,510
New York City	1,005,110
Milford	121,560
Providence	28,860
Boston	172,960

Courtesy National Bureau of Standards

TABLE 3-2

1975 AUTO MODE CHARACTERISTICS WITH AND WITHOUT VTOL COMPETITION

	Washington	Baltimore	Philadelphia	Trenton	No.Jersey	New York	Milford	Providence	Boston
Washington		65,47,--	165,204,--	189,257,--	251,337,-	282,375,--	329,423,--	461,575, --	499,626, --
Baltimore			126,163,--	150,210,--	211,296,-	243,334,--	290,383,-	422,534, --	460,585, --
Philadelphia				50, 51,--	114, 133,-	150, 173,--	196,219,-	328,371, --	359,423, --
Trenton					79, 66,-	119, 108,--	165,155,-	297,307,--	333, 358, --
North Jersey						68, 58,--	107, 95,-	233, 247,--	270,297, --
New York							94, 86,-	220,238,--	250,269, --
Milford								147,158,--	180,203, --
Providence									92,69 --
Boston									

Note: Impedances (non-diagonal entries) are times (in minutes), fares (in cents), and frequency (in one-way departures) in that order and refer to the line haul portion of the trip only. Entries on diagonal are access times(in minutes) and costs (in cents). Therefore,for example, to obtain total trip time from Washington to Baltimore, one adds the first component in each of the matrix positions (1,1), (1,2), and (2,2).

Courtesy National Bureau of Standards

TABLE 3-3

1975 BUS MODE CHARACTERISTICS WITH AND WITHOUT VTOL COMPETITION

	Washington	Baltimore	Philadelphia	Trenton	No.Jersey	New York	Milford	Providence	Boston
Washington	34,40	50,193,63	181,569,15	184,562, 13	225,948,9	228,965, 58	338,1287, 16	452,1743,13	505,1866, 18
Baltimore		25,34	124,416,20	126,409, 18	205,731, 14	198,796, 34	304,1117, 8	438,1574,12	473,1708, 12
Philadelphia			43,54	--	97,364,3	112,422, 47	223,741, 16	341,1200,7	388,1351, 18
Trenton				84,216	99,357,3	--	105,322, 31	223,772,14	268,901, 23
North Jersey					51,113	28,64,32	138,386, 9	256,842,3	302,965, 8
New York						51,57	104,322, 31	223,772,14	268,901, 22
Milford							34,53	119,486,1	186,638, 1
Providence							--	23,29	73,228, 10
Boston									31,36

Note: Impedances (non-diagonal entries) are times (in minutes), fares (in cents), and frequency (in one-way departures) in that order and refer to the line haul portion of the trip only. Entries on diagonal are access times(in minutes) and costs (in cents). Therefore,for example, to obtain total trip time from Washington to Baltimore, one adds the first component in each of the matrix positions (1,1), (1,2), and (2,2).

Courtesy National Bureau of Standards

Investment costs, operating cost and policy items were obtained for the baseline LIM/Wheeled TVS defined during TRW's 1967-68 HSGT system engineering studies program. Many of these cost parameters were supplied by RMC and other DOT subcontractors.

Investment Factors: The investment items for a transportation system include:

- Fixed plant
- Land
- Vehicles

The fixed plant investment factors that must be input to the TRANSOP II code are:

- Guideway and route preparation
- System electrification
- Command, controls and communication systems
- Terminals
- Yards and shops
- Research and development (RDT&E)
- Vehicles

The guideway, route preparation, and system electrification costs based on the defined TVS configuration and RMC cost data are shown in Table 3-4. Investment requirements for command and control were estimated based on the HSR parameters as a function of the number of terminals and route mileage. Relationships generated during the HSR "C" study were used to relate the costs of terminals to passenger capacity and the yard and shop costs to the fleet size. For this analysis an RDT&E cost of 210×10^6 was assumed.

Land requirements for vehicle storage and for shops were taken to be 87×10^6.

Vehicle costs were $\$6.0 \times 10^5$ per 48 passenger vehicles.

Operating Costs. The following direct operating costs must be input to the TRANSOP II computer code:

TABLE 3-4

TVS GUIDEWAY AND ROUTEWAY PREPARATION COSTS

	Millions of Dollars
Tunnels	2772
Steel Tube	975
Concrete Tube Saddles	22
Rail Support Concrete	196
Rails	173
Third Rails	217
Reaction Rail	109
Power Substation	35
Vacuum Pump	11
Vacuum Valves	.4
Ventilation Fans	1
Total	4,511.4

- Energy Costs
- Crew costs
- Vehicle maintenance costs
- Guideway maintenance costs
- Power and control system maintenance costs
- Maintenance burden.

Energy costs were obtained by curve fitting the energy requirements for the defined TVS as a function of distance, travel time and number of vehicles per train. A cost of 2¢ per kilowatt-hour was used which should be conservative.

Crew costs were obtained based on the following crew complement and rates of pay:

- Chief engineer - one per train @ $15 per hour
- Assistant engineer - one per train @ $8 per hour
- Stewardess - one per vehicle @ $4 per hour.

This results in high crew costs, however, it was considered a conservative approximation.

Vehicle maintenance costs were taken as 20¢/car-mile equivalent to HSR "C". Present maintenance studies indicate that with a high degree of automation this number is achievable for TVS.

The guideway maintenance and power and control system maintenance costs were estimated using the relationships developed for the HSR "C" study. Guideway maintenance is a function of track mileage and car mileage. Power and control system maintenance was taken as $4.6 x 10^6 per year. Maintenance burden was 66 percent of the vehicle and power system maintenance costs.

The total annual indirect operating costs were estimated as a function of car-miles and passenger trips using the HSR "C" relationships.

Policy: Based on the characteristics of the defined TVS, the maximum allowable service frequency is 23 departures per hour in one direction. A two-minute station dwell time was assumed. No more than 13 cars per train are allowed, resulting in a maximum train capacity of 576 passengers. Diurnal variations in demand are similar to HSR "C" and consider peak, off-peak, and night-time levels of service.

Demand calculations were based on the number of family units in the Northeast Corridor during 1980. It was felt that implementation of a TVS would occur in 15 to 20 years. The costs of the guideway were amortized over 35 years; the costs of the vehicle were amortized over 14 years; and the land costs were amortized over 400 years. For purposes of this analysis, the salvage values of the guideway and vehicles were assumed to be zero.

3.5 CONVERGED TVS DESIGNS

The final demand data inputs to the TRANSOP program in the iterative equilibrium search process are the travel times, costs and service frequencies for the combined air mode (including conventional as well as STOL service) and/or the VTOL mode. Table 3-5 contains the final converged sets of service attributes for the combined air mode used in the analysis of TVS without VTOL competition. Table 3-6 contains the corresponding

TABLE 3-5

COMBINED AIR MODE CHARACTERISTICS VS. TVS WITHOUT VTOL COMPETITION

	Washington	Baltimore	Philadelphia	Trenton	No.Jersey	New York	Milford	Providence	Boston
Washington	37,136	19,1177,8	37,1601,4	40,1676,3	57,1834, 13	64,1949,48	95,2187,9	154,2593,19	102,2748, 78
Baltimore		33,152	24,1290,2	31,1459,2	50,1615, 10	63,1709,14	85,1969,8	102,2348,7	99,2529, 36
Philadelphia			44,150	14,1043,2	31,1212,3	40,1323,9	63,1536,9	84,1949,8	70,2099, 25
Trenton				28,143	27,1158,2	26,1200,4	64,1460,4	84,1869,3	84,2021,5
North Jersey					46,151	--	33,1255,4	55,1664,4	57,1814, 19
New York						44,128	26,1209,7	48,1596,17	49,1750, 69
Milford							45,145	33,1360,2	52,1521, 1
Providence							--	35,139	27,1179, 4
Boston									40,166

Note: Impedances (non-diagonal entries) are times (in minutes), fares (in cents), and frequency (in one-way departures) in that order and refer to the line haul portion of the trip only. Entries on diagonal are access times(in minutes) and costs (in cents). Therefore,for example, to obtain total trip time from Washington to Baltimore, one adds the first component in each of the matrix positions (1,1), (1,2), and (2,2).

Courtesy National Bureau of Standards

TABLE 3-6

COMBINED AIR MODE CHARACTERISTICS VS. TVS WITH VTOL COMPETITION

	Washington	Baltimore	Philadelphia	Trenton	No.Jersey	New York	Milford	Providence	Boston
Washington	37,136	19,1177,8	37,1601,4	40,1676,3	57,1834, 13	64,1949,48	95,2187,9	154,2593, 19	102,2748, 78
Baltimore		33,152	24,1290,2	31,1459,2	50,1615, 10	63,1709,14	85,1969,8	102,2348,7	99,2529, 36
Philadelphia			44,150	14,1043,2	31,1212,3	40, 1323, 9	63,1536,9	84,1949,8	70,2099, 25
Trenton				28,143	27,1158,2	26,1200,4	64,1460, 4	84,1869,3	84,2021, 5
North Jersey					46, 151	--	33, 1255, 4	55,1664,4	57,1814, 19
New York						44, 128	26, 1209, 7	48,1596,17	49, 1750, 69
Milford							45,145	33, 1360,2	52, 1521, 1
Providence							--	35,139	27, 1179, 4
Boston									40,166

Note: Impedances (non-diagonal entries) are times (in minutes), fares (in cents), and frequency (in one-way departures) in that order and refer to the line haul portion of the trip only. Entries on diagonal are access times(in minutes) and costs (in cents). Therefore,for example, to obtain total trip time from Washington to Baltimore, one adds the first component in each of the matrix positions (1,1), (1,2), and (2,2).

Courtesy National Bureau of Standards

combined air mode attributes for runs with VTOL competition. Likewise Table 3-7 contains the VTOL service attributes used in runs with VTOL competition.

3.6 TVS SERVICE CONFIGURATIONS

This section summarized the converged, TRANSOP output performed in the baseline TVS system service analysis for the NEC. The values in Table 3-8 have been extracted from the complete TRANSOP output listing which are included in the appendices to this report.

Figure 3-1 presents a breakdown of the TVS operating costs by cost category for the baseline case with VTOL competition. As may clearly be seen, the capital changes due to the large guideway and routeway preparation costs dominate the annual operating costs.

Figure 3-2 presents the share of the total NEC transportation market held by each of the competitive systems under equilibrium conditions with VTOL included in the available choices to the traveller.

TABLE 3-7

VTOL MODE CHARACTERISTICS VS. TVS

	Washington	Baltimore	Philadelphia	Trenton	No.Jersey	New York	Milford	Providence	Boston
Washington	36,48	15,674,28	44,1258,29	50,1450,8	67,1677, 30	71,1814, 85	100,2340, 36	128,2970,23	138,3204, 31
Baltimore		25,63	31,1053,14	42,1242,4	59,1469, 18	62,1605, 42	91,2132, 31	118,2763,23	126,2995, 33
Philadelphia			45,140	14,654, 10	28,881,25	33,1016, 41	64,1401, 29	95,2141, 20	104,2406, 24
Trenton				28,143	19,760,10	22,823,22	50,1209, 20	80,1840, 16	95,2213, 24
North Jersey					46,157	--	26,889, 14	61,1521,14	71,751, 36
New York						46,126	25,847, 29	55,1479,22	68,1709, 57
Milford							43,119	35,1092,6	45,1323, 10
Providence							--	26,94	17,727,9
Boston									33,105

Note: Impedances (non-diagonal entries) are times (in minutes), fares (in cents), and frequency (in one-way departures) in that order and refer to the line haul portion of the trip only. Entries on diagonal are access times(in minutes) and costs (in cents). Therefore,for example, to obtain total trip time from Washington to Baltimore, one adds the first component in each of the matrix positions (1,1), (1,2), and (2,2).

Courtesy National Bureau of Standards

TABLE 3-8

SUMMARY OF TVS SERVICE CHARACTERISTICS IN NEC

	Without VTOL	With VTOL
Costs		
Total Investment ($ Billions)	5.138	5.123
Annual IOC ($ Millions)	61.437	51.907
Annual DOC ($ Millions)	73.211	62.117
Annual Total ($ Millions)	668.717	646.070
Per Pass. ($)	22.16	24.559
Per Pass. Mile ($)	.1633	.1867
Per Seat Mile ($)	.1033	.1208
Revenues		
Annual Total ($ Millions)	352.440	298.992
Per Pass ($)	11.68	11.37
Per Pass. Mile ($)	.0860	.0865
Per Seat Mile ($)	.0545	.0559
Deficits		
Annual Total ($ Millions)	316.277	347.078
Per Pass ($)	10.48	13.19
Per Pass. Mile ($)	.0772	.1004
Per Seat Mile ($)	.0489	.0649
HSGT Demand		
Pass./Yr. (Millions)	30.171	26.304
Pass. Miles/Yr. (Billions)	4.096	3.46
Pass. Hrs./Yr. (Millions)	88.833	77.639
Misc. Parameters		
Fleet Size	164	141
# A units	47	45
# B units	117	96
Average Load Factor (%)	63.3	64.7
Average Trip Length (Miles)	135.75	131.6
Service Frequency (Dep./Day)		
Wash.-Boston	44	41
Phil.-Milford	86	78
Seat Miles/Yr. (Billions)	6.472	5.345
Vehicle Miles/Vehicle hour	174	176

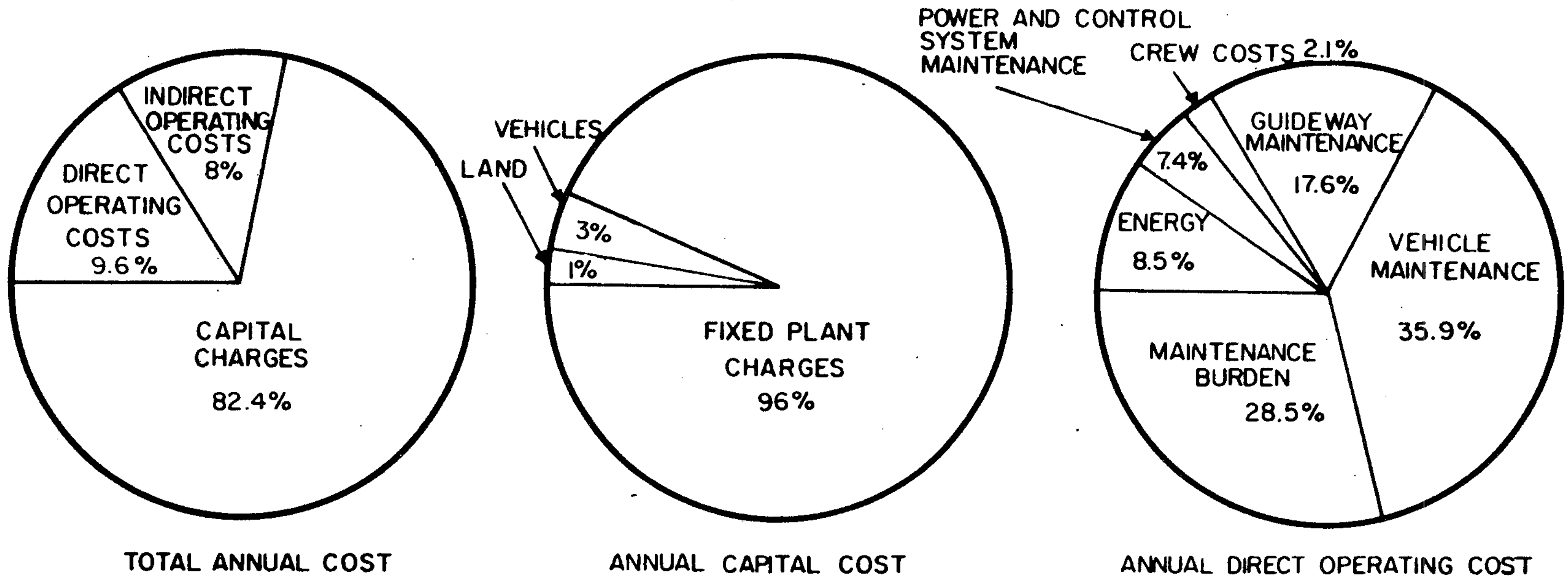

Figure 3-1. TVS Operating Cost Breakdown for Baseline System with VTOL Competition

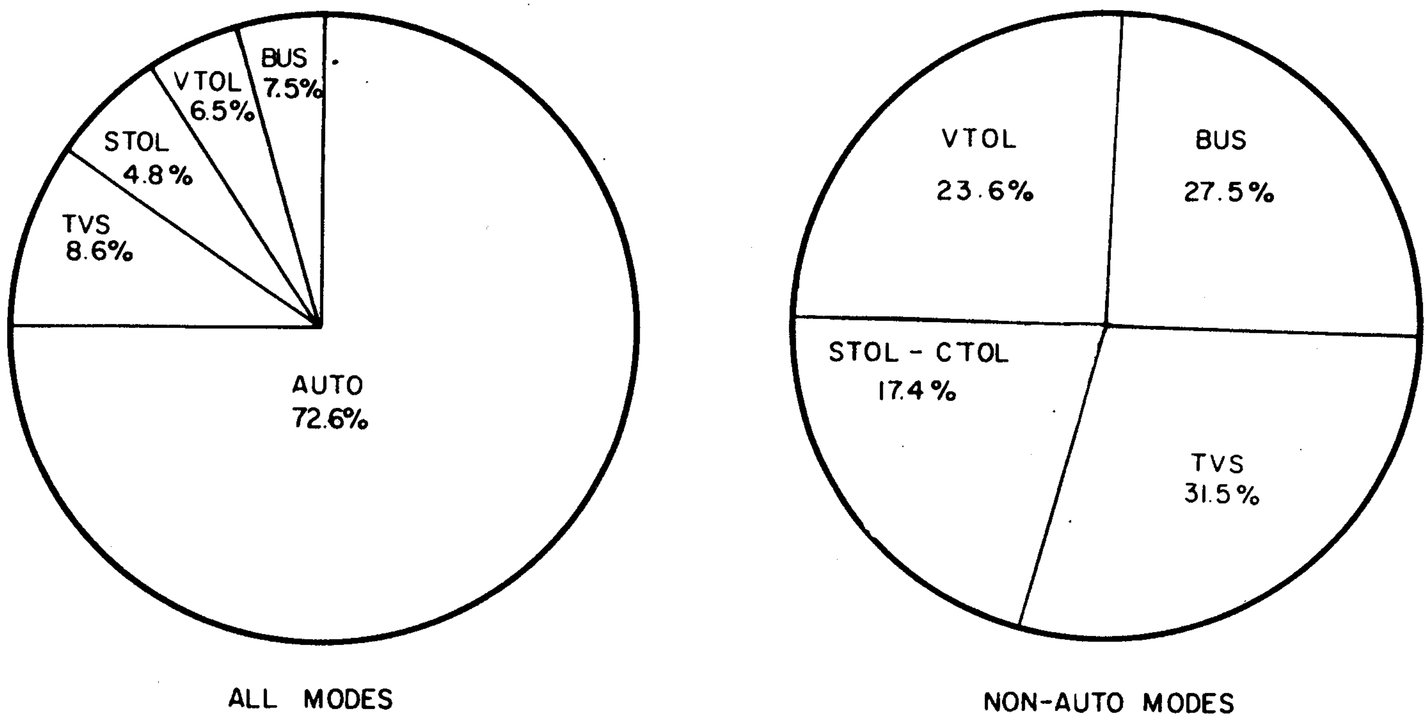

Figure 3-2. NEC MODAL Split with TVS Operating with VTOL Competition (1980)

4.0 PARAMETRIC TVS SERVICE ANALYSIS

As mentioned earlier, the TVS service analysis was based upon a nominal or baseline TVS configurations. Moreover, a number of assumptions were employed to expedite the investigation. In the main the need for these assumptions arises from the uncertainity of the forecasting and cost estimating procedures. In consequence, in order to determine the impact of the uncertainties on the characteristics of the TVS service, a series of parametric analyses were performed using the TRANSOP procedures. The principal variations considered in this study were:

(1) Interest rate sensitivities for TVS operating with VTOL competition.

