The Application of Benefit-Cost Ratios to an Expressway System

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Benefit-cost ratios have most often been used to determine which is the best choice of several locations or designs for a single highway improvement. Two other uses of benefit-cost ratios have often been neglected. These are: first, to help determine the fiscal feasbility of constructing a network of expressways for a metropolitan area; and, second, to determine construction priorities for parts of the expressway network.

The benefit-cost ratio is defined as the ratio of the average annual benefits accruing to future users of the expressway to the discounted annual cost of building and maintaining the expressway. The method for calculating these ratios may be summarized as follows:

An appropriate time period must be determined over which the investment in the expressway system is to be amortized. For the Detroit area, this was assumed to be 25 years, which is the amortization period under the Michigan Revenue Bond Plan. Zone-to-zone interchange volumes are forecasted to an intermediate point that represents an average of traffic volumes throughout the entire 25-year period. The zonal interchange volumes are assigned to an expressway network. Calculations are made for each section of the network of the vehicle miles of travel on the expressway and of the vehicle miles of travel on alternate facilities for which expressway travel is being substituted. Appropriate unit costs per mile are applied to the estimated vehicle miles of travel to obtain an estimate of total user costs on the expressway and what these costs would have been on an alternate facility. Benefits accruing to expressway users are then equal to what the user costs are on an alternate facility less what these costs are on the expressway. Finally, knowing the discounted annual cost of building and maintaining the expressway, the benefit-cost ratio can be calculated.

Research has shown that unit costs per mile for travel on surface streets vary greatly between downtown and suburban areas while costs of using an expressway remain quite constant. Thus the benefits accruing to expressway users will vary greatly according to the type of area through which the trip is being made. This is a result of the amount of congestion encountered, the average speed, number of stops, and so on.

Areas for future research are pointed out, such as the need for more precise measures of the effect of traffic congestion on operating costs and the need to include all possible benefits and costs before the benefit-cost technique can be a conclusive tool. Among the latter are considerations of the effect of expressway locations on real estate values and retail trade.

● TRAFFIC congestion wastes resources. The high rates of fuel consumption, the wear and tear on drivers and vehicles, and the high accident rates occasioned by traffic congestion are but a few examples of this waste. As far back as the mid-1920's, it was estimated *(1)* that traffic congestion cost the country two billion dollars annually. Since then the rapid rate of growth of car ownership and of vehicle miles of travel as compared to highway construction would raise this cost substantially.

Improvements to the highway plant that

relieve congestion provide benefits that can be measured in money terms as a reduction of waste. The dollar volume of these benefits in relation to the cost of constructing and maintaining the improvement then provide a measure of the economic justification of such an improvement. It can be argued that the profitability or rate of return on an investment is just as applicable for government as it is for private enterprise in determining the worthwhileness of any capital outlay. Thus, a ratio of benefits to costs greater than unity indicates an investment may be valid since the public is receiving more for the service than it is paying to get it. And, the higher the benefit-cost ratio, the greater is the return to the public and consequently the better is the investment. Therefore, if these benefit-cost ratios can be calculated with reasonable accuracy, the various parts of a highway program can be assessed in terms of their feasibility and priority of construction.

Since any highway has a useful life of many years, its costs are amortized and the benefits provided are accrued through many years. The benefit-cost ratio is then equal to the total benefits derived through this life span divided by the total cost for the same period. For computational purposes it is easier to state this ratio as the benefits for a mean or average year divided by the discounted annual cost of the highway for that year. The reason for this is that as an area grows, traffic volumes grow and benefits grow and it is easier to predict traffic volumes for a mean year sometime in the future than to predict the incremental increases in those volumes for each year in the life of the highway. Thus, the calculation of benefits for any highway program first requires the prediction of traffic volumes for some future point in time.

Calculating benefit-cost ratios therefore presents a three-fold problem. First, some assumptions must be made concerning the appropriate time period to be used in comparing benefits to costs. Secondly, estimates must be made of the cost of constructing and maintaining the highway improvement. Finally, the types of benefits accruing from a highway improvement must be categorized, measured and assigned to traffic volumes so that estimates of the total amount of benefits can be made. Each of these problems will be discussed in detail in the following sections.

25-YEAR TIME PERIOD

Highways built over 100 years ago are still providing good service in the transportation system. Their original cost and the cost of maintaining and improving them has been paid for many times and will continue to be paid for over and over throughout the total life span of the facility by the economic services they render.

It is apparent that in reality costs are amortized and economic services are accrued over the entire life span of a highway. On the other hand, it can be argued that a highway expenditure must be amortized in a "reasonable" length of time to make it economically feasible.

In both the public and private sectors of the economy, investments are made from some source of funds and it is expected that these investments will be amortized over a predetermined time period. The length of this time period should not vary according to the means of financing, e. g. bond issue vs. current revenue, except as the amount of risk varies between the alternate methods of financing. Even so, a time period can be fixed by administrative policy so that the amount of risk would be solely determined by the interest rate. It can then be argued that this rate of interest is a just measure of the cost of capitalizing a highway improvement regardless of the means of financing. Thus, a time period for amortizing highway investments can be determined by the life of the highway bond issue. Further, the average annual cost can be determined knowing the time period, the type of bond issue and the interest rate applicable to it.

Since this paper is primarily concerned with benefit-cost applications for the Detroit area, the financing methods applicable to this area are the ones to be considered. The Michigan Revenue Bond Plan (*2*) had been used for partial financing of expressways now under construction. Local highway officials anticipate the continued use of this plan in financing an expressway network. This plan utilizes a 25-year bond issue with principal payments deferred for the first three years. The interest rate applicable to this bond issue was 2.125 percent. It is plausible to assume that this interest rate will hold for future bond issues for two reasons. First, local credit has already been accepted at this rate. Secondly, the interest rate on municipal bond issues has been staying quite close to this figure for the last few years (*3*).

