NATIONAL BUREAU OF STANDARDS REPORT

10 554

PROSPECTS FOR HIGH SPEED GROUND TRANSPORT IN THE NORTHEAST CORRIDOR

Project Report

Prepared for the NECTP

NBS

U.S. DEPARTMENT OF COMMERCE

NATIONAL BUREAU OF STANDARDS

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PROSPECTS FOR HIGH SPEED GROUND TRANSPORT IN THE NORTHEAST CORRIDOR

ABSTRACT

Nine investment alternatives for future Northeast corridor high speed ground transportation systems are evaluated. Different combinations of technologically new systems together with the further extension of the current Metroliners and the Turbotrains service comprise these nine alternatives. Passenger demands are forecasted, characteristics of the systems are described, and the methodology used in estimating costs is presented. The multiperiod analysis takes into account the timing of revenues, investment and operating costs during the evaluation period, which extends to 1999, as well as potential salvage values after operation. The analysis shows in broad terms what might be expected of high speed ground transportation modes in the Northeast corridor. The results indicate that increased utilization of Metroliners and Turbotrains on the existing Northeast corridor rail facilities would return more than it would cost and that the subsequent introduction of a tracked air cushion vehicle system in the southern half (Washington to New York) could be made financially viable depending on the length of the construction period and the fares charged.

Keywords: Northeast Corridor, NECTP, Tracked Air Cushion Vehicle, Present Value Analysis, Transportation Planning, High Speed Ground Transportation

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Introduction

Although its importance has declined dramatically since the end of the World War II, the passenger train still shows signs of usefulness for short-distance intercity travel judging from the experiences of the Northeast corridor Metroliners in this country and the Tokaido lines in Japan. Moreover, the factors that have contributed to the decline of short-distance passenger trains, namely the increasing use of automobiles and airplanes, begin to show negative returns both directly by affecting the travel time and level of comfort and indirectly by affecting the quality of the environment. The positive factors for the future development of passenger trains, the increasing urbanization and population density, are expected to become more important in the Northeast corridor region. It becomes imperative, therefore, for public authorities to evaluate the potentials of passenger trains or any other similar ground-based mass-transit system. These systems collectively are called high speed ground transportation (HSGT) systems, and it is the purpose of the material that follows to evaluate the financial profitabilities of such systems. Needless to say, the financial considerations presented here constitute only a part of an over-all societal evaluation in guiding the formulation of public transportation policies.

In evaluating the several candidate systems the approach taken differs from that of the previous Northeast Corridor Project report [1/]

1/ "Northeast Corridor Transportation Project Report," NECTP Report No. 209, Department of Transportation, May, 1970.

in that the analyses take into consideration revenues and costs of the entire operating lives of the systems rather than considering the case of any particular target year (e.g., 1985) as was the case in the previous analysis. The new approach applies the generally accepted method of investment project evaluation used in both the private and public sectors. Its intent is to account for, as far as possible, all the revenues and costs as they might materialize in the future, and then compare the costs and revenues by eliminating the time element from the analysis through discounting to present values. The single-period analysis was discarded mainly because it presents only a snapshot picture of the future possibilities, thus possibly giving a biased picture depending on which particular year happened to be chosen. The multi-period analysis, by presenting an aggregate picture, gives a more balanced and realistic assessment of the contemplated transportation alternatives.

In the present study nine investment project alternatives for future Northeast corridor high speed ground transportation systems are evaluated. These are combinations of the further extension of the current Metroliners and the Turbotrains on the one hand, combined with the subsequent introduction of technologically new systems on the other. In addition to the presentation of the results obtained from the nine principal alternative analyses, there is included a description of a number of parametric variational analyses which serve to indicate the significance of the various parameters and the sensitivity of the main results to variations in their values.

In succeeding sections, the forecasts of passenger demands for the respective systems are described first, followed by detailed descriptions of the characteristics of the various high speed ground modes and the methodology used in estimating their costs. A section describing the analysis and its results follows, and a section setting forth the recommendations based on the results concludes the study.

Demand Forecasts

Background. In 1968 there were about 150 million intercity passenger trips made within the Northeast Corridor region and of these about 6% of the trips were made by rail. By 1985 the number of intercity trips being made within the region could increase to about 300 million per year. This estimate results from an assumed growth rate of 4%, which corresponds to the national annual transportation growth rate experienced during the period 1950 to 1965. Under this circumstance, if the rail mode were to maintain its current share of the travel market, a reversal of previous trends, approximately 17 million trips would be made by rail. It should be pointed out, however, that considering only common carrier travel, excluding the dominating influence of the tremendous increase in auto travel, the national growth rate for this portion of the travel market has been only about 2% per year during the past decade. This more conservative rate results in an estimated 12.5 million trips by rail in 1985. It would appear, therefore, that if it is possible to maintain the competitive status quo, the rail mode could be expected to experience a demand of between 12.5 and 17 million by 1985.

On the other hand, these figures reflect the possibilities of rail transportation maintained at almost the nadir of rail demand. Modification of the existing rail service between Washington, D.C. and New York City in the southern portion of the corridor and between New York City and Boston in the northern portion, to include a full

complement of Metroliner service and Turbotrains on an upgraded right-of-way, the so-called "demonstration" trains, could considerably enhance the attractiveness of the rail mode. This could possibly result in patronage levels well in excess of what might otherwise be expected. The introduction of even more pronounced changes, such as completely replacing the present service with a more advanced form of technology, e.g. the tracked air cushion vehicle operating on a wholly new right-of-way, could stimulate patronage to increase to an even higher level than that conceivable for the demonstration service. From 1950 to 1965 air patronage increased five-fold during a period of rapid technological innovation which included conversion to jet aircraft. If development and operation of an advanced high speed ground transport system had a similar effect and, as a result, the rail mode's patronage increased four or five-fold over the next fifteen years, the current annual figure of 9 million intercity rail passengers in the corridor could become between 36 and 45 million by the mid 1980's. The potential demand for an attractive high speed ground transport mode could be great. Whether, or to what extent, this potential demand can be realized is in part a matter for speculation. The following discussion attempts to supplant as much of this speculation as possible by providing some degree of analytic basis for the formulation of public policy with respect to the future of intercity rail passenger travel in the Northeast corridor.

Discussion. If intercity passenger rail service is to be improved in the Northeast Corridor region, the choice must be made from among several currently available options. The most modest among these would involve an extension of the present rail demonstration service by replacing the remaining conventional trains with either Metroliners or Turbotrains and undertaking the continued improvement of the existing right-of-way, including the elimination of certain grade crossings and related track improvement projects. This option has been referred to as the DEMO service in earlier reports. 2/ The completion of a set of additional improvements to the DEMO system results in what has been referred to as the "HSRA" system, one consisting exclusively of Metroliner-type vehicles operating on a completely electrified right-of-way and capable of sustaining a speed of 150 miles per hour. 3/

A more ambitious undertaking would replace the trains of the demonstration service with those representative of a more advanced technological development. Consideration could be given to a high speed rail service capable of attaining operating speeds of 200 miles per hour. Such service would enhance the attractiveness of the rail mode as a means of travel in the corridor, but its feasibility is questionable with respect to the compatibility and coordination of

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2/ A discussion and analysis of this option is contained in "Northeast Corridor Transportation Project Report," NECTP Report No. 209, Department of Transportation, May, 1970, pp. T4-3 - T4-5 and T5-1 - T5-13.

3/ Ibid, pp. T4-14 - T4-16 and TRW, Inc. "HSGT Mode Service Analysis in NEC," NECTP Report No. 214, Department of Transportation, May, 1970.

its operation on the same right-of-way as the presently extensive freight operations of rail carriers in the corridor region. Projected demand levels for a passenger service of this sort would require train departures at intervals of between 15 to 25 minutes during the day on the most heavily traveled segments of the route. United Research estimated that in 1960 the most heavily traveled freight routes were operating at about 50% of capacity and projected an increase in utilization at an average rate of about 2% per year. 4/ Thus by 1985 the approximately 25% unused capacity would apparently afford little opportunity for the intensive operation envisioned for a high speed passenger service. For this reason high speed rail service will be considered only in terms of operation on a right-of-way to be constructed on newly acquired land; this is the so-called "HSRC" option described in detail previously 5/ as a high speed rail system connecting a line of eleven stations between Washington and Boston with a new right-of-way suitable for sustaining operating speeds of up to 200 miles per hour.

Another option is an outgrowth of the previous one. If it is possible to consider a new right-of-way in order to gain the advantages of high speed rail technology, then there exist other systems whose implementation would be contingent upon the establishment of a new

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4/ United Research Inc. "Intercity Freight Transportation Requirements of the Washington-Boston Corridor in 1980," Dept. of Commerce Clearinghouse No. PB 166885, November, 1963.

5/ NECTP Report No. 209, op. cit., pp. T4-17 - T4-18 and NECTP Report No. 214, op. cit.

right-of-way. Foremost among the more advanced technologies, whose development and implementation are feasible with respect to the 1985 time frame, is the tracked air cushion vehicle (TACV). The TACV system would be designed for a 300 miles per hour cruise speed and would serve essentially the same line of cities in the corridor between Washington and Boston as the previously discussed options.

A more detailed description of the ground transportation systems which provides a better over-all picture of their composition and how they operate follows in the "Systems Description" section.

Demand Projections. Simple trend analysis is a useful and reasonably accurate method of short-term forecasting. This method, however, is dependent upon the assumption of "all relationships remaining equal," i.e., that the changes taking place over time are those that are the result of a natural evolution from previous circumstances. The degree to which this equivalence of relationships does not hold is often a strong indication of the degree to which the trend forecast is likely to be inaccurate, and this is very much the case with respect to forecasting the demand for new transportation modes. To circumvent this problem, the Northeast Corridor Transportation Project (NECTP) chose to formulate a mathematical expression which combines variables describing the demographic nature of the corridor region with variables describing the transportation services available in the region. The theory is that trends of demographic variables can be obtained by regression and other conventional methods and the transportation system characteristics postulated, and from these the transportation

demand can be computed using mathematical formulae. The difficulties and hazards in doing this are well-recognized and the results of such computations must be used with a great deal of caution. 6/ The numbers that are presented below, data drawn from NECTP analyses, are offered within this spirit of reservation.

The data used in this report are primarily from two sources. One set of data is derived from extensive analyses performed by the NECTP during 1969. The focus of these analyses was the evaluation of transportation system performance in the horizon year 1975 with some lesser amount of attention being given to evaluations for the year 1985. The second set of data comes from analyses performed by the NECTP in support of the Department of Transportation Civil Aviation Research and Development (CARD) Study. These analyses are divided between the years 1975 and 1985. It should be pointed out that the mathematical models used in these two sets of analyses are different, with those used in the CARD Study being somewhat improved versions of those used in the 1969 analyses. The differences in results obtained, however, were not substantial. The analyses conducted in 1969 showed demands of 12.4, 14.3, and 14.6 million passengers per year for DEMO services in 1975 with the differences resulting from different sets of assumed circumstances. The more recent analyses conducted for the CARD Study estimated annual DEMO demand for the year 1975 to be about 18 million with variations of

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6/ For a partial elaboration on this subject, see "Modeling for the NECTP" by NBS, NECTP Report No. 213, Department of Transportation, May, 1970.

plus or minus 4% depending on the circumstances assumed. In view of the fact that projections of current demand levels using 2% and 4% growth rates, which would be appropriate if the traditional services were to be maintained, results in estimated annual patronage in 1975 of between 10 and 11.5 million passengers, it was decided to use the 14.3 million estimate as a conservative value for what demands might be realized from the improvements associated with full DEMO service. The HSRA and HSRC systems were subjected to fewer analytic variations than the DEMO in the 1969 analyses, and they were not included in the CARD Study. Estimates of 20.4 million HSRA passengers in 1975 and 35.3 million HSRC passengers in 1985 derived in the 1969 analyses were the figures selected for the multi-period analysis. These values seem optimistic, but they have been assumed as indicative of demand levels possibly attainable by HSRA and HSRC systems.

Since a TACV system is not likely to become operational for another decade, it was decided to choose the year 1985 as the base point for demand estimates for this mode. Estimates available from the 1969 analyses indicated annual demands of between 36.3 and 42.7 million passengers, the former figure arising under conditions of relatively more intense competition from air services than those assumed for the latter value. The analyses performed for the CARD Study resulted in estimates of between 44 and 48 million passengers for TACV in the forecast year of 1985. However, more recently completed CARD analyses resulted in a lower figure of about 38 million passengers. In light of these various estimates, a representative value of 40 million

patrons per year was selected for use as the base point for TACV demand.

Table 1 lists the demand projections derived from the base point estimates using a 3% annual growth rate assumed as a compromise between the more conservative 2% (corresponding to population growth) and 4% (corresponding to economic growth) rates. These projections are implicit in the analyses that follow.

Table 1

Demand Projections [in millions]

(3% annual growth)

	DEMO	HSRA	TACV	HSRC
1970	12.3	17.6	0	0
1971	12.7	18.1	0	0
1972	13.1	18.7	0	0
1973	13.5	19.2	0	0
1974	13.9	19.8	0	0
1975	14.3	20.4	0	0
1976	14.7	21.0	0	0
1977	15.2	21.6	0	0
1978	15.6	22.3	0	0
1979	16.1	23.0	0	0
1980	16.6	23.6	34.5	30.4
1981	17.1	24.4	35.5	31.3
1982	17.6	25.1	36.6	32.3
1983	18.1	25.8	37.7	33.2
1984	18.7	26.6	38.8	34.2
1985	19.2	27.4	40.0	35.3
1986	19.8	28.2	41.2	36.3
1987	20.4	29.1	42.4	37.4
1988	21.0	30.0	43.9	38.5
1989	21.6	30.9	45.0	39.7
1990	22.3	31.8	46.4	40.9
1991	23.0	32.7	47.8	42.1
1992	23.6	33.7	49.2	43.4
1993	24.6	34.7	50.7	44.7
1994	25.1	35.8	52.2	46.0
1995	25.8	36.8	53.8	47.4
1996	26.6	38.0	55.4	48.8
1997	27.4	39.1	57.0	50.3
1998	28.2	40.3	58.7	51.8
1999	29.1	41.5	60.5	53.3

Systems Description 7/

Demonstration train. The demonstration train (DEMO) expands the Metroliner and Turbotrain service presently being offered in the Washington to Boston corridor. Aside from an investment in vehicle development, testing and procurement and an expansion of the maintenance facilities to accommodate the increased number of vehicles, no major investments are required for implementation of the DEMO system. The speed between stations for the DEMO averages 72.4 miles per hour. This slow speed is related to the curvature of the track and the speed limitations imposed by the conventional rail over much of the route.

High speed rail "A" (HSRA). The HSRA system utilizes the existing Penn Central route from Washington to Boston, upgraded to permit HSRA trains to carry passengers at 150 mph. The present track, signal systems, and catenary all require major work to permit operation at the increased speed (e.g., new bridges, curve easements, continuous welded rails, new catenary systems, electrification extended from New Haven to Boston). Either new or existing stations placed at present locations will be used at Washington, Baltimore, Wilmington, Philadelphia, Trenton, New York, New Haven, Providence, Route 128 and Boston. The new suburban stations at the Capital Beltway near Lanham, Maryland, and a site known as Metropark near Woodbridge, New Jersey, will be upgraded to permanent facilities.

7/ The material in this section is based on NECTP Report No. 214, where a more detailed discussion of the HSRA and HSRC systems may be found. The TACV system configuration described is different from the one described in Report No. 214.

The HSRA vehicles are self-propelled, multiple-unit electric cars and are similar to the present Metroliners. The average speed between stations for HSRA would be 114 miles per hour. Allowing for station stops, the travel time from Washington to New York would be about 2 hours and from New York to Boston also about 2 hours. The time saved over the Metroliner is 1-1/2 hours from Washington to New York and about 1-3/4 hours over the present Turbotrain from New York to Boston. Service during peak traffic periods would be as frequent as a departure every 15 minutes, and train lengths would vary from a maximum of 10 cars to a minimum of 2 cars.

High speed rail "C" system (HSRC). Conceptually similar to the Japanese new Tokaido line, but with superior performance, the HSRC would serve the centers of nine major Northeast corridor cities and four suburban park-and-ride terminals near major highways. The new system would utilize existing terminals at Washington, New York and Boston, but the right-of-way would be entirely new. New underground stations would be built at Baltimore and Philadelphia, as well as surface stations at Lanham, Md., Wilmington, Del., Trenton, N. J., Meadows, N. J., Yonkers, N. Y., Milford, Conn., Providence, R. I., and Rt. 128, Mass.

The route from Washington to New York would not deviate significantly from the present one. To avoid the excessive curvature which plagues the present route north of New York the route would run further inland, and tunneling would be required. New tunnels under the Hudson and East Rivers are also required for the new service.

Although 200 miles per hour is the anticipated maximum cruising speed, both physical limitations of the guideways and scheduled stops reduce average speed to about 159 mph. HSRC trains could operate as often as every 15 minutes during peak hours on the new system. Two basic services are contemplated, one from Washington to Boston and return, and the other cycling between Philadelphia and Milford, Conn. The combined services of the two cycles could result in daily frequencies at the center of the Corridor being approximately double those available at the ends of the network. Commuter type trips between the suburban and adjacent downtown stations or between New York and Meadows would not be allowed. The HSRC system will use the same type of cars as the HSRA, but with increased tractive power. Two exterior configurations will be used: A-units with a streamlined nose and a control cab, and B-units to serve as intermediate cars. The maximum feasible size for a train appears to be ten cars of which eight are B-units with a capacity of 70 persons and two are A-units with a capacity of 64 persons.

The system would be completely electrified using an overhead catenary system with the roadbed on a concrete slab or beam structure designed for speeds not in excess of 200 mph because of the wheel-rail interaction and power pick-up problems which occur beyond 200 mph.

<u>Tracked air cushion vehicle (TACV) system</u>. The TACV is a concept for establishing a very high-speed ground transportation mode in the NEC. The vehicle is supported by forcing air between the vehicle and the guideway with sufficient pressure to lift the vehicle thus eliminating mechanical contact. Air cushions are also employed which act against vertical

surfaces to constrain the vehicle to one degree of freedom. The concept is inherently suitable for higher speeds than rail and is designed for a 300 mph cruise speed. The propulsion for TACV is provided by linear induction motors.

The TACV considered has a vehicle capacity of 100 passengers and operates on a box beam guideway.8/ The entire routeway will be evaluated providing a twin-track within a 100 foot width. The TACV configuration considered in this analysis differs from the TACV system considered in previous Northeast Corridor Project analyses in vehicle size (100 passengers versus the previous 150), less expensive guideway configuration (box beam versus channel concept), and the narrower right-of-way required for an all elevated system (100 feet wide versus 200 feet for at-grade guideway).

Although a smaller width right-of-way is required for the TACV system than for the HSRC, the same route and terminal locations are utilized. The same type of service as that for HSRC has also been selected with one type of train service between Washington and Boston and the other between Philadelphia and Milford, Conn. The superior terminal to terminal speed of 212 mph allows for trips from Washington to New York in 1 hour 12 minutes and from New York to Boston in 1 hour and 7 minutes including stops at stations along the route. As with HSRC, commutation trips between New York and Meadows and downtown and adjacent suburban stations are not allowed.

8/ Resources Management Corporation Memorandum from Paul Dienemann, "Cost Estimate for Revised TACV: Route C." 11/2/70.

Table 2 summarizes some of the quality of service measures for the ground transportation systems being analyzed. The service characteristics in Table 2 may be compared with current Metroliner service which operates 7 round trips daily between Washington and New York requiring 3 hours travel time and charging a fare of $17.00.

Table 2

Quality of Service Measures

	Average User Terminal to Terminal Speed (mph) a/	Trip Time (hrs.)		Design Cruise Speed (mph)	Frequency b/ Departures/Day		Passenger Fares
		Wash.-N.Y.	N.Y.-Boston		Wash.-Boston	Phila.-Milford	Washington-N.Y. ($)
DEMO	72	2.99	3.58	120	16	31	18.49
HSRA	114	2.04	2.13	150	20	38	18.49
HSRC	159	1.49	1.41	200	33	68	18.00
TACV	212	1.19	1.12	300	33	66	18.00

a/ Does not include station delays

b/ The departure per day for DEMO and HSRA correspond to operation in 1975 while for HSRC and TACV the 1985 conditions are assumed.

Systems Costs

Discussion. The costs required to implement the four ground transportation systems described have been documented in a previous NECTP document.[9/] Comparison of the costs of the systems becomes difficult because of the considerable differences in technology, timing, and cost information available; e.g., although the DEMO and HSRA systems can be described in detail (similar vehicles have been built and are operating, and the right-of-way is known to within a few feet), the HSRC and TACV systems are in a conceptual stage at present (the right-of-way can only be described by a general route on a map, and the effects of high speed on car and guideway maintenance can be estimated but with uncertainty.) The comparison of the systems, however, requires that cost estimates be placed on as consistent a basis as possible. The cost estimates which have been developed are suitable for relative comparisons and long-range planning studies, but should not be viewed as firm estimates of actual cost.

Investment costs. The investment costs for the systems considered are based on Resource Management Corporation (RMC) studies which document the cost analyses for the high speed ground transportation systems.[9, 10/] Investment costs for each of the HSGT modes are obtained for the following categories: (1) fixed plant-research, development, test and evaluation, guideway construction, guideway electrification, command, control and

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9/ NECTP Report No. 222, "Cost Analyses for NECTP, Volume I, High Speed Ground Modes, Department of Transportation, December 1969.

10/ RMC Memorandum, op. cit., The memo discusses the differences in the TACV systems and itemizes the revised TACV's costs.

communication, terminal construction, and yards and shops (2) land acquisition, and (3) vehicle procurement.

The terminal construction costs are based upon serving future passenger demands for each of the systems and therefore account for greater capacity than is initially required. The size of the vehicle fleet, however, is based upon the number of vehicles required for the passenger demand experienced during the first year of operation. Unlike terminal capacity, the vehicle fleet is allowed to grow to accommodate increasing demand, and the cost for the additional vehicles is incorporated into the analysis on a marginal cost basis. (Appendix A contains a more detailed discussion of terminal and vehicle investment costing).

The demonstration train's fixed investment costs (not included in RMC's NECTP report #222) consists of a $30.0 million investment in development and testing of vehicle equipment in order to increase operational efficiency and limit maintenance costs. Presently, multiple-unit cars operated by the Penn Central are repaired at three shop locations. None of these shops is adequate either in capacity or condition to handle the anticipated fleet of cars. An investment of $2.0 million would be required to be able to maintain between 190 and 215 cars.

The investment costs utilized in the evaluation of each of the ground transportation systems are compiled in Table 3.

Operating Costs. A transportation system's operating costs can be divided into direct and indirect operating costs. Direct operating

Table 3

Investment Costs for Ground Transportation Systems

(millions of 1970 dollars)

	Demonstration Train	HSRA	HSRC	TACV
Fixed Plant	32	1329	1964	2265
Routeway Preparation & Guideway Construction		1050	1459	1593
System Electrification		71	83	211
Command Control & Communication		77	148	106
Yards & Shops	2	2	34	42
Research, Development, Test & Evaluation	30	30	60	113
Terminal Construction		100	180	200
Land		214	472	261
Vehicle Investment	74 A/	79 B/	74 C/	165 D/

A/ Fleet size to accommodate 12.9 million passengers, each additional passenger requires an investment of $5.75.
B/ Fleet size to accommodate 20.4 million passengers, each additional passenger requires an investment of $3.97.
C/ Fleet size to accommodate 30.5 million passengers, each additional passenger requires an investment of $2.01.
D/ Fleet size to accommodate 40.0 million passengers, each additional passenger requires an investment of $3.38.

costs can be defined as those costs incurred as a result of, and directly related to, operating a vehicle. Indirect operating costs are not related directly to running a vehicle, but are costs incurred in providing service. Direct operating costs have been segregated into energy, crew, vehicle maintenance, guideway maintenance, power and control maintenance, terminal operation and maintenance, and maintenance burden costs. RMC has developed estimates of the unit costs associated with operation of HSRA, HSRC and TACV based upon engineering studies of the systems. [11/] Table 4 summarizes these operating costs parameters.