(2) Passenger fare policy sensitivity for TVS operating with VTOL competition.

(3) Demographic projections for the 1980 - 1985 time period for TVS systems operating with VTOL competition.

(4) Variation of assumptions regarding terminal access and egress times for operating with VTOL competition.

4.1 INTEREST RATE SENSITIVITY

To a large extent, the economic characteristics of the TVS mode are dominated by large capital investments in the fixed plant, land and vehicles. The baseline analyses assumed on 8% annual charge for land and a 10% interest rate of fixed plant and rolling stock investments which were amortized to zero salvage value in 35 years and 14 years respectively. In the TVS mode, as defined in the baseline configuration, the resulting annual charges on total system investment represent 82.4% of the annual system operating costs. Since these costs tend to determine the economic viability of these systems, a series of TRANSOP runs were made utilizing the baseline TVS mode, with VTOL competition, with interest rate on the fixed plant and rolling stock investments parametrically varied between 5% and 10%. Land acquisition interest was maintained at 8% in all runs.

Figure 4-1 shows the variation in annual costs, revenues and subsidies for the TVS mode operating with VTOL competition, as the capital charges vary between 5% and 10% annually. The annual costs increase appreciably with increasing interest rate. System revenues remain constant due to the

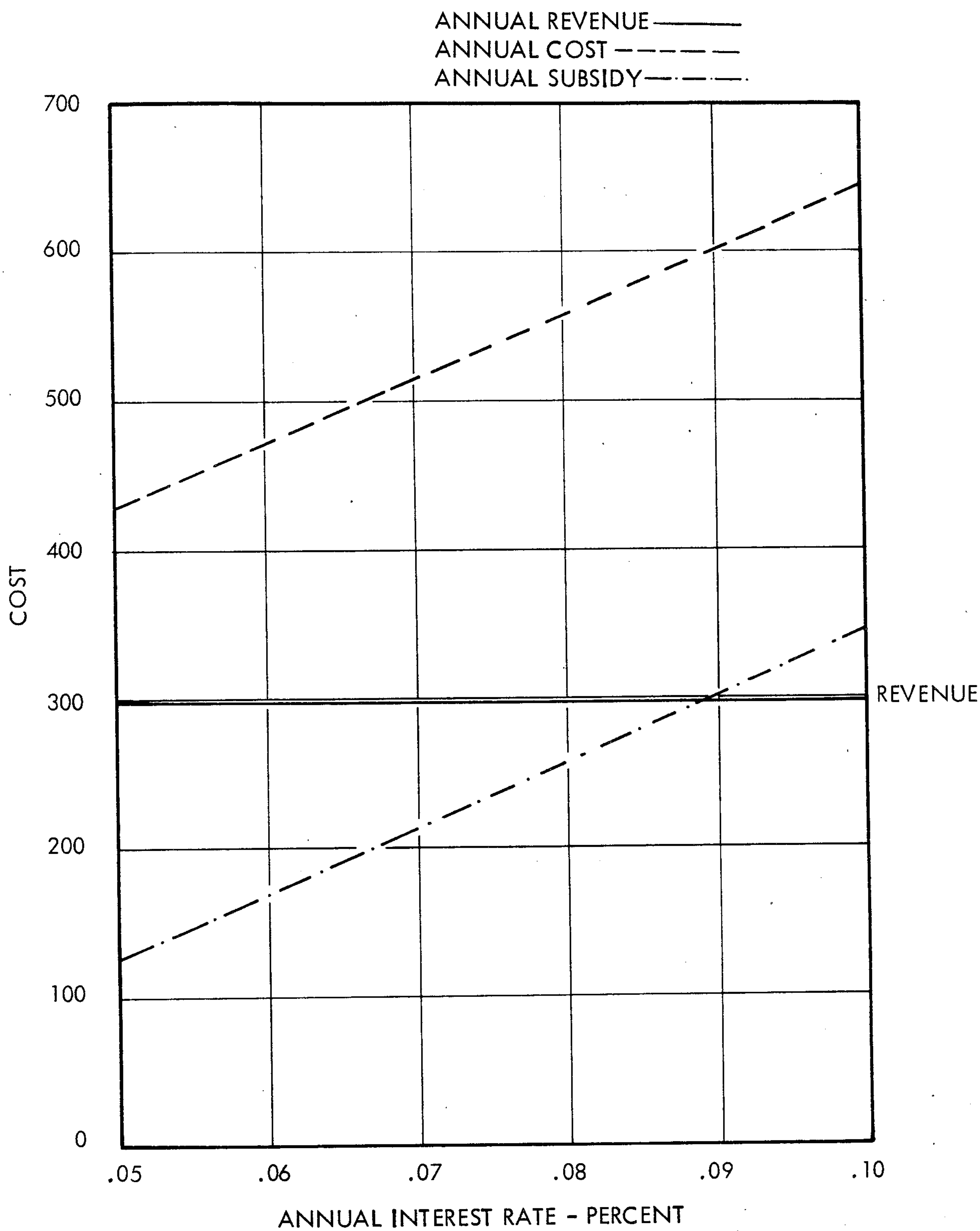

Figure 4-1. Economic Estimates of Interest Rate Variation for TVS in NEC with VTOL Competition

fact that the principal determinant of demand, i.e., trip costs to the traveler, was held constant at the baseline fare policy of a fixed portion of $1.50 and a variable portion of 7.5 cents per trip mile. Thus, operating deficities increase appreciably as the capital charges increase. The presence of VTOL competition, by diverting patronage from the ground mode, decreases revenues and thus increases required subsidy for the TVS system.

4.2 FARE POLICY VARIATION

To assure that the TVS mode would be reasonably competitive and in line with present railroad pricing policy the passenger fares utilized in the baseline series of HSGT service definitions by the Northeast Corridor project consisted of a fixed ticket price of $1.50 and a mileage related portion of 7.5 cents per mile.

A set of runs were made to determine the ticket price required for "break-even" operation of the system. However, the resulting fares turned out to be in a regime which was clearly outside the range for which the current demand model could be considered valid. Hence, it was decided to examine the sensitivity of service to various combinations of fixed and variable portions of ticket price. The rationale behind the variation of both portions is that increases in the fixed portion above tend to discriminate against shorter distance travel. The following combinations of fixed and variable portions of ticket price were selected for this analysis:

		Mileage Related Component (¢/passenger mile)		
		5	7.5	10
	0	X	X	X
Fixed	1.50	X	R	X
Component	3.00	X	X	X
($)	5.00	X	X	0

x - to be run

0 - not to be run

R - completed (baseline)

The results of these analyses for the TVS mode operating with VTOL competition are presented in Figures 4-2, 4-3, and 4-4. All of these results were obtained by maintaining the converged competition of air, bus and auto modes at the point of TVS mode fare of \$1.50 + 7.5¢/passenger mile. Figure 4-2 presents the annual system costs, revenues and subsidies over the range of 5¢ to 10¢ per passenger mile for the variable portion and a fixed portion of \$1.50. The second and third figures present the demand estimates under the same conditions.

Certain observations concerning the behavior of the system with variations in fare policy can be stated:

- System cost, revenues and subsidies are relatively insensitive to allowable fare policy variations about the nominal \$1.50 + 7.5¢/passenger mile for all three reactive ground modes.
- The absolute levels of demand is <u>not</u> insensitive to fare policy.
- The revenue for the TVS system is inelastic (Section 2.3) with respect to price, in that revenue monotonically increase with increasing value of fare components.

4.3 ACCESS/EGRESS TIME VARIATIONS

One of the significant determinants or modal patronage with the CN 25 demand model is the origin to destination time required to make a trip. A significant portion of this door-to-door time is attributed to the time to travel from the passenger origin to HSGT terminal and from the HSGT terminal to the passenger destination. With the TVS mode, the line haul portion of a Washington to Baltimore tr p is 10.7 minutes while the sum of the average access and egress times contribute 56 minutes to the total trip time. Clearly changes in access time would have a large impact on the TVS mode service characteristics.