The Michigan Plan explains the financing procedure for local funds. The inclusion of federal funds into the financing program must also be considered. This requires certain assumptions. First, it is assumed that the use of federal funds is subject to investment decisions and hence financing charges in a manner similar though not identical to those for using local funds. Second, it is assumed that an investment time period comparable to that used for local bond issues is applicable in the use of federal money. Third, it is assumed that an interest rate of 3 percent is appropriate for federal funds since this is the current rate on federal borrowing as pegged by Federal Reserve Board policy. Finally, it is assumed the financing ratio of 50 percent Federal and 50 percent local funds will be used for the expressway network in the Detroit area.

A summary of the effect of these assumptions indicates a 25-year bond issue with principal payments deferred for three years at an average interest rate of 2.55 to 2.60 percent. If the average interest rate is assumed to be 2.6 percent (the higher rate is chosen as the more conservative estimate of the amount of money available from a given bond issue), then $1,000,000 of highway improvement can be purchased at an annual cost of about $56,000 or a total cost of about $1,403,000. Any expense incurred in the administration and accounting of the bonds and the bond payments must, of course, be added to the above figures.

MEASUREMENT OF HIGHWAY COSTS

Like any other investment, there are two types of costs involved in the use of a highway. First is the capital outlay required to construct the highway. This is that portion of the total cost that is amortized at $56,000 per year for each million dollars of construction as discussed in the previous section. Secondly, there are the current costs in operating and maintaining the highway. Operational costs include such items as the need for additional police for traffic control. Maintenance costs include keeping the roadway in good condition, snow removal, and so on. Thus, the average annual total cost can be found by adding the average annual capital cost and the average annual current costs. Estimates of both capital and current costs must be made for any benefit-cost analysis. For purposes of this type of analysis in the Detroit area, estimates of construction costs have been provided by agencies participating in the Detroit Traffic Study. It is assumed that operational and maintenance costs will be offset by a reduction of these costs on other streets as expressways relieve traffic volumes on these streets.

CLASSIFICATION OF TYPES OF BENEFITS

Benefits accruing to the public from the construction and use of a new highway facility can be roughly classified according to whether they accrue to users or to non-users of the facility and whether they are direct or indirect benefits. This provides the following four categories, each of which will be discussed in some detail:

1. Direct-user benefits;
2. Indirect-user benefits;
3. Direct non-user benefits;
4. Indirect non-user benefits.

Direct-user benefits are those which accrue to users of the highway and can be measured in direct money terms. Examples include reductions in fuel and oil consumption, maintenance costs, losses due to accidents, and wages to operators of commercial vehicles.

Indirect-user benefits include those intangibles accruing to users for which some money value must be assigned. For example, they may be reductions in driving time, decreased driver strain, increased comfort and convenience, and so on.

Direct non-user benefits are those received by people who do not use the facility but whose livelihood is improved by it. For example, property values adjacent to an expressway may rise relative to other areas because of increased accessibility. This implies increased trade, retardation of urban blight, and so on.

Finally, indirect non-user benefits are those intangibles accruing to the community through improved transportation facilities. For example, juvenile delinquency and the crime rate may fall as blighted areas are given a new lease on life. Or, the ability to evacuate a city faster in the event of atomic attack surely has some value in the potential saving of human lives.

The measurement of all of these benefits constitutes an enormous task. Such a computation is probably prohibitive from the standpoint of current technology. Further, the inclusion of all of these benefits is justifiable only if the social costs involved in building a highway are added to the costs of right-of-way acquisition and construction. By the same token that the appreciation of land values and improved civil defense are social benefits, so also the disruption of neighborhood patterns and the forced movement of people from the acquired right-of-way are social costs. This argument dictates that social or non-user benefits should be excluded from consideration until such time as the technology is sufficiently advanced to provide precise measures for both these types of benefits and for social costs.

Thus, the calculation of benefit-cost ratios involves the comparison of user benefits and highway construction costs. In the current political climate, it may be best that such a calculation is the one used. To the extent that user taxes are the basis for financing highway improvements, then such a calculation gives a measure of the monetary rate of return on investments made with these taxes. A case might be made for the diversion of money from the general tax fund to help finance highway improvements because of the social benefits accrued. However, in the interests of conservatism, it is probably better to use only the direct comparisons until the techniques for measuring social benefits and costs are known and the legislative milieu is such that general tax fund diversion for highway expenditures can be considered.

Application of User Costs

It has been argued above that benefits derived from a new or improved facility can be defined as a reduction of resource waste resulting from the alleviation of traffic congestion. It has been further argued that these benefits should be measured as a reduction in highway user costs. Knowing the values for the components of these user costs, the total user costs for both the new facility and for an alternate one can be determined. Then, the benefits are the difference between the total user costs for the two highways. This can be defined in the equation:

$$B = V_e \cdot A \cdot C_a - V_e(X \cdot C_e + L \cdot C_a) \quad (1)$$

where:

B = the total benefits;

V_e = the volume using the new facility (expressway);

A = the length of the alternate route in miles;

C_a = the unit cost per mile of alternate route;

X = the length of the expressway portion of the expressway trip in miles;

C_e = the unit cost per mile on the expressway;

L = the length of the city street portion of the expressway trip in miles.

This equation states that the total benefits derived from the new facility are accrued only by users of the facility (V_e) and are the differences in costs to these people occasioned by using this expressway in preference to the alternate route. Here the cost per user on the alternate route is equal to the length of the route times the cost per mile. Similarly, the cost per user of the expressway is equal to the length of that portion of the trip on the expressway and the length of that portion of the trip on city streets multiplied by the appropriate cost per mile factors. It is assumed that the cost per mile for the non-expressway legs of the expressway trip is the same as the cost per mile on the alternate route since both are on city streets.

