The Annual Cost of Highways

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•A METHOD for determining annual cost of highways has many uses in highway economics, including a comparison of pavement types. To date, several State highway departments are not using any economic yardsticks to select pavement types, as shown in a recent Stanford Research Institute study (1) which found that only 7 of 21 States examined used some type of formalized procedure toward this objective. Inasmuch as the American Association of State Highway Officials has not yet adopted a method for solving this important problem of comparison, this paper may serve to create further interest in this subject.

BASIC FACTORS

The following are the basic factors needed to solve the problem of the annual cost of highways:

1. First cost.
2. Maintenance cost.
3. Operation cost.
4. Administration and overhead cost.
5. Cost of resurfacing and resurfacing frequency.
6. Salvage value.
7. Interest rate.
8. Analysis life or period.

First Cost

First cost should include the cost of construction and of right-of-way. Construction costs should be separated between the cost of the traveled way (or the pavement, its foundations, and the shoulders) and all other construction costs. Such a division of construction costs is made to facilitate the comparison of the annual costs of pavement types.

Maintenance Cost

The total annual maintenance costs also should be separated into the costs of maintaining the traveled way and the costs of performing all other types of maintenance work. Care should be exercised to include the present worth of future periodic maintenance cost multiplied by the appropriate capital recovery factor (CRF), explained later.

Operation Cost

Operation costs should include the cost of providing services to the road user (other than maintaining the capital investment), such as snow removal, sanding, signs, signals, striping and marking, and policing. Many States charge some of these items to maintenance; for the purpose of determining annual highway costs, the separation of these items is not necessary.

Administration and Overhead Cost

The administration and overhead costs, including field surveys and office design, are

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considerable and must be charged to the miles of highways in the system in order to determine the total annual cost. It is suggested that these costs be prorated over the miles on the system on the basis of first cost of construction.

Cost of Resurfacing and Resurfacing Frequency

Resurfacing costs and frequencies are estimated on the basis of past experience. As the surface becomes older, the pavements generally become rougher. The serviceability index decreases and finally resurfacing of the pavement is required to give the public reasonable service. The cost of future resurfacing may differ from the present cost of such operations. Past experience is a guide in making estimates.

Annual Costs for Traveled Way Only

When economic studies are to be made between the selection of pavement types, the first cost should be of the traveled way only. This includes the cost of the pavement, its foundations, and the shoulders. Maintenance costs should be the annual cost of maintaining the traveled way only. Other construction costs, right-of-way costs, the cost of administration and overhead, and operation costs may be disregarded because such costs apply to all types of pavements. The costs should be on a mileage basis for a two-lane pavement.

Salvage Value

Salvage value, which represents the value of a facility at the end of its service life, may vary from 0 to 100 percent. If an old road is abandoned, the salvage value is practically zero. For the most part this seldom happens, as the old road is generally shifted from one highway system to another and continues to serve the public as a minor traffic road.

Perhaps the best way would be to consider the future salvage value of a new road on the Interstate or Federal-Aid Primary System. Such a modern highway has a geometric design based on the maximum speed that a driver can operate a motor vehicle with reasonable safety, and is in accord with the reaction perception time of the average driver. AASHO has adopted such standards for the geometric design of highways.

However, AASHO has not adopted structural design standards, other than those for bridges. Standards for the structural design of pavements and pavement foundations are sorely needed. Some States have excellent standards, others have not.

The interim guide procedure for designing pavements by the AASHO committee on design, based on the findings of the AASHO Road Test, is a scientific approach to this problem which is quite worthwhile. It is hoped that such efforts will finally result in the adoption of a standard design procedure by AASHO.

Past results over many years have shown that pavement structural design in most States has been adequate to give satisfactory service under varying conditions of soils, climate, and frequency of load application. Reasonable enforcement of statute load restrictions by police action is, of course, necessary. Lack of enforcement or increase in statute weights will require a change in design of new projects and possible early resurfacing of others.

Highways are now designed for traffic forecasts 20 years in the future, with provision for the construction of additional traffic lanes when required. As a result, when properly maintained and resurfaced periodically, these roads should not suffer from either geometric or structural inadequacy for a long time to come.

There are other factors, such as possible technological changes in the transportation pattern, which may make present highways obsolete in the future. It is therefore prudent to amortize the investment in a highway project, at a selected rate of interest, within the analysis period. If such action is taken, the salvage value at the end of the analysis life of the project may be considered as being zero.

Interest Rate

Although the necessity to charge interest on money borrowed to finance toll highways is not contested, there are some people who argue that highways built from tax monies should be free from interest charges. However, cash money has a definite rental value, and whether the investment be made with public or private funds, and derived from taxes, cash, or borrowed funds, interest must be charged to determine the relative value for the economic justification of the project. The interest charge is clearly in the nature of a periodic payment for the use of the money. If built with borrowed funds, interest payments obviously accrue to the security holders. If on the other hand, the project is funded from owner's revenues, interest is in the nature of a fixed charge against the project to compensate for the loss of earning power of the funds "frozen" therein. In the case of the public funds derived from taxes, these funds, if not so captured, could have been invested by the public to yield a safe and reasonable return and, therefore, the interest charge represents a cost. Quoting from "Highway Engineering Handbook," (3):

> The interest rate to use in economic analyses and highway annual-cost estimates is that rate which represents a fair rate of earning to the public....Further, the method of financing the facility has no bearing upon the desirable rate of interest to use in economy or cost studies.... Regulated public utilities earn five to seven percent per year return.... The public as a whole is paying five to 12 percent on its mortgaged property, payment plans, and short-term borrowings. In view of these interest rates, an annual rate of five to eight percent would be reasonable in economic analyses of proposed highway improvements.

In another article, Winfrey (4) advocates a 6 percent interest rate in a highway economic valuation. Grant (5) recommends an interest rate of 7 percent in highway economic studies. Likewise Grant and Oglesby (6) use a 7 percent interest rate in studies in highway economics. Other economists use interest rates up to 10 percent.

It is recommended that the interest rate used in determination of the annual highway cost be 6 percent per annum.

Analysis Period

It is true that, when roads are properly built, well-maintained, and resurfaced at periodic intervals, they last a long time and may continue to give satisfactory service for many years to come. However, a definite period of time should be chosen to retire the investment at a selected rate of interest. Any sound investment should be able to return its costs within a reasonable period of time. In determining the annual cost of highways, this period of time may be termed the "analysis period."

Those investments funded on the payment of interest only may reach a time when obsolescence may totally depreciate the value of the investment. Future technological changes may make present-day roads obsolete and render more attractive a different type of transportation investment. There is no present indication that such changes will jeopardize the billions of dollars now being invested in roads. However, discretion requires that present and future beneficiaries carry the requisite costs to retire the investment within a reasonable period of time.

The Bureau of Public Roads statistically classifies pavements as being retired when they are resurfaced, reconstructed, abandoned, or transferred from one system to another. Data on this subject have been published in 1941, 1949, and 1956. The 1956 article (7) reported on about 184,000 miles of road retired during the last half-century. Of this amount, the major portion (57 percent) was resurfaced, 3 percent was abandoned, 31 percent was reconstructed, and 9 percent was transferred from one system to another. The higher types of surfaces had an average life of 16.8 years for bituminous concrete and 25.5 years for portland cement concrete pavement. Quoting from the 1956 Bureau report:

> As a result of improvements which are constantly being made in design standards for example, such factors as excessive grades, sharp curves, narrow roadway widths, and restricted sight distances formerly contributing to early obsolescence or structural failure are gradually being reduced to a minimum, or being eliminated.

The use of the data on service life compiled by the Bureau of Public Roads is not appropriate to this study for the following reasons:

1. Modern roads, such as described under "Salvage Value," should not suffer from geometric or structural inadequacy, and reconstruction should not be necessary during a 40-year analysis period. This is the type of road being considered, for the most part, in the determination of a method to measure its annual costs.
2. Periodic resurfacing renews a pavement's life; it does not terminate it.
3. Old roads may be transferred from one highway system to another but, in general, they continue to serve the public as minor traffic roads.
4. Few roads are ever abandoned.

The analysis period should be long enough to complete the cycle well past the first resurfacing period to demonstrate fully all average annual costs over a fairly long period of time. It should be short enough to avoid the obsolescence due to major technological changes that may materially alter the pattern of transportation. Probably the minimum period should not be less than 30 years, or the maximum more than 50 years. However, because the resurfacing period is sometimes as long as 30 to 35 years, the analysis period must exceed this time.

The "Highway Engineering Handbook" (3) recommends an analysis period of not more than 40 years. The Stanford Research Institute study on the annual costs of highways (1) selected 40 years. It is suggested that 40 years be chosen as the analysis period in the determination of the annual cost of highways.

AGG METHOD

Agg (2) in 1929 presented a method for determining annual cost of highways. He stated:

> The annual cost of a road...may be expressed as the total average yearly expenditure that will construct, replace and maintain in perpetuity in standard serviceable condition any existing road under existing traffic and climatic conditions. This amount may be calculated...by determining the amount of money which if set aside today will return in perpetuity as interest, sums sufficient to pay annual interest charges on construction cost, to provide a sufficient annual maintenance charge, and to accumulate periodically necessary replacement costs; and by multiplying that amount by the rate of interest prevailing in current financing.

His equation is

$$C = r\left[A + \frac{B}{r} + \frac{E}{(1+r)^{n} - 1} + \frac{E_1}{(1+r)^{n_1} - 1} + \dots\right] \quad (1)$$

in which

- C = average annual road cost per mile;
- A = cost to construct per mile;
- B = yearly maintenance cost (every year) per mile; and
- E (or E_1) = expenditure for periodic maintenance every n (or n_1) years per mile (replacement is an E-value); and
- r = rate of interest prevailing in current State financing.

The expression $\frac{r}{(1+r)^{n} - 1}$ can be found in tables given in the "Highway Engineering Handbook" (9) as the sinking fund.

BREED METHOD

Breed (8) presents a method for determining annual highway costs, as follows:

$$C = \frac{(A + S)r}{2} + \frac{A - S}{n} + B + \frac{E}{n} \qquad (2)$$

in which

C = average annual road cost per mile;
A = original capital cost per mile;
B = annual maintenance cost per mile;
r = rate of interest;
n = estimated life, in years, of surface before renewal is required;
S = estimated salvage value at end of n years; and
E = any periodic maintenance required during life n.

Three of the State highway departments selected by the Stanford Research Institute used this method, which uses simple rather than compound interest. No consideration is given the timing of the various resurfacings, or the present worth of such operations.

STANFORD RESEARCH INSTITUTE METHOD

The Stanford Research Institute (1) also proposed a method for determining the annual cost of highways. This method does not include all costs for determining the total annual cost, but only those for the traveled way. This permits a simpler comparison of alternate pavement types. The traveled way includes the pavement, its foundations, and the shoulders. The method can be expanded, however, to include all highway costs.

Essentially, the method may be described as follows: The annual cost of one mile of two lanes of traveled way equals the appropriate CRF times the summation of the initial cost, which is the construction cost of the traveled way plus the present worth of the first resurfacing cost plus the present worth of the second resurfacing cost, if any, minus the present worth of the residual value of the last resurfacing cost. To this is added the average annual maintenance cost of the traveled way, based on a 26-year period.

The analysis period is 40 years and the interest rate is varied from 3 to 7 percent. Resurfacing of both types of pavement is to be done with asphalt pavement. Both the CRF and the present worth factor (PWF) are well explained in the literature of engineering economics and in textbooks on the mathematics of investment.

Capital recovery is the combined equal annual return on capital (depreciation) plus the return on the undepreciated portion of the investment (interest). Full depreciation less salvage value, if any, plus interest on the undepreciated cost, is accomplished during the analysis period. The capital includes the present worth of future resurfacings.

The CRF is expressed in a formula, given later, and the uniform annual payment of capital recovery is obtained by multiplying the present worth of the sum of the capital investments by the CRF, which factor may also be found in tables elsewhere (9).

Present worth is the value now of an expenditure to be made at a given time in the future. It is equal to the amount, which if invested now at a specified compound interest rate, would equal the expenditure at the time it is to be made.

The PWF of a single payment may also be obtained from tables elsewhere (9). When a proposed future expenditure is multiplied by the appropriate PWF, the present worth of the future expenditure is obtained.

RECOMMENDED METHOD

The method recommended for determining annual cost of highways has two formulas which express the preceding method with certain modifications. The first,

$$C = CRF_n \left[A + E_1\, PWF_{n_1} + E_2\, PWF_{n_1} - \left(1 - \frac{Y}{X}\right)(E_1 \text{ or } E_2)\, PWF_n \right] + M + O + D \qquad (3)$$

in which

C = total annual cost, per mile;

$CRF = \frac{r(1+r)^n}{(1+r)^n - 1}$;

r = interest rate;
n = analysis period;
A = total construction and right-of-way cost, per mile;
E_1 = first resurfacing cost, per mile;
E_2 = second resurfacing cost, per mile;
n_1 = number of years after construction that future work is performed;
Y = number of years between time of last resurfacing and end of analysis period;
x = estimated life, in years, of last resurfacing;
M = total annual maintenance cost, per mile;
O = annual operation cost, per mile;
D = annual administration and overhead cost, per mile; and
PWF = present worth factor, for a single payment, defined as $\frac{1}{(1+r)^{n_1}}$.

includes all cost of building, maintaining, operating, and administering the highway.

The cost of future work is multiplied by the appropriate PWF to obtain the present worth of future expenditures. The analysis period is 40 years, the interest rate is 6 percent, and the salvage value is zero.

Both types of pavement are to be resurfaced with asphaltic concrete. The resurfacing cost of the rigid type is, as a rule, more expensive than that of the flexible type. In general, the time period after construction and before the first resurfacing is longer in the case of the rigid-type pavement. The Stanford Research Institute Study (1) indicated a period of 26 years for the rigid type and 18 years for the flexible type, and the cost of the first resurfacing of the rigid type was about 20 percent more than the cost of resurfacing the flexible type. Subsequent resurfacing of both types may be considered as equal to the cost of the first resurfacing of the flexible type for the purposes of this study.

Use of E_1 (or E_2) in Eq. 3 to determine the present worth of the residual value of the cost of the last resurfacing affects the value of the annual cost of the rigid type only, because the cost of the initial and subsequent resurfacing costs of the flexible type are considered identical. To make the selection for the rigid type, the sum of the estimated period of time after the initial construction and up to the first resurfacing and the period of time after the first resurfacing and to the second resurfacing is computed. If this sum equals or exceeds the analysis period, n, which is 40 years, only one resurfacing is required and the value of E_1 is used in the equation. If the sum is less than 40 years but more than 26 years, two resurfacings are required and the value of E_2 is used in the equation. Pavements of either type, if properly designed and maintained, should not require more than two resurfacings in an analysis period of 40 years, but if three resurfacings are required, the values of E_2 should be used.

The second formula

$$C_1 = CRF_n \left[A_1 + E_1\, PWF_{n_1} + E_2\, PWF_{n_1} - \left(1 - \frac{Y}{x}\right)(E_1 \text{ or } E_2\ \ PWF_n\right] + M_1 \qquad (4)$$

in which

C_1 = annual cost of traveled way, per mile;
A_1 = initial construction cost of traveled way, per mile (consists of the pavement, its foundations, and the shoulders);
M_1 = annual maintenance cost of traveled way, per mile; and
all other items are as defined for Eq. 3

includes only the costs necessary to compare pavement types. It is identical with Eq. 3 except that the initial cost is that of the traveled way only, the maintenance cost is that of the traveled way, and the right-of-way operation, administration, and overhead costs are eliminated.

In these computations, the analysis period is 40 years and the interest rate is 6 percent. The value of the other variables must be supplied by the user. Tables can be found for CRF and PWF in the "Highway Engineering Handbook" (9).

In some tables the expression for CRF represented by $\frac{r(1+r)^n}{(1+r)^n - 1}$ is shown in different forms, as $r + \frac{r}{(1+r)^n - 1}$ or $\frac{r}{1-(1+r)^{-n}}$, and is known as the annual capital charge or the annuity whose present value is 1. It is easy to convert from one form of the expression to the other. Regardless of the name and form of expression used, the factors given in the tables for the varying time periods and interest rates are identical.

The assumption is made that all types of pavement will be resurfaced by the required thickness of hot-mix, high-type, asphaltic concrete.

COMPARISON OF FORMULAS

To compare the results from the three methods for determining the annual cost, it is assumed that a 4-lane Interstate highway in a rural area is to be paved with asphaltic concrete and later resurfaced with the same material. Further, it is assumed that $A = \$500{,}000$ per mile; $M + O + D = \$7{,}000$ per mile per year, or B; $E = \$40{,}000$ per mile; $n = 18$ years; and $r = 6$ percent.

Using the Agg method, B is replaced by M + O + D and the preceding values are substituted in Eq. 1: $C = 0.06 \times \$500{,}000 + \$7{,}000 + \frac{0.06 \times \$40{,}000}{(1 + 0.06)^{18} - 1} = \$30{,}000 + \$7{,}000 + \$40{,}000 \times 0.03236 = \$38{,}294$, the annual highway cost for perpetuity.

The recommended method has an analysis life of 40 years, not perpetuity. Inserting the preceding values into Eq. 3, $C = 0.066462\ [\$500{,}000 + \$40{,}000 \times 0.350344 + \$40{,}000 \times 0.12274 - (1 - 4/18)\ \$40{,}000 \times 0.09722] + \$7{,}000 = \$41{,}288$.

Inasmuch as the analysis period is different, some other comparison will be helpful.

Under the Agg method the annual highway cost is \$38,294. If \$638,233 were set aside today at 6 percent interest it would provide, as interest, the \$38,294 required to service the annual highway cost. In like manner, \$688,133 is needed to be set aside at 6 percent interest to provide the annual interest required to service an annual highway cost of \$41,288, which is necessary under the recommended method. The difference in the sums to be set aside is \$49,900 in favor of the Agg method. This sum at 6 percent compound interest equals \$513,257 in 40 years.

The first cost is \$500,000. The present worth of the future resurfacing cost, as computed by Eq. 3, is \$15,900. In consequence, the total of both the first cost and the resurfacing cost can be paid, approximately, at the end of the 40-year analysis period, if the difference in the sums set aside be invested at 6 percent compound interest for this purpose.

The Agg method pays the interest on the principal and on future renewals, but does not pay the first cost or the present worth of future payments. The recommended method pays all costs, both principal and interest, in a definite time interval. In consequence, the Agg method does not give the true annual highway cost except for perpetuity, which is not a reasonable period of time. Some contend that the annual highway cost should not include the interest on the capital invested. The Agg method eliminates the payment of the principal. The recommended method pays both, which gives a true measure of the annual cost of highways.

When the Breed method (Eq. 2) is used and it is assumed that $n = 40$ years and $S = O$, $C = \frac{0.06\ (\$500{,}000 + \$0)}{2} + \frac{(\$500{,}000 - \$0)}{40} + \frac{\$80{,}000}{40} + \$7{,}000 = \$36{,}500$.

The annual cost by the recommended method is \$41,288, which is \$4,588 or 13.1 percent more than the Breed method. If the salvage value S is 100 percent or \$500,000 at the end of 40 years, it is necessary to subtract the present worth of the salvage value from the first cost in determining the annual cost by the recommended method. When the formula is used, the first cost becomes \$500,000 less \$48,611, or \$451,389. The solution shows that the annual cost under the recommended method is $38,057.

Using the Breed formula with a 100 percent salvage value, the annual cost is $39,000. From this should be subtracted $943, the overcharge on resurfacing as computed by the recommended method. This leaves $38,057 which is the identical amount computed by the recommended method.

The Breed method uses simple, rather than compound interest, understates the annual cost when the salvage value is less than 100 percent, and has an obvious error in the computation of the cost of resurfacing. The recommended method gives a correct answer under all conditions.

EFFECT OF INFLATION

Mention has been made previously of the possibility of the increased cost of resurfacing after original construction. The annual cost of maintenance, operation, and administration may also increase with the years. The difference will not be as great as it may appear. For instance, if a flexible pavement is to be resurfaced 18 years after construction and is to be followed by a second resurfacing after another 18 years, the present worth of an expenditure to be made 18 years hence is about one-third of that cost, and the expenditure to be made 36 years from now has a present worth of about one-tenth that cost, at an interest rate of 6 percent.

The tendency to inflate the cost has been considerably offset by improvements in machinery and methods. As a result, labor costs have decreased and production has increased. For instance, the costs of grading and asphaltic concrete paving items have increased relatively little during the past 35 years.

The Bureau of Public Roads has records of cost through the years, with respect to various items of highway construction, which will be of great help in making future estimates. Some States have similar data which are more applicable to their regions.

SERVICEABILITY INDEX

An HRB report on the AASHO Road Test states that the prime function of a highway is to serve the traveling public, and sets up a measuring stick termed the "Serviceability Index."

For many years the Oregon State Highway Department has carried on a method of periodic pavement maintenance whereby all holes, depressions, ruts, and broken pavement of both types are repaired by the use of hot-mix asphaltic concrete that leaves the sections of pavement smooth and even-riding. As the years have gone by, the pavements so maintained have become stronger and the amount of required patching for a section has decreased. Although the annual maintenance cost is higher, the need for resurfacing of both pavement types has been deferred for many years. What is more important, the public always has smooth pavements; the serviceability index of these pavements is high. This type of maintenance will reduce the annual cost of both types of pavement and give better service to the public at all times.

CONCLUSION

The method recommended for determining the annual cost of highways will be of material assistance in the solution of the benefit-cost ratio, which can be used to measure the relative value to the public of the various projects in the selection of a construction program. Likewise, such information will be of great aid in making a choice between alternate highway locations, and also as a check on the design of a project. If the benefit-cost ratio is less than one, the annual benefits of the project are not enough to justify the annual cost and the need for a less expensive design is indicated. This, of course, should be based on estimated traffic 20 years in the future. Finally, selection of the pavement type that will afford the lowest annual cost requires the use of a method for determining the annual cost of highways covering all phases of the situation, which the recommended method does.

Highway authorities are charged with a great responsibility, which has increased materially in the past few years due to the large expenditures now being made. It is more and more important to base highway design on scientific research and to control highway expenditures by sound economics.

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Discussion

HAROLD W. HANSEN, Senior Planning Engineer, Portland Cement Association, Chicago, Illinois—The annual cost procedure given by Mr. Baldock fails to recognize that street and road agencies are an arm of government and necessarily operate differently than private enterprises. However, his fundamental error lies in not recognizing that government, in providing public highways, provides real benefits directly to highway users and indirectly to the public at large.

Earnings on the capital invested in highways (in the form of benefits) may be large or small. The scale is in direct relation to the judiciousness of the highway investment.

Frugal use of public highway funds requires that no more money be spent than is necessary to supply the required level of service. Choosing the alternative which results in the lowest annual disbursement avoids wasting the Nation's material and manpower resources and is clearly in the public interest. Annual disbursement information is an exceedingly useful tool to avoid unwarranted taxation and to get the greatest return from each dollar spent for highway pavement construction. Such decisions cannot be made unless theoretical charges for interest are omitted from economic analyses.

Imputed Interest

In discussing interest, Mr. Baldock makes it clear that the kind of interest used in his procedures is not interest on borrowed money. Yet his reason for applying interest to highway construction money is that "cash money has a definite rental value."

This is somewhat confusing. He argues that because interest is paid on borrowed money (used for toll highway construction), interest should also be charged whether "the investment be made with public or private funds, and derived from taxes, cash, or borrowed funds." What he has not made clear is that the "imputed" interest, which he argues should be included in analyses procedures, is money which no one actually pays out or receives as with borrowed money. It is an entirely fictional charge.

He also states: "In the case of the public funds derived from taxes, these funds, if not so captured, could have been invested by the public to yield a safe and reasonable return." This argument is less than convincing. For example, what becomes of funds not taken from the public in a situation where highway income has been reduced? In this situation those who contribute to the support of highways now have certain "new" funds at their disposal.

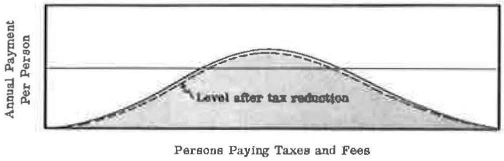

Figure 1. Idealized distribution of financial support for public highways, streets, and roads.

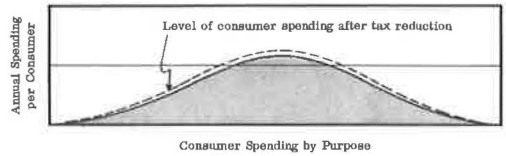

Figure 2. Idealized distribution of consumer spending by purpose.

Figure 1 is a simplified representation of the effect this would have on payments made by individuals for highway purposes. The dashed line represents the level of payment in this idealized situation after the tax reduction has taken place. The "saving" per person would not be large if the highway organization receiving tax funds is to continue to function.

Regardless of how much savings are passed on, individual people will have certain added expendable personal funds. What uses would be made of these funds? It is not realistic to expect that all the people involved will invest an intermittent accumulation of pennies or dollars not spent on highway user taxes. It is instead, more realistic to think in terms of Figure 2, which indicates that people will spend their share of the assumed tax saving principally for consumer items which they normally buy. The truth is that although the public could invest elsewhere funds derived from taxes if not used for highway purposes, very little would be used in this way. The bulk of such funds would be used for other purposes.

The foregoing leads to a more penetrating question: Is it better that the money in question be used for highway purposes, or are the advantages connected with increasing consumer spending greater? The answer depends largely on the following.

In general, it is beneficial to the business sector of the economy that the purchasing power of the consuming public be at a high level. Any action which increases the public's real purchasing power is wholesome (assuming it does not add to inflationary forces).

On the other hand, spending money for highway construction feeds public funds back into the economy. Wages for labor, together with purchases of materials and equipment, have the same wholesome effect on the economy as does an increase in the public's real purchasing power.

Where the needs for highway, street and road construction, maintenance and administration have been determined in an impartial and factual manner, and where a decision has been made that it is in the public interest to support a highway program at the level required to pace highway improvement with economic growth and development, a program of taxation should be enacted which will make this possible.

Thus the view proposed by the author ignores the controlling economic forces which are at work and proposes instead the adoption of a philosophy parallel to the time-worn concept that the highway plant should be regarded as plant owned by a public utility which obtains capital funds by borrowing. It is well known that there are some serious shortcomings associated with the "public utility" concept.

For example, control over highway affairs is broadly diffused. Statutes affecting highways are enacted by the Congress, by the 50 State legislatures, and by thousands of units of local government. In addition, intergovernmental relationships are extensive and complex and include a considerable number of agencies beyond those whose primary mission is public streets or roads.

Arising out of this complex are systems of revenue collection, allocation, incumbrance, expenditure, accounting and reporting fundamentally unlike those in private business. One of the important underlying differences was described by the Committee on Highway Costs in its report to the 24th Annual Meeting of the Highway Research Board (1944), as follows:

> In modern public highway finance capital is in general not carried as a separate item and procured from investment sources but is obtained for the most part from the same sources and in exactly the same way as money for running expense. This is one reason why public financing is not exactly analogous to the methods used in those private business enterprises where the capital is accounted for independently. It is upon disbursements, past and anticipated, that public highway financial policy has been predicated. (10)

The "public utility" concept just does not do justice to relationships between taxpayers who supply the funds and highway or street organizations which manage highway and street systems.

Mr. Baldock either ignores or has failed to recognize the fundamentals of capital formation. For example, people who hold the common stock of a business corporation do not earn a "rate of interest" on their investment. In the long run their chance for earning a return depends on whether the income to the firm exceeds expenses.

Highway Benefits

Although not stated explicitly, it is clear that Mr. Baldock assumes that the funds invested in public works do not earn a return and that therefore an implicit or imputed cost should be introduced to account for the theoretical penalty or economic cost to which taxpayers are in theory forced to submit.

Highways do, however, earn a return. Planners, economists and engineers are gradually improving their understanding of the benefits arising out of highways. Although still inadequately understood, progress is being made in developing new techniques that identify the intrinsic nature and size of highway benefits.

In somewhat the same way that persons who invest in a corporation earn a return when corporate income exceeds cost, the persons who contribute to public works earn a return when the benefits arising out of public works exceed costs.

Some taxpayers who directly support public roads are not necessarily users, or do not use specific road systems in proportion to their contribution to these systems. Nonetheless there is a considerable amount of equity in this respect. When one views the matter broadly so as to include indirect payments by nonusers together with indirect benefits, it is seen that to a considerable extent the paying public reaps whatever benefits arise from public highways, streets and roads.

At least five general types of highway benefits have been identified by such experts as Mohring and Harwitz (11) and Goldstein (12), as follows:

1. Direct Benefits. —Highway construction projects are frequently referred to as highway improvements. The connotation is not inappropriate. For a long period of time the general level of service rendered by highways, streets and roads has been moving gradually but steadily upward.

One of these upward steps came when the controlled access highway was introduced. Unