Preliminary Engineering Economy Analysis of Puget Sound Regional Transportation Systems

HOWARD DUKE NIEBUR, Highway Research Engineer, U. S. Bureau of Public Roads

•THIS paper is a preliminary engineering economy analysis of five alternative urban transportation systems formulated and studied by the Puget Sound Regional Transportation Study (PSRTS). Each transportation system is based on the possible inclusion and use of the following facilities in various degrees: highway facilities (freeways, expressways, and arterials), bus transit facilities, rapid rail transit facilities, automobile parking facilities, ferry vessels, and a floating bridge.

The paper has more merit for development of concept and methods of procedure than it does for quantitative answers. One problem encountered was determining what costs of providing and operating transportation facilities are relevant and significant in conducting an engineering economy analysis of urban transportation systems.

The principles of engineering economy analysis are applied to the evaluation of PSRTS transportation systems using three methods of engineering economy analysis: (a) the total annual transportation cost method; (b) the benefit-cost ratio method; and (c) the rate-of-return method.

The overall land-use plan on which a transportation system is based can be a critical factor which affects the economy of the transportation system relative to other transportation systems. Because of relatively light density population in the land-use plans, the predicted level of use of rapid rail transit facilities, as a component of a transportation system, was not high enough to indicate economy of rapid transit facilities over highway facilities for which it was a substitute.

The paper is a guide for evaluation of transportation systems containing multi-modes of transportation. It does not evaluate the socioeconomic factors which must be considered in transportation planning, but it does present to transportation planning administrators one of the most important tools needed in the decision-making process—the means to establish the relative order of economy of transportation systems based on tangible costs.

DESCRIPTION OF PROPOSED TRANSPORTATION SYSTEMS

This description of proposed Puget Sound regional transportation systems contains figures extracted from a few of the more than 20 major studies and reports made by the Puget Sound Regional Transportation Study (PSRTS). Figure 1 shows the location of the study area in the Puget Sound region of the State of Washington.

The alternative transportation systems analyzed in this report were based on two land-use plans and were developed, tested, and evaluated as to their ability to serve the future needs of the Puget Sound region for the year 1990. Plan A is based on a continuation of present trends and policies with respect to residential development. Plan B is based on a concept of cities, corridors, and open spaces. Plan B has smaller travel demands than Plan A because the close proximity of places of employment to home in Plan B decreases the length of trips. As a result, there is a decrease in numbers of lanes required for many sections of highways in Plan B when compared to Plan A.

Five regional transportation systems loaded with 1990 travel demands were analyzed. Table 1 summarizes the component parts of each transportation system.

Paper sponsored by Committee on Highway Engineering Economy and presented at the 46th Annual Meeting.

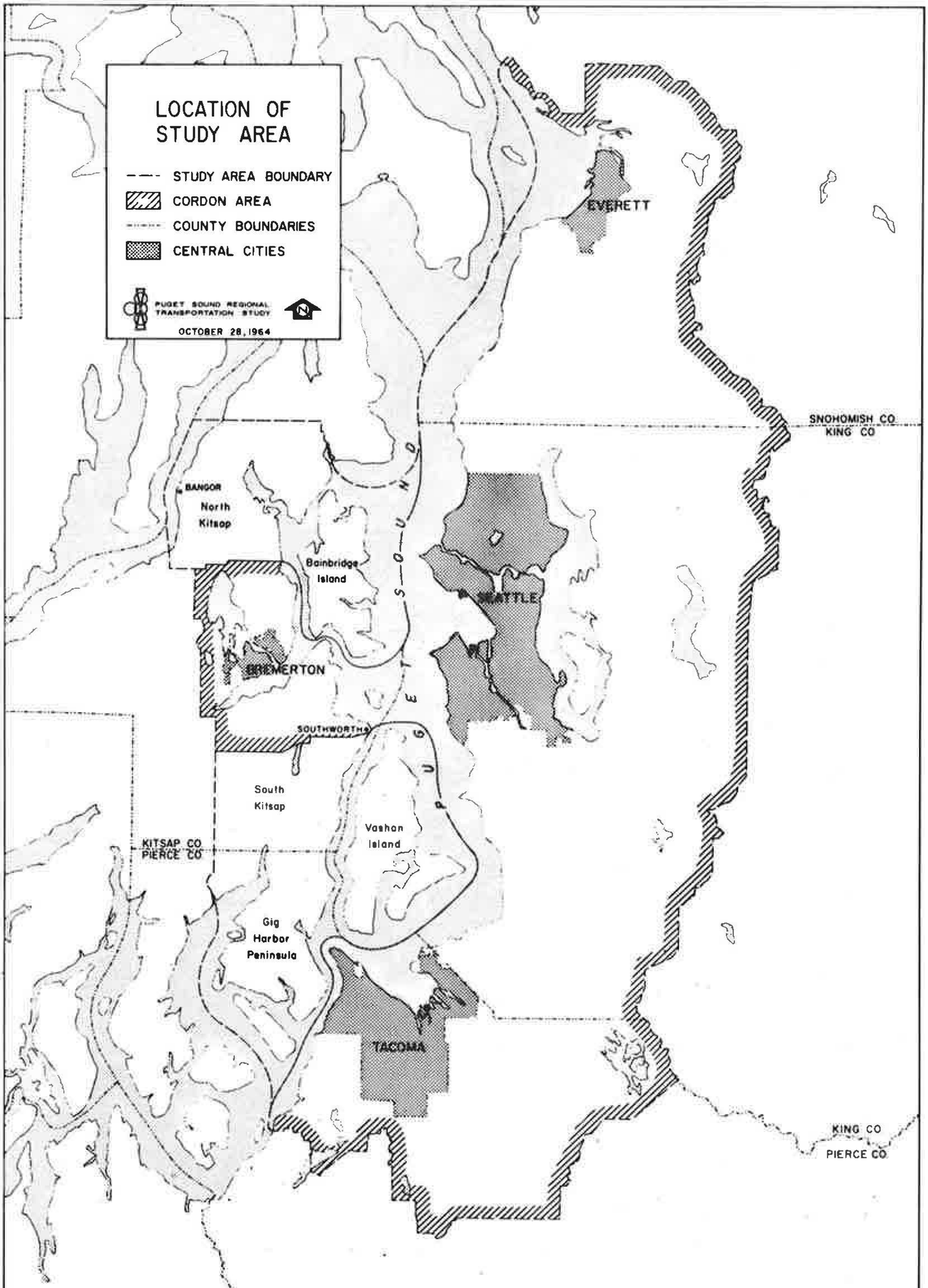

LOCATION OF STUDY AREA
STUDY AREA BOUNDARY
CORDON AREA
COUNTY BOUNDARIES
CENTRAL CITIES
PUGET SOUND REGIONAL TRANSPORTATION STUDY
OCTOBER 28, 1964
EVERETT
SNOHOMISH CO
KING CO
BANGOR
North Kitsap
Bainbridge Island
SEATTLE
BREMERTON
PUGET SOUND
SOUTHWORTH
South Kitsap
Vashon Island
KITSAP CO
PIERCE CO
Gig Harbor Peninsula
TACOMA
KING CO
PIERCE CO

Figure 1.

TABLE 1

TRANSPORTATION SYSTEMS AND THEIR COMPONENT PARTS

Transportation System Number and Basic Components of the System	
Land-use Plan A—The continuation of present trends and policies with respect to residential development.	Land-use Plan B—The concept of satelite cities, corriders, and open spaces which generate less total miles and hours of travel demand than Plan A.
System 2A Highway facilities obligated for construction by early 1970's loaded with 1990 travel demands of land-use Plan A. Bus transit facilities. Ferry facilities. Parking facilities.	System 5B Highway facilities obligated for construction by early 1970's loaded with 1990 travel demands of land-use Plan B. Cross-Sound bridge facilities. Bus transit facilities. Ferry facilities. Parking facilities.
System 3A Highway facilities in System 2 with additional miles of highways to accommodate 1990 travel demands of land-use Plan A. Bus transit facilities. Ferry facilities. Parking facilities.	System 6B Highway facilities in System 5 with additional miles of highways to accommodate 1990 travel demands of land-use Plan B. Cross-Sound bridge facilities. Bus transit facilities. Ferry facilities. Parking facilities.
System 4A Highway facilities similar to those in System 3 except that certain highway facilities competitive with rapid rail transit facilities were deleted. Rapid rail transit facilities. Bus transit facilities. Ferry facilities. Parking facilities.	

Transportation System 2A

The highway facilities included in System 2A were the existing plus committed and budgeted facilities which will be completed by the early 1970's. The system includes 110 miles of freeways and expressways which were in use in 1961 plus an additional 215 miles which were then under construction or budgeted (Fig. 2).

The bus transit facilities in System 2A include almost 750 miles of transit route compared to the approximately 575 route miles which were being operated in the region in 1961.

Travel across Puget Sound is accommodated by ferry facilities.

The system includes 35,000 additional parking spaces above those available in 1961.

Transportation System 3A

The highway facilities in System 3A include approximately 140 miles of freeway and expressway in addition to the 325 miles in existence in 1961 or committed and budgeted for construction by the early 1970's (Fig. 3).

The bus transit facilities, ferry facilities, and parking facilities are essentially the same as in System 2A.

Transportation System 4A

The highway facilities in System 4A include approximately 103 miles of freeways and expressways in addition to the 325 miles included in System 2A (Fig. 4). The highway facilities are similar to those in System 3A except that certain routes competitive with rapid rail transit facilities were deleted.

System 4A includes 20 miles of rapid rail transit facilities between the northwest portion of Seattle, downtown, and across Lake Washington to Bellevue (Fig. 5). In conjunction with the rapid rail transit route, an integrated network of local, feeder, and express buses was provided. In rapid rail transit corridors, the bus facilities were oriented to serve the rapid rail transit stations. The freeway eliminated by rapid rail transit facilities in northwest Seattle can be found by comparing Figure 4 with Figure 3.