The terms in equation (1) can be shuffled around so that:

$$B = V_e \cdot (A - L) \cdot C_a - V_e \cdot X \cdot C_e \quad (1a)$$

Then, dividing both sides of the equation by "X" to obtain a measure of benefits per expressway mile yields the following:

$$B/X = V_e \cdot (A - L)/X \cdot C_a - V_e \cdot C_e \quad (2)$$

The factor $(A - L)/X$ is a measure of the amount of the trip on the alternate route for which the driver is substituting a mile of travel on an expressway. For example, if this factor equalled 0.8, the driver would be choosing to travel 1.0 miles on an expressway in preference to 0.8 miles on city streets; or similarly, the choice would be for 4.0 miles of travel on an expressway rather than 3.2 miles on city streets. This factor therefore accounts for the fact that many people will divert to an expressway even though they must drive a greater distance in so doing.

From equation (2) it is apparent that the factor $(A - L)/X$ can be applied directly to the expressway volumes. The appropriate unit cost figure per mile can then be multiplied by these volumes, and the difference between the total user costs represents the amount of benefits per expressway mile.

The usage of an expressway by any particular zone-to-zone interchange is normally expressed as a percentage of the total interchange, this percentage bieng a function of comparative measures of distance, time, speed or a combination of these variables. Thus, assignment of anticipated traffic volumes to a new facility can be made. Similarly, assignment to an expressway network can be made with the additional proviso that trips must be routed through the network. Then, the anticipated traffic volume for any particular section of the network is equal to the sum of the assigned zonal interchange volumes converging on that particular section.[1]

In a similar fashion, the assigned traffic volumes multiplied by their appropriate $(A - L)/X$ factor can be summarized for any particular section of any expressway network. Then, for any mile on a given expressway section, the assigned traffic volume is equal to the vehicle miles of travel. Further, the factored traffic volume represents the number of vehicle miles of travel on an alternate surface street for which expressway travel is being substituted.

The benefits per expressway mile for any section of the network can then be found by applying the appropriate user unit cost per mile to each of the volumes and taking the difference as follows:

$$B/X = C_a \cdot \sum [V_e \cdot (A - L)/X] - C_e \cdot \sum V_e \qquad (3)$$

where V_e and $V_e \cdot (A - L)/X$ now refer to traffic volumes and factored traffic volumes for individual zonal interchanges as they are assigned to the expressway system and then summated for any particular section. Examples of the procedure for routing zonal interchanges through an expressway system and the accumulation of the assigned and factored traffic volumes is shown in Figure 1.

[1] For detailed discussion of assignment see: Campbell, E. W., "Traffic Assignment," Detroit Metropolitan Area Traffic Study, October, 1955.

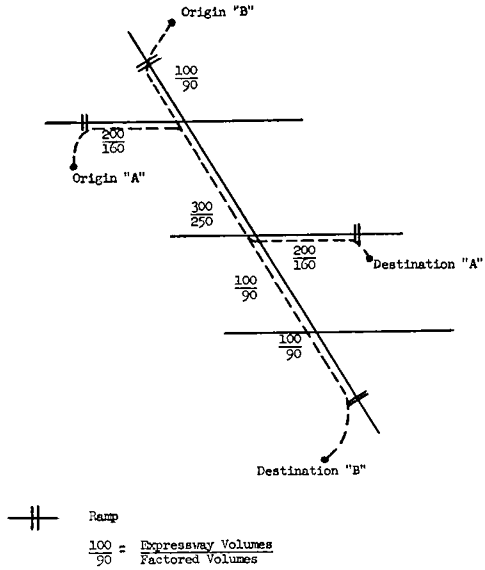

Figure 1. Illustration of trip routing through an expressway system and the accumulation of assigned volumes.

Forecasting Traffic Volumes

It has been mentioned that the benefits derived from an expressway are accrued by future rather than present traffic and that an estimate of these benefits therefore requires the prediction of future traffic volumes. The Detroit Metropolitan Area Traffic Study inventoried traffic as of 1953 and forecasted traffic volumes for 1980. Further, the Study Staff assigned these traffic volumes to an expressway network from the 1953 inventory and the 1980 forecast. These assigned volumes represent an estimate of what the vehicular flow volumes would be on the expressway network for these two points in time.

Knowing the expressway volumes for 1953 and 1980, the problem arises of predicting what these volumes are for the mean or average year used in the calculation of benefits. The Michigan Revenue Bond Plan has been used as the basis for calculating the average annual costs of the highway. It is assumed that the three-year deferment of principal payments in the Michigan Revenue Bond Plan roughly corresponds to the amount of time required for right-of-way acquisition and construction of a section of a new urban expressway. Implicit in this assumption is that the expressway section is long enough to be effectively utilized. It is further assumed that right-of-way acquisition and construction cannot begin prior to 1956. Then, 1956 plus 14 years (3 years as described above plus 11 years until the mid-point of retirement of principal) would make 1970 the year representing the mid-point of the time period during which the cost of an expressway section started in 1956 would be amortized by the benefits accruing to its users.

Knowing 1953 and 1980 zonal interchange volumes, 1970 volumes are obtained by a linear interpolation. Being a linear interpolation, the 1970 volumes also represent average volumes over the time period of amortization. This interpolation is not technically correct because traffic volumes usually follow a growth curve. Other research has shown that this curve is probably S-shaped for small areas and similar to the curves depicting population growth, rate of land use development and many other variables. Since growth of the Detroit Study area appears to be in the upper portion of an S-curve, a linear interpolation would understate the average traffic volumes. However, growth curves are not available with sufficient detail or precision to permit their use in this analysis. Hence, a linear interpolation is used, knowing that it will understate traffic volumes and that the resultant benefit-cost ratios will therefore be conservative.

Components of User Costs

User cost figures to be applied to the expressway volumes described above are comprised of many parts. These include:

1. Fuel consumption;
2. Oil consumption;
3. Tire wear;
4. Maintenance costs;
5. Accident costs;
6. Commercial wages;
7. Personal time.