In consequence a systematic percentage modification of access times at all nodes on all modes was undertaken to measure the impact of access time uncertainties. As in the case of the fare policy analysis, the TVS mode was configured in competition with VTOL, STOL, CTOL, bus and auto modes. The access times were uniformly changed for all modes from 75% to 150% of the baseline values. The ratio of access times to the nominal values is γ. Figures 4-5 and 4-6 represent the variation of cost

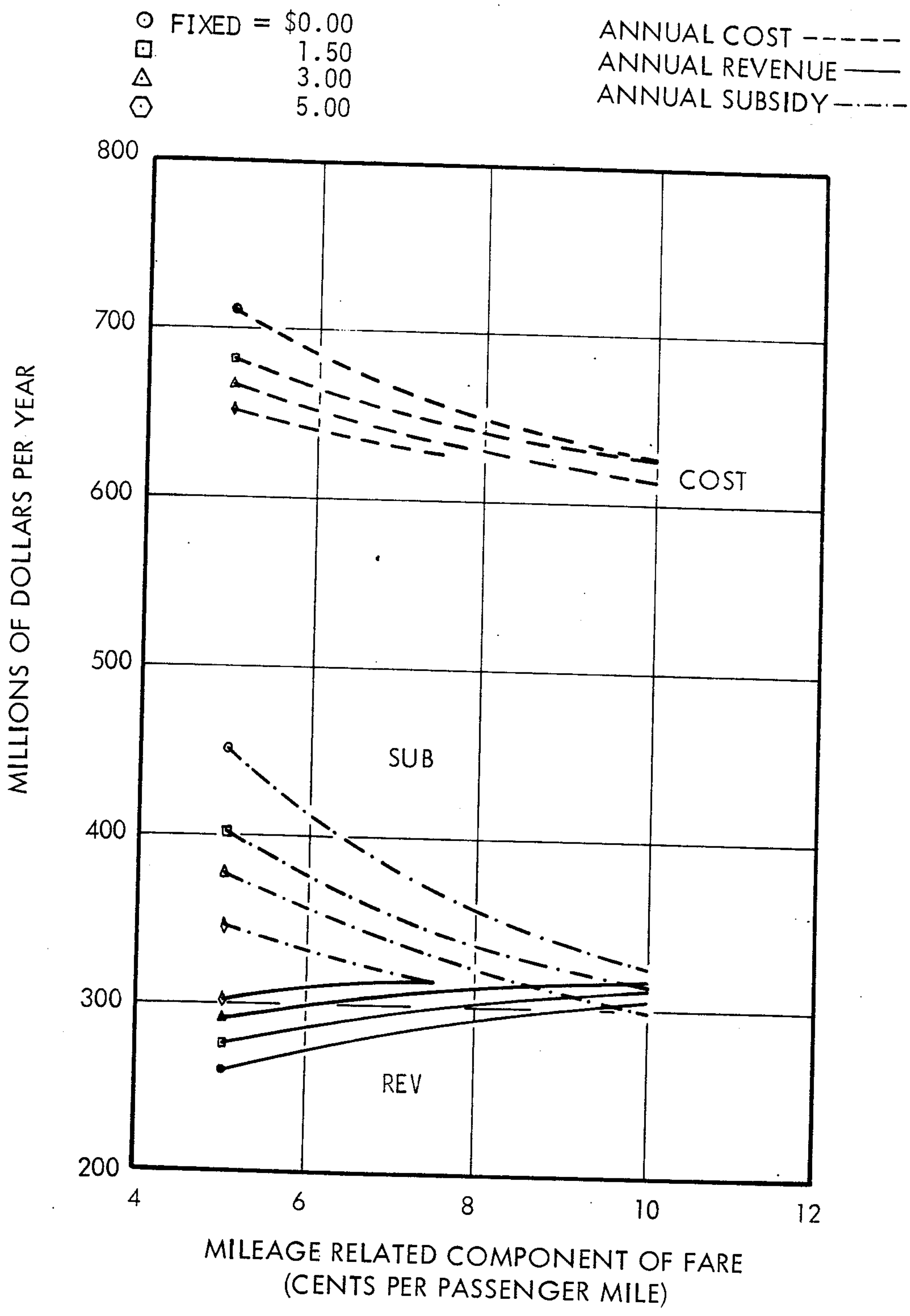

Figure 4-2. Economic Estimates of Fare Policy Variation for TVS in NEC

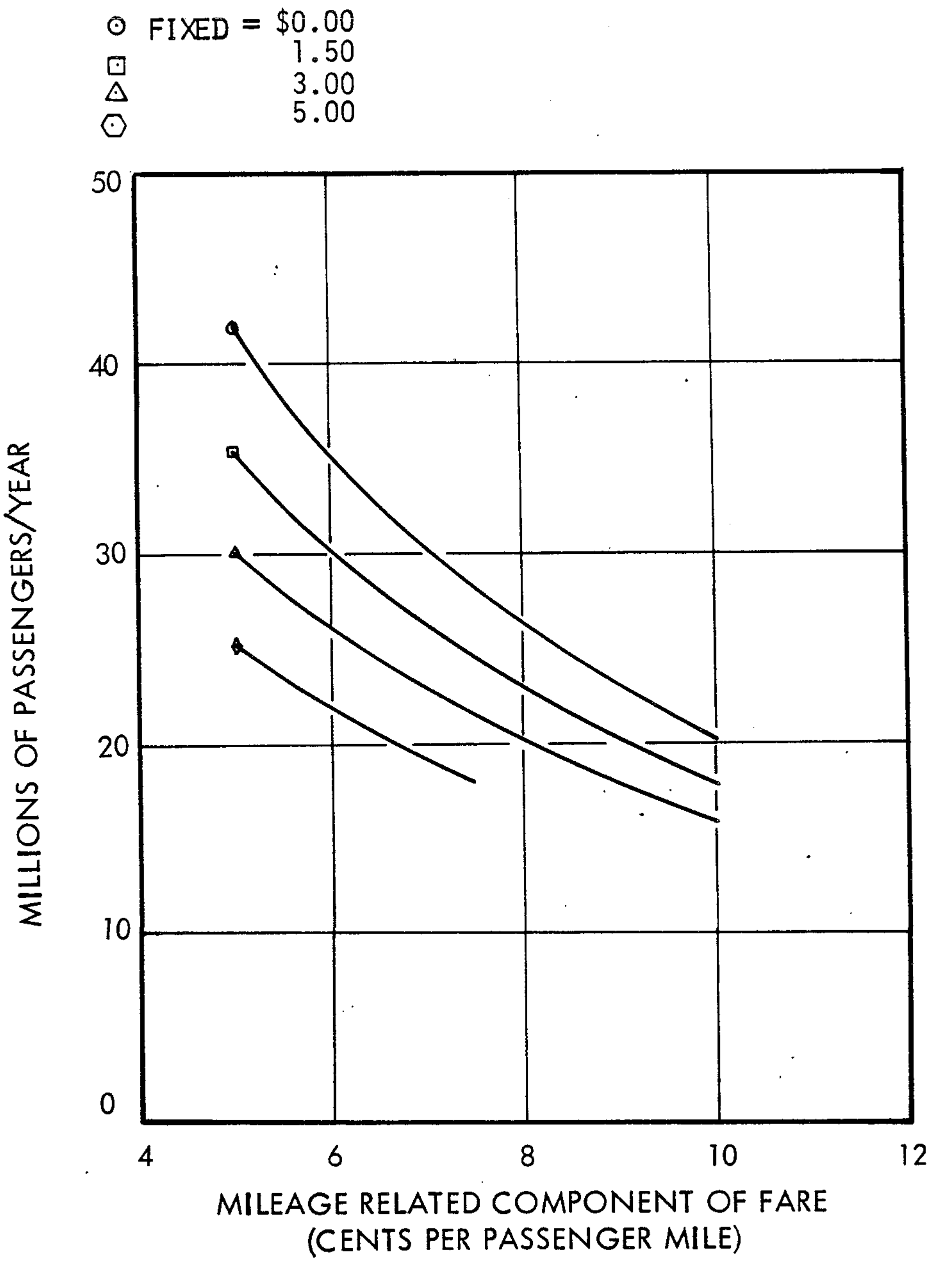

Figure 4-3. Fare Policy Impact on TVS Mode Demand in Passengers Per Year with VTOL Competition

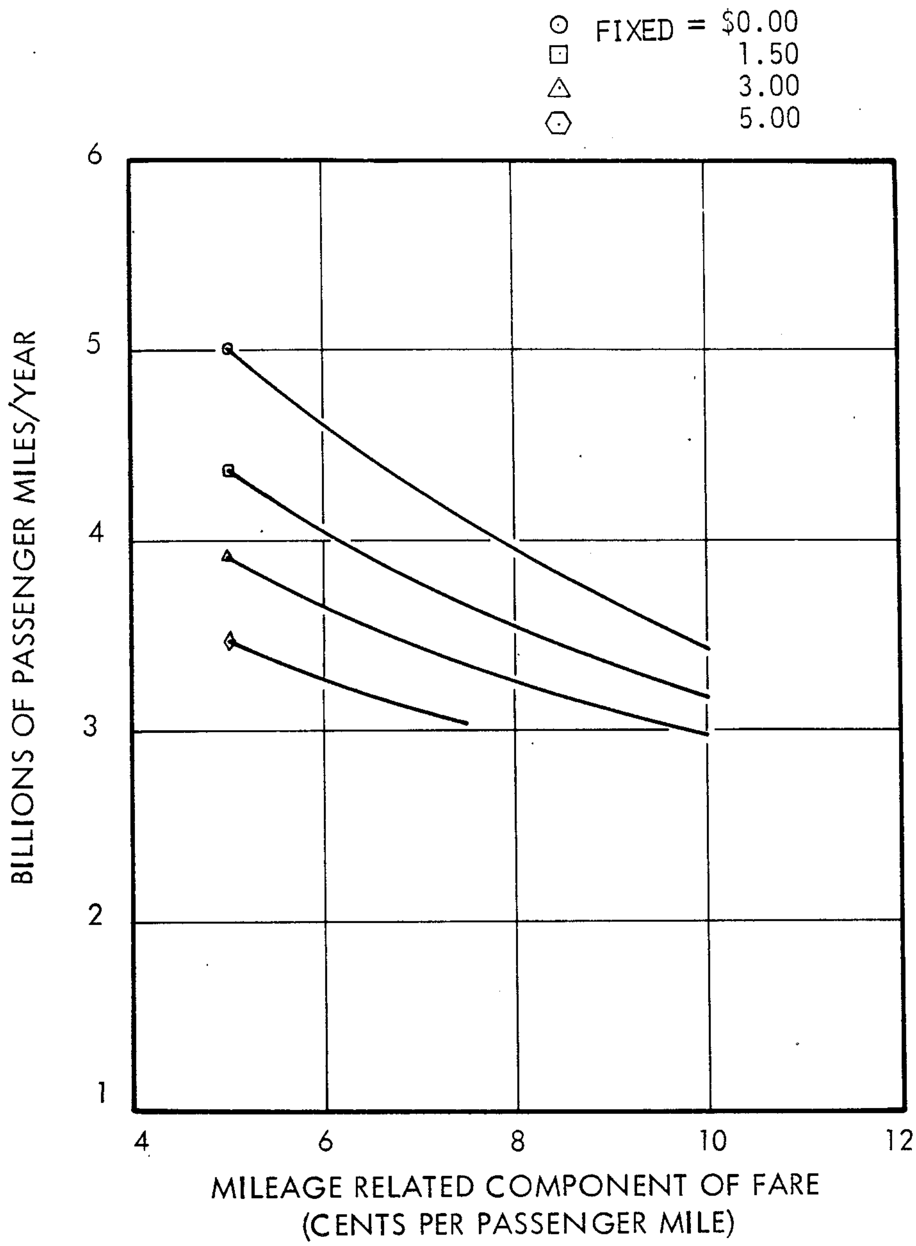

Figure 4-4. Fare Policy Impact on TVS Mode Demand (in Passenger Miles Per Year) with VTOL Competition