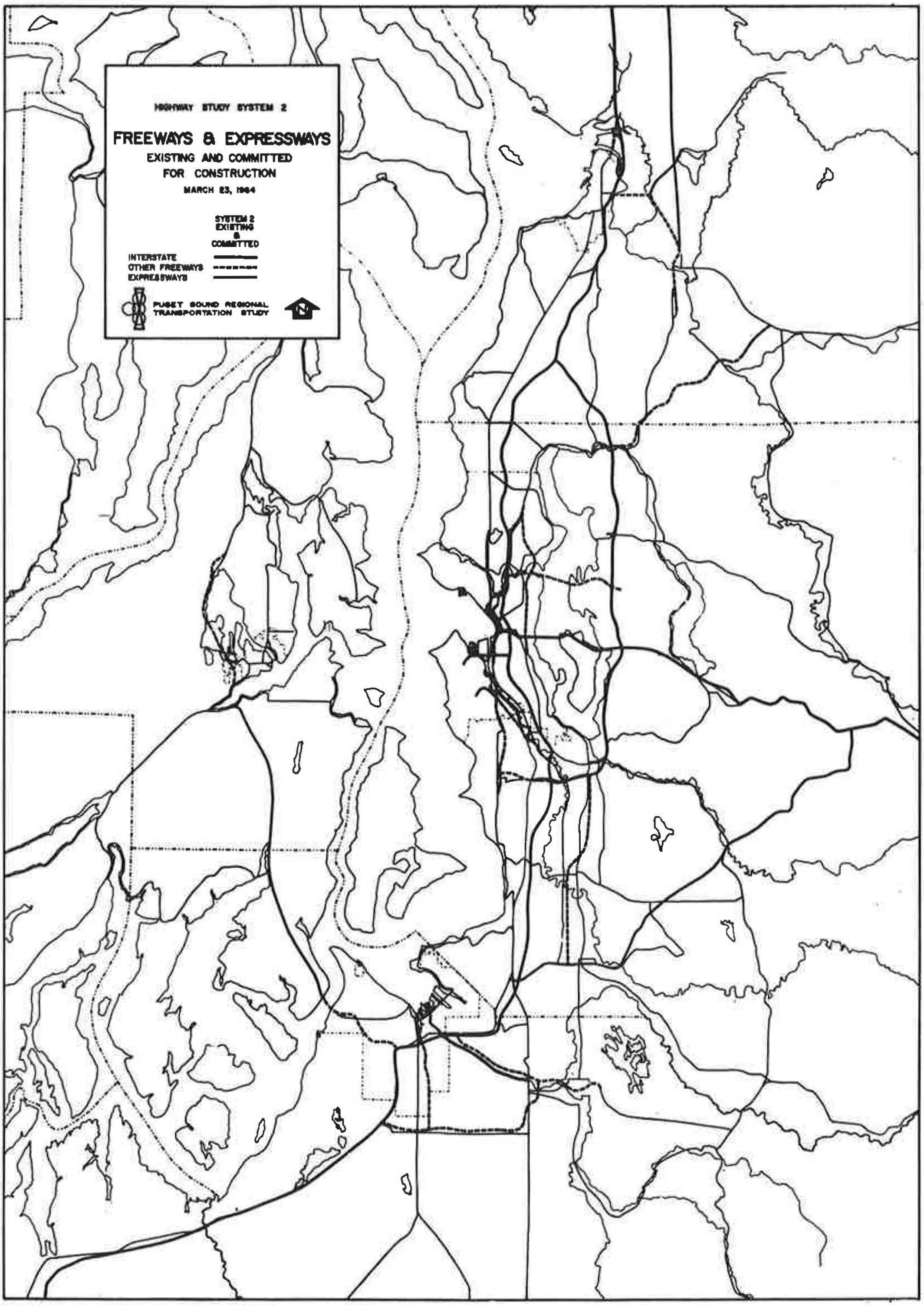

HIGHWAY STUDY SYSTEM 2
FREEWAYS & EXPRESSWAYS
EXISTING AND COMMITTED
FOR CONSTRUCTION
MARCH 23, 1964
SYSTEM 2
EXISTING
&
COMMITTED
INTERSTATE
OTHER FREEWAYS
EXPRESSWAYS
PUGET SOUND REGIONAL
TRANSPORTATION STUDY
N

Figure 2.

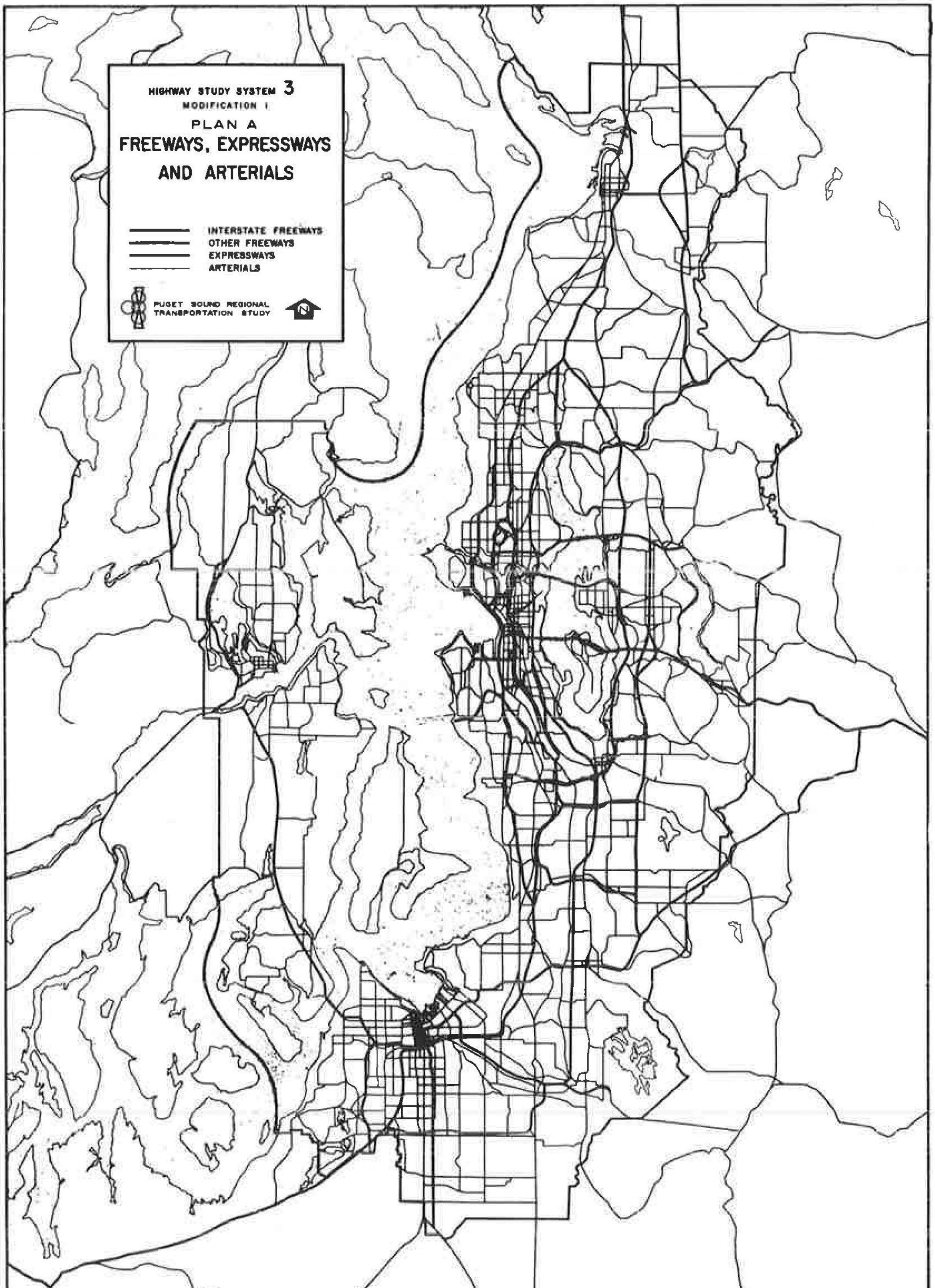

HIGHWAY STUDY SYSTEM 3
MODIFICATION I
PLAN A
FREEWAYS, EXPRESSWAYS
AND ARTERIALS
INTERSTATE FREEWAYS
OTHER FREEWAYS
EXPRESSWAYS
ARTERIALS
PUGET SOUND REGIONAL
TRANSPORTATION STUDY

Figure 3.

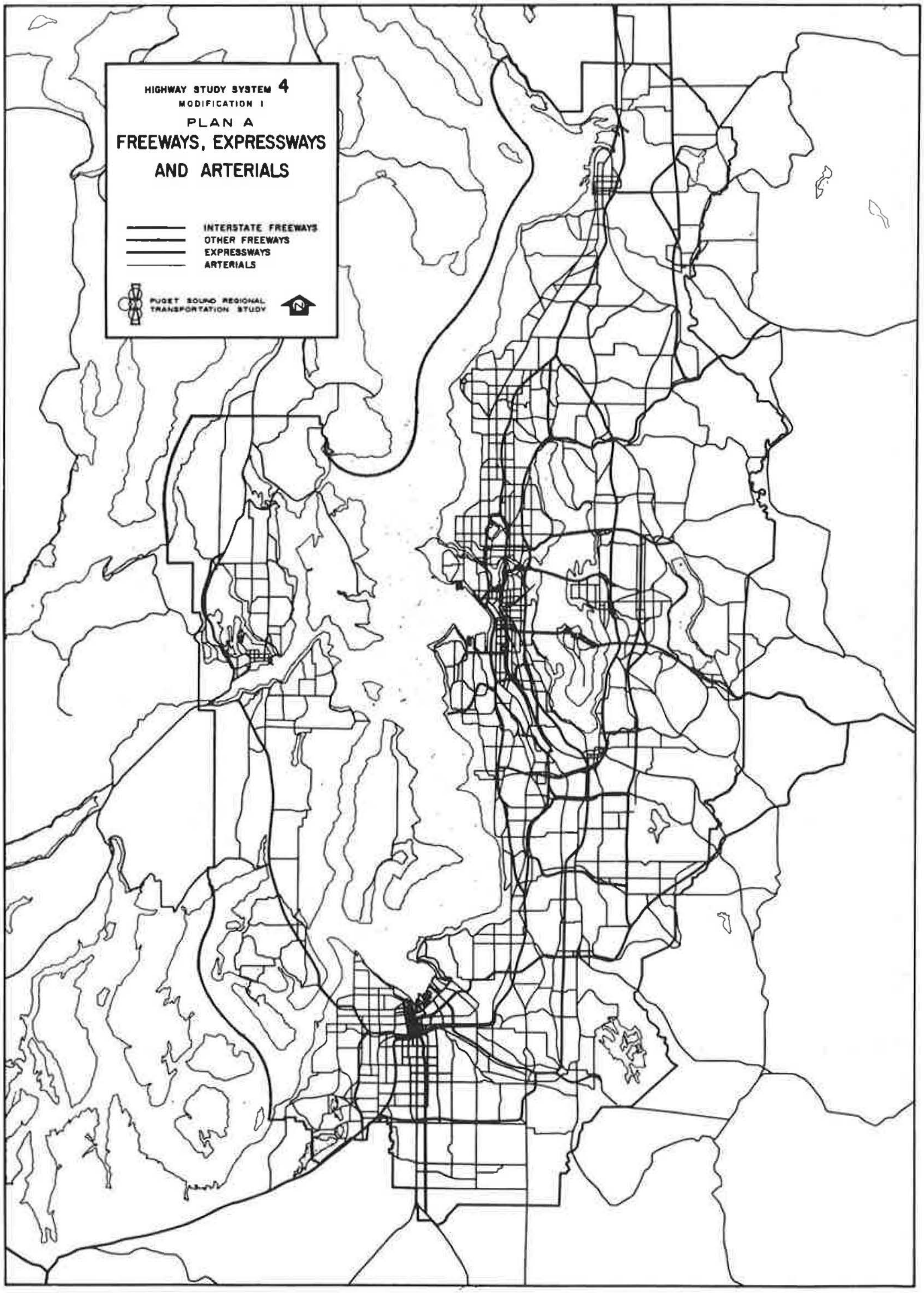
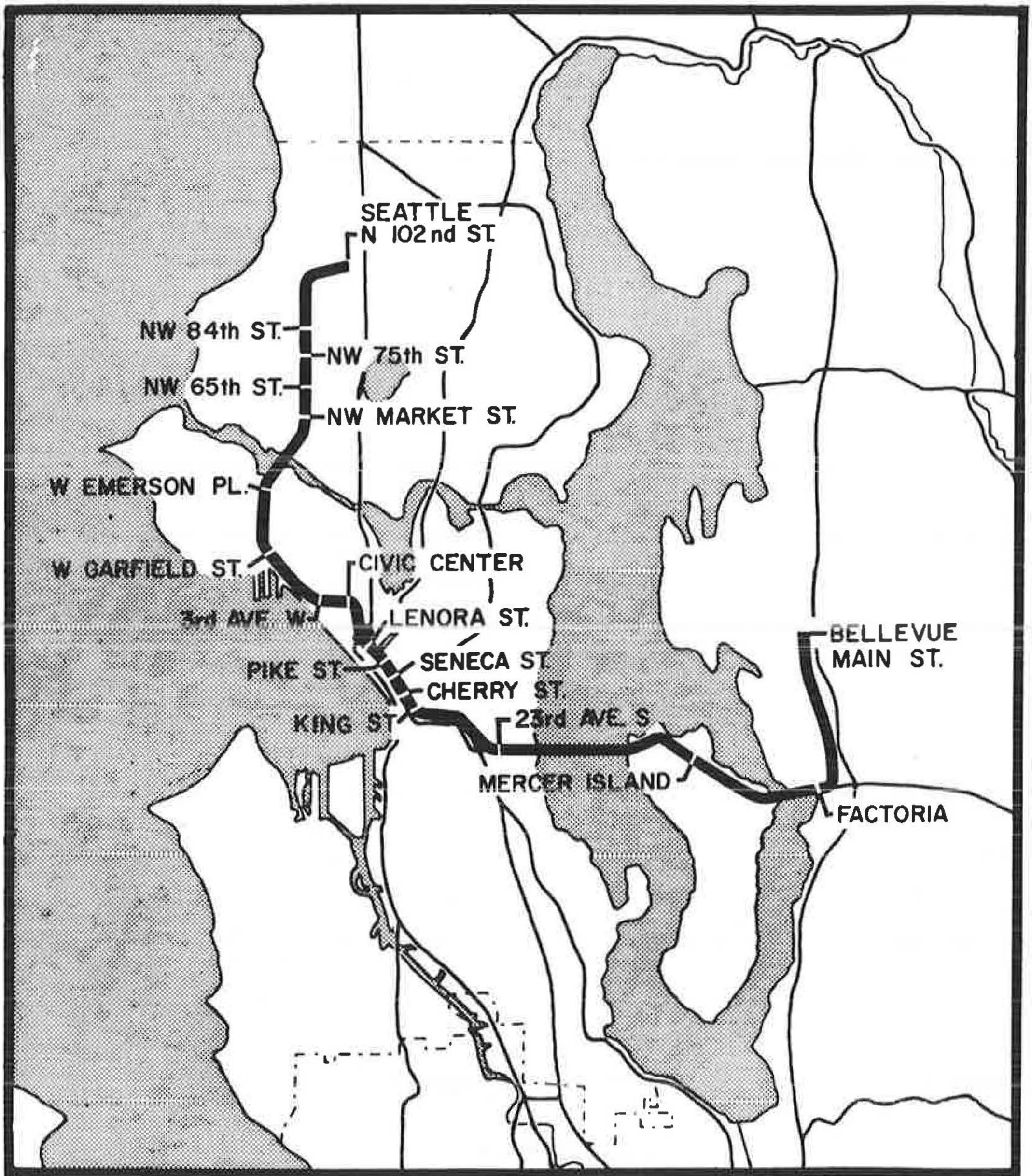