Each of these components must be analyzed in sufficient detail to permit their use as speeds and driving conditions differ between expressway travel and city street travel and also as these conditions vary according to the type of area, e. g. downtown vs. suburban travel.

Fuel consumption, oil consumption, and tire wear have also been subdivided into two parts. The first part described rates of usage at nominal running speeds. The second shows the rate of additional usage occasioned by stopping and starting at varying speeds of approach to the stop.

Fuel consumption at nominal running speeds is shown in Figure 2.[2] A second-degree parabola fits the data very well through its entire range. As indicated, a correlation of 0 .992 is obtained for the equation:

$$Y = 0.0545 - 0.000587\,X + 0.0000129\,X^2 \quad (4)$$

where:

Y = fuel consumption in gallons per mile;
X = the nominal running speed.

Excess fuel consumption for each stop at varying approach speeds is shown in Figure 3.[3] Here a linear fit provides a correlation of 0.974 for the equation:

$$Y = -0.00020 + 0.00019\,X \quad (5)$$

where:

Y = the excess fuel consumption per stop in gallons per mile;
X = the speed for approach.

For computing costs of fuel consumption, it was assumed that gasoline costs 35 cents per gallon. This is the current price for premium gasoline in the Detroit Area. This is undoubtedly higher than the average price per gallon paid by motorists because many people

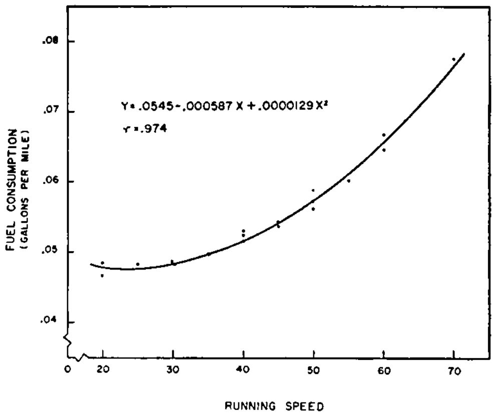

Figure 2. Fuel consumption at nominal running speeds.

[2] Sources for the information on fuel consumption include General Motors Corporation, Ford Motor Company, and the following article: Bone, A. J., "Travel Time and Gasoline Consumption Studies in Boston," Highway Research Board Proceedings, 1952.

[3] Sources for this information include the Ford Motor Company and the following article: Gibbons, John W., and Proctor, Albert, "Economic Costs of Traffic Congestion," Highway Research Board, Bulletin 86, 1954.

use the standard grade. On the other hand, the secular rise in gasoline prices should more than compensate for any discrepancy between the 35 cent figure that is used and what the average price actually is. Hence, costs of gasoline consumption will probably be conservative.

Oil consumption is assumed to be 9 percent of fuel consumption. This is roughly equal to the use of six quarts of premium oil and one chassis lubrication per 2000 miles. This is quite probably a conservative estimate of oil usage. Further, the long trend of rising prices would also make the cost per mile figures for oil consumption even more conservative.

Tire wear at nominal running speeds is shown in Figure 4.[4] A second-degree parabola fits the data well for a range of 20 to 60 miles per hour. Running speeds outside of this range present no problem because they are not encountered in practice. This type of fit yields a correlation of 0.964 for the equation:

$$Y = 0.00444 - 0.000256\,X + 0.00000744\,X^2 \tag{6}$$

where:

Y = tire wear in 0.001 inches per mile;
X = running speed in miles per hour.

Excess tire wear per stop caused by stop and go travel is shown in Figure 5.[5] The data are fitted to a semi-logarithmic curve that has a correlation of 0.998 for the following equation:

$$\text{Log}\ Y = -3.731 + 0.0457\,X \tag{7}$$

where:

Y = tread wear in 0.001 inches per mile;
X = the approach speed in miles per hour.

For computing costs of tire wear, it was assumed that a set of four tires costs \$104 and that there was 0.350 inches of tread per tire.[4]

Studies in maintenance costs done in California (*4*), indicate that driving on city streets results in a maintenance cost of 0.0020 dollars per mile for brakes and clutch. They assume that if there are five stops per mile on city streets that expressway travel would eliminate 90 percent of this cost. For lack of more precise data, a similar assumption is made for this analysis. By pro-rating these savings equally

[4] Sources for data on tire wear include Firestone Rubber Company, U. S. Rubber Company, and the following publication: "Road User Benefit Analysis for Highway Improvements," American Association of State Highway Officials, 1952.

[5] Sources for this figure are recent contracts made by the UAW-CIO and the AFL Teamsters Union.

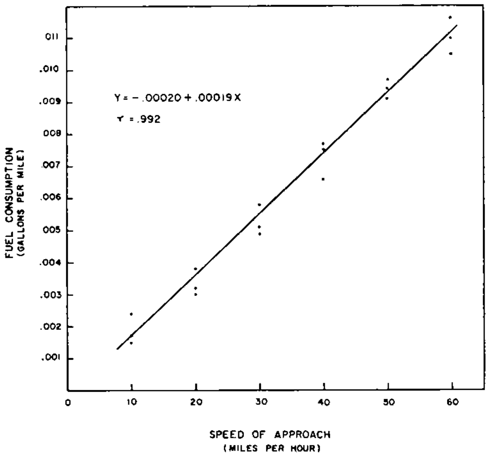

Figure 3. Excess fuel consumption per stop at varying speeds of approach.

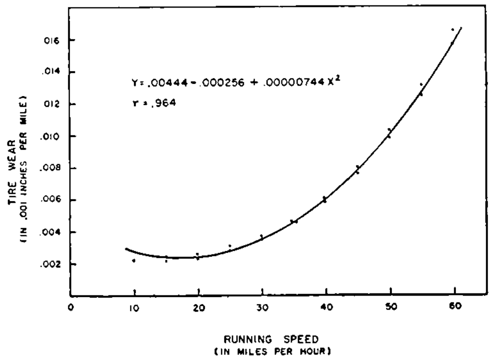

Figure 4. Tire wear at nominal running speeds.