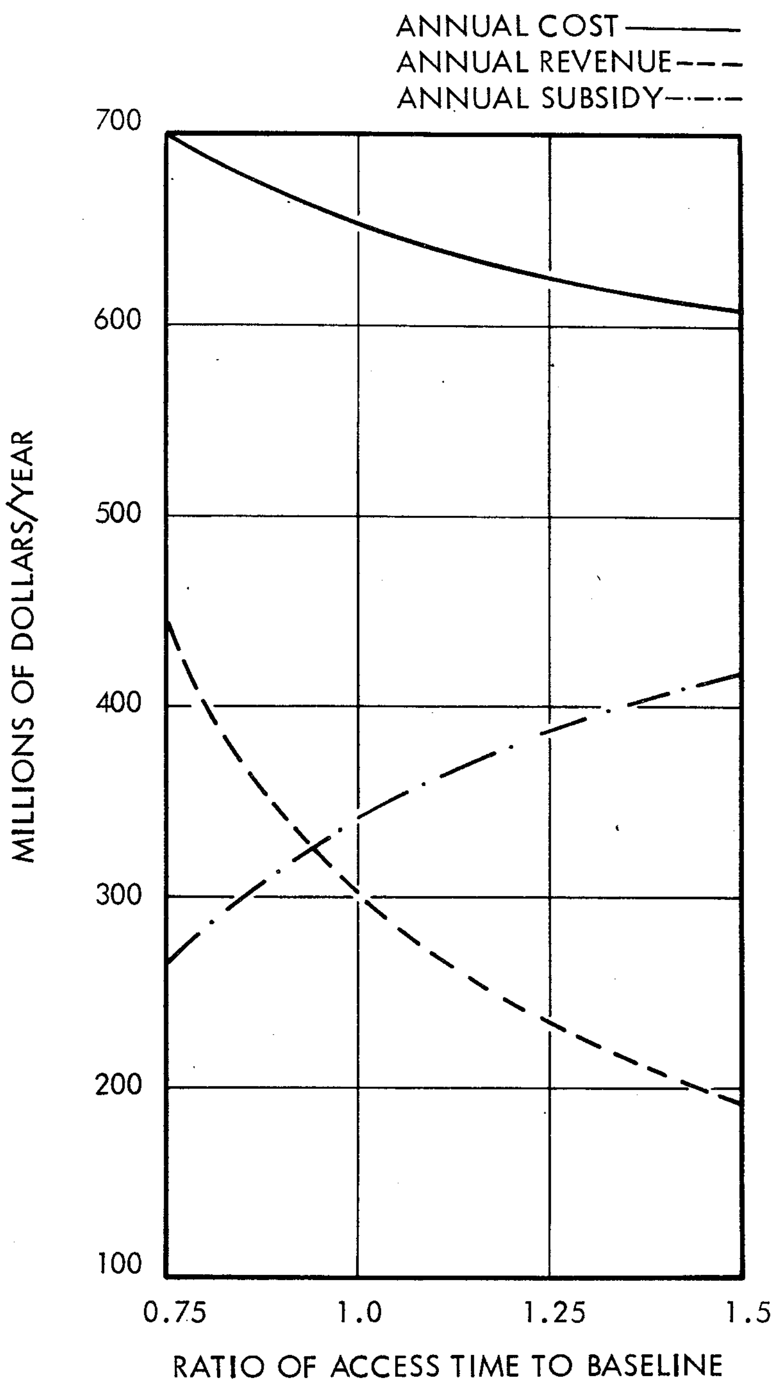

Figure 4-5. Economic Variations of TVS With Access Times

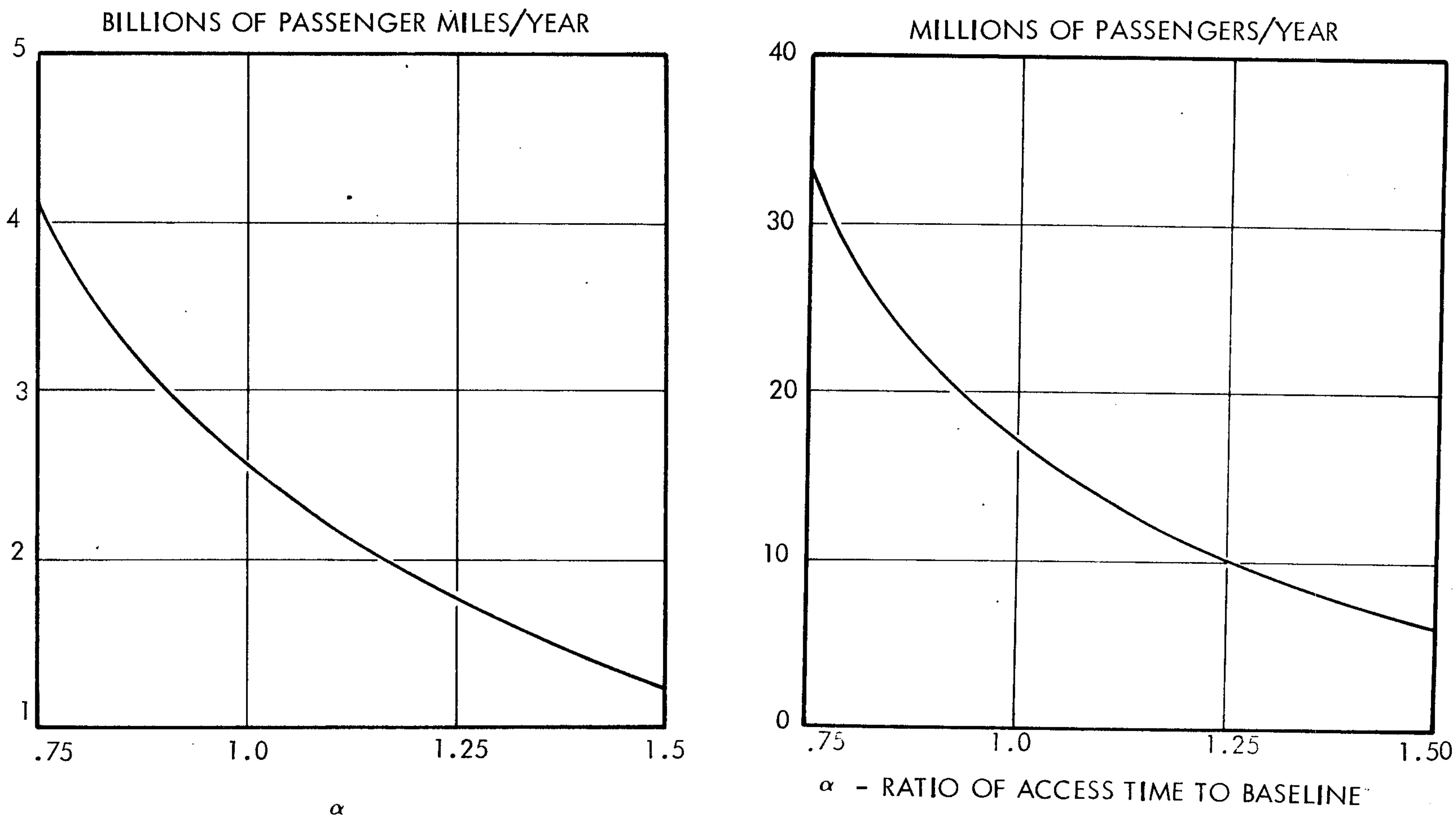

Figure 4-6. Access Time Variation of Demand for TVS Mode

and demand items for the TVS mode. While the range of runs performed was not extended to the breakeven condition, it nevertheless appears that a ratio (γ) of approximately 50% of nominal would allow break-even for the TVS system.

4.4 DEMOGRAPHIC PROJECTION RUNS

The baseline series of record runs indicated that, subject to the myriad of assumptions and demand model characteristics, the TVS mode will incur significant operating deficities if introduced in the NEC in the year 1980. In each case the demand attracted to the TVS mode at the nominal fares is too small to provide sufficient revenue. The demand on this mode is dependent not only on the relative service it provides with respect to competing modes, but also upon the total demand for travel for each origin-destination pair. This total demand, moreover, is a function of certain demographic parameters, which are included in an attempt to model the propensity to travel. The explicit demographic parameter used in the CN 25 demand model is the number of family units within each nodal market region which have annual incomes in excess of $10,000.

In order to account for the changes in the corridor influencing the total propensity to travel, the explicit demographic parameter (the number of family units with annual income exceeding $10,000) was estimated for each nodal market region based upon natural population growth trends. The specific values of N_i for the nine nodal market areas in 1985 are listed in Table 4-1.

These parameter variations result in the demand estimates for the TVS system operating with VTOL competition plotted in Figure 4-7. As anticipated, the demand for service on the HSGT modes increase with increasing time frame. Figure 4-7 also presents the economic projections for the system with VTOL competition through 1985. While not computed, it appears as though that revenue would equal costs on any of the three between 1990 and 1995.

TABLE 4-1

DEMOGRAPHIC PROJECTION DATA*

Modal Market Region	Number of Family Units with Annual Incomes in Excess of $10,000 1985
Washington	382,900
Baltimore	105,840
Philadelphia	295,780
Trenton	24,730
New Jersey	362,950
New York	1,120,430
Milford	135,500
Providence	29,910
Boston	178,150

*Data supplied by the Technical Analysis Division of the National Bureau of Standards

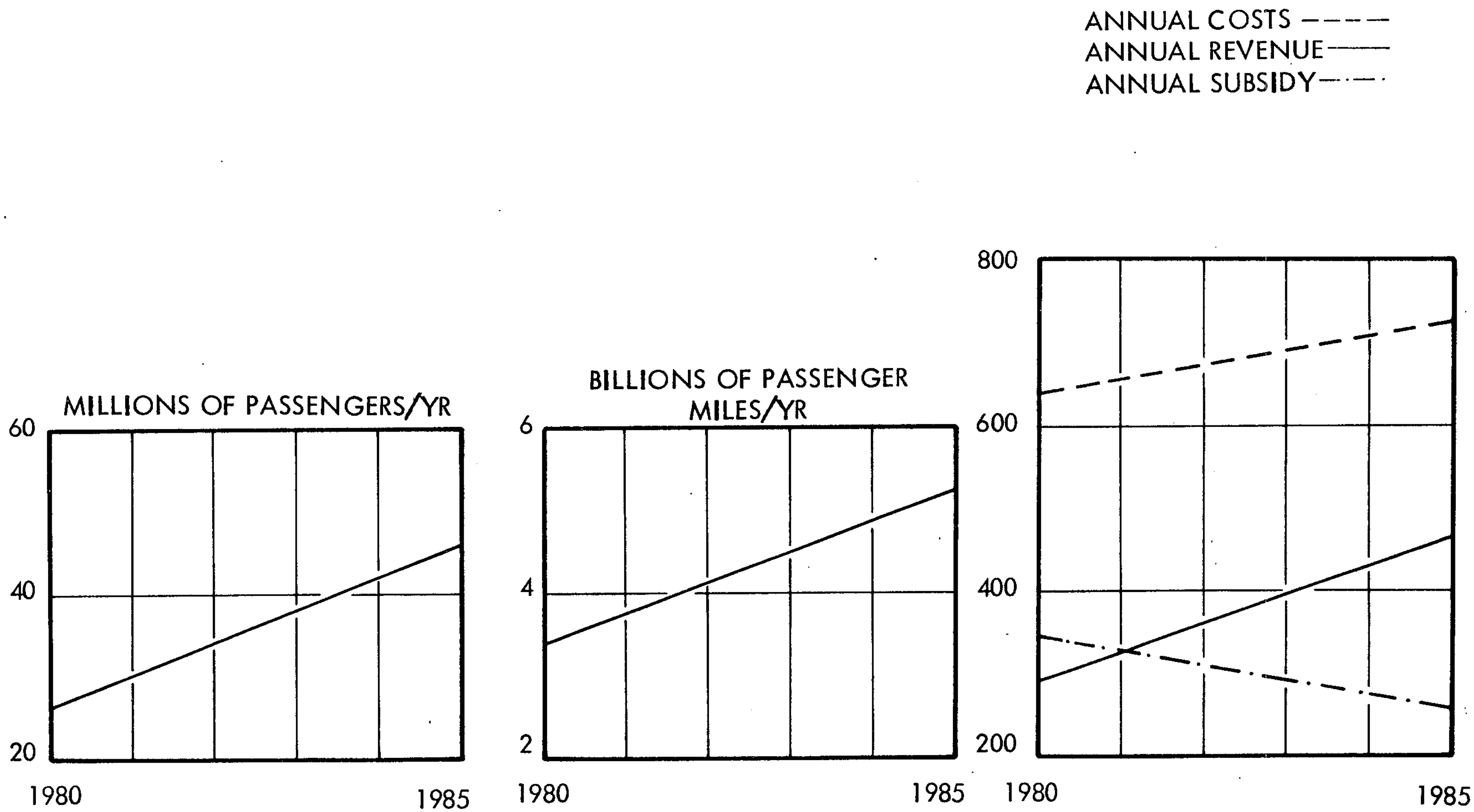

Figure 4-7. Economic and Demand Projections for TVS in NEC

APPENDIX A

TRANSOP OUTPUT FOR TVS BASELINE WITHOUT VTOL COMPETITION

INTERMODAL DEMANDS AND DETERMINATES OF DEMAND

DATE 11-17-69

TVS- SYSTEM

PASS 2 - INTEGER NUMBER OF VEHICLES PER TRAIN

TOTAL SYSTEM PASSENGER-MILES PER YEAR = 4.096 BILLION

	INTERMODAL CITY PAIR	INTERMODAL DEMAND MILLION PASSENGER-TRIPS PER YEAR	TICKET PRICE DOLLARS	PASSENGER TRIP TIME HOURS	SERVICE FREQUENCY DEPARTURES PER DAY
1	WASHINGTON - BALTIMORE	2.374	4.42	1.112	44.47
2	WASHINGTON - PHILADELPHIA	1.949	11.36	1.785	44.47
3	WASHINGTON - TRENTON	.262	13.57	1.648	44.47
4	WASHINGTON - WOODBRIDGE	1.135	17.62	2.310	44.47
5	WASHINGTON - NEW YORK	2.806	18.00	2.392	44.47
6	WASHINGTON - MILFORD	.355	23.44	2.648	44.47
7	WASHINGTON - PROVIDENCE	.081	31.80	2.868	44.47
8	WASHINGTON - BOSTON	.295	34.80	3.083	44.47
9	BALTIMORE - PHILADELPHIA	1.125	8.44	1.507	44.47
10	BALTIMORE - TRENTON	.153	10.65	1.370	44.47
11	BALTIMORE - WOODBRIDGE	.589	14.70	2.032	44.47
12	BALTIMORE - NEW YORK	1.461	15.07	2.113	44.47
13	BALTIMORE - MILFORD	.175	20.51	2.370	44.47
14	BALTIMORE - PROVIDENCE	.039	28.87	2.590	44.47
15	BALTIMORE - BOSTON	.139	31.87	2.805	44.47
16	PHILADELPHIA - TRENTON	.461	3.71	1.263	86.13
17	PHILADELPHIA - WOODBRIDGE	1.786	7.76	1.925	86.13
18	PHILADELPHIA - NEW YORK	4.717	8.14	2.007	86.13
19	PHILADELPHIA - MILFORD	.505	13.57	2.263	86.13
20	PHILADELPHIA - PROVIDENCE	.111	21.94	2.483	44.47
21	PHILADELPHIA - BOSTON	.386	24.94	2.698	44.47
22	TRENTON - WOODBRIDGE	.383	5.55	1.428	86.13
23	TRENTON - NEW YORK	1.113	5.92	1.510	86.13
24	TRENTON - MILFORD	.102	11.36	1.767	86.13
25	TRENTON - PROVIDENCE	.022	19.72	1.987	44.47
26	TRENTON - BOSTON	.074	22.72	2.202	44.47
27	WOODBRIDGE - NEW YORK	0.000	1.87	1.648	86.13
28	WOODBRIDGE - MILFORD	.842	7.31	1.905	86.13
29	WOODBRIDGE - PROVIDENCE	.189	15.67	2.125	44.47
30	WOODBRIDGE - BOSTON	.637	18.67	2.340	44.47
31	NEW YORK - MILFORD	2.396	6.94	1.790	86.13
32	NEW YORK - PROVIDENCE	.529	15.30	2.010	44.47
33	NEW YORK - BOSTON	1.771	18.30	2.225	44.47
34	MILFORD - PROVIDENCE	.158	9.86	1.620	44.47
35	MILFORD - BOSTON	.515	12.86	1.835	44.47
36	PROVIDENCE - BOSTON	.536	4.50	1.148	44.47
	TOTAL SYSTEM	30.171			

TICKET PRICE = 1.50 DOLLARS PER PASSENGER-TRIP PLUS 7.50 CENTS PER PASSENGER-MILE

SYSTEM COST PER PASSENGER-MILE = 16.33 CENTS

GROSS PROFIT =-316.277 MILLION DOLLARS PER YEAR

SUBSIDY TO SYSTEM = 316.277 MILLION DOLLARS PER YEAR

GROSS RATE OF RETURN = -.06156

TERMINAL DATA

DATE 11-17-69

TVS- SYSTEM

PASS 2 - INTEGER NUMBER OF VEHICLES PER TRAIN

	TERMINAL	COST OF TERMINAL ACCESS DOLLARS PER PASSENGER-TRIP	TERMINAL ACCESS TIME MINUTES PER PASSENGER-TRIP	TRAIN STOP TIME MINUTES PER STOP	PEAK TERMINAL USAGE PASSENGERS PER HOUR
1	WASHINGTON	.73	30.00	0.00	2029.11
2	BALTIMORE	.63	26.00	2.00	1327.13
3	PHILADELPHIA	1.01	43.00	2.00	2419.72
4	TRENTON	.87	24.00	2.00	563.33
5	WOODBRIDGE	1.38	48.00	2.00	1218.64
6	NEW YORK	1.15	47.00	2.00	3242.21
7	MILFORD	1.66	43.00	2.00	1106.73
8	PROVIDENCE	1.01	29.00	2.00	364.96
9	BOSTON	.90	29.00	0.00	954.01

LINK (TERMINAL TO TERMINAL) DATA

DATE 11-17-69

TVS- SYSTEM

PASS 2 - INTEGER NUMBER OF VEHICLES PER TRAIN

	LINK	TERMINAL TO TERMINAL DISTANCE MILES	TERMINAL TO TERMINAL TRIP TIME HOURS	LINK DEMAND MILLION PASSENGER-TRIPS PER YEAR
1	WASHINGTON - BALTIMORE	39.00	.1783	9.2578
2	BALTIMORE - PHILADELPHIA	92.50	.3567	10.5646
3	PHILADELPHIA - TRENTON	29.50	.1467	15.4562
4	TRENTON - WOODBRIDGE	54.00	.2283	16.2741
5	WOODBRIDGE - NEW YORK	5.00	.0650	14.0486
6	NEW YORK - MILFORD	72.50	.2900	8.6479
7	MILFORD - PROVIDENCE	111.50	.4200	4.9453
8	PROVIDENCE - BOSTON	40.00	.1817	4.3527
	TOTAL SYSTEM	444.00		

TRAIN DATA

DATE 11-17-69

TVS- SYSTEM

PASS 2 - INTEGER NUMBER OF VEHICLES PER TRAIN

AVERAGE SYSTEM LOAD FACTOR .... .833 PASSENGER-MILES PER SEAT-MILE

PEAK SERVICE FREQUENCY .... 3.080 DEPARTURES PER HOUR
AVERAGE SERVICE FREQUENCY .... 1.853 DEPARTURES PER HOUR
MAXIMUM ALLOWABLE SERVICE FREQUENCY .... 23.000 DEPARTURES PER HOUR

TRAIN	TERMINAL TO TERMINAL	SERVICE FREQUENCY DEPARTURES PER HOUR PEAK	DAY	NIGHT	LOAD FACTOR PEAK	DAY	NIGHT	PASSENGERS PER TRAIN PEAK	DAY	NIGHT
1	WASHINGTON - BOSTON	3.191	2.128	.638	.945	.886	.910	363	340	218
2	PHILADELPHIA - MILFORD	3.241	2.315	0.000	.804	.704	0.000	193	169	0

PASSENGER-SEATS PER VEHICLE 48
VEHICLE LENGTH .... 83 FEET
MAXIMUM ALLOWABLE TRAIN LENGTH .... 1000 FEET
VEHICLE UTILIZATION FACTOR .... .952
SPARE VEHICLE ALLOWANCE FACTOR .... .080

TRAIN	TERMINAL TO TERMINAL	TRAINS IN SERVICE PEAK	DAY	NIGHT	VEHICLES PER TRAIN PEAK	DAY	NIGHT	TRAIN LENGTH FEET PEAK	DAY	NIGHT
1	WASHINGTON - BOSTON	15.0	10.0	3.0	8.0	8.0	5.0	664	664	415
2	PHILADELPHIA - MILFORD	7.0	5.0	0.0	5.0	5.0	0.0	415	415	0

FLEET SIZE = 47.0 TYPE A VEHICLES PLUS 117.0 TYPE B VEHICLES = 164.0 VEHICLES

SYSTEM INVESTMENTS

IN MILLIONS OF DOLLARS

DATE 11-17-69

TVS- SYSTEM

PASS 2 - INTEGER NUMBER OF VEHICLES PER TRAIN

TOTAL INVESTMENT IN FIXED PLANT		4944.400
INVESTMENT IN GUIDEWAY AND PREPARATION	4511.400	
INVESTMENT IN SYSTEM ELECTRIFICATION	0.000	
INVESTMENT IN COMMAND- CONTROL- AND COMMUNICATIONS SYSTEMS	132.000	
INVESTMENT IN TERMINALS	91.000	
INVESTMENT IN YARDS AND SHOPS	0.000	
INVESTMENT IN RESEARCH AND DEVELOPMENT	210.000	
TOTAL INVESTMENT IN LAND		87.000
INVESTMENT IN LAND FOR GUIDEWAY	0.000	
INVESTMENT IN LAND FOR YARDS AND SHOPS	87.000	
TOTAL INVESTMENT IN VEHICLES		106.272
INVESTMENT IN TYPE A VEHICLES	30.456	
INVESTMENT IN TYPE B VEHICLES	75.816	
TOTAL INVESTMENT IN SYSTEM		5137.672

DATA USED TO COMPUTE ANNUAL CHARGES FOR INVESTMENTS

	PLANT	LAND	VEHICLES
COST OF CAPITAL	.100	.080	.100
AMORTIZATION PERIOD (YEARS) ..	35	400	14
SALVAGE FRACTION	0.000	1.000	0.000
FRACTION OF INVESTMENT CHARGED AS A COST PER YEAR ...	.104	.080	.136

ANNUAL SYSTEM COSTS

IN MILLIONS OF DOLLARS PER YEAR

DATE 11-17-69

TVS- SYSTEM

PASS 2 - INTEGER NUMBER OF VEHICLES PER TRAIN

ANNUAL CHARGE FOR TOTAL INVESTMENT IN SYSTEM		534.069
ANNUAL CHARGE FOR INVESTMENT IN FIXED PLANT	512.683	
ANNUAL CHARGE FOR INVESTMENT IN LAND	6.960	
ANNUAL CHARGE FOR INVESTMENT IN VEHICLES	14.426	

TOTAL ANNUAL DIRECT OPERATING COSTS		73.211
ENERGY COSTS	6.343	
CREW COSTS	1.448	
VEHICLE MAINTENANCE COSTS	26.965	
GUIDEWAY MAINTENANCE COSTS	13.022	
POWER AND CONTROL SYSTEMS MAINTENANCE COSTS	4.600	
MAINTENANCE BURDEN	20.833	

TOTAL ANNUAL INDIRECT OPERATING COSTS		61.437
VEHICLE-MILES ALLOCATED INDIRECT OPERATING COSTS	2.022	
PASSENGER-TRIPS ALLOCATED INDIRECT OPERATING COSTS	45.257	
	-------	-------
TOTAL ANNUAL SYSTEM COSTS		668.717

SYSTEM INCOME

IN MILLIONS OF DOLLARS PER YEAR

DATE 11-17-69

TVS- SYSTEM

PASS 2 - INTEGER NUMBER OF VEHICLES PER TRAIN

TOTAL SYSTEM REVENUES	352.440
PLUS SUBSIDY TO SYSTEM	316.277

TOTAL SYSTEM INCOME	668.717
LESS TOTAL ANNUAL SYSTEM COSTS	668.717

GROSS SYSTEM PROFIT	0.000
LESS TAXES	0.000

NET SYSTEM PROFIT	0.000

GROSS RATE OF RETURN ....-.0616

NET RATE OF RETURN ......-.0616

TOTAL SYSTEM PASSENGER-MILES PER YEAR ... 4.096 BILLION	COST PER PASSENGER-MILE ... 16.33 CENTS
TOTAL SYSTEM SEAT-MILES PER YEAR .... 6.472 BILLION	COST PER SEAT-MILE .... 10.33 CENTS
TOTAL SYSTEM TRAIN-MILES PER YEAR .... 19.310 MILLION	COST PER TRAIN-MILE .... 34.63 DOLLARS
TOTAL SYSTEM VEHICLE-MILES PER YEAR .....134.824 MILLION	COST PER VEHICLE-MILE ..... 4.96 DOLLARS
TOTAL SYSTEM VEHICLE-HOURS PER YEAR .... 748.250 THOUSAND	COST PER VEHICLE-HOUR .... 893.71 DOLLARS

APPENDIX B

TRANSOP OUTPUT FOR TVS BASELINE WITH VTOL COMPETITION

INTERNODAL DEMANDS AND DETERMINATES OF DEMAND

DATE 11-25-69

TVS- SYSTEM

PASS 2 - INTEGER NUMBER OF VEHICLES PER TRAIN

TOTAL SYSTEM PASSENGER-MILES PER YEAR = 3.460 BILLION

	INTERNODAL CITY PAIR	INTERNODAL DEMAND MILLION PASSENGER-TRIPS PER YEAR	TICKET PRICE DOLLARS	PASSENGER TRIP TIME HOURS	SERVICE FREQUENCY DEPARTURES PER DAY
1	WASHINGTON - BALTIMORE	2.270	4.42	1.112	41.06
2	WASHINGTON - PHILADELPHIA	1.684	11.36	1.785	41.06
3	WASHINGTON - TRENTON	.221	13.57	1.648	41.06
4	WASHINGTON - WOODBRIDGE	.925	17.62	2.310	41.06
5	WASHINGTON - NEW YORK	2.272	18.00	2.392	41.06
6	WASHINGTON - MILFORD	.288	23.44	2.648	41.06
7	WASHINGTON - PROVIDENCE	.064	31.80	2.868	41.06
8	WASHINGTON - BOSTON	.236	34.80	3.083	41.06
9	BALTIMORE - PHILADELPHIA	.991	8.44	1.507	41.06
10	BALTIMORE - TRENTON	.134	10.65	1.370	41.06
11	BALTIMORE - WOODBRIDGE	.483	14.70	2.032	41.06
12	BALTIMORE - NEW YORK	1.172	15.07	2.113	41.06
13	BALTIMORE - MILFORD	.141	20.51	2.370	41.06
14	BALTIMORE - PROVIDENCE	.030	28.87	2.590	41.06
15	BALTIMORE - BOSTON	.109	31.87	2.805	41.06
16	PHILADELPHIA - TRENTON	.451	3.71	1.263	77.64
17	PHILADELPHIA - WOODBRIDGE	1.627	7.76	1.925	77.64
18	PHILADELPHIA - NEW YORK	4.145	8.14	2.007	77.64
19	PHILADELPHIA - MILFORD	.438	13.57	2.263	77.64
20	PHILADELPHIA - PROVIDENCE	.090	21.94	2.483	41.06
21	PHILADELPHIA - BOSTON	.319	24.94	2.698	41.06
22	TRENTON - WOODBRIDGE	.366	5.55	1.420	77.64
23	TRENTON - NEW YORK	.985	5.92	1.510	77.64
24	TRENTON - MILFORD	.090	11.36	1.767	77.64
25	TRENTON - PROVIDENCE	.017	19.72	1.987	41.06
26	TRENTON - BOSTON	.060	22.72	2.202	41.06
27	WOODBRIDGE - NEW YORK	0.000	1.87	1.648	77.64
28	WOODBRIDGE - MILFORD	.786	7.31	1.905	77.64
29	WOODBRIDGE - PROVIDENCE	.153	15.67	2.125	41.06
30	WOODBRIDGE - BOSTON	.518	18.67	2.340	41.06
31	NEW YORK - MILFORD	2.264	6.94	1.790	77.64
32	NEW YORK - PROVIDENCE	.435	15.30	2.010	41.06
33	NEW YORK - BOSTON	1.475	18.30	2.225	41.06
34	MILFORD - PROVIDENCE	.138	9.86	1.620	41.06
35	MILFORD - BOSTON	.433	12.86	1.835	41.06
36	PROVIDENCE - BOSTON	.495	4.50	1.148	41.06
	TOTAL SYSTEM	26.304			