HIGHWAY STUDY SYSTEM 4
MODIFICATION I
PLAN A
FREEWAYS, EXPRESSWAYS AND ARTERIALS
INTERSTATE FREEWAYS
OTHER FREEWAYS
EXPRESSWAYS
ARTERIALS
PUGET SOUND REGIONAL TRANSPORTATION STUDY

Figure 4.



TRANSIT STUDY SYSTEM 4

RAIL RAPID TRANSIT ROUTE AND STATIONS

Figure 5.

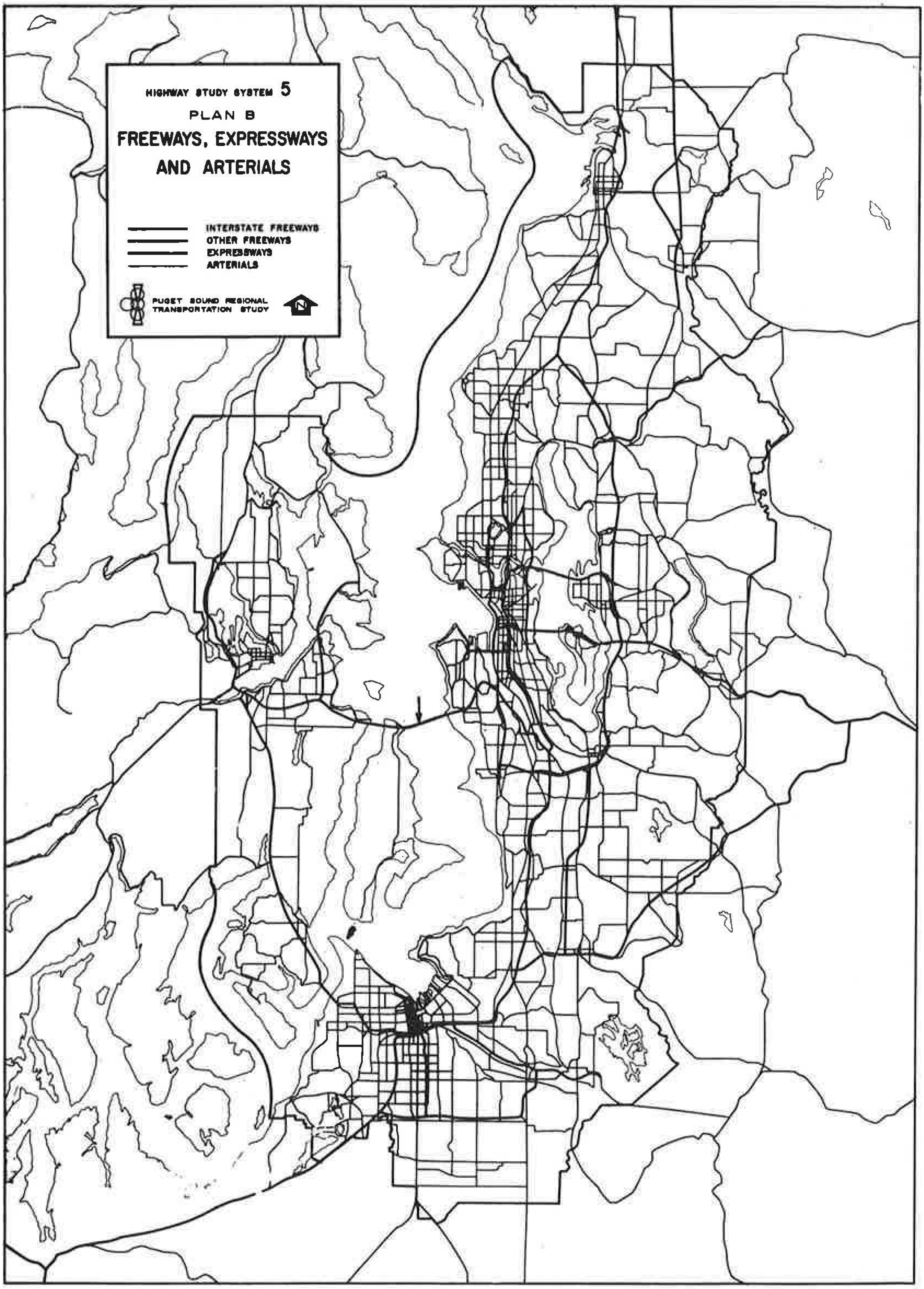

HIGHWAY STUDY SYSTEM 5
PLAN B
FREEWAYS, EXPRESSWAYS AND ARTERIALS
INTERSTATE FREEWAYS
OTHER FREEWAYS
EXPRESSWAYS
ARTERIALS
PUGET SOUND REGIONAL TRANSPORTATION STUDY
N

Figure 6.

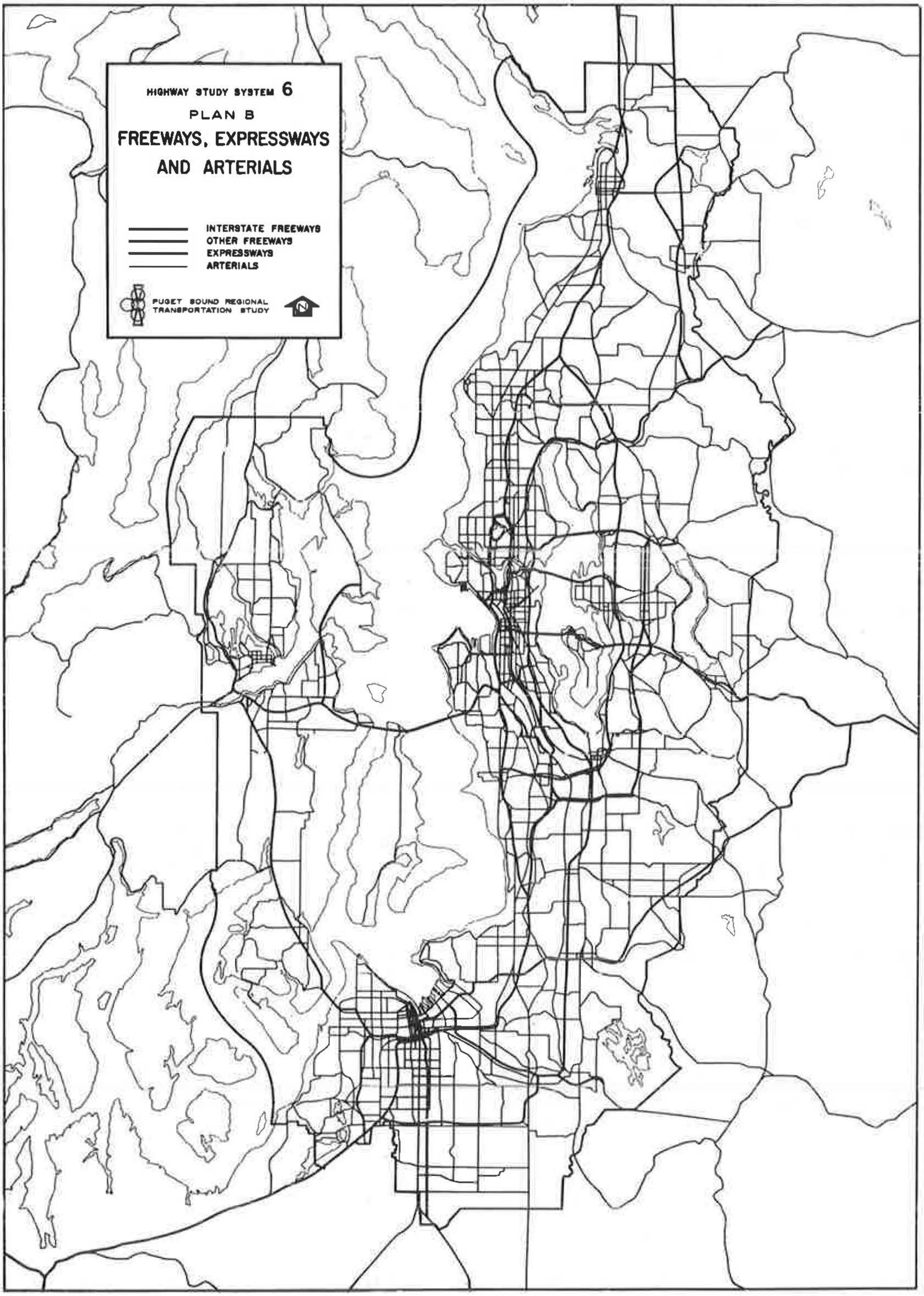

HIGHWAY STUDY SYSTEM 6
PLAN B
FREEWAYS, EXPRESSWAYS
AND ARTERIALS
INTERSTATE FREEWAYS
OTHER FREEWAYS
EXPRESSWAYS
ARTERIALS
PUGET SOUND REGIONAL
TRANSPORTATION STUDY
N

Figure 7.