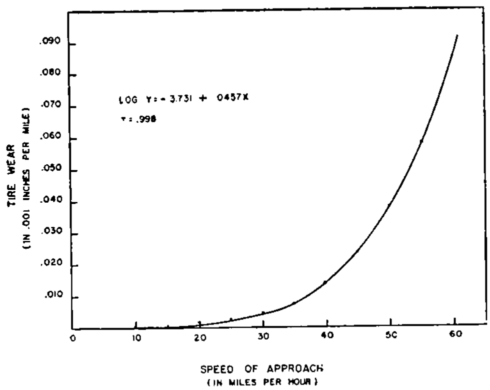

Figure 5. Excess tire wear per stop at varying speeds of approach.

across all stops, the following equation is obtained:

$$Y = 0.0002 + 0.000036\,X \qquad (8)$$

where:

Y = the maintenance cost in dollars per mile;

X = the number of stops per mile.

All of the above costs per mile are for passenger cars only. These costs must be corrected for the number of trucks in the traffic flow. Traffic counts on expressways in the Detroit area indicate that about 10 percent of the vehicles are trucks. Further, 10 percent of the vehicular trips reported in origin-destination survey of the Detroit area were truck trips. This analysis therefore uses 10 percent as the percentage of trucks using expressways. It is assumed that the operating costs of trucks are twice that of passenger cars. This, if anything, is conservative as evidenced by studies done in Los Angeles (*5*). Therefore, a factor of 1.1 is applied to the unit-cost-per-mile figure that can be prorated across all vehicles.

Estimates of the cost of accidents have been made by the National Safety Council (*6*). These figures extrapolated to 1955 prices along with accident rates prevalent in the Detroit area are summarized in Table 1. Thus, the resultant accident costs per vehicle mile of travel on expressways and on city streets can be computed.

Time savings accrue to both commercial and private passenger vehicles. The savings made by commercial vehicles are directly measurable in the form of commercial wages. For the Detroit area, the current wage rate is approximately $2.00 per hour.[5] This figure can be prorated across all vehicles at the rate of $.20 per hour because 10 percent of the vehicles in the traffic stream are trucks. The value of time savings to private passenger cars was assumed to be equal to $1.00 per hour. Prorated to all vehicles, this figure becomes $.90 per hour.

TABLE 1
COMPARISON OF ACCIDENT COSTS FOR EXPRESSWAYS AND CITY STREETS

	Accident Rate*	Cost per Accident†	Cost per Mile
Expressways			
Property damage	230	$ 184	$.00042
Personal injury	48	1,050	.00050
Fatality	3.0	28,000	.00084
Total			$.00176
City Streets			
Property damage	2,050	184	.00377
Personal injury	365	1,050	.00382
Fatality	6.5	28,000	.00182
Total			$.00942

* Per 100 million vehicle miles of travel for the year 1954.
† All costs are at 1955 prices.

User Costs Vary According to Driving Conditions

It is apparent that the use of most of the cost components described requires a knowledge of the average speed on expressways and city streets. Yet these average speeds vary according to the driving conditions prevalent in different parts of an urban area. For example, average speeds are lower in downtown areas than in suburban areas. On the other hand, the number of stops per mile is higher downtown than in the suburbs. It cannot be assumed that these differences will cancel out and that two user cost figures, one for expressways and the other for city streets, can be used throughout an urban area. Instead, the area must be partitioned into meaningful segments with each segment having similar driving conditions.

The Detroit Study Area was partitioned into rings (see Figure 6) and the prevailing driving conditions were established for each ring. The average speeds and number of stops per mile for each ring are shown in Table 2.

It is apparent that the average speed and the running speed are identical for the non-stop travel characteristic of expressways. On the other hand, the average speed is lower than the running speed on city streets due to the number of stops that must be made, either because of intersections or because of other vehicles stopping in the traffic stream for turns and the use of abutting business establishments, or both.

The total cost figures shown in Table 3 bear out the statement that differences in driving conditions throughout an urban area do not cancel out to permit the use of a single cost figure. Whereas costs to expressway users remain fairly constant, user costs on city streets decline steadily as distance from the downtown area increases. Thus, benefits per mile accruing to expressway users are greater in the down-

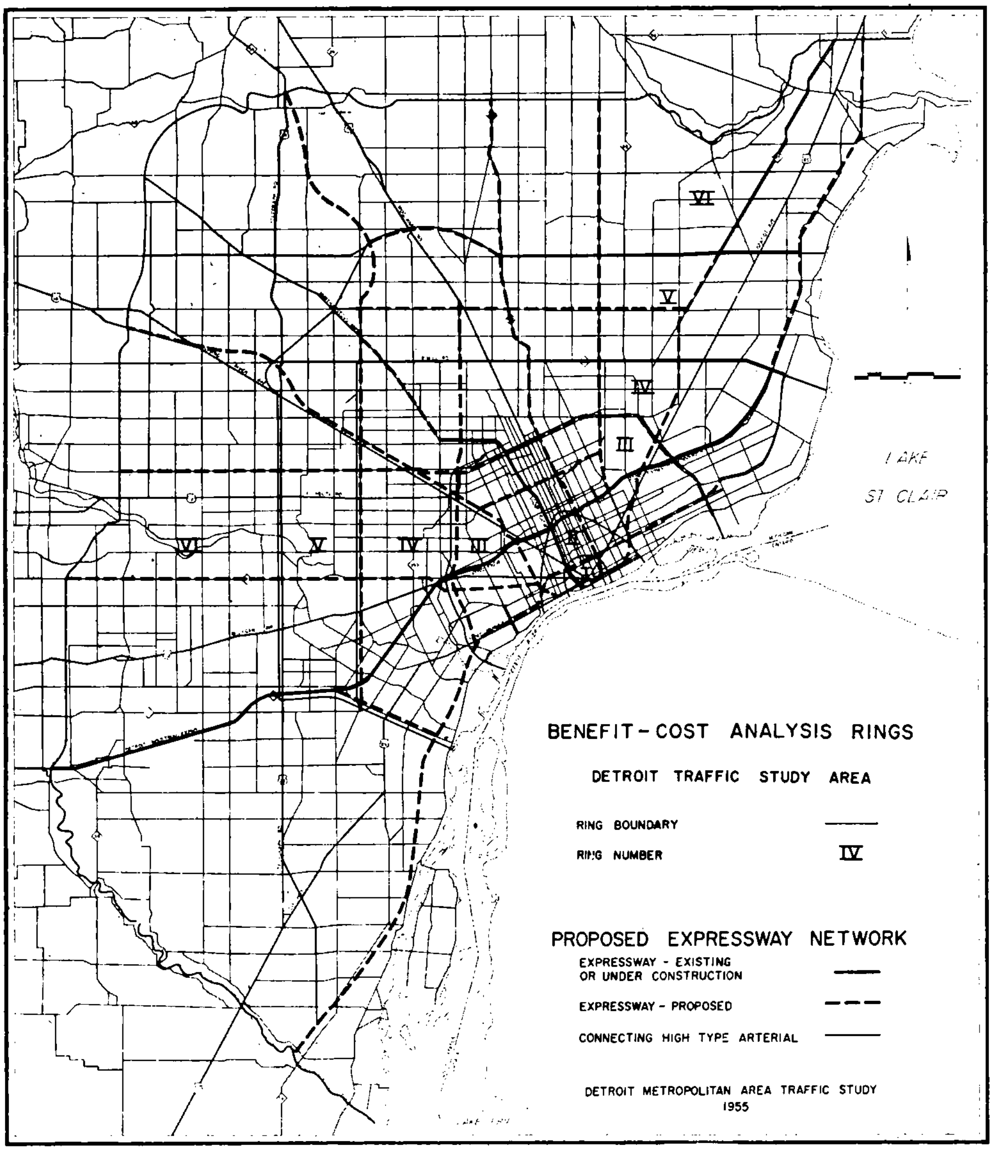

Figure 6.

town area than in the suburbs, all other things being equal.

WORK SHEET FOR CALCULATING BENEFIT-COST RATIOS

The actual computation of benefit-cost ratios can be done rapidly by inserting the appropriate figures into a worksheet. A sample worksheet could be made out with the following items:

1. Expressway section;
2. The sum of the 1970 expressway volumes multiplied by their individual $(A - L)/X$ factors;
3. The sum of the 1970 expressway volumes;
4. Unit user cost per mile on city streets;

TABLE 2
AVERAGE SPEEDS AND STOPS PER MILE BY RING FOR EXPRESSWAY AND CITY STREET TRAVEL

Ring	Expressways			City Streets		
	Average speed	Running speed	Stops per mile	Average speed	Running speed	Stops per mile
I	40	40	0	20	25	6
II	45	45	0	22.5	27.5	5
III	50	50	0	25	30	4
IV	50	50	0	25	30	3
V	55	55	0	27.5	32.5	2
VI	55	55	0	27.5	32.5	1

TABLE 3
UNIT-USER COST PER MILE FOR EXPRESSWAY AND CITY STREETS, BY RING
(in dollars)

Cost	Ring					
	I	II	III	IV	V	VI
Expressway						
Running fuel	$.0181	$.0190	$.0201	$.0201	$.0214	$.0214
Stop and go fuel	—	—	—	—	—	—
Running oil	.0017	.0017	.0018	.0018	.0020	.0020
Stop and go oil	—	—	—	—	—	—
Running tires	.0018	.0024	.0030	.0030	.0038	.0038
Stop and go tires	—	—	—	—	—	—
Maintenance	.0002	.0002	.0002	.0002	.0002	.0002
Sub-total	.0218	.0233	.0251	.0251	.0274	.0274
Times truck factor	.0240	.0256	.0276	.0276	.0301	.0301
Accident cost	.0018	.0018	.0018	.0018	.0018	.0018
Commercial wages	.0056	.0049	.0044	.0044	.0040	.0040
Sub-total	.0314	.0323	.0338	.0338	.0359	.0359
Personal time	.0225	.0200	.0180	.0180	.0164	.0164
Total	.0539	.0523	.0518	.0518	.0523	.0523
City Street						
Running fuel	$.0168	$.0168	$.0170	$.0170	$.0172	$.0172
Stop and go fuel	.0099	.0091	.0080	.0060	.0043	.0022
Running oil	.0015	.0015	.0016	.0016	.0016	.0016
Stop and go oil	.0009	.0008	.0007	.0006	.0004	.0002
Running tires	.0008	.0009	.0010	.0010	.0012	.0012
Stop and go tires	.0045	.0051	.0053	.0040	.0036	.0018
Maintenance	.0024	.0020	.0016	.0013	.0009	.0006
Sub-total	.0368	.0362	.0352	.0315	.0292	.0248
Times truck factor	.0405	.0398	.0387	.0347	.0321	.0273
Accident cost	.0094	.0094	.0094	.0094	.0094	.0094
Commercial wages	.0111	.0099	.0089	.0089	.0081	.0081
Sub-total	.0610	.0591	.0570	.0530	.0496	.0448
Personal time	.0450	.0400	.0360	.0360	.0327	.0327
Total	.1060	.0991	.0930	.0890	.0823	.0775

5. Unit user cost per mile on expressways;
6. Total user cost on city streets, equal to (4) times (2);
7. Total user cost on expressways, equal to (5) times (3);
8. Expressway benefits, equal to (6) minus (7);
9. Annual expressway benefits, assuming average daily expressway volumes are used, equal to 365 times (8);
10. Total expressway costs per mile;
11. Annual expressway costs per mile, equal to (10) times 56,000 divided by 1,000,000;
12. Benefit-cost ratio, equal to (9) divided by (11).

APPLICATION TO PROPOSED EXPRESSWAY PLAN FOR THE DETROIT AREA

The procedure described above was used to calculate benefit-cost ratios for the various sections of the expressway plan proposed for the Detroit area. The results of this application are shown in Figure 7. On this map, an expressway section is defined as being that portion of the expressway between the cordon line of the area and the first major interchange or as that portion between two consecutive interchanges.

At first glance, the wide range of benefit-cost ratios may not appear to have any pattern. However, closer examination of individual expressways will show some pattern of consistently high or low ratios. Further, the sections can be combined into larger, more meaningful segments. By multiplying the benefits per mile and costs per mile of a given section by the length of that section, the total benefits and total costs for the section are obtained. These can be added together and new benefit-cost ratios can be computed for any desired combination of sections.

Table 4 presents benefit-cost ratios summarized in this manner. This summarization was made with an attempt toward grouping the sections in a manner which would be useful for programming the order in which new expressways, or portions thereof, would be constructed. Benefit-cost ratios obtained by this grouping indicate that the Vernor-Fort expressway should be given top priority in programming new construction. Since the higher the ratio the greater is the return to the public per dollar of investment, the Vernor-Fort is the most profitable from the public viewpoint. Similarly, the John Lodge expressway would have second priority, Southfield third, and so on in descending order.

The benefit-cost ratio of 1.1 for the entire system indicates that if the entire system were

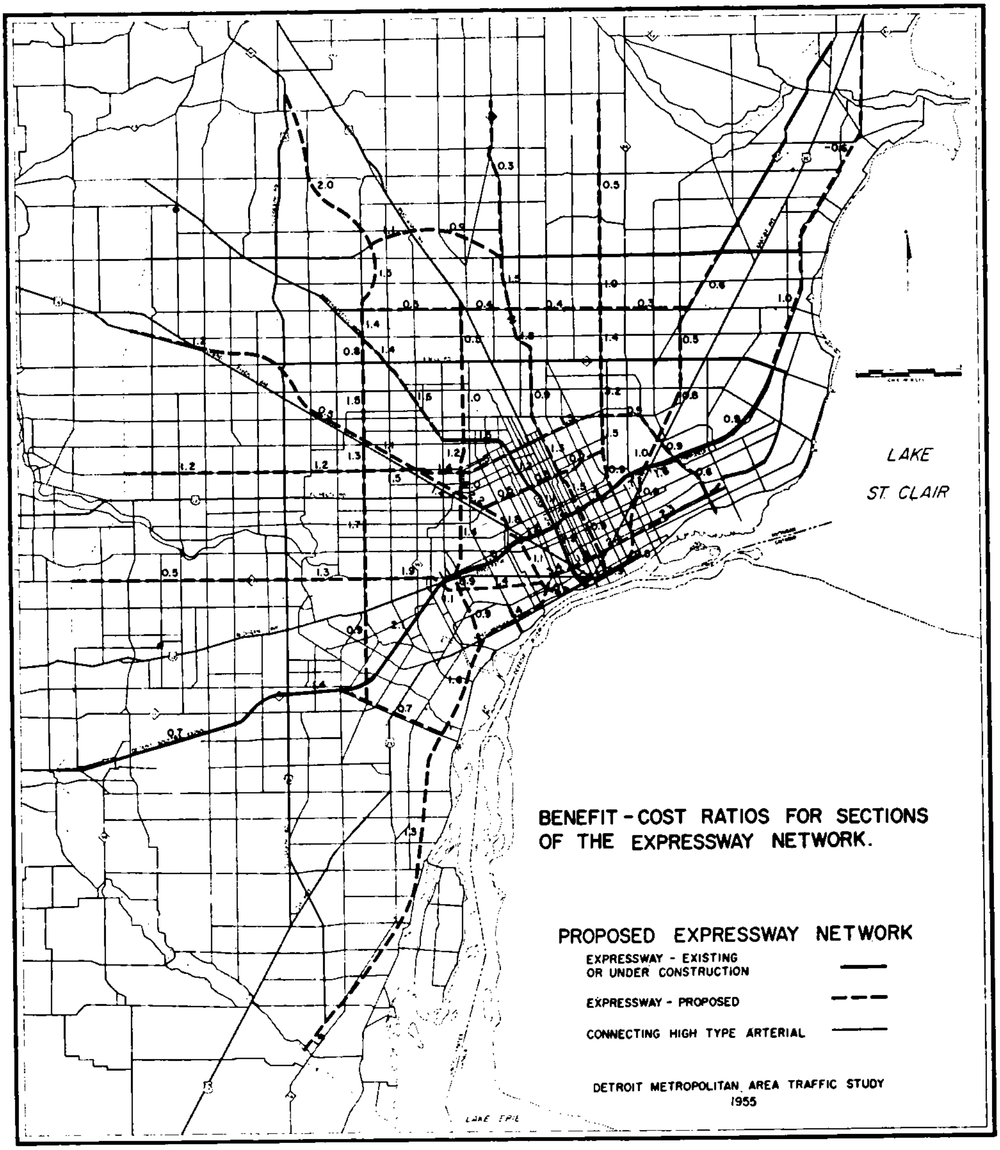

Figure 7.

built immediately, its costs would be offset by benefits to motorists in less than 25 years. Thus an economic justification for building the system is provided within the assumptions of the foregoing analysis.