Estimates of indirect operating costs for the modes are derived from the experience of the airline industry. RMC has modified airline indirect operating costs by adjusting them to eliminate items related solely to aircraft operations and to exclude costs already included elsewhere.[12/] Indirect operating cost parameters related to passenger load factors and average block speeds have been calculated on a per-passenger-mile basis. As seen in Table 4, increasing the block speed decreases the indirect operating cost per passenger mile. An intermediate level of customer service for the HSGT modes has been selected which is an improvement over existing railroad service but falls short of the current airline operations. One attendant per car has been allowed for DEMO and HSRA, while HSRC and TACV are serviced by two attendants. A minimum food and beverage service is included with revenues assumed to cover costs. Costs not included

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11/ NECTP Report No. 222, op. cit. and RMC Memorandum, op. cit.

12/ The Boeing Co., Cost Factors in the Operation of Subsonic and Supersonic Airplanes, TSR-300-33CR (1966)

Table 4

Operating Cost Parameters

(in 1970 dollars)

	HSRA	HSRC	TACV
Direct Operating Cost			
Energy (Average) $.01 per kwh	.04/car mile	.054/car mile	.163/car mile
Crew	.90/train mile	.20/train mile	.17/train mile
Vehicle Maintenance	.20/car mile	.20/car mile	.66/car mile
Guideway Maintenance	.04/car mile	.09/car mile & 2,000/track mile	7,600/track mile
Power & Control Maintenance	1.88 million per year	4.60 million per year	13.0 million per year
Terminal Operation & Maintenance			6.0 million per year
Maintenance Burden	66% of vehicle and power and control maintenance cost	66% of vehicle and power and control maintenance cost	included in cost estimate
Indirect Operating Costs	.017/passenger mile	.015/passenger mile	.013/passenger mile

in the indirect operating costs are commissions to travel agents, and promotional advertising and publicity.

The direct and indirect operating cost parameters specified in Table 4 were used in the 1969 NECTP analyses as cost parameters in a transportation system optimization model (TRANSOP).[13/] This model takes the technological specifications such as power requirements and speed limitations and fixed network properties for a high speed ground mode and determines the optimal level of service to be provided within the constraints. The model determines the passenger demand for the mode and the total system costs as a function of the level of service in such a way that, under the specified constraints, an objective function (which can be changed) is optimized. The optimization, which reflects the trade-off between supply and demand factors, can be stated variously as the maximization of return on investment or, alternately, as the maximization of patronage. TRANSOP includes the investment costs for the system components such as guideways, vehicles, and terminals in terms of three investment categories: fixed plant, vehicles, and land acquisition. The TRANSOP model computes the total investment and operational costs from the exogenously supplied cost parameters and from those variables which are determined as providing the optimal level of service in terms of train-miles per year, vehicle-miles per year, fleet size, peak service frequency, etc. The direct operating cost includes the costs for crew; vehicle, guideway, and power and control system maintenance; and energy and fuel consumption. Each of these costs

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13/ NECTP Report No. 214, op. cit.

results, as appropriate, from one or more of the variables which define the level of service.

The 1969 TRANSOP analyses together with updated cost information supplied by RMC provide the basis for deriving the generalized operating cost equations used in subsequent portions of this analysis.[14/] A number of sensitivity analyses were made with the TRANSOP model in which service and external parameters such as fares, terminal access-egress times, and demographic data were varied. The sensitivity analyses provided 24 different levels of passenger demand and associated costs for each of the systems (except DEMO). For the HSRA and HSRC cases, operating costs are taken directly without further modification. The cost relationships for the DEMO system are derived from an analysis using the present network of stations and assuming direct operating costs equal to the HSRA cost estimating relationships in Table 4.[15/] Indirect operating costs are adjusted to reflect the slower block speeds and load factors used in the TRANSOP analysis.

Major modifications to the TACV system as configured in previous project analyses necessitated revision of the TRANSOP results to

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14/ RMC Memorandum, op. cit.

15/ The HSRA operating costs do not include a charge (rent) for use of the existing right of way; however, improvements to the right of way are charged to the HSRA with no assessment against freight trains sharing the right of way. The DEMO system does not improve the right of way and, aside from a cost for guideway maintenance, is not charged for use of the right of way.

reflect changes in the operating costs. As already discussed, the new TACV configuration utilizes a smaller vehicle, an all elevated right-of-way minimizing land acquisition costs, and a less expensive box beam guideway. The TRANSOP model's indicators of system utilization, i.e., passengers, passenger-miles, train-miles, vehicle-miles and vehicles and the revised costs estimates shown in Table 4 have been utilized to generate operating costs for the modified TACV system.[16/]

The TRANSOP documentation provides a sufficient range of operating costs and passenger demand data, the nature of the relationship between which being such that it appears reasonable to postulate a linear relationship and therefore to apply linear regression techniques to obtain its parameters. (A description of the regression analysis and a discussion of the accuracy of the resulting linear approximations may be found in Appendix A.)

The operating cost equations derived from the regression (Table 5) are of the form C=aX+b, where C designates operating cost, X is the demand, b is the fixed annual operating cost associated with certain maintenance functions such as power and control system maintenance and a is the marginal cost per passenger which includes components varying with demand, e.g., energy cost, crew cost, vehicle maintenance. These cost equations are used in the analysis section which follows.

16/ The number of vehicles and vehicle miles has been multiplied by 150/100 to compensate for the smaller vehicle configuration.

Table 5

Generalized Operating Cost Estimating Relationships

Demonstration Train	C = \$4.208 (no. of passengers per year) + \$3.12 million per year
HSRA	C = \$3.316 (no. of passengers per year) + \$10.42 million per year
HSRC	C = \$3.239 (no. of passengers per year) + \$14.78 million per year
TACV	C = \$3.362 (no. of passengers per year) + \$34.48 million per year

where C = operating cost

Analysis

Method. As far as the techniques are concerned, the multi-period analysis involves the calculation of the present value of expected revenues and costs of a contemplated system using the compounding interest formula. The important consideration pertains not to the form of the formula used but to the choice of a particular discount rate, the gestation periods of various investments, and the growth rates of demand for passenger transportation. The reasons for specific choices will be presented later when the alternative transportation configurations are explained, but the assumptions and reasons that apply to all alternatives will be explained in this subsection.

The alternative systems were compared in terms of their net present values, i.e., all discounted revenues less all discounted costs. This involves the difficult problem of choosing the appropriate discount rate, and the reasons for choosing the particular 10% rate will be explained shortly. But more importantly, the net present values were calculated because they bring out more clearly the extent of financial profitabilities involved in the construction and operation of the newer systems. Additionally, internal rates of return were calculated for the representative or nominal case to be defined shortly.

The demand for all HSGT modes, as was pointed out in the Demand Forecasts section, were assumed to grow at the constant rate of 3% per year. Since the direct operating costs can be represented as varying proportionately with passenger volume, the same 3% growth rate

applies to the increases of direct operating costs for each system. The vehicle fleet sizes likewise were assumed to vary with passenger growth; hence, the same 3% growth rate was applied. Although the annual adjustment of vehicle fleet sizes to meet growing passenger volumes may not appear totally realistic, the particular scheme was thought to approximate the practices of making periodic lump-sum investments when long enough operating periods are considered. Moreover, large fleet sizes are purchased in the initial year of operation to meet the demands of that year; the annual 3% growth in fleet sizes applies to the increase in the number of passengers above the initial year's demands.

The discount rate chosen was 10% to conform to the Bureau of Budget specification. 17/ The choice of 10% rate is arbitrary in a broad economic sense because the choice involves the considerations of such matters as institutional and organizational arrangements, intertemporal and intratemporal welfare comparisons, and the extent of risk and uncertainty assumed in the analysis. In short, discount rates are often expected to subsume much of the difficulties associated with evaluating alternative investments, as well as reflecting the borrowing rate of investment capital. The 10% rate used in this analysis closely reflects the current borrowing cost of long-term capital in the private market, and hence should be viewed as a neutral

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17/ See Bureau of Budget circular A94, June 29, 1969, and Bureau of Budget memorandum to the Secretary of Transportation, February 2, 1970.

rate in the sense of incorporating only the financial effect but excluding other important considerations mentioned above. It should, in other words, be viewed as a pure borrowing rate for an ordinary private venture. What was attempted in the present analysis was to evaluate the respective HSGT systems strictly on a financial basis as far as the choice of discount rate goes, and to add other considerations, such as the risk problem, explicitly at other places in the analysis.

One means of explicitly incorporating the problem of uncertainty and risk is to limit the analysis to a short-time horizon in the future. In the present analysis, the cut-off year of 1999, 30 years from the base year of 1970, falls considerably short of the economic lives attributed to the equipment of the new systems, especially for the HSRC and TACV systems for which long lead times are needed and for which fixed guideways are assumed to have economic lives of 35 years from the beginning of operations in 1980 or 1985. Although it is more desirable to analyze the effects of operating the new systems for their full economic lives, technological as well as institutional uncertainties that affect both the supply and demand for intercity transportation services preclude the extension of analysis too far into the future. More specifically, the operation of new HSGT systems will not prevent the improvement of existing competing modes nor the subsequent introduction of possibly more efficient HSGT modes such as the magnetic levitation or evacuated tube vehicles. The former problem was taken into account in estimating the HSGT demands, and the latter by truncating the evaluation period for the new HSGT systems.

Another difficult problem involves the determination of the length of investment gestation periods and the distribution of investments within them. Actually, this is a problem only because the needed engineering data are unavailable, and there is no short-cut alternative by which to gain the necessary information. In the present analysis, construction of the guideways for the new HSGT systems were assumed to take 7 to 15 years and investments were equally distributed to the construction years. It is assumed here that the development can be divided into a number of construction projects which can be scheduled over time as separate activities involving separate commitment of funds. Since no revenues can arise until the completion of the guideways while any given sum further in the future has lower present value, the particular assumptions on the gestation periods and the allocation of funds might have imposed some bias on the analysis results. (The high sensitivity of profitability to changes in gestation periods was brought out in the analysis and will be discussed shortly.)

Analysis Results. Although many development schedule possibilities were conceivable involving the four candidate systems (DEMO, HSRA, HSRC, and TACV) specified before, nine cases were selected for analysis. The point should be emphasized that the nine were chosen to be representative of the options and that there are no specific plans associated with any one of them. Since DEMO alone is readily implementable and since it was thought unlikely that DEMO would be an attractive choice beyond 1980 or 1985, all nine cases combine DEMO

with one of the newer systems. The nominal, or reference case, was defined as the combination of DEMO operating from 1971 to 1984 and TACV from 1985 to 1999. The TACV system was chosen on the assumption that it was the most attractive HSGT mode in the near future in terms of its service characteristics, and the 1985 date was chosen on the conservative estimate of the long construction period for guideways. Each alternative in the analysis has two net present values, one with and the other without the salvage value of the fixed plant and the land. 18/ The salvage values of fixed plant and of land depend upon whether they will be used for the same purpose or abandoned because of obsolescence. Salvage values should be included in the first case, but not in the second.

Altogether nine investment project combinations or alternative cases have been analyzed. These are listed in Table 6 with their schedules. Case I represents the nominal or reference case. In this case DEMO is assumed to attain a level of full-scale operation in 1971 and to continue in operation until TACV begins operation in 1985. The entire period from the present until the beginning of TACV operation is taken as its gestation period. As explained previously, the period under examination extends to 1999.

18/ The discounted salvage value of the fixed investment was derived assuming research and development costs to be sunk and irrecoverable, land costs fully recoverable, and the remaining investment items salvageable subject to depreciation, assumed as linear. The assumption of fully recovering the land costs is conservative since the appreciation of land values from 1970 to 1999 is not considered.

Table 6

Investment Project Alternatives

Case	Mode*	Development Period	Years of Operation
I	Demo	--	1971-1984
	TACV	1971-1984	1985-1999
II	Demo	--	1971-1984
	HSRC	1971-1984	1985-1999
III	Demo	--	1971-1974
	HSRA	1971-1974	1975-1984
	TACV	1971-1984	1985-1999
IV	Demo	--	1971-1974
	HSRA	1971-1974	1975-1999
V	Demo	--	1971-1979
	TACV	1971-1979	1980-1999
VI	Demo	--	1971-1984
	TACV	1978-1984	1985-1999
VII	Demo (South)	--	1971-1979
	Demo (North)	--	1971-1984
	TACV (South)	1971-1979	1980-1999
	TACV (North)	1971-1984	1985-1999
VIII	Demo (South)	--	1971-1979
	Demo (North)	--	1971-1999
	TACV (South)	1971-1979	1980-1999
IX	Demo (South)	--	1971-1979
	Demo (North)	--	1971-1999
	TACV (South)	1973-1979	1980-1999

* Where applicable, "south" designates Washington, D. C. to New York City; "north" designates New York City to Boston.

As can be seen from Table 6, the remaining eight cases can be viewed as variations on the reference case. Case II replaces TACV with the HSRC mode. Case III foreshortens the period of operation for DEMO and envisions sufficient investment and subsequent development to permit the introduction and operation of the HSRA mode between the years of DEMO and TACV operations. Case IV assumes that HSRA is not subsequently replaced by TACV and continues operation until 1999.

Rather than the more conservative assumptions implicit in Case I, Case V assumes that a TACV mode could become an operational reality in ten years thus foreshortening its gestation period to nine years and beginning operations in 1980. Case VI, like Case V, assumes a shorter gestation period for TACV than the reference case, that is, the minimum estimate of seven years is used, but operation is not set to begin until 1985. The shorter gestation periods in these cases (V and VI) result in a shorter period of elapsed time between the initial commitment of investment funds and the commencement of returns on the investment in the form of revenues and thus enhances the attractiveness of the alternatives. On the other hand, the difference between the two cases, beginning TACV operation in 1985 as opposed to 1980, is intended to indicate the effects of delaying operation until a larger potential market is available.

Cases VII, VIII, and IX consider separately the portions of the corridor north and south of New York City. Thus, in Case VII, TACV replaces DEMO in 1980 in the south and in 1985 in the north; this case assumes that construction can be scheduled so that the earlier

operation on a portion of the system is possible and that investment costs can be divided equally. Case VIII is similar to Case VII except that DEMO is not replaced by TACV in the north. Finally, Case IX is distinguished from Case VIII by the shorter length of the TACV gestation period; in this case the minimum period of seven years for development is used.

The principal reason for investigating the northern and the southern legs separately is the observation that the existing and forecasted demands are disproportionately distributed. Although New York City is the dominating factor in the corridor, the southern half is more densely populated with larger cities between New York City and Washington whereas such comparable cities are missing in the north. The ratio of actual train passengers, for example, was 3:1 for the south versus the north in 1968. 19/ Since the distances of the northern and the southern legs are about the same, thus necessitating a comparable level of construction costs, the disparity in demands should result in unequal profitability outcomes. The existence of a large population base is a necessary condition for the profitability of capital-intensive high speed ground modes; 20/ hence, it would be

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19/ Rail Passenger Statistics in the Northeast Corridor, U. S. Department of Transportation, Office of High Speed Ground Transportation, Demonstrations Division, February, 1969.

20/ The success of the Japanese Tokaido trains is the result of its ability to attract large patronage which in 1968 amounted to 181,000 passengers per day or 66 million per year. (Baltimore Sun, September 7, 1969). Although the Japanese experience suggests the possibility of success in the Northeast Corridor, some basic differences between the two areas should not be overlooked. The Tokyo-Osaka corridor, in particular, is characterized by a less developed highway system with a smaller percentage of car ownership, easier access and egress to and from the center city terminals from the suburbs, and a higher level of train services even prior to the introduction of the super express trains.

interesting to investigate separately the profitability prospects of the southern and the northern legs.

The basic structure of the multiperiod value analysis is represented by the linear algebraic equation

$$NPV=R-C-I_f-(I_v-S)$$

where NPV is the net present value, R is the discounted annual revenue stream, C is the cumulative discounted annual operating costs, I_f is the discounted total investment in fixed facilities and land, I_v is the discounted vehicle investment and S is the discounted vehicle salvage value. The derivation of this equation and its components is presented in Appendix B; the basic premises underlying the model are those described in the sections on demand forecasts and mode costing. The case analyses incorporate an average revenue per passenger based on a fare structure of \$1.50 per passenger plus \$0.075 per passenger mile and average trip distances of 134.7 miles for TACV, 127.7 miles for HSRC, 122.7 miles for HSRA, and 113.4 miles for DEMO. These average trip distances were obtained from previous Northeast corridor analyses. Several variations of the parameters were also examined for the nine principal cases, the results of which will be presented along with the main results that follow.

The main results are shown in Tables 7 and 8. Table 7 contains present value results for each component entering into the net present value computation. These results are summarized in Table 8 in which the net present value for each case is given in the first four columns

Case Results*
(millions of 1970 dollars)

Case/System		NET PRESENT VALUE		COMPONENTS OF NPV					
		NPV	NPV(S*)	R	C	I_f	I_V	S	S*
I	DEMO	500	500	1089	481	29	83	4	—
	TACV	-667	-573	1094	386	1329	58	12	94
II	DEMO	500	500	1089	481	29	83	4	—
	HSRC	-685	-587	919	299	1282	30	6	98
III	DEMO	170	171	419	186	29	72	38	1
	HSRA	-607	-307	1027	362	1223	58	9	300
	TACV	-667	-573	1094	386	1329	58	12	94
IV	DEMO	170	171	419	186	29	72	38	1
	HSRA	-179	-142	1718	597	1223	81	4	37
V	DEMO	358	358	809	358	29	79	15	—
	TACV	-562	-487	1773	639	1616	88	8	75
VI	DEMO	500	500	1089	481	29	83	4	—
	TACV	-240	-146	1094	386	902	58	12	94
VII	DEMO(N)	138	138	278	108	15	18	1	—
	DEMO(S)	259	259	602	278	15	62	12	—
	TACV(N)	-439	-392	356	118	665	15	3	47
	TACV(S)	-112	- 75	1196	441	808	65	6	37
VIII	DEMO(N)	204	204	393	151	15	25	2	—
	DEMO(S)	259	259	602	278	15	62	12	—
	TACV(N)	—	—	—	—	—	—	—	—
	TACV(S)	-112	- 75	1196	441	808	65	6	37
IX	DEMO(N)	204	204	393	151	15	25	2	—
	DEMO(S)	259	259	602	278	15	62	12	—
	TACV(N)	—	—	—	—	—	—	—	—
	TACV(S)	- 30	7	1196	441	726	65	6	37

NPV(S) = NPV + S* where S* = discounted salvage value of fixed plant and land.

Table 8

Net Present Value (millions of 1970 dollars)

Case	Demo	HSRA	HSRC	TACV	Total All Modes	Total with Salvage*
I	500	—	—	-667	-167	-73
II	500	—	-685	—	-185	-87
III	170	-607	—	-667	-1104	-709
IV	170	-179	—	—	-9	29
V	358	—	—	-562	-204	-129
VI	500	—	—	-240	260	354
VII	(N) 138 (S) 259	—	—	(N) -439 (S) -112	-154	-70
VIII	(N) 204 (S) 259	—	—	(N) — (S) -112	351	388
IX	(N) 204 (S) 259	—	—	(N) — (S) -30	433	470

*The discounted salvage values included in the totals are for fixed plant and land.

for each mode comprising the case. The value for the total project is given in the fifth column. The last column is derived from the previous column by including all possible salvage values.

In addition to the nine cases examined above, four variations were studied involving parametric variations to test the sensitivity of some of the results obtained. More specifically, these additional analyses are further examinations of TACV which, as the present values of Table 8 show, is the most promising new HSGT system. Actually, the difference in net present values between TACV and HSRC is slight as the results of Cases I and II show, but TACV was chosen for further examination because it, in direct comparison to HSRC, had potential advantages in safety, speed, and passenger comfort.

First, the TACV fares were raised by doubling the fixed component of the nominal fare from \$1.50 to \$3.00 for Cases I, VIII, and IX. Assumption (1) 21/ is based on the results of the NECTP analysis performed for the CARD Study, and assumption (2) is an estimate based on the parameters of the NECTP mathematical formula for forecasting travel demand. The fare increase is only a moderate one especially for longer distance trips: the increase is 16.7% for a 100-mile trip and 8.3% for a 200-mile trip. Or, for the one-way trip between New York and Washington, the nominal fare comes out to be \$18.49 and the modified one \$19.99. The decreases in the deficits in the net present values for these three cases are shown in Table 9.

21/ The following assumptions were made in this analysis:
(1) trips are stratified by purpose as 87% for business and 13% for non-business
(2) price elasticities are respectively -0.5 for business and -1.5 for non-business trips.

Table 9

Fare Variations for TACV
Net Present Values

(Millions of 1970 Dollars)

Case	Nominal Fare	Modified Fare
I	-667.1	-587.0
VIII	-111.6	- 13.3
IX	- 29.3	69.0

The second variation was to change the TACV demand estimates by ±10% for the nominal case (i.e., Case I). As described in the section on demand, the demand estimate chosen to obtain the main results was the middle one, a compromise between the higher and lower projections. The results are presented in Table 10.

Table 10

Demand Variations for TACV in Case I

Net Present Values

(Millions of 1970 Dollars)

Case	DEMO	TACV	Total All Modes	Total with Salvage
I	500.0	-667.1	-167.1	-73.1
I (+10%)	500.0	-600.0	-100.0	-6.0
I (-10%)	500.0	-744.4	-244.4	-150.4

The third variation was to obtain the 1985 demand level which makes the net present value of Case I zero, i.e., to find the passenger volumes for the financial break-even point. The passenger volumes in 1985 that

made the net present value zero are as follows: (a) 74.0 million for TACV without salvage values for the fixed plant and land, (b) 48.7 million for TACV and DEMO without salvage values, and (c) 43.8 million for TACV and DEMO with the salvage values. Compared to the nominal estimate of 40 million for TACV in 1985, the resulting figures are greater by 85.0%, 21.7%, and 9.5% respectively.

The final variation considered was the determination of the discount rate for which the present value of revenues equals the present value of costs (internal rate of return) for Case I. With TACV alone, the rates are 5.15% without, and 6.55% with, the salvage values; with DEMO and TACV combined, the rates are 8.50% without, and 9.40% with, the salvage values.

The results of the computations involving net present values and internal rates of return for Case I are presented in Figure 1 below. Each curve traces the relationship between discount rates and net present values. In particular, the net present values corresponding to the results of the preceding analysis can be read along the vertical line of 10% discount rate, and the internal rates of return on the horizontal axis where net present value is zero.

Interpretation of Results. The results for the nine cases were given in Table 8. Although the figures presented are self-explanatory in most cases, systematic interpretation of the figures should bring out economic implications of the results more clearly.

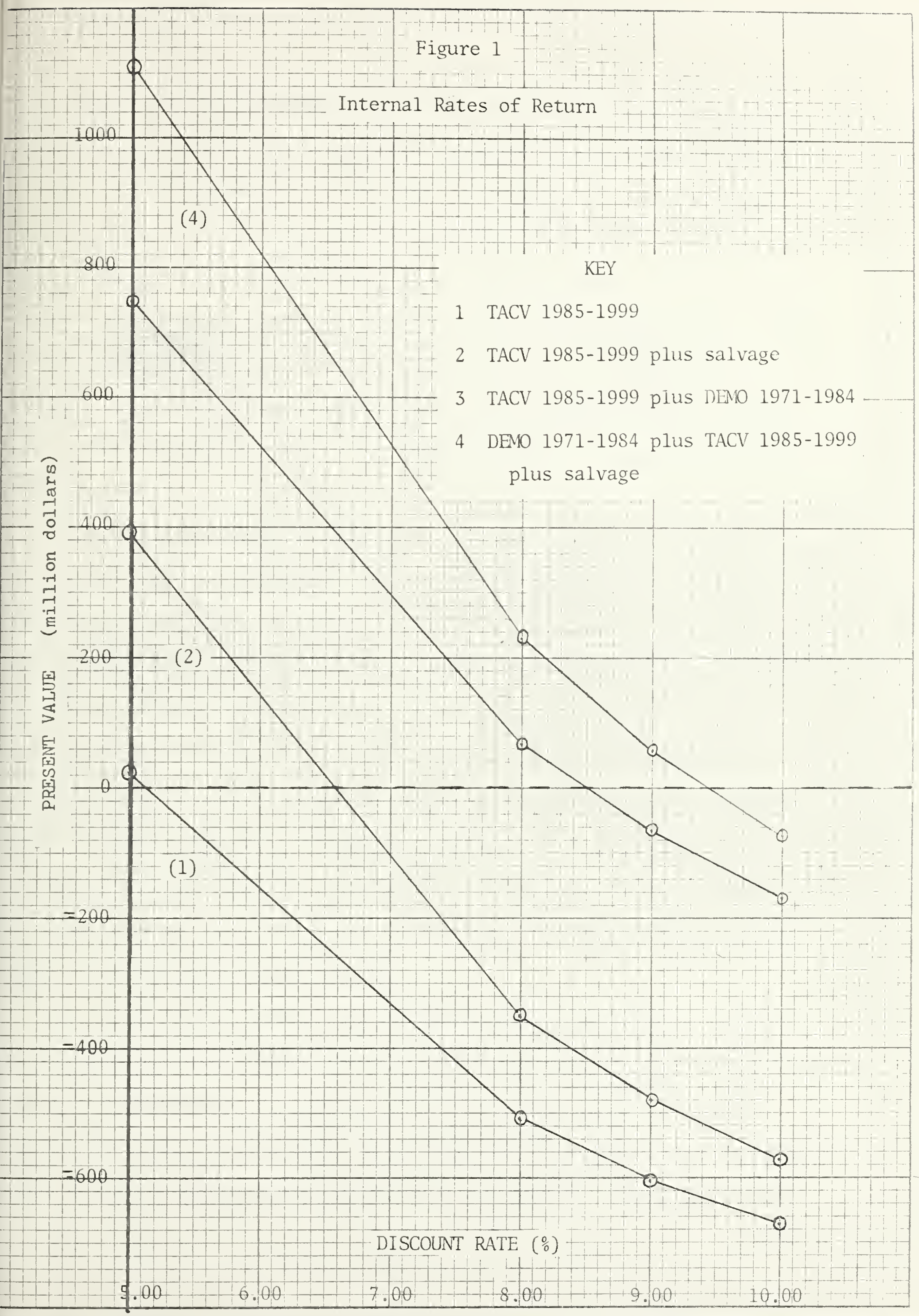

Figure 1
Internal Rates of Return
KEY
1 TACV 1985-1999
2 TACV 1985-1999 plus salvage
3 TACV 1985-1999 plus DEMO 1971-1984
4 DEMO 1971-1984 plus TACV 1985-1999 plus salvage
(4)
(2)
(1)
PRESENT VALUE (million dollars)
1000
800
600
400
200
0
-200
-400
-600
DISCOUNT RATE (%)
5.00
6.00
7.00
8.00
9.00
10.00

One of the most striking aspects of the figures in Table 8 is the profitability of DEMO and the general unprofitability of newer systems. This is due to the absence of the need for large-scale construction of new guideways with accompanying long investment gestation periods for DEMO. Because of the relatively high discount rate used, a long gestation period penalizes the revenues that arise in the future years while accentuating the burden of high construction costs in the immediate future. That is why Cases I and VI, which are identical except for the differences in the beginning of construction dates, give markedly different results.

The relative financial prospects of the alternative cases may be viewed from another perspective. Since DEMO turned out to be profitable for all cases examined, the DEMO operation can be viewed as subsidizing the newer system or systems. Such subsidizations are sufficient to offset the deficits of newer systems in some, but not all, cases. This discussion of subsidization does not, however, involve institutional considerations. In other words, the question whether the overall profit shown for some cases are a sufficient inducement to elicit some form of private investment cannot be answered from the analysis results alone. The figures merely state that some combinations of DEMO and newer systems appear to be financially profitable.

One question that may be raised from reviewing the analysis results is the possibility of operating only the DEMO system up to 1999. One possible objection to such a proposal is the unlikelihood of sustaining the 3% growth rate of demand for DEMO beyond 1980 or 1985, because improvements in other transportation modes could make the DEMO system relatively

less attractive in the not-too-distant future. It is also possible to argue the converse case, that overcrowding in highways and airways might become so critical that the DEMO system would become an even more attractive alternative. In the latter case, some further investments in guideways will be needed to meet the growing demand for the use of existing Penn Central routes for freight and local passenger movements. The more likely prospect seems to be, however, that some competitive non-HSGT improvements would be made if DEMO is the only contemplated HSGT system so that the continued 3% growth in demand is not likely to be maintained.

The relative profitabilities of the new modes can be compared from the results of Cases I, II, III, and IV. Cases I and II, representing TACV and HSRC, are directly comparable since the gestation and operation periods are the same. HSRA, represented by Case IV, takes advantage of the shorter gestation period, resulting in the smallest deficit among the three new systems. The financial advantage of HSRA, however, must be counterbalanced by the same considerations that worked against the long-term operation of DEMO, namely the capacity limitations of the jointly used fixed facilities. HSRA, after all, is an improved version of the existing rail facilities so that it, as DEMO, is not likely to be able to provide sufficient capacity to relieve greatly the future congestion on highways and air facilities.

The results of Case III when compared to those of Case IV bring out clearly the difficulty facing the transportation industries requiring large fixed facilities. In Case III, the operating period of ten years

is too short a time to recoup the initial investment costs. The additional operating period of 15 years in Case IV helps to reduce the deficits associated with HSRA from $607 million to $179 million, or about one-third of the former level.

As for HSRC and TACV, the differences in the net present value are so slight as to be insignificant. The deciding factors, as mentioned earlier, must be non-monetary, such as safety, speed, and the level of passenger comfort. Although the noise problem of TACV appears to be a cause of much concern, TACV is a decidely superior system in other respects. The safety problem, especially, appears to be a difficulty for HSRC which is at about the technological limit of the steel-flanged wheel vehicle.

One alternative to extending the operating periods of new systems into the future is to bring such periods nearer to the present, like the TACV system in Case V. Beginning the operating period earlier than 1980, however, appears to be infeasible because of engineering considerations. Case V has a small TACV deficit since the earlier generation of revenues helps to reduce the investment costs. On the other hand, the operating period of DEMO is reduced, lowering its revenues contribution. The net result of lowering TACV deficit and DEMO revenues works against the outcome for the total project, that is, the financial prospect would appear to be worsened by the earlier operation of TACV.

Another way to achieve the effect of lowering the TACV deficit is to postpone the start of the construction period, resulting in a shorter

gestation period. Such a possibility was examined for Case VI. The effect of such postponement is rather dramatic, TACV deficit decreasing from $667.1 million to $239.5 million, and the combined net present value of DEMO and TACV becoming positive. In fact, Case VI is the only alternative where the combined result showed a surplus when the new systems were operative the full length of the Northeast Corridor. In interpreting this result, the important point to note is not so much the postponement of the construction period but the bringing of the expenditure and revenue streams closer together. Since a short time horizon and high discount rate were chosen for the present analysis, the long delay in the generation of revenues compared to the early beginning of the expenditure time stream is one of the principal reasons for large deficits of new systems. The shortening of gestation periods mitigates this problem. One possible way to achieve this end in the actual development of the HSGT systems would be to allocate funds for research and development in the earlier years but delay the actual construction investments for the physical facilities.

Cases VII, VIII, and IX show the effect of segmenting TACV construction to southern and northern legs. Because of the large fixed costs associated with TACV, a higher degree of utilization lowers unit costs. The distances and hence the fixed costs are about the same for the southern and northern legs whereas the utilization level is much higher in the southern leg because of the higher population density. The deficits, as the result of Case VII shows, is four times greater in the northern leg. It appears that the northern leg is not able to sustain TACV. The combined result

for DEMO and TACV shows a greater net present value when the southern leg alone is operated (Case VIII) compared to the most favorable instance of complete TACV operation (Case VI) in which a shorter gestation period is assumed. The effect of shortening the gestation period for the case of the southern leg alone, as seen in Case IX, is more dramatic: the deficit associated with TACV almost disappears (-$29.3 million) whereas the combined net present value of DEMO and TACV is $433 million, about twice that of Case VI where both southern and northern legs are operated with TACV.

It should be noted in interpreting the results of segmented TACV operation of Case VII that the combined deficit of northern and southern legs does not match either the total TACV deficits calculated for Cases I or V. The disparity is the result of differing operating periods, more specifically because of the staggered operating periods of Case VII.

The net present values of Case I, V, and VII illuminate an interesting aspect of the prospects for TACV in response to changes in the inauguration of operations. Operation begins in 1980 for Case V and 1985 for Case I while that of Case VII falls between them. Alternatively, the transition from Case V to Case VII may be viewed as delaying the opening of the northern leg by five years while the transition from Case VII to Case I may likewise be viewed as delaying the opening of the southern leg by five years as well. The effect of delaying the northern leg improves the profitability prospects (i.e., decreases the deficit from $561.5 million to $550.6 million) whereas the delaying of southern leg

operations worsens such prospects (i.e., increases the deficit from $550.6 million to $667.1 million). These analysis results show again the tendency for the greater potential of the southern leg to sustain the TACV operation.

The results of the sensitivity analysis on fares and passenger volumes can be summarized briefly since detailed explanations of them have already been given. In the three cases (I, VIII, and IX) examined in Table 9, the absolute reductions in deficits from the nominal to modified fares are about the same, $80.1 million for Case I as against $98.3 million for Cases VIII and IX. The effects, however, are quite different.

TACV in the southern leg, as the results of Cases VIII and IX in Table 9 show, can be considered a self-sufficient system since the modified fares are reasonable ones in that they are comparable to the present Metroliner fares. The reduction in deficits or increase in profits as a result of fare variation, of course, is a reflection of relatively inelastic aggregate demand schedules for travel. The magnitudes of elasticities assumed may not be appropriate for large variations of fares from the initial level, but the small variation used in the present analysis does not appear to violate the elasticity assumptions.

As stated before, the purpose of varying passenger volumes on the nominal case was to examine the consequences of assuming optimistic and pessimistic demand projections for TACV. The results, as shown in Table 10 seem to indicate that the effects on net present value of varying TACV demands are relatively small. The differences in deficit are approximately equal to the respective changes in demand.

Two observations may be made from the sensitivity analysis on TACV demands. First, errors in estimating aggregate passenger demands, unless they are quite large, do not seem to affect greatly the overall trends suggested by the analyses. Second, to make TACV operation in the Northeast Corridor in 1985 profitable would require demand to be approximately double that of the nominal estimate, as was shown by the analysis that indicated that a 1985 demand estimate of between 70 to 75 million passengers would be required for the TACV to attain a break-even net present value. Such a large demand appears improbable and other means of achieving TACV profitability, as were discussed above, should be considered.

Conclusions and Recommendations

Conclusions. The amount of empirical information presently available is not sufficient to permit a thorough analysis, and hence the analysis presented is not as complete as desired. It can be said with some degree of confidence, however, that the analysis shows in broad terms what might be expected for high speed ground transportation modes in the Northeast Corridor. The results seem to conform to what has been commonly assumed, that is, that it is generally unprofitable to build and operate new passenger transportation systems with fixed guideways.

The prospect does not appear to be completely hopeless for high speed ground modes in every instance, however. The DEMO system, or the full utilization of the existing rail facilities between Washington and Boston with the Metroliners and Turbotrains, seems to return more than it costs. On the other hand, the existing rail capacities are such that the DEMO system may be incapable of providing sufficient service to alleviate the ever-increasing overcrowding of highways and air facilities. This would be so especially in the southern half of the Northeast Corridor. It is also in the southern half of the Corridor that TACV, taken by itself, seems to show financial viability if the construction period can be foreshortened and fares set at a level slightly higher than the present Metroliner fares.

Recommendations. Based on the analysis presented, the following set of actions may be suggested: (1) implement the full-scale DEMO or some similar system as soon as possible between Washington and Boston,

(2) replace DEMO with the TACV system between New York and Washington in or around 1980, beginning the construction of TACV guideways and terminals in or around 1973, and (3) maintain the DEMO service between New York and Boston beyond 1980.

Appendix A

Parametric Cost Relationships

Purpose. The derivation of the cost relationships used in the analyses is explained in this appendix. The derivation of terminal construction and vehicle investment costs and a discussion of the operating cost relationships obtained from regression analyses are included.

Terminal Costs. The selection of the terminal size was approached with the aim of constructing terminals large enough to avoid repeated expansion projects. Therefore, the demand levels anticipated for the later years of operation were heavily weighted in establishing station capacities for each of the high speed ground modes. The assumption was made, however, that terminal capacity to accommodate the peak demand in the final year of operation over the entire operating period for the HSGT modes was excessively wasteful and, therefore, an unacceptable alternative. The station capacities selected were designed to satisfy peak passenger loads for TACV and HSRC five years prior and for HSRA three years prior to their respective final year of operation. The peak loads in the systems' final years would be assumed to be handled by rescheduling to accommodate the additional demand.

The costing equations used to determine terminal investment requirements consisted of a two-part equation for each of the terminals considered in the analysis, a fixed investment component mostly to cover platform construction (which would be required regardless of passenger demand), and a variable investment component to cover areas necessary

for access, waiting, baggage, ticketing, concessions, etc. (the magnitude of which would be directly affected by the peak passenger demand for the terminal). Terminal costing parameters shown in Table A-1 were the basis for the analysis.

TRANSOP utilized the terminal cost parameters (table A-1) to compute terminal investments for various passenger demands. The aggregated terminal costs for the HSGT modes requiring terminal investment for two demand levels are tabulated in Table A-2. The relationship between demand and terminal investment was determined from the data presented. In the case of HSRA, for example, a demand of 20.82 million passengers required an investment of 94.2 million dollars in terminals while a demand of 9.85 million passengers required a terminal investment of 79.58 million dollars. The marginal terminal cost derived from these figures was 1.33 dollars per passenger. The marginal terminal costs shown in Table A-2 were used to calculate terminal investment requirements for the projected demand during the years selected for analysis. Since the terminal cost parameters were given as linear, extrapolation beyond the range of terminal sizes calculated in TRANSOP was assumed to be reasonable. The year 1994 was selected for establishing terminal capacity for HSRC and TACV, and the corresponding cost of $180 and $200 million respectively were used in subsequent analyses of these systems. For HSRA the passenger demand of 1982 was chosen as a design target with a cost of $100 million used for HSRA.

Vehicle Investment. Vehicle costs were calculated in two phases. The initial number of vehicles was determined from the projected passenger demand for each system in the proposed initial year of operation. The

annual incremental cost for additional vehicles, was derived on a marginal cost basis from cost relationships used in the 1969 NECTP analyses. The costs associated with two widely varying passenger demand levels were selected as the basis for calculation of the marginal vehicle cost per passenger. For example, in the case of HSRA, the following vehicle cost data were available from the 1969 analyses: a demand of 19.34 million passengers required a vehicle investment of 74.98 million dollars while a demand of 9.85 million passengers required only 37.26 million dollars. The marginal vehicle cost calculated from these figures was 3.97 dollars per passenger. A sample calculation follows for a given demand of 20.4 million passengers in 1975:

$$V\ I = \$74.98M + \$3.97\ (20.40 - 19.34)\ M$$
$$= \$79.2M, \text{ where } V\ I = \text{initial vehicle investment and } M = 10^6.$$

Thus the initial vehicle investment for HSRA is 79 million dollars with a marginal vehicle cost of 3.97 dollars per additional passenger over 20.4 million. Similar computations were made for DEMO and HSRC, and the results tabulated in Table 3 in the text.

The design change in TACV vehicles previously explained in the text eliminates direct use of the 1969 NECTP analyses for this mode. The 1969 analyses were used, however, to determine the additional number of vehicles* (about 3) required to transport a million passengers

* The number of vehicles in the 1969 analyses was adjusted by multiplying by $\frac{150}{100}$ to compensate for the smaller vehicle capacity.

per year. In order to remain consistent with the other ground systems, a translation to a marginal vehicle cost per passenger was necessary. The equation for a 100 passenger, 300 mph TACV vehicle used to compute average costs in millions of dollars is**:

$$\text{Average Vehicle Cost} = 3.83Q^{-.234}$$

where Q = quantity procured and includes a 5 percent allowance for maintenance float. The cost equation assumes an 85 percent "learning effect" and yields an average cost of 1.3 million dollars per vehicle at the 100th unit. In order to calculate the marginal vehicle cost per passenger, the passenger demands for 1980 and 1999 were selected as the initial and final points for the vehicle fleet growth; calculations were made to determine the number of vehicles required in these years to satisfy the projected passenger demand, and the costs for these vehicles were calculated using the equation for the average cost. Starting with the 34.5 million passengers projected for 1980 and a calculated vehicle investment of 150 million dollars, an additional investment of 3.38 dollars per incremental passenger is required to expand the vehicle fleet to accommodate a projected 60.5 million passengers and effect an accumulated 227.0 million dollar vehicle investment in 1999.

A limitation associated with this scheme to increase the size of the vehicle fleet involves the practical aspects of production. The "learning effect" is a production phenomenon which enables procurement of larger quantities at a lower average vehicle cost than does the

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** RMC Memorandum, op. cit.

Table A-1

Terminal Cost Parameters[a]
(millions of 1970 dollars)

Terminal Location	HSRA Costs	HSRC/TACV Costs
Washington, D.C.	0.0	6.0 + .006 pph
Lanham, Md.	4.0 + .004 pph[b]	3.2 + .004 pph
Baltimore, Md.	15.0 + .006 pph	12.0 + .006 pph
Wilmington, Del.	- -	6.0 + .006 pph
Phila., Pa.	1.0	12.0 + .006 pph
Trenton, N.J.	7.5 + .006 pph	6.0 + .006 pph
Metro Park, N.J.	7.5 + .006 pph	- -
Meadows, N.J.	- -	6.0 + .006 pph
New York, N.Y.	5.0	24.0
Milford, Conn.	- -	6.0 + .006 pph
New Haven, Conn.	7.5 + .006 pph	- -
Yonkers, N.Y.	- -	3.2 + .004 pph
Providence, R.I.	7.5 + .006 pph	6.0 + .006 pph
Rt. 128	4.0 + .004 pph	3.2 + .004 pph
Boston, Mass.	7.5 + .006 pph	6.0 + .006 pph

[a]HSRA terminal cost parameters were from NECTP Report No. 222, op. cit. and the HSRC/TACV parameters were from RMC Memorandum, op. cit.

[b]pph - peak passengers per hour

Table A-2

Derivation of Aggregate Terminal Cost Relationships

Mode	Demand 1 (Pass.x10^6)	Terminal Cost 1 (\$x10^6)	Demand 2 (Pass.x10^6)	Terminal Cost 2 (\$x10^6)	Δ Demand (Pass.x10^6)	Δ Terminal Cost (\$x10^6)	$\frac{\Delta \text{ Terminal Cost}}{\Delta \text{ Demand}}$ (\$/Pass.)
HSRA	20.819	94.209	9.852	79.581	10.967	14.628	1.33
HSRC	27.635	146.949	13.176	122.265	14.459	24.684	1.71
TACV	32.247	160.660	15.410	128.782	16.837	31.880	1.88

procurement of smaller quantities. By projecting passenger demands for the final years of the analysis and calculating vehicle investments, it is assumed these vehicles will be produced as part of a large production run. Procurement of smaller quantities of vehicles on an annual basis facilitates the analysis, but is probably not a realistic method of procurement. It is believed that the error introduced by this limitation is not significant when compared to the magnitude of other investments and operating costs.

Operating Costs. In addition to those operating costs which vary with passenger demand, e.g., energy costs, crew costs, vehicle maintenance, there are other operating costs which are invariant whether the system transports 1 or 10 million passengers. The mathematical formulation used to calculate operating costs assumes the requirement for a fixed annual component (corresponding to invariant operating costs) as well as a variable component.

The TRANSOP analyses provided operating cost data which were plotted as a function of passenger demand for HSRA, HSRC and TACV*** and are shown in Figures A-1, 2 and 3 respectively. The equations for the fitted lines through the data points were determined from regression analyses. The statistical parameters associated with the regression coefficients are:

*** The TACV costs have been modified as explained in the text.

Figure A-1

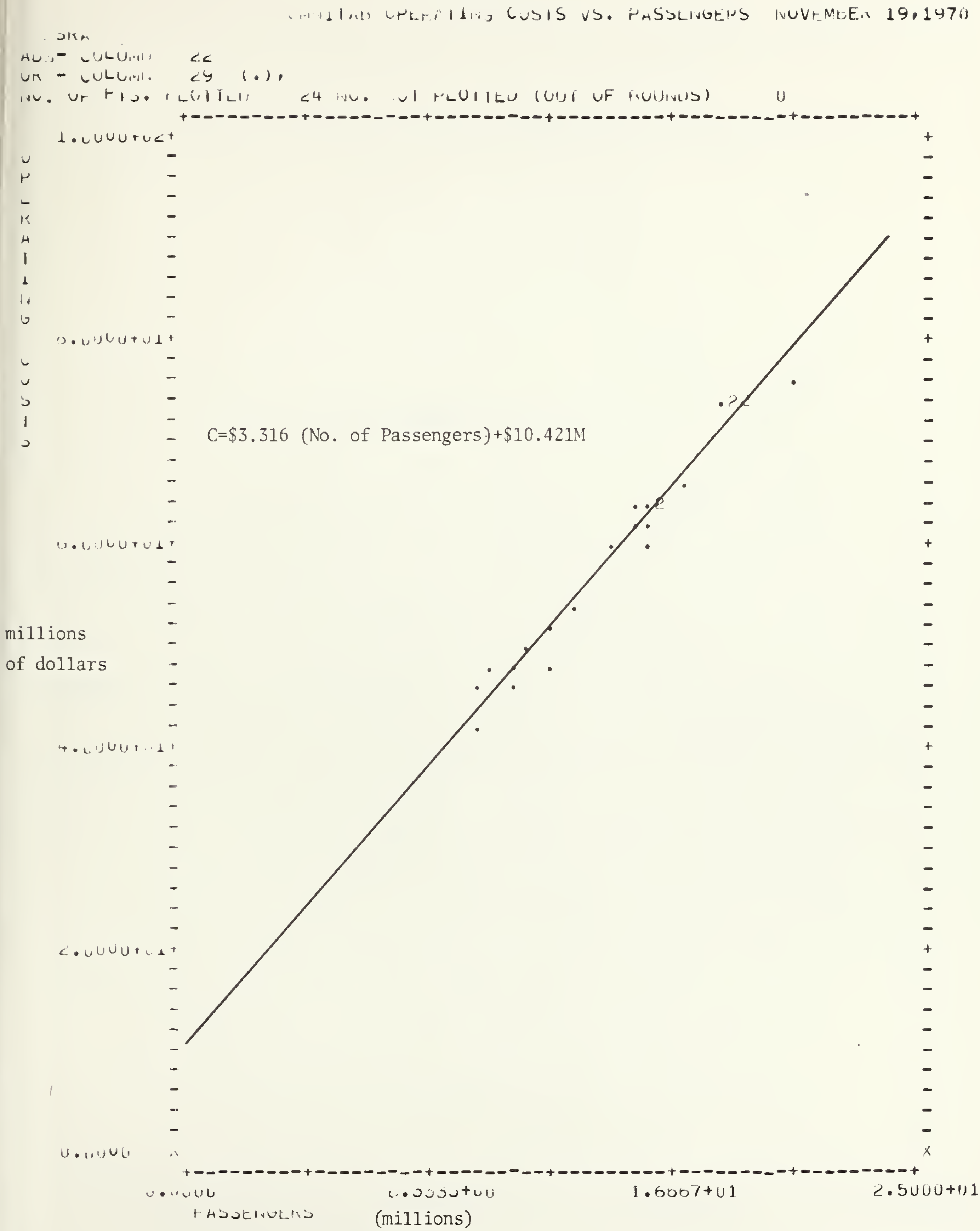

C=$3.316 (No. of Passengers)+$10.421M
millions
of dollars
1.6667+01
2.5000+01
(millions)

Figure A-2

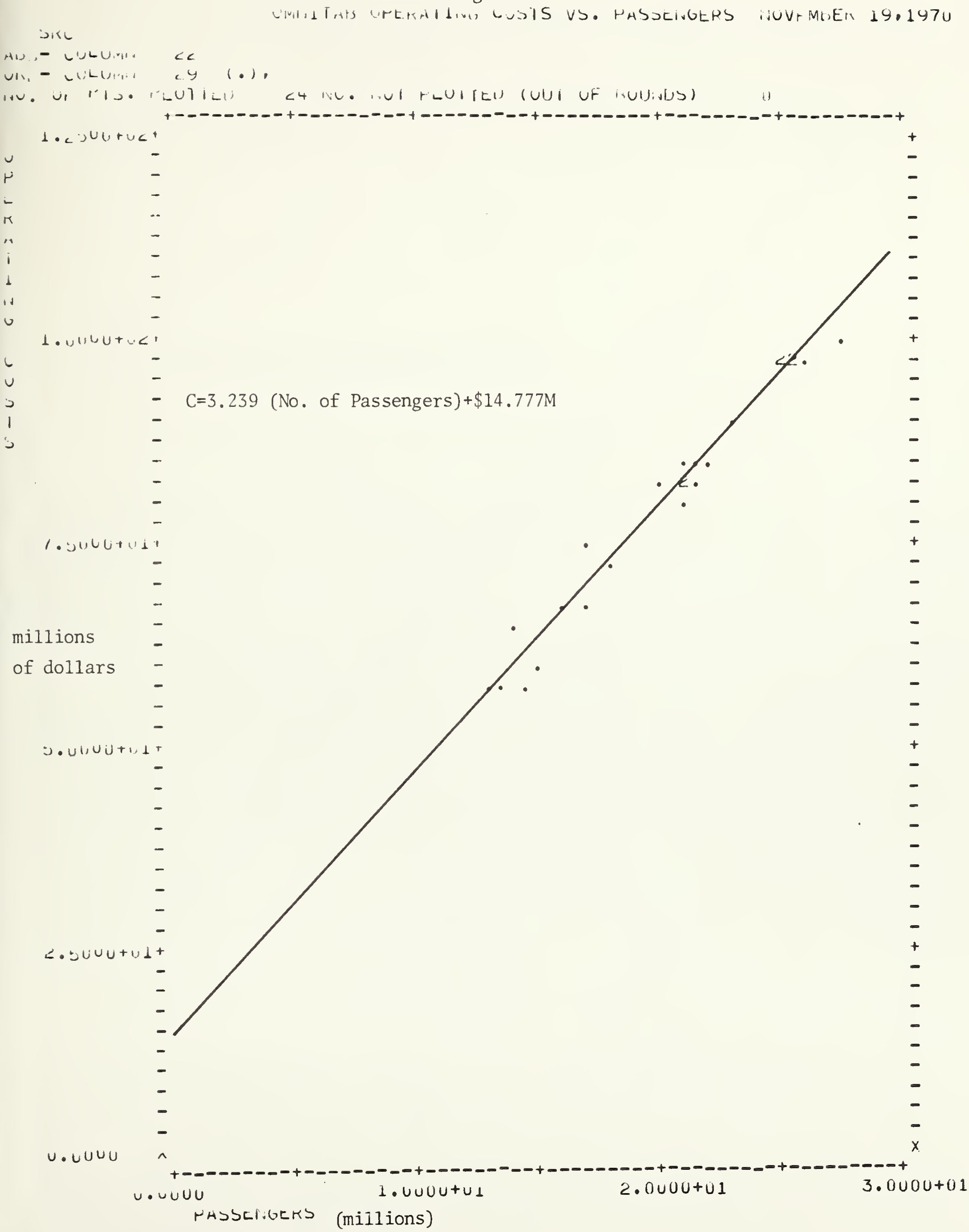
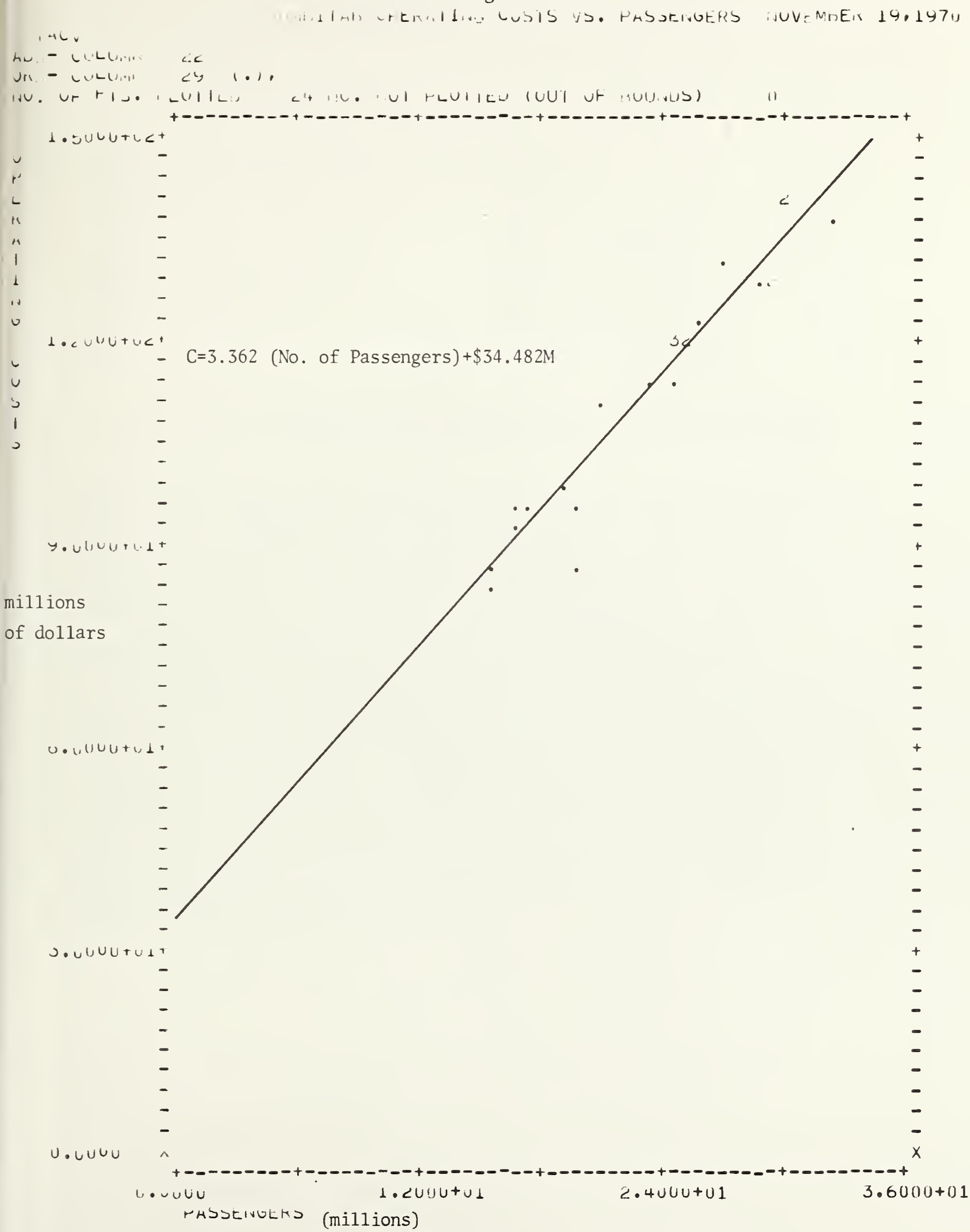

C=3.239 (No. of Passengers)+$14.777M
millions
of dollars
(millions)

Figure A-3


COSTS VS. PASSENGERS
NOVEMBER 19,1970
C=3.362 (No. of Passengers)+$34.482M
millions
of dollars
1.2000+01
2.4000+01
3.6000+01
PASSENGERS
(millions)

Linear Regression Operating Cost Model

Parameters	HSGT Modes		
	HSRA	HSRC	TACV
Variable Cost ($/passenger)	3.316	3.239	3.362
standard deviation	.103	.108	.207
t value[a]	32.18	30.02	16.23
Fixed Cost (million $/year)	10.421	14.777	34.482
standard deviation	1.584	2.225	5.006
t value	6.58	6.64	6.89
R^2	.979	.976	.923

[a] All "t values" were computed with 23 degrees of freedom

Conventional statistical tests of significance for the intercept and slope of the regression lines show significance at the 99 percent confidence limits. Therefore, the linear relationships represented by the regression lines were used to obtain operating costs.

Care must be taken when extrapolating the linear relationship beyond the range of demand considered in the TRANSOP analyses. Since the parameters upon which the TRANSOP analyses were based (see Table 4 in the text) are assumed to be invariant to the level of passenger demand, use of the derived linear equations for increased passenger demand does not seem inappropriate.

APPENDIX B

Derivation of Net Present-Value Equation

The basic structure of the multiperiod value analysis is represented by the linear algebraic equation

$$NPV=R-C-I_f-(I_v-S)$$

where NPV is the net present value, R is the discounted annual revenue stream, C is the cumulative discounted annual operating costs, I_f is the discounted total investment in fixed facilities and land, I_v is the discounted vehicle investment and S is the discounted vehicle salvage value.

Each of these factors will be derived and formulated, but first it is necessary to introduce and define parameters that are essential to the explication.

Let r_1=discount rate
r_2=demand growth rate
Z_0=demand in base year (=1970)
K_0=base year (=1970)
K_1=first year of construction
K_2=first year of operation
K_3=last year of operation
L =vehicle life time, in years
I =investment in facilities and land.

and define:

$$Z_K=Z_0(1+r_2)^{K-K_0}, \text{ as the demand in year K} \qquad (2)$$

$$F=\frac{1+r_2}{1+r_1} \qquad (3)$$

Revenues

The revenue stream realized from the operation of a transportation system is expressed as

$$R=\sum_{t=K_2-K_0}^{K_3-K_0} \frac{PZ_t}{(1+r_1)^t} \qquad (4)$$

where p is the trip price per passenger, and is represented by a fixed and a variable component in the following equation

$$P=P_f+P_v d \qquad (5)$$

where d is the average trip distance. Using equation (2) in equation (4) yields

$$R=\sum_{t=K_2-K_0}^{K_3-K_0} PZ_0\left(\frac{1+r_2}{1+r_1}\right)^t \qquad (6)$$

Since pZ_0 is not dependent on the summation index t, R may be written as:

$$R=pZ_0\sum_{t=K_2-K_0}^{K_3-K_o}\left(\frac{1+r_2}{1+r_1}\right)^t \qquad (7)$$

and by applying the standard form for the summation of a geometric progression, the summation in equation (7) is:

$$\sum_{t=K_2-K_0}^{K_3-K_0}\left(\frac{1+r_2}{1+r_1}\right)^t = \frac{F^{K_2-K_0-1}-F^{K_3-K_0}}{F^{-1}-1},$$

then R becomes:

$$R=pZ_0\left[\frac{F^{K_2-K_0-1}-F^{K_3-K_0}}{F^{-1}-1}\right] \tag{8}$$

Operating Costs

The operating costs, C, are defined as the sum over a discounted factor having a fixed component, C_f, defined as the fixed operating cost, and a variable component C_vZ_t, which is the product of the variable operating cost per passenger and the demand. Operating costs are defined as:

$$C=\sum_{t=K_2-K_0}^{K_3-K_0}\left\{\frac{C_vZ_t+C_f}{(1+r_1)^t}\right\} \tag{9}$$

which can be expanded and written as:

$$C=C_vZ_0\sum_{t=K_2-K_0}^{K_3-K_0}F^t+C_f\sum_{t=K_2-K_0}^{K_3-K_0}\left(\frac{1}{1+r_1}\right)^t \tag{10}$$

or:

$$C=C_vZ_0\left[\frac{F^{K_2-K_0-1}-F^{K_3-K_0}}{F^{-1}-1}\right]+\frac{C_f}{r_1}\left\{\left(\frac{1}{1+r_1}\right)^{K_2-K_0-1}-\left(\frac{1}{1+r_1}\right)^{K_3-K_0}\right\} \tag{11}$$

Investment in Facilities and Land

The present value of the investment in facilities and land, I_f, is computed using the assumption that the total investment I is scheduled such that equal payments are made in each year of the gestation period, which begins in year K_1 and ends in year K_2-1, just prior to the first year of operation. Each payment is discounted, therefore, over the time period, K_1 through K_2-1.

The equation for I_f becomes:

$$I_f = \frac{I}{K_2-K_1} \sum_{t=K_1-K_0}^{(K_2-1)-K_0} \left(\frac{1}{1+r_1}\right)^t \qquad (12)$$

And applying the equation for the sum of a geometric progression to equation (12), we obtain:

$$I_f = \frac{I}{r_1(K_2-K_1)} \left[\left(\frac{1}{1+r_1}\right)^{K_1-K_0-1} - \left(\frac{1}{1+r_1}\right)^{K_2-1-K_0}\right]. \qquad (13)$$

Vehicle Investment

The vehicle investment, I_v, is the sum of two terms I_{v_i} and I_{v_a}. I_{v_i} is defined as the discounted present value of the initial investment in rolling stock and its replacement n times, based on a vehicle life of L years. The parameter n is defined to be the greatest integer in the quantity $(K_3-K_2)/L$. I_{v_a} is defined as the discounted present value of the investment made in rolling stock required to accomodate an annual increase in demand and subsequent replacements thereof after each year's investment is depreciated over a vehicle life of L years.

Consequently, we have:

$$I_{v_i} = \sum_{M=0}^{n} \frac{I_{K_2+LM}}{(1+r_1)^{K_2-K_0+LM}} \qquad (14)$$

where $I_{K_2} = I_{K_2+L} = \ldots = I_{K_2+LM}$, and is defined as the initial investment in rolling stock in year K_2 and repeated in years K_2+L, $K_2+2L, \ldots, K_2+Ln$.

The equation for I_{v_a} becomes:

$$I_{v_a} = M_v \sum_{t=K_2-K_0+1}^{K_3-K_0} (Z_t - Z_{t-1}) \left\{ \left(\frac{1}{1+r_1}\right)^t + \left(\frac{1}{1+r_1}\right)^{t+L} \right\} \tag{15}$$

Since investments for additions to the rolling stock are made beginning in the second year of operation, the summation index, t, is started at K_2-K_0+1. The two terms in the discount portion of equation (15) come about as a result of an assumption that L is such that incremental investments will require replacement only once (L years later) in the evaluation period. M_v in equation (15) is defined as the additional vehicle cost per person above the initial investment cost for the vehicles associated with the first year. Equation (15) may be expanded and rewritten as:

$$I_{v_a} = M_v \sum_{t=K_2-K_0+1}^{K_3-K_0} \left(\frac{Z_t - Z_{t-1}}{(1+r_1)^t} \right) + M_v \sum_{t=K_2-K_0+L+1}^{K_3-K_0} \left(\frac{Z_{t-L} - Z_{t-L-1}}{(1+r_1)^t} \right)$$

which can be further reduced to

$$I_{v_a} = \frac{r_2 M_v Z_0}{(1+r_2)} \sum_{t=K_2-K_0+1}^{K_3-K_0} F^t + \frac{r_2 M_v Z_0}{(1+r_2)^{L+1}} \sum_{t=K_2-K_0+L+1}^{K_3-K_0} F^t \tag{16}$$

and by replacing the summations with the equation for computing the sum of a geometric progression, as before, we obtain:

$$I_{v_a} = r_2 M_v Z_0 \sum_{M=0}^{n} \left(\frac{1}{1+r_2}\right)^{LM+1} \left[\frac{F^{K_2-K_0+LM} - F^{K_3-K_0}}{F^{-1}-1} \right] \tag{17}$$

Finally $I_v = I_{v_i} + I_{v_a}$ becomes

$$I_v = \sum_{M=0}^{n} \left\{ \frac{I_{K_2+LM}}{(1+r_1)^{K_2-K_0+LM}} + \frac{r_2 M_v Z_0}{(1+r_2)^{LM+1}} \left[\frac{F^{K_2-K_0+LM} - F^{K_3-K_0}}{F^{-1}-1} \right] \right\} \tag{18}$$

Salvage Value of Vehicles

The salvage value of vehicles, S, is the sum of two terms, S_a and S_b. S_a is defined as the discounted salvage value of the investment to accommodate the annual increase in demand, and in this formulation is assumed to be one-half of the existing incremental investment over and above the initial rolling stock. S_b is defined simply as the discounted value of the depreciated bulk investment. Recalling that M_v is the marginal investment in vehicles required per passenger, the equation for S_a is:

$$S_a = \frac{1/2\ M_v Z_0}{(1+r_1)^{K_3-K_0}} \left[(1+r_2)^{K_3-K_0} - (1+r_2)^{K_2-K_0} \right], \tag{19}$$

and S_b is:

$$S_b = \frac{I_{K_2}}{(1+r_1)^{K_3-K_0}} \left\{ \frac{L-[K_3-K_2+1-Ln]}{L} \right\}$$

Finally, $S=S_a+S_b$ is:

$$S = \left(\frac{1}{1+r_1}\right)^{K_3-K_0} \left\{ 1/2\ M_v Z_0 [(1+r_2)^{K_3-K_0} - (1+r_2)^{K_2-K_0}] + I_{k_2} \left[\frac{L-K_3+K_2-1+Ln}{L} \right] \right\} \tag{20}$$

where I_{K_2} is defined as the initial investment in vehicles in the first year of operation, K_2. The development of the equation for S_a, equation (19), is based on discounting the incremental increase of vehicle acquisition after year K_2 through year K_3, and can be represented parametrically as:

$\alpha\ (Z_{K_3} - Z_{k_2})\ M_v$, where α is either a scalar, or a more complex representation of the proportion of vehicles that retain some salvage value at year K_3. The value of α is dependent upon the cut-off year, K_3, and its relation to the period of time covered by K_2+L, and also upon the response of yearly incremental vehicle fleet increases to variable demand requirements.

It was considered reasonable in the numerical calculation of the net present value (NPV) for the cases analyzed in the body of the report, to assume that α could be equated to one-half and obtain a reasonable result for S_a. This expression is used, then, as the basic formulation from which S_a is derived.

Summary.

We have developed equations for the five variables in equation (1), and they are presented here for convenience:

$$R = pZ_0 \left[\frac{F^{K_2-K_0-1} - F^{K_3-K_0}}{F^{-1} - 1} \right] \tag{21}$$

$$C = C_v Z_0 \left[\frac{F^{K_2-K_0-1} - F^{K_3-K_0}}{F^{-1} - 1} \right] + \frac{C_f}{r_1} \left\{ \left(\frac{1}{1+r_1}\right)^{K_2-K_0-1} - \left(\frac{1}{1+r_1}\right)^{K_3-K_0} \right\} \tag{22}$$

$$I_f = \frac{I}{r_1(K_2-K_1)} \left[\left(\frac{1}{1+r_1}\right)^{K_1-K_0-1} - \left(\frac{1}{1+r_1}\right)^{K_2-1-K_0} \right] \tag{23}$$

$$I_v = \sum_{M=0}^{n} \left\{ \frac{I_{K_2+LM}}{(1+r_1)^{K_2-K_0+LM}} + \frac{r_2 M_v Z_0}{(1+r_2)^{LM+1}} \left[\frac{F^{K_2-K_0+LM} - F^{K_3-K_0}}{F^{-1}-1} \right] \right\} \tag{24}$$

$$S = \left(\frac{1}{1+r_1}\right)^{K_3-K_0} \left\{ 1/2\, M_v Z_0 \left[(1+r_2)^{K_3-K_0} - (1+r_2)^{K_2-K_0} \right] + I_{K_2} \frac{[L-K_3+K_2-1+Ln]}{L} \right\} \tag{25}$$

and

$$NPV = R - C - I_f - (I_v - S) \tag{26}$$

An examination of equations (21) - (25) will reveal that, for a given case of interest, all of the parameters are known; and consequently NPV, and each term in equation (26), can be expressed as a linear equation with Z_0 as the independent variable. I_f is independent of Z_0,

and is, therefore, an invariant once the parameters are given. If

$$R = a_1 Z_0 + b_1 \text{ , then}$$

$$a_1 = pD, \text{ and } b_1 = 0, \text{ where } D = \left[\frac{F^{K_2-K_0-1} - F^{K_3-K_0}}{F^{-1}-1}\right]$$

Similarly

$$C = a_2 Z + b_2, \text{ then}$$

$$a_2 = C_v D, \text{ and } b_2 = \frac{C_f}{r_1}\left\{\left(\frac{1}{1+r_1}\right)^{K_2-K_0-1} - \left(\frac{1}{1+r_1}\right)\right\}^{K_3-K_0},$$

also

$$I_v = a_3 Z_0 + b_3, \text{ where}$$

$$a_3 = \sum_{m=0}^{n} \frac{r_2 M_v}{(1+r_2)^{LM+1}} \left[\frac{F^{K_2-K_0+LM} - F^{K_3-K_0}}{F^{-1}-1}\right], \text{ and } b_3 = \sum_{M=0}^{n}\left\{\frac{I_{K_2+LM}}{(1+r_1)^{K_2-K_0+LM}}\right\}$$

and finally

$$S = a_4 Z_0 + b_4, \text{ with}$$

$$a_4 = \left(\frac{1}{1+r_1}\right)^{K_3-K_0}\left\{1/2\, M_v \left[(1+r_2)^{K_3-K_0} - (1+r_2)^{K_2-K_0}\right]\right\} \text{ and } b_4 = \left(\frac{1}{1+r_1}\right)^{K_3-K_0} I_{K_2}\left(\frac{L-K_3+K_2-1+Ln}{L}\right)$$

Then $NPV = aZ_0 + b$, we have:

$$a = a_1 + a_2 + a_3 + a_4, \text{ and } b = b_2 + b_3 + b_4 + I_f.$$

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