The ferry facilities are essentially the same as those in System 2.

The need for additional parking spaces in System 4A with rapid rail transit facilities is reduced to 29,000. It will be recalled that Systems 2A and 3A, which did not include rapid rail transit facilities, required 35,000 parking spaces above those available in 1961.

Transportation System 5B

The highway facilities in System 5B are identical to those in System 2A except that cross-Sound bridge facilities partially substitute for ferries. The cross-Sound bridge is shown by the arrow in Figure 6.

Because land-use Plan B relative to Plan A results in smaller travel demands, the bus facilities and service required are not as great. The requirement for parking facilities relative to System 2A are also smaller.

Transportation System 6B

The highway facilities in System 6B include approximately 110 miles of freeways and expressways in addition to those in System 5B (Fig. 7). The transit facilities, cross-Sound bridge facilities, ferry facilities, and parking facilities are identical to those in System 5B.

TRANSPORTATION SYSTEM COSTS

The primary purpose of this report is to present a procedure for economic evaluation of transportation systems based mainly on tangible costs. It would require a great deal of space to present the development of cost estimates made as a co-effort with PSRTS. The summarized cost estimates will be presented with limited discussion but additional comments will be made as to costs that should be included or excluded from engineering economy analyses. Preliminary PSRTS transportation cost estimates as of May 1, 1965, are used to demonstrate the engineering economy analysis of transportation systems.

A basic concept used in this analysis is that transportation system costs are based on the estimated costs to provide and operate transportation system facilities. The source of funds, whether it be from cash box fares, taxes, bond issues, or the state or federal government, is not relevant to the problem of determining the relative economy of one transportation system to another. Also, the possible profits to be derived from some components of a transportation system, whether those profits be accrued as a result of public or private investment of capital, are irrelevant to the problem. Regardless of whether an investment, such as for parking facilities, is to be made by a public agency or a private firm, the costs that are relevant to an economy analysis are those to provide and operate the facilities.

Two major categories of costs that are included in the engineering economy analysis are (a) the capital costs or outlays for construction of the transportation facilities and purchase of transportation equipment, and (b) annual costs for the items of operation, maintenance, accidents, and travel time costs.

TABLE 2

CAPITAL COST FOR TRANSPORTATION SYSTEM CONSTRUCTION AND EQUIPMENT
(in thousands of dollars)

Component	Transportation System				
	2A	3A	4A	5B	6B
Highways	885,761	1,396,494	1,321,647	861,694	1,279,745
Cross-Sound bridge facilities	—	—	—	134,002	134,002
New buses	22,932	22,932	20,696	15,860	15,860
New ferries	70,300	70,300	70,300	25,250	25,250
Parking facilities	97,330	97,330	85,136	53,462	53,462
Rapid rail transit facilities	—	—	147,000	—	—
Total	1,076,323	1,587,056	1,644,806	1,090,268	1,508,319

TABLE 3

TOTAL NET ANNUAL COSTS FOR EACH TRANSPORTATION SYSTEM BASED ON VARIOUS UNIT COSTS FOR TRAVEL TIME
(in thousands of dollars)

Travel Time Cost Per Person Per Hour	Transportation System				
	2A	3A	4A	5B	6B
$0.00	649,536	667,549	680,293	573,850	581,288
0.50	896,341	859,658	905,675	762,262	748,786
1.00	1,143,146	1,051,769	1,131,059	950,636	916,285
1.50	1,389,951	1,243,877	1,356,441	1,139,090	1,083,784
2.00	1,636,756	1,435,987	1,581,825	1,327,502	1,251,282

Capital outlays for transportation system construction and purchase of transportation equipment, as estimated for PSRTS systems, are shown in Table 2. The major construction items include highways (freeways, expressways, new arterial streets, and improvement of arterial streets); cross-Sound bridge facilities; parking facilities; and rapid rail transit facilities. Included in all these items are the costs of land and engineering. The major transportation equipment items include new buses and new Puget Sound ferries. Capital outlays for rapid rail transit facilities include the cost of land; construction of track, tunnels, stations, and maintenance facilities; engineering; and purchase of rolling stock. Note that the order of increasing total capital cost of the transportation systems is 2A, 5B, 6B, 3A, and 4A.

The net total annual cost for maintenance, operation, accidents, and travel time costs for each PSRTS transportation system is shown in Table 3. The travel time costs are based on the unit travel time costs per person per hour shown in the first column. The $1.00 per hour per person figure is most commonly used in engineering economy analyses. Various unit travel time costs were used to discern the sensitivity of the final results of the analysis to the values of travel time. Travel time includes walking time to transit stops and waiting time for transit vehicles as well as actual travel time on all modes of transportation.

The estimates of costs are in general based on 1964 price levels. Where cost records for 1964 were limited, data from prior years were updated by the use of cost indexes in order to increase the reliability of unit cost estimates.

Table 3 is comprised of costs for the following items (additional comments are provided as to the costs which should be included or excluded from engineering economy analyses):

1. Motor vehicle operating costs for the cost of fuel, tires, oil, maintenance and repairs, and depreciation. The additional operating and time costs for stopping, idling, and resuming speed at intersections (or as a result of traffic congestion delays) over uniform speed operation should be included. Motor vehicle operating costs in engineering economy analyses should exclude fuel taxes as they are transfer payments used for highway construction.

2. Maintenance costs of all highway facilities. In the case of the cross-Sound bridge this includes maintenance of the bridge, toll-booth operation, and insurance premiums.

3. Motor vehicle accident costs, including fatalities, injuries, and property damage, on highways with various levels of access control.

4. Operating costs of bus transit facilities. In the PSRTS analysis this includes items for payrolls, maintenance, insurance, and overhead.

5. Operating costs of ferries. In the PSRTS analysis this includes items for payrolls, maintenance, insurance, and overhead.

6. Operating costs of parking facilities. In the PSRTS analysis this includes maintenance, insurance, and overhead.

7. Operating costs of rapid rail transit facilities. In the PSRTS analysis this includes payrolls, maintenance, insurance, and overhead.

The discussion of costs as related to PSRTS systems is limited and for further detail, reference can be made to the PSRTS staff report on transportation system costs.

In general, appreciation of costs to account for rising prices in the future is not included in an engineering economy analysis. However, when the result of such an analysis is sensitive to appreciation of costs that factor should be considered for each item of cost. The PSRTS transportation systems cost estimates were not based on appreciation of costs related to rising prices.

The dates when capital outlays would be made in the future for the transportation systems are unknown. Therefore, for the purpose of this preliminary engineering economy analysis, the total capital costs show what it would cost if all capital outlays were made now. Technically speaking, future capital expenditures have not been adjusted or discounted for the time value of money in order to arrive at total capital costs.

ECONOMIC ANALYSIS

The engineering economy analysis is a systematic approach to making a selection of the most economic transportation system from among the several alternative transportation systems studied. The basic proposal is a "do nothing" alternative. In other words, the base transportation system includes no further construction than what has already been scheduled for construction by the early 1970's. All other alternative transportation systems are compared to this base system for justification. All transportation systems are then compared to one another in order to study their relative economy. The latter comparison emphasizes the fact that it is the differences between the transportation systems which are important.

The benefits to be rendered by any transportation facility in the future must at least be equal to the costs over the period the benefits are rendered. In order to compare benefits and costs, both must be determined over the same time period and must be reduced to dollar values as far as reasonably possible. The time period used and the procedure used to express all costs on a comparable basis will be discussed.

Analysis Period

A 25-year economic analysis period was used in this report. There were several reasons for this. Traffic predictions were based on a population and level of development which will occur by 1990, or roughly 25 years in the future. The economic analysis period then was equal to the period covered by traffic predictions. An increase in the length of the period for which traffic predictions were made would decrease the reliability of traffic predictions and the related estimates of transportation system user benefits. Possible changes in transportation technology, public travel trends, and rate of population growth make it risky to predict the need and use of proposed transportation systems beyond a 25-year period. The possibility of new and better means of transportation (which may compete with the proposed systems) increases with the length of the analysis period chosen. Therefore, it is reasonable to require that the value of the benefits to be rendered by the proposed transportation facilities be equal to or greater than the costs over the period that reliable predictions can be made (1).

Benefits

Benefit as used in this analysis is the net reduction in the total of annual maintenance, operating, accident, and travel time costs resulting from any additional expenditure of capital made in order to obtain those benefits. Higher total capital costs for any transportation system compared to another system should result in benefits. Since the dates when capital expenditures would be made were unknown, the time periods over which benefits (reductions in the net annual costs mentioned above) would be rendered were also unknown. Therefore, the analysis was based on the benefits determined by loading each transportation system with 1990 travel demands and using the resulting benefits over a 25-year analysis period. Any attempt to state whether the benefits determined on that basis are high or low would be questionable. For the sake of this preliminary analysis, however, it is the most equitable basis for comparison of the systems.