It will be noted in Figure 7 and Table 4 that parts of the system have benefit-cost ratios less than one. This presents no major problem for several reasons. First, not all of the system can be constructed at once. Then, as construction is staged through different time periods, the time period for amortizing construction costs will shift farther into the future when volumes will tend to be higher and consequently the benefit-cost ratios will be higher. Second, since a secular price rise will have a greater effect on benefits than on costs, and it will because it will be effective over a much

TABLE 4
BENEFIT-COST RATIOS FOR EXPRESSWAYS IN THE PROPOSED PLAN FOR THE DETROIT AREA

Expressway	Benefit-Cost Ratio
Willow Run-Edsel Ford	
Cordon line to Michigan Avenue	1.3
Michigan Avenue to Eight Mile Road	1.3
Eight Mile Road to Cordon Line	0.1
Total	1.1
John Lodge	
Downtown to Wyoming Avenue	1.4
Wyoming Avenue to Southfield Expressway	1.5
Total	1.4
Vernor-Fort	1.8
Ford Road	1.2
Clairmount-Joy	0.5
Schoolcraft-Davison-Conner	
Cordon line to John Lodge Expressway	1.3
John Lodge Expressway to Hastings-Oakland Expressway	1.1
Hastings-Oakland Expressway to East Jefferson Avenue	0.9
Total	1.1
Grand River	1.1
Southfield	1.3
Livernois	1.1
Hastings-Oakland	
Downtown to Six Mile Road	1.2
Six Mile Road to Cordon Line	0.9
Total	1.0
Mound Road	1.2
Gratiot-Groesbeck	0.7
Ten Mile Road	0.3
Twelve Mile Road	0.9
Grand Total for System	1.1

greater time period, then the benefit-cost ratios shown above are understated. Finally, it is quite plausible to assume that certain portions of an expressway network must be included even if their benefit-cost ratios are less than 1.00 to permit the entire network to operate efficiently.

Hence, the benefit-cost ratios shown above perform a two-fold function. The first is to aid in the selection of construction priorities when used in conjunction with other measurements such as the relief of localized congestion provided by the expressway. The second is a measure of the profitability of the entire network.

SUMMARY

Benefits resulting from the construction of a new expressway are obtained by a reduction in the waste of human and economic resources. This reduction is the result of decreased vehicle operating cost, time savings, increased mobility, and many other economic factors.

Though these benefits are accrued over the entire life span of the facility, they must amortize the cost of the facility within a reasonable length of time for the construction of the expressway to be a profitable investment. For the Detroit area, bond financing for new expressways has used a 25-year issue. It is assumed that this represents the investment decision of responsible government officials as to the appropriate time period over which the investment should be amortized.

The measurement of all types of benefits and costs is prohibitive from the standpoint of current technology. Consequently, only benefits accruing to expressway users and costs of right-of-way acquisition and construction are considered in this analysis.

Benefits are calculated as the difference between user costs on the expressway and what user costs would have been on an alternate surface facility. These user costs must be applied directly to the miles of expressway travel and miles of city street travel because many people will travel a greater distance to use an expressway and this distance differential must be considered. Therefore, no single figure representing benefits per mile of expressway travel can be used with accurate results.

Further, these user costs will vary according to the type of area in which the expressway is being constructed, i.e. downtown vs. suburban. It has been shown in this paper that these costs vary widely according to the type of area, with the benefits to expressway users being much higher in downtown areas than in suburban areas, all other things being equal.

Knowing future traffic volumes and how these volumes are assigned to an expressway network, vehicle miles of travel for any section of an expressway network can be obtained. At the same time, the vehicle miles of travel on city streets for which travel on a section of the expressway network is being substituted can be obtained. Then appropriate user costs can be applied to these mileages and the benefits accruing to expressway users so obtained as the difference between these costs.

The average annual benefits accruing to the expressway users can be divided by the discounted annual cost to obtain a benefit-cost ratio. This benefit-cost ratio is then a measure of the profitability of a government investment in the expressway.

Benefits and costs for different expressway sections can be combined in any way desired to obtain benefit-cost ratios for anticipated construction phases. The resultant ratios obtained by combining different sections can be used as an aid in determining construction priorities.

CRITICISMS AND SUGGESTED RESEARCH

The benefit-cost ratios obtained in this type of analysis are by no means conclusive. These ratios are to a great extent a function of the volumes appearing on the different sections of the expressway network. These volumes are obtained by assignment of travel to an entire network and are not what would be expected as portions of the network are completed and opened to use. Since construction of new facilities is staged through different time periods, the benefit-cost ratios will vary according to changes in anticipated future volumes resulting from assignment of traffic volumes to only part of the network. Thus changes in the priority schedule might result.

It is also apparent that the best programming is one that will maximize the benefit-cost ratio of the entire network. This ratio may vary for different programming schedules because of varying rates of growth in future traffic volumes. Benefit-cost ratios should therefore be computed for alternate programming schedules. Then the best schedule is the one maximizing return to the public for each dollar spent. It is questionable if there would be any major changes in the construction schedule from what is obtained by a one-shot calculation as used in this paper. On the other hand, there would probably be minor changes that could add up to considerable savings for the motorist.

Additional research needs to be done in measuring all of the benefits and all of the costs incurred in building new expressways. This paper has only considered benefits accruing to expressway users. More precision is needed in measuring some of these benefits, such as values for personal time and driver strain and fatigue. More precision is also needed for measuring localized driving conditions rather than using blanket assumptions for large areas as in the above analysis. A great amount of research is needed to measure other benefits and other costs, such as the effect of new expressways on property values, urban growth, and civil defense. Not until all of the economic measures associated with expressway construction are accurately measured can the benefit-cost technique provide a highly accurate method for determining the profitability of building an expressway network and the programming of construction for the various parts of the network.

In summary, the principle contribution of this paper is in presenting a method for comparing certain types of benefits to certain types of costs for assessing government expenditures on highway construction. As such, a useful tool for analysis is obtained. In addition, areas for much needed future research are indicated. It is hoped that this research will be carried out by persons interested in the problem and that precise measures will be developed for comparing all highway benefits to all highway costs. When this is done, the benefit-cost technique can provide answers to many of the problems facing highway planners today.

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