TICKET PRICE = 1.50 DOLLARS PER PASSENGER-TRIP PLUS 7.50 CENTS PER PASSENGER-MILE

SYSTEM COST PER PASSENGER-MILE = 18.67 CENTS

GROSS PROFIT =-347.078 MILLION DOLLARS PER YEAR

SUBSIDY TO SYSTEM = 347.078 MILLION DOLLARS PER YEAR

GROSS RATE OF RETURN = -.06775

TERMINAL DATA

DATE 11-25-69

TVS- SYSTEM

PASS 2 - INTEGER NUMBER OF VEHICLES PER TRAIN

	TERMINAL	COST OF TERMINAL ACCESS DOLLARS PER PASSENGER-TRIP	TERMINAL ACCESS TIME MINUTES PER PASSENGER-TRIP	TRAIN STOP TIME MINUTES PER STOP	PEAK TERMINAL USAGE PASSENGERS PER HOUR
1	WASHINGTON	.73	30.00	0.00	1744.43
2	BALTIMORE	.63	26.00	2.00	1168.30
3	PHILADELPHIA	1.01	63.00	2.00	2135.87
4	TRENTON	.87	24.00	2.00	509.34
5	WOODBRIDGE	1.39	58.00	2.00	1064.78
6	NEW YORK	1.15	47.00	2.00	2794.17
7	MILFORD	1.66	43.00	2.00	1003.27
8	PROVIDENCE	1.01	29.00	2.00	311.63
9	BOSTON	.96	29.00	0.00	798.93

LINK (TERMINAL TO TERMINAL) DATA

DATE 11-25-69

TVS- SYSTEM

PASS 2 - INTEGER NUMBER OF VEHICLES PER TRAIN

	LINK	TERMINAL TO TERMINAL DISTANCE MILES	TERMINAL TO TERMINAL TRIP TIME HOURS	LINK DEMAND MILLION PASSENGER-TRIPS PER YEAR
1	WASHINGTON - BALTIMORE	39.00	.1783	7.9589
2	BALTIMORE - PHILADELPHIA	92.50	.3567	8.7495
3	PHILADELPHIA - TRENTON	29.50	.1467	13.1453
4	TRENTON - WOODBRIDGE	54.00	.2283	13.8566
5	WOODBRIDGE - NEW YORK	5.00	.0650	11.9125
6	NEW YORK - MILFORD	72.50	.2900	7.5126
7	MILFORD - PROVIDENCE	111.50	.4200	4.0777
8	PROVIDENCE - BOSTON	40.00	.1417	3.6451
	TOTAL SYSTEM	444.00		

TRAIN DATA

DATE 11-25-69

TVS- SYSTEM

PASS 2 - INTEGER NUMBER OF VEHICLES PER TRAIN

AVERAGE SYSTEM LOAD FACTOR .... .647 PASSENGER-MILES PER SEAT-MILE

PEAK SERVICE FREQUENCY .... 2.911 DEPARTURES PER HOUR
AVERAGE SERVICE FREQUENCY .... 1.711 DEPARTURES PER HOUR
MAXIMUM ALLOWABLE SERVICE FREQUENCY .... 23.000 DEPARTURES PER HOUR

TRAIN	TERMINAL TO TERMINAL	SERVICE FREQUENCY DEPARTURES PER HOUR			LOAD FACTOR			PASSENGERS PER TRAIN		
		PEAK	DAY	NIGHT	PEAK	DAY	NIGHT	PEAK	DAY	NIGHT
1	WASHINGTON - BOSTON	2.979	1.915	.638	.958	.931	.774	322	313	186
2	PHILADELPHIA - MILFORD	3.241	1.852	0.000	.720	.787	0.000	173	189	0

PASSENGER-SEATS PER VEHICLE 48
VEHICLE LENGTH .... 83 FEET
MAXIMUM ALLOWABLE TRAIN LENGTH .... 1000 FEET
VEHICLE UTILIZATION FACTOR .... .952
SPARE VEHICLE ALLOWANCE FACTOR .... .080

TRAIN	TERMINAL TO TERMINAL	TRAINS IN SERVICE			VEHICLES PER TRAIN			TRAIN LENGTH FEET		
		PEAK	DAY	NIGHT	PEAK	DAY	NIGHT	PEAK	DAY	NIGHT
1	WASHINGTON - BOSTON	14.0	9.0	3.0	7.0	7.0	5.0	581	581	415
2	PHILADELPHIA - MILFORD	7.0	4.0	0.0	5.0	5.0	0.0	415	415	0

FLEET SIZE = 45.0 TYPE A VEHICLES PLUS 96.0 TYPE B VEHICLES = 141.0 VEHICLES

SYSTEM INVESTMENTS

IN MILLIONS OF DOLLARS

DATE 11-25-69

TVS- SYSTEM

PASS 2 - INTEGER NUMBER OF VEHICLES PER TRAIN

TOTAL INVESTMENT IN FIXED PLANT		4944.400
INVESTMENT IN GUIDEWAY AND PREPARATION	4511.400	
INVESTMENT IN SYSTEM ELECTRIFICATION	0.000	
INVESTMENT IN COMMAND- CONTROL- AND COMMUNICATIONS SYSTEMS	132.000	
INVESTMENT IN TERMINALS	91.000	
INVESTMENT IN YARDS AND SHOPS	0.000	
INVESTMENT IN RESEARCH AND DEVELOPMENT	210.000	
TOTAL INVESTMENT IN LAND		87.000
INVESTMENT IN LAND FOR GUIDEWAY	0.000	
INVESTMENT IN LAND FOR YARDS AND SHOPS	87.000	
TOTAL INVESTMENT IN VEHICLES		91.368
INVESTMENT IN TYPE A VEHICLES	29.160	
INVESTMENT IN TYPE B VEHICLES	62.208	
TOTAL INVESTMENT IN SYSTEM		5122.768

DATA USED TO COMPUTE ANNUAL CHARGES FOR INVESTMENTS

	PLANT	LAND	VEHICLES
COST OF CAPITAL	.100	.080	.100
AMORTIZATION PERIOD (YEARS) ..	35	400	14
SALVAGE FRACTION	0.000	1.000	0.000
FRACTION OF INVESTMENT CHARGED AS A COST PER YEAR ...	.104	.080	.136

ANNUAL SYSTEM COSTS

IN MILLIONS OF DOLLARS PER YEAR

DATE 11-25-69

TVS- SYSTEM

PASS 2 - INTEGER NUMBER OF VEHICLES PER TRAIN

ANNUAL CHARGE FOR TOTAL INVESTMENT IN SYSTEM		532.046
ANNUAL CHARGE FOR INVESTMENT IN FIXED PLANT	512.683	
ANNUAL CHARGE FOR INVESTMENT IN LAND	6.960	
ANNUAL CHARGE FOR INVESTMENT IN VEHICLES	12.403	

TOTAL ANNUAL DIRECT OPERATING COSTS		62.117
ENERGY COSTS	5.283	
CREW COSTS	1.321	
VEHICLE MAINTENANCE COSTS	22.270	
GUIDEWAY MAINTENANCE COSTS	10.909	
POWER AND CONTROL SYSTEMS MAINTENANCE COSTS	4.600	
MAINTENANCE BURDEN	17.734	

TOTAL ANNUAL INDIRECT OPERATING COSTS		51.907
VEHICLE-MILES ALLOCATED INDIRECT OPERATING COSTS	1.670	
PASSENGER-TRIPS ALLOCATED INDIRECT OPERATING COSTS	39.457	
	-------	-------
TOTAL ANNUAL SYSTEM COSTS		646.070

SYSTEM INCOME

IN MILLIONS OF DOLLARS PER YEAR

DATE 11-25-69

TVS- SYSTEM

PASS 2 - INTEGER NUMBER OF VEHICLES PER TRAIN

```
TOTAL SYSTEM REVENUES ............................ 298.992
     PLUS SUBSIDY TO SYSTEM ...................... 347.078
                                                   -------
TOTAL SYSTEM INCOME .............................. 646.070
     LESS TOTAL ANNUAL SYSTEM COSTS .............. 646.070
                                                   -------
GROSS SYSTEM PROFIT ..............................   -.000
      LESS TAXES .................................   0.000
                                                   -------
NET SYSTEM PROFIT ................................   -.000
```

GROSS RATE OF RETURN ....-.0678

NET RATE OF RETURN ......-.0678

TOTAL SYSTEM PASSENGER-MILES PER YEAR ... 3.460 BILLION	COST PER PASSENGER-MILE ... 18.67 CENTS
TOTAL SYSTEM SEAT-MILES PER YEAR .... 5.345 BILLION	COST PER SEAT-MILE .... 12.09 CENTS
TOTAL SYSTEM TRAIN-MILES PER YEAR .... 17.608 MILLION	COST PER TRAIN-MILE .... 36.69 DOLLARS
TOTAL SYSTEM VEHICLE-MILES PER YEAR .....111.350 MILLION	COST PER VEHICLE-MILE ..... 5.80 DOLLARS
TOTAL SYSTEM VEHICLE-HOURS PER YEAR .... 619.770 THOUSAND	COST PER VEHICLE-HOUR .... *42.44 DOLLARS