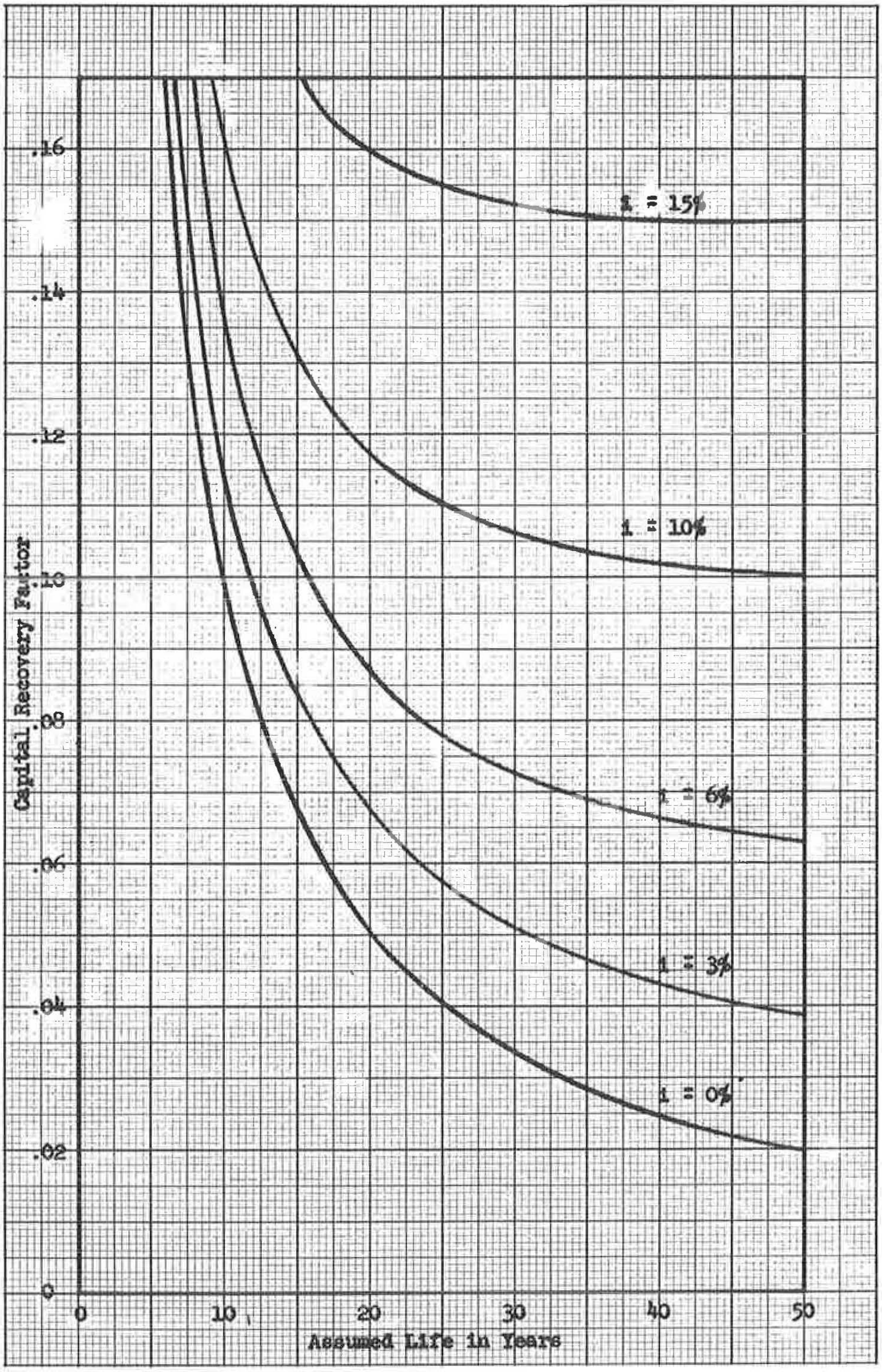


Figure 8. Capital recovery factors for selected interest rates (i) and periods of years.

Interest Rates

Interest is the rent paid on borrowed money. It is a concept of return on productive capital investments in physical assets. In private enterprise the return is in a monetary form. In the case of public transportation systems the return is in the form of general benefits evaluated in dollars.

The selection of the minimum attractive rate of return or the interest rate to use in the analysis of transportation systems was based on consideration of the following factors: the rate of interest commonly paid by the government on borrowed funds, the risks and uncertainties involved, and the "opportunity cost" of captial.

The fact that funds can be obtained by the government by the sale of bonds at relatively low interest rates is misleading when considering the cost of money on the market. Low interest rates are available because of the usual tax reduction provisions allowed by the government and the virtually risk-free guarantee to repay the principle plus interest. Considering the tax reductions granted to the purchasers of such bonds, the low 3 to 4 percent interest rate paid by the government effectively equals a much higher rate.

The minimum attractive rate of return should increase with the degree of risk and uncertainty involved in the investment. Therefore, if the soundness of an investment is in doubt the potential return on the investment should be higher in order to warrant the risk of capital funds.

Another factor considered in the selection of the minimum attractive rate of return was the "opportunity cost" or capital or the investment opportunities forgone by the taxpayers who provide the funds for investment in the transportation systems. It is common knowledge that a large portion of the population in the United States borrow money and make purchases on credit. The taxpayer could use his tax funds to help pay his existing debts and in so doing obtain a risk free return on his capital equal to at least 6 percent and usually higher.

Another example of taxpayer "opportunity cost" is that of persons making investments in one manner or another in the stock market or private enterprise. It is common for private enterprises to stipulate at least a minimum attractive rate of return equal to 10 percent, after taxes, as criteria for investment of capital (2).

In consideration of these factors it is reasonable to require that the justification for construction of transportation systems should be based on the proof that government administrators can invest taxes as productively as could the taxpayer. The measuring stick used for such a comparison is the rate of return on investment or the minimum attractive rate of return.

The minimum attractive rate of return selected for use in this report is 6 percent per annum. This report also includes analyses based on other interest rates (0, 3, 6, 10, and 15 percent in total) in order to study the sensitivity of the economic analysis to changes in interest rates.

Another concept of interest was employed in this report. Interest is also a mathematical concept by which values at one point in time may be converted to equivalent values at another point in time. Or it can be used to convert values at one point in time to a series of equivalent uniform annual values over a period of time. The latter approach was used in this analysis to convert total capital costs to equivalent uniform annual capital costs. When expressed on an annual basis the capital costs can be compared to or combined with annual maintenance, operating, accident, and travel time costs. In order to convert total capital costs to equivalent uniform annual capital costs, the total capital cost for each transportation system component was multiplied by the capital recovery factor related to each interest rate and assumed years of life for the particular component. Figure 8 is a graph from which the capital recovery factor can be obtained for the various interest rates and assumed lives used in this report for transportation system components (3). The particular capital recovery factors used are shown in Table 4.

Annual Capital Costs

The results of multiplying the total capital costs shown in Table 2 by the capital

TABLE 4

CAPITAL RECOVERY FACTORS FOR VARIOUS INTEREST RATES AND PERIODS

Period (years)	Interest Rate (%)				
	0	3	6	10	15
15	0.06667	0.08377	0.10296	0.13147	0.17102
25	0.04000	0.05743	0.07823	0.11017	0.15470

recovery factors shown in Table 4 are shown in Table 5. The results are equivalent uniform annual capital costs.

The amortization period or the period used to select the capital recovery factor for the transportation system components was 25 years for highways, parking facilities, ferries, and rapid rail transit facilities, and 15 years for new buses. For this preliminary engineering economy analysis the life of the present bus fleet was ended at the 10th year of the 25-year economic analysis period. The purchase of the new bus fleet was assumed to occur in the 10th year making the end of the service life coincide with the end of the economic analysis period.

The reader will note that the amortization period of 25 years used for some of the transportation system component costs is shorter than their probable lives. For

TABLE 5

EQUIVALENT UNIFORM ANNUAL CAPITAL COSTS OF TRANSPORTATION SYSTEM COMPONENTS BASED ON VARIOUS INTEREST RATES
(in thousands of dollars)

Transportation System and its Components	Interest Rate (%)				
	0	3	6	10	15
2A					
Highways	35,430	50,869	69,293	97,584	137,027
New buses	1,529	1,921	2,361	3,015	3,922
New ferries	2,812	4,037	5,500	7,745	10,875
Parking facilites	3,093	5,590	7,014	10,723	15,057
Total	43,664	62,417	84,768	119,067	166,881
3A					
Highways	55,859	80,201	109,248	153,852	216,038
New buses	1,529	1,921	2,361	3,015	3,922
New ferries	2,812	4,037	5,500	7,745	10,875
Parking facilities	3,893	5,590	7,614	10,723	15,057
Total	64,094	91,749	124,723	175,335	245,892
4A					
Highways	52,867	75,904	103,395	145,609	204,463
New buses	1,380	1,734	2,131	2,721	3,539
New ferries	2,812	4,037	5,500	7,745	10,875
Parking facilities	3,405	4,889	6,660	9,379	13,171
Rapid rail transit	5,880	8,442	11,500	16,195	22,741
Total	66,344	95,006	129,186	181,649	254,789
5B					
Highways	34,468	49,487	67,410	94,933	133,304
Cross-Sound bridge facilities	5,360	7,696	10,483	14,763	20,730
New buses	1,057	1,329	1,633	2,085	2,712
New ferries	1,010	1,450	1,975	2,782	3,906
Parking facilities	2,138	3,070	4,182	5,890	8,271
Total	44,033	63,032	85,683	120,453	168,923
6B					
Highways	51,190	73,496	100,114	140,990	197,977
Cross-Sound bridge facilities	5,360	7,696	10,483	14,763	20,730
New buses	1,057	1,329	1,633	2,085	2,712
New ferries	1,010	1,450	1,975	2,782	3,906
Parking facilities	2,138	3,070	4,182	5,890	8,271
Total	60,755	87,041	118,387	166,510	233,596

example, two of the major cost items for highway construction are right-of-way and grading. In reality the life of right-of-way is perpetuity. From just general observation of old highway and railway cuts and fills it also appears that grading for roadways, with reasonable maintenance, could have a life in excess of 40 years. The life of parking garages is another good example of possible physical life exceeding 25 years. Last of all, the estimated service life of rapid rail transit rolling equipment was estimated to be 40 years (by transit consultant Deleuw Cather and Company). There were three factors which were considered in the decision to amortize capital costs over a 25-year period for those components and their parts having lives in excess of 25 years.

The first factor considered was that there are three types of probable lives which have to be dealt with and the differences between them are significant (4). They are actual physical life, service life, and economic life. Actual physical life is ended because of physical deterioration. Service life is the length of time the facility is used in its major original function without major rebuilding. Economic life is that life which is ended at the time the services rendered by the facility could be produced at a lower cost by a new facility. It is readily apparent that it is the economic life which is significant and should be used to amortize the costs of transportation system components in this analysis. This economic life was considered to be 25 years.

The second factor considered, related to the preceding one and already discussed under the heading "Analysis Period," was that the increasing rate of change in transportation technology increases the chances that the proposed transportation system components will be competing with new, better and more desirable means of transportation in the future. When one considers the general reluctance of the public today to use transportation facilities and equipment approaching 25 years in age (transit facilities, for example), it would be unwise to amortize costs over a longer period.

The third and final factor considered can be explained with the use of Figure 8. The discussion of interest rates gave the reasons for stipulating that the rate of return on the investment in transportation facilities should be above 6 percent. In Figure 8 it can be seen that the change in the capital recovery factor decreases as the assumed life in years increases. It can also be observed that as the interest rate increases there are smaller percentage decreases in the capital recovery factor between any given range of years. For example, the capital recovery factor for the 6 percent interest rate falls from 0.078 at 25 years to 0.066 at 40 years, a 15 percent decrease. The capital recovery factor for the 10 percent interest rate falls from 0.110 at 25 years to 0.102 at 40 years, a decrease of 7 percent. Though the assumed life was increased by 60 percent in going from 25 years to 40 years, the resulting changes in the capital recovery factor were only 15 percent at the 6 percent interest rate and only 7 percent at the 10 percent interest rate. The point to be made is that as the minimum attractive rate of return increases, any change in the assumed life above 25 years plays a role of decreasing importance in the analysis. Also, since predictions of transportation system use and therefore the benefits to be received cannot be made with a high degree of reliability beyond 25 years, it would be unwise to amortize capital costs over a period exceeding the 25 years.

Salvage Values

For this preliminary analysis salvage values were considered to be negligible or zero at the end of the 25-year economic analysis period. Estimates of salvage values 25 years in the future usually prove to vary from the true figure by wide margins. Also, the use of reasonably high rates of return tends to nullify the importance of salvage values. Figure 9, which shows the relationship between salvage value at the end of the study period and the present worth of that salvage, demonstrates the principle. For example, use of the curve based on the 6 percent rate of return and the analysis period of 25 years, and using salvage values in the range of 10 percent to 20 percent of first cost, shows that the present worth is effectively 2 to 5 percent of first cost. The difference between including and excluding salvage values was considerably less than the possible variations in other estimates. Therefore, salvage values were not included in the analysis.

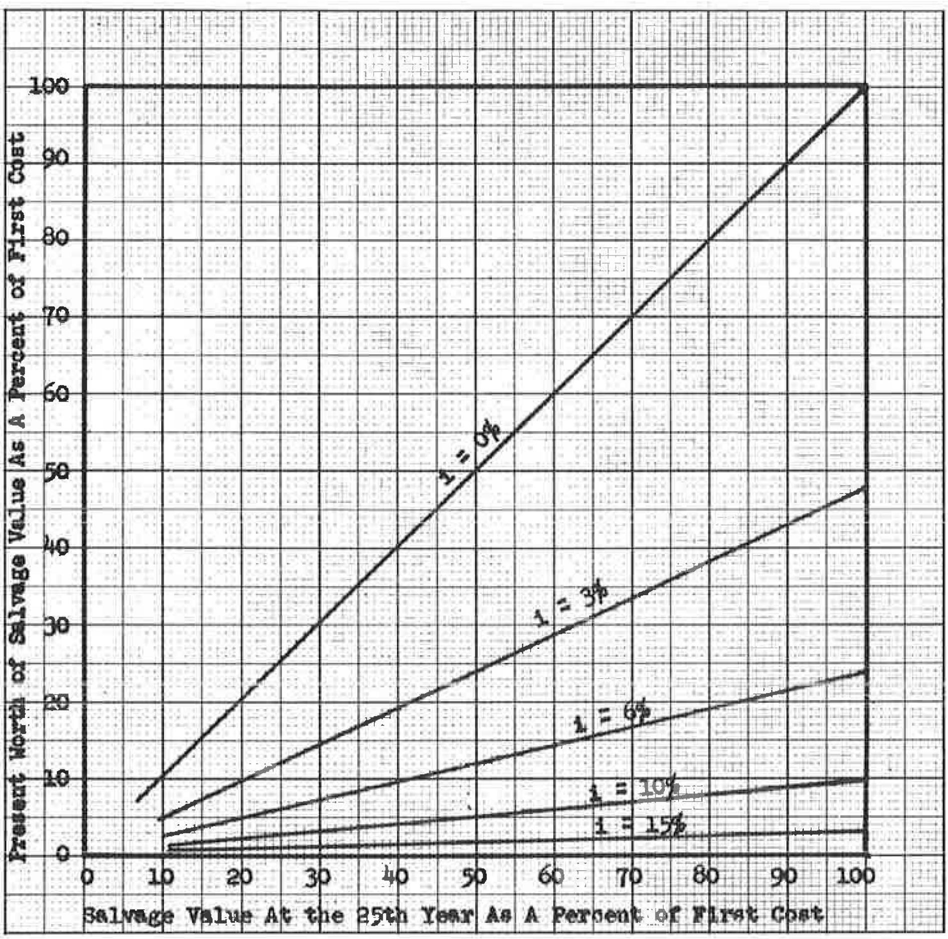


Figure 9. Relationship between salvage value at end of 25-year study period and present worth of salvage value (5, p. 35).

Engineering Economy Analysis Methods

Three methods of engineering economy analysis are used in this report. They are the total annual transportation cost method, the benefit-cost ratio method, and the rate-of-return method. The basic ingredients in all the methods include total capital costs or their equivalent uniform annual value, and annual costs for maintenance, operating, accident, and travel time costs. Though the methods use the ingredients in different ways the result of each method is the selection of the same transportation system as being the most economic when based on similar minimum attractive rates of return and unit travel time costs.

In the total annual transportation cost method the systems are analyzed as a group to find the one most likely to produce the minimum total annual cost. In the benefit-cost ratio method and the rate-of-return method, however, the analysis is accomplished by the use of pairs when one transportation system alternative is compared to another transportation system alternative. Successive comparisons eliminate the poorest systems economy-wise until only the best one is left.

Total Annual Transportation Cost Method

The concept of the total annual transportation cost method is that the transportation user or society in general deserves to obtain transportation at the lowest cost. Therefore,

TABLE 6

TOTAL ANNUAL TRANSPORTATION COSTS BASED ON VARIOUS CONDITIONS
(in thousands of dollars)

Transportation System	Travel Time Cost Per Person Per Hour	Interest Rate (%)				
		0	3	6	10	15
2A	$0.00	693,200	711,953	734,304	768,603	816,417
	0.50	940,005	958,758	981,109	1,015,408	1,063,222
	1.00	1,186,810	1,205,563	1,227,914	1,262,213	1,310,027
	1.50	1,433,615	1,452,368	1,474,719	1,509,018	1,556,832
	2.00	1,680,420	1,699,173	1,721,524	1,755,823	1,803,637
3A	0.00	731,643	759,298	792,272	842,884	913,441
	0.50	923,752	951,407	984,381	1,034,993	1,105,550
	1.00	1,115,863	1,143,518	1,176,492	1,227,104	1,297,661
	1.50	1,307,971	1,336,626	1,368,600	1,419,212	1,489,769
	2.00	1,500,081	1,527,736	1,560,710	1,611,322	1,681,879
4A	0.00	746,637	775,299	809,479	861,942	935,082
	0.50	972,019	1,000,681	1,034,861	1,087,324	1,160,464
	1.00	1,197,403	1,226,065	1,260,245	1,312,708	1,385,848
	1.50	1,422,785	1,451,447	1,485,627	1,538,090	1,611,230
	2.00	1,648,169	1,676,831	1,711,011	1,763,474	1,836,614
5B	0.00	617,883	635,882	659,533	694,303	742,773
	0.50	806,295	825,294	847,945	882,715	931,185
	1.00	994,669	1,013,668	1,036,319	1,071,089	1,119,559
	1.50	1,183,123	1,202,122	1,224,773	1,259,543	1,308,013
	2.00	1,371,535	1,390,534	1,413,185	1,447,955	1,496,425
6B	0.00	642,043	668,329	699,675	747,798	814,884
	0.50	809,541	835,827	867,173	915,296	982,382
	1.00	977,040	1,003,326	1,034,672	1,082,795	1,149,881
	1.50	1,144,539	1,170,825	1,202,171	1,250,294	1,317,380
	2.00	1,312,037	1,338,323	1,369,669	1,417,792	1,484,878

TABLE 7

RELATIVE ORDER OF ECONOMY OF TRANSPORTATION SYSTEMS AS DETERMINED BY TOTAL ANNUAL TRANSPORTATION COST METHOD

Travel Time Cost Per Person Per Hour	Order of Increasing Cost	Interest Rate (%)				
		0	3	6	10	15
$0.00	1	5B	5B	5B	5B	5B
	2	6B	6B	6B	6B	6B
	3	2A	2A	2A	2A	2A
	4	3A	3A	3A	3A	3A
	5	4A	4A	4A	4A	4A
$0.50	1	5B	5B	5B	5B	5B
	2	6B	6B	6B	6B	6B
	3	3A	3A	2A	2A	2A
	4	2A	2A	3A	3A	3A
	5	4A	4A	4A	4A	4A
$1.00	1	6B	6B	6B	5B	5B
	2	5B	5B	5B	6B	6B
	3	3A	3A	3A	3A	3A
	4	2A	2A	2A	2A	2A
	5	4A	4A	4A	4A	4A
$1.50	1	6B	6B	6B	6B	5B
	2	5B	5B	5B	5B	6B
	3	3A	3A	3A	3A	3A
	4	4A	4A	2A	2A	2A
	5	2A	2A	4A	4A	4A
$2.00	1	6B	6B	6B	6B	6B
	2	5B	5B	5B	5B	5B
	3	3A	3A	3A	3A	3A
	4	4A	4A	4A	2A	2A
	5	2A	2A	2A	4A	4A

TABLE 8

INCREMENTAL BENEFITS BASED ON VARIOUS UNIT TRAVEL TIME COSTS
(in thousands of dollars)

Transportation Systems Compared	Travel Time Cost Per Person Per Hour				
	$0	$0.50	$1.00	$1.50	$2.00
2A-5B	75,686	134,079	192,510	250,861	309,254
2A-6B	68,248	147,555	226,861	306,167	385,474
2A-3A	-18,013	36,683	91,377	146,074	200,769
2A-4A	-30,757	-9,334	12,087	33,510	54,931
5B-6B	-7,438	13,476	34,351	55,306	76,220
5B-3A	-93,699	-97,396	-101,133	-101,787	-108,485
5B-4A	-106,433	-143,413	-180,423	-217,351	-254,323
6B-3A	-86,261	-110,872	-135,484	-160,093	-184,705
6B-4A	-99,005	-156,889	-214,774	-272,657	-330,543
3A-4A	-12,744	-46,017	-79,290	-112,564	-145,838

all the costs related to each transportation system are totaled on an annual basis to determine the one resulting in the minimum total annual cost. Table 6 shows the result of adding the equivalent uniform annual capital costs from Table 5 and the maintenance, operating, accident, and time costs from Table 3 for each system. Table 7 shows the transportation systems arranged by order of increasing total annual transportation cost for the various interest rates and unit travel time costs. Based on the use of $1.00 per hour per person travel time costs and the 6 percent interest rate, system 0B has the lowest total annual cost.

Benefit-Cost Ratio Method

One measure of economic desirability in comparing two proposed alternate transportation systems is the ratio of net annual benefits to net annual capital costs. In order to satisfy the concept that benefits must at least equal costs, the benefit-cost ratio must be 1.0 or larger.

Benefit-cost ratios were calculated for all possible comparisons of paired alternative transportation systems. Two general uses were made of those ratios. The first use was to determine whether or not the construction and equipment costs of Systems 3A, 4A, 5B and 6B would result in benefits that would justify construction of the systems when compared with the base transportation system, 2A, which will soon be in existence. The second use was to determine whether or not each increment of capital cost in going to successively more costly transportation systems also resulted in benefits. The latter use of the benefit-cost ratio method is a systematic approach

TABLE 9

INCREMENTAL EQUIVALENT UNIFORM ANNUAL CAPITAL COSTS BASED ON VARIOUS INTEREST RATES
(in thousands of dollars)

Transportation Systems Compared	Interest Rate (%)				
	0	3	6	10	15
2A-5B	369	615	915	1,386	2,042
2A-6B	17,071	24,624	33,619	47,443	66,715
2A-3A	20,430	29,332	39,955	56,268	79,011
2A-4A	22,680	32,589	44,418	62,582	87,908
5B-6B	16,722	24,009	32,704	46,057	64,673
5B-3A	20,061	28,717	39,040	54,882	76,969
5B-4A	22,311	31,974	43,503	61,196	85,866
6B-3A	3,339	4,708	6,336	8,825	12,296
6B-4A	5,589	7,965	10,799	15,139	21,193
3A-4A	2,250	3,257	4,463	6,314	8,897

that selects the most economic transportation system. It eliminates the need for some of the paired comparisons of transportation systems, but all comparisons are shown for the reader's perusal.

The incremental benefit for each paired comparison of transportation systems is shown in Table 8. The figures are based on the data in Table 3. For example, System 2A compared with the higher total capital cost System 3A at the $1.00 per hour unit travel time cost show respective net annual totals of maintenance, operating, accident, and travel time costs equal to $1,143,146,000 and $1,051,769,000. Therefore, the benefit or net reduction is equal to $91,377,000 as shown in Table 8 for the paired system comparison. Sometimes the comparisons do not result in reductions of net annual totals of maintenance, operating, accident, and travel time costs; instead of a reduction there may be an increase. In that situation the benefits shown in Table 8 are indicated as being negative.

The incremental cost for each paired comparison is shown in Table 9. The figures are based on data in Table 5. For example, System 2A compared with the higher total capital cost System 3A at the 6 percent interest rate shows respective equivalent uniform annual capital costs equal to $84,768,000 and $124,723,000. Therefore, the increment or increase in equivalent uniform annual costs is $39,955,000 as shown in Table 9 for the paired comparison. The increments of equivalent uniform annual capital costs will always be positive since the lower total capital cost transportation system is always the base for the paired comparisons.

The result of dividing incremental benefits by incremental costs for each paired comparison of systems is summarized in Table 10. Using the paired comparison of

TABLE 10

INCREMENTAL BENEFIT-COST RATIOS BASED ON VARIOUS INTEREST RATES AND UNIT COSTS FOR TRAVEL TIME

Transportation Systems Compared	Travel Time Cost Per Person Per Hour	Interest Rate (%)				
		0	3	6	10	15
2A-5B	$0 00	205.1	123.1	827.2	54.6	37.1
	0.50	363.4	218.0	146.5	96.7	65.7
	1.00	521.7	313.0	210.4	138.9	94.3
	1.50	679.8	407.9	274.2	180.9	122.9
	2.00	838.1	502.9	338.0	223.1	151.4
2A-6B	0.00	4.0	2.8	2.0	1.4	1.0
	0.50	8.6	6.0	4.4	3.1	2.2
	1.00	13.3	9.2	6.7	4.8	3.4
	1.50	17.9	12.4	9.1	6.5	4.6
	2.00	22.6	15.7	11.5	8.1	5.8
2A-3A	0.00	*	*	*	*	*
	0.50	1.8	1.2	0.9	0.7	0.5
	1.00	4.5	3.1	2.3	1.6	1.2
	1.50	7.1	5.0	2.3	1.6	1.2
	2.00	9.8	6.8	5.0	3.6	2.5
2A-4A	0.00	*	*	*	*	*
	0.50	*	*	*	*	*
	1.00	0.5	0.4	0.3	0.2	0.1
	1.50	1.5	1.0	0.8	0.5	0.4
	2.00	2.4	1.7	1.2	0.9	0.6
5B-6B	0.00	*	*	*	*	*
	0.50	0.8	0.6	0.4	0.3	0.2
	1.00	2.0	1.4	1.1	0.7	0.5
	1.50	3.3	2.3	1.7	1.2	0.9
	2.00	4.6	3.2	2.3	1.7	1.2
5B-3A	0 - 2.00	*	*	*	*	*
5B-4A	0 - 2.00	*	*	*	*	*
6B-3A	0 - 2.00	*	*	*	*	*
6B-4A	0 - 2.00	*	*	*	*	*
3A-4A	0 - 2.00	*	*	*	*	*

*Negative benefit-cost ratios.

TABLE 11

TRANSPORTATION SYSTEMS ARRANGED BY ORDER OF INCREASING TOTAL CAPITAL COSTS

Transportation Systems	Total Capital Cost	Transportation Systems	Total Capital Cost
2A	$1,076,323,000	3A	$1,587,056,000
5B	1,090,268,000	4A	1,644,806,000
6B	1,508,319,000		

Systems 2A and 3A again, the incremental annual benefits ($91,377,000) based on the $1.00 per hour unit travel time costs when divided by the incremental equivalent uniform annual capital cost ($39,955,000) based on the 6 percent rate, produces the benefit-cost ratio of 2.3 shown in Table 10. Therefore, the benefits to be derived by the reduction of the net annual total of maintenance, operating, accident and travel time costs exceed the additional capital cost required in order to obtain the benefits. On that basis the investment of the increment of capital costs for System 3A compared with 2A would be economical.

Benefit-cost ratios lower than 1.0 or negative in sign indicate that the investment of the increment of capital for the paired comparison of transportation systems would be uneconomical. The asterisks in Table 10 indicate negative benefit-cost ratios.

Transportation System Economy and Justification—The paired comparisons of Systems 2A-5B, 2A-6B, 2A-3A, and 2A-4A by the benefit-cost ratio method of analysis indicate that three of the transportation systems can be economically justified. Using the 6 percent minimum attractive rate of return and the $1.00 per hour unit travel time costs, Systems 5B, 6B and 3A, when compared with the base System 2A, each show benefit-cost ratios larger than 1.0.

The largest benefit-cost ratio does not necessarily indicate the most economical transportation system. It will be noticed that the largest benefit-cost ratios occur for the paired comparison of Systems 2A and 5B. System 5B will have to be compared with the other transportation systems having higher total capital costs in order to determine if the increment of cost in going to the more expensive system would result in incremental benefits that exceed the increment of costs. Thus, the need for a systematic approach in analyzing the economy of the transportation systems is established.

Economy of Transportation System Formulation—The following discussion describes the systematic approach that is used in selecting the most economical transportation system using benefit-cost ratios. It is an approach commonly used in engineering economy analysis to select the most economical alternative from among a list of multiple alternatives (5, p. 24).

TABLE 12

EXAMPLE OF PROCEDURE USED TO DETERMINE MOST ECONOMICAL TRANSPORTATION SYSTEM USING INCREMENTAL BENEFIT-COST RATIO METHOD BASED ON 6 PERCENT INTEREST RATE AND $1.00 PER HOUR TRAVEL TIME COSTS PER PERSON

Transportation Systems Compared		Incremental Annual Benefits Resulting from Net Reductions in Maintenance, Operation, Accident and Travel Time Costs	Incremental Equivalent Uniform Annual Capital Costs	Incremental Benefit-Cost Ratio	Conclusion
Base Alternative Transportation System for Comparison ("Contender")	Next Most Costly Transportation System Based on Total Capital Costs ("Challenger")				
2A	5B	$192,510,000	$ 915,000	210.39	Drop 2A
5B	6B	34,351,000	32,704,000	1.05	Drop 5B
6B	3A	-135,484,000	6,336,000	< 1.00	Drop 3A
6B	4A	-214,774,000	10,799,000	< 1.00	Drop 4A 6B is the winner

TABLE 13

MOST ECONOMICAL TRANSPORTATION SYSTEM AS DETERMINED BY INCREMENTAL BENEFIT-COST RATIO METHOD BASED ON VARIOUS INTEREST RATES AND UNIT TRAVEL TIME COSTS

Travel Time Cost Per Person Per Hour	Interest Rates (%)				
	0	3	6	10	15
$0.00	5B	5B	5B	5B	5B
0.50	5B	5B	5B	5B	5B
1.00	6B	6B	6B	5B	5B
1.50	6B	6B	6B	6B	5B
2.00	6B	6B	6B	6B	6B

Successive paired comparisons of transportation systems are made in the order determined by increasing total capital costs. The alternative systems arranged by order of increasing total capital costs are shown in Table 11.

An example of the procedure used is shown in Table 12 based on the 6 percent minimum attractive rate of return and unit travel time costs of $1.00 per hour per person. The incremental annual benefits shown in column 3 for each paired comparison of transportation systems were taken from Table 8. The incremental equivalent uniform annual capital costs were taken from Table 9. The first comparison is that of Systems 2A and 5B. System 2A, the "contender," must meet the "challenge" by System 5B. The benefit-cost ratio for that comparison is 210 which shows that System 5B is superior to System 2A. Because of the superiority of 5B to 2A a comparison of the three remaining alternative systems with 2A has no relevance in choosing among the five original alternatives. The conclusion as shown in Table 12 is to drop System 2A from any further comparison with the other systems.

The next paired comparison takes System 5B as the "contender" and its "challenger" as the next most costly system, which is 6B. The benefit-cost ratio is slightly greater than 1.0 and the conclusion then is to drop 5B from further comparison with other transportation systems.

System 6B is now challenged by System 3A. But the resulting benefit-cost ratio is less than 1.0, so System 3A is dropped and 6B remains to meet the last remaining challenger, System 4A. The resulting benefit-cost ratio is less than 1.0 and System 6B is the winner or the most economical transportation system.

It is evident that in comparing System 6B with any transportation system having lower total capital costs, the prospective increments of benefits in going to 6B are more than the prospective increments of costs. It is also evident that for all the transportation systems having higher costs than 6B, the prospective increment of benefits as compared to 6B is less than the prospective increment of costs.

A similar approach was used for the selection of the most economical transportation system based on the use of other interest rates and unit travel time costs per person. The results are shown in Table 13. A line has been drawn through the table to delineate the interest rates and unit travel time costs where the selection of the most economical system changes from 5B to 6B and vice versa.

Rate-of-Return Method

The rate-of-return method of analysis is the one to be preferred to both the total annual transportation cost method and the benefit-cost ratio method. The rate-of-return method measures the benefits shown by comparisons of transportation systems in a term easily understood and used in business decisions. Another advantage of the rate-of-return method is that it makes it unnecessary to select an interest rate for the amortization of total capital costs over the analysis period.

The rate-of-return method is similar to the benefit-cost ratio method of analysis in two respects. Transportation systems are paired for the purpose of making comparisons, and the systematic approach described earlier can be used for the selection of the

TABLE 14

INCREMENTAL TOTAL CAPITAL COSTS RESULTING FROM COMPARISONS OF TRANSPORTATION SYSTEMS

Transportation Systems Compared	Increment of Total Capital Cost (000)
2A-5B	$ 13,945
2A-6B	431,996
2A-3A	510,733
2A-4A	658,483
5B-6B	418,051
5B-3A	496,788
5B-4A	554,538
6B-3A	78,737
6B-4A	136,487
3A-4A	57,750

most economical system. The minimum attractive rate of return is used instead of the benefit-cost ratio of 1.0 to serve as an indicator of the economy for each paired comparison of systems. The incremental benefit shown by any paired comparison of transportation systems for the rate-of-return method is the same as those used in the benefit-cost ratio method (Table 8).

In the rate-of-return method the benefit shown by any paired comparison of transportation systems is divided by the increment of total capital cost between the two systems. The increment of total capital cost between paired comparisons is shown in Table 14. The quotient from the division is the capital recovery factor for the 25-year analysis period. The capital recovery factors for all the paired comparisons are shown in Table 15.

These capital recovery factors were used to enter interest tables and select the appropriate rate of return (3). An example can be made by the use of Table 4. For

TABLE 15

CAPITAL RECOVERY FACTORS FOR TRANSPORTATION SYSTEM COMPARISONS
(Incremental Annual Benefits Divided by Incremental Total Capital Costs)

Transportation Systems Compared	Travel Time Cost Per Person ($)				
	0	0.50	1.00	1.50	2.00
2A-5B	5.4275	9.6148	13.8049	17.9893	22.1766
2A-6B	0.1580	0.3416	0.5251	0.7087	0.8923
2A-3A	*	0.0718	0.1789	0.2860	0.3931
2A-4A	*	*	0.0104	0.0509	0.0034
5B-6B	*	0.0322	0.0822	0.1323	0.1823
5B-3A	*	*	*	*	*
5B-4A	*	*	*	*	*
6B-3A	*	*	*	*	*
6B-4A	*	*	*	*	*
3A-4A	*	*	*	*	*

*Negative benefits (capital recovery factor not applicable).

TABLE 16

PERCENTAGE RATES OF RETURN ON INCREMENTS OF INVESTMENT BASED ON VARIOUS UNIT TRAVEL TIME COSTS

Transportation Systems Compared	Travel Time Cost Per Person Per Hour ($)				
	0	0.50	1.00	1.50	2.00
2A-5B	543	961	1380	1799	2218
2A-6B	15	34	53	71	89
2A-3A	*	5	18	29	39
2A-4A	*	*	0	2	7
5B-6B	*	0	7	13	18
5B-3A	*	*	*	*	*
5B-4A	*	*	*	*	*
6B-3A	*	*	*	*	*
6B-4A	*	*	*	*	*
3A-4A	*	*	*	*	*

*Negative benefits (loss on the incremental investment of capital).

TABLE 17

EXAMPLE OF PROCEDURE USED TO DETERMINE MOST ECONOMICAL TRANSPORTATION SYSTEM USING INCREMENTAL RATE-OF-RETURN METHOD BASED ON MINIMUM ATTRACTIVE RATE OF RETURN AND $1.00 PER HOUR TRAVEL TIME COSTS PER PERSON

Transportation Systems Compared		Incremental Annual Benefits Resulting from Net Reductions in Maintenance, Operation, Accident and Travel Time Costs	Incremental Total Capital Costs for Transportation System Construction and Equipment	Incremental Capital Recovery Factor	Rate of Return (%)	Decision
Base Alternative Transportation System for Comparison ("Contender")	Next Most Costly Transportation System Based on Total Capital Costs ("Challenger")					
2A	5B	$192,510,000	$ 13,945,000	13.8049	1380	Drop 2A
5B	6B	34,351,000	418,051,000	0.0822	7	Drop 5B
6B	3A	-134,484,000	79,737,000	*	*	Drop 3A
6B	4A	-214,774,000	136,487,000	*	*	Drop 4A 6B is the winner

*Negative benefits do not produce a return on increments of investment.

the paired comparison of Systems 5B and 6B at unit travel time costs of $1.00 per hour per person, Table 15 shows a capital recovery factor of 0.0822. Entering Table 4, for a period of 25 years the interest rate for a capital recovery factor of 0.0822 can be interpolated to be near 7 percent. Thus the rate of return shown in Table 16 for the example is 7 percent.

Economy of Transportation System Justification—The comparison of Systems 5B, 6B, 3A, and 4A with the base System 2A by the rate-of-return method shows that three of the systems can be economically justified when using a 6 percent minimum attractive rate of return and $1.00 per hour travel time costs per person (Table 16). Systems 5B, 6B, and 3A each show rates of return in excess of 6 percent when compared with System 2A. System 4A compared with 2A did not result in benefits large enough to meet the 6 percent minimum attractive rate of return and, therefore, 4A cannot be economically justified.

An asterisk has been used in Table 16 to indicate those paired comparisons of transportation systems that would result in negative rates of return on investment of the increment of total capital costs. Such incremental investments of total capital, therefore, would not be economical.

The highest rate of return shown in Table 16, which results from the comparison of Systems 5B and 2A, does not necessarily indicate the most economical transportation system. Again, as for the benefit-cost ratio method, the procedure for selecting the most economical alternate from a list of multiple alternatives is used to select the most economical transportation system.

Economy of Transportation System Formulation—An example is shown in Table 17 of the procedure used to select the most economical transportation using the incremental

TABLE 18

MOST ECONOMICAL TRANSPORTATION SYSTEM AS DETERMINED BY INCREMENTAL RATE-OF-RETURN METHOD BASED ON VARIOUS UNIT TRAVEL TIME COSTS AND MINIMUM ATTRACTIVE RATES OF RETURN

Travel Time Cost Per Person Per Hour	Minimum Attractive Rates of Return (%)				
	0	3	6	10	15
$0.00	5B	5B	5B	5B	5B
0.50	5B	5B	5B	5B	5B
1.00	6B	6B	6B	5B	5B
1.50	6B	6B	6B	6B	5B
2.00	6B	6B	6B	6B	6B

rate-of-return method based on a 6 percent minimum attractive rate of return and $1.00 per hour travel time costs per person. The transportation systems are compared by pairs in the order of increasing total capital costs. The incremental benefits shown in column 3 are taken from Table 8 for the respective transportation system comparisons at the $1.00 per hour unit travel time costs per person. The increments of total capital costs shown in column 4 are taken from Table 14 for the respective comparisons of transportation systems. The capital recovery factor shown in column 5 is obtained by dividing the incremental annual benefits in column 3 by the incremental total capital costs in column 4. For capital recovery factors above 0.28 based on the 25-year analysis period the percentage rate of return can be determined by moving the decimal point two places to the right. For capital recovery factors smaller than 0.28 interpolation must be made in interest tables showing capital recovery factors for the 25-year period in order to determine the interest rate.

The first comparison is System 2A, the "contender," meeting the next higher total capital cost "challenger," System 5B. The incremental rate of return exceeds the 6 percent minimum attractive rate of return so System 2A is dropped as a contender for further comparisons. System 5B becomes the new contender and it is successfully challenged by 6B, so 5B is dropped from further comparisons. System 6B is now challenged by the next higher total capital cost transportation system, which is 3A. System 3A does not prove to be a successful challenger as it does not show a return on the increment of investment. The contender, System 6B, remains to be challenged by System 4A, but it too does not show a return on the increment of investment of total capital costs. Therefore, System 6B is the winner or the most economical transportation system based on a 6 percent minimum attractive rate of return and $1.00 per hour travel time costs per person.

A similar approach was used for the selection of the most economical transportation system based on the use of various rates of return and unit travel time costs per person. The results are shown in Table 18. The line through the table is a visual aid. It delineates the change in the most economical transportation system based on various interest rates and unit travel time costs.

SELECTION OF THE MOST ECONOMICAL SYSTEM

The selection of the most economical transportation system by the three methods of engineering economy analysis is shown in Tables 7, 13, and 18. The tables show that the methods confirm one another in the selection of the most economical transportation system when using the same interest rate and unit travel time costs. For reasons given earlier an interest rate or minimum attractive rate of return equal to 6 percent and unit travel time costs of $1.00 per person per hour were considered preferable for use in this analysis. Based on these conditions, System 6B is the most economical transportation system.

Tables 7, 13, and 18 indicate the sensitivity of the analysis to interest rates and travel time costs. At low unit travel time costs ($0.00-$0.50) and relatively high interest rates (10-15%), System 5B is the most economical. However, low unit travel time costs in effect do not give credit for the decrease in traffic congestion and travel time that would result from providing additional transportation facilities over those included in System 5B. Also, the use of high interest rates favors any transportation system with relatively low total capital costs, as is the case for System 5B. System 2A and 5B in reality are unacceptable as systems to accommodate 1990 travel demands. But they must be used as base comparisons in order to determine the economy of other transportation systems. Realizing these conditions, it is significant that System 6B is indicated as being the next most economical system for the conditions of low unit travel time costs.

It should be noted that the presentation of all possible comparisons of the transportation systems enables a selection to be made of the most economical transportation system based on individual land-use plans. The selection from land-use Plan A would be System 3A and from land-use Plan B it would be System 6B. Where resulting total costs for transportation systems based on different land-use plans vary on a wider scale than in this analysis, such an approach may be preferred by analysts. Of course that approach is dependent on a sufficient number of study systems, based on each land-use plan, being available for analysis. Since there is an admitted limitation in comparing incremental benefits and incremental costs for systems based on different land-use plans, it is safe to predict that there will be increased emphasis on, and use of, the method of total annual transportation system costs. Though it has been proven many times that the results by the three methods of analysis are the same, the method of total annual costs is more convincing when transportation systems are based on different land-use plans.

LIMITATIONS OF THE ANALYSIS

Engineering economy analysis is used as a means to compare the tangible costs of competing alternative uses of funds. Socioeconomic or intangible factors, although they are important considerations, are difficult to evaluate in monetary terms. These intangible factors are not included in an engineering economy analysis. Because of their importance, however, they must be included as part of the decision-making process. Realizing these limitations, it should be understood that this particular economic analysis is a tool delineating, on an overall region-wide basis, the best choice (based only on tangible costs) among a series of alternative transportation systems.

There were a large number of transportation systems that could have been analyzed. Because of the limitations of manpower and time only five general transportation systems were selected for study in detail by PSRTS. Rapid rail transit facilities were not included in any Plan B transportation system. Since the Plan B land-use concept of cities and corridors would decrease transit usage as compared to Plan A transportation systems, that limitation was not significant.

Within the five transportation systems analyzed, Plan A systems did not include cross-Sound bridge facilities and the significance of that fact was not clear-cut. The presence of cross-Sound bridge facilities in the most economical transportation system (a Plan B system) does not necessarily mean that it would be best to replace ferry service by a bridge from a cost standpoint. The cross-Sound bridge would have to be studied by the use of engineering economy analysis methods to determine the advisability of including the bridge in either land-use plan.

CONCLUSIONS

The engineering economy analysis of alternative transportation systems established that the worst course of action from a cost standpoint that could be followed in the future would be to construct no new freeway, expressway, or other major street and highway facilities after completion of those currently being constructed and those budgeted for near-future construction.

The Plan B land-use pattern, which was the goal-oriented development pattern, from a cost standpoint was obviously preferable to Plan A, which represents a continuation of present trends in development following the current planning and land-use zoning of separate governmental jurisdictions in the region.

The most costly alternative transportation system from the standpoint of meeting regional objectives was found to be the one which includes a rapid transit system in the Seattle area.

REFERENCES

1. Winfrey, Robley. Concepts and Applications of Engineering Economy in the Highway Field. HRB Spec. Rept. 56, pp. 19-33, 1960.
2. Grant, E. L. Interest and the Rate of Return on Investments. HRB Spec. Rept. 56, pp. 82-90, 1960.
3. Grant, Eugene L., and Ireson, W. Grant. Principles of Engineering Economy, 4th Edition. The Ronald Press Co., New York, pp. 538-557, 1961.
4. Woods, K. B. Highway Engineering Handbook. McGraw-Hill Book Co., New York, pp. 3-11, 1960.
5. Grant, Eugene L., and Oglesby, Clarkson. Economy Studies for Highways. HRB Bull. 306, pp. 23-38, 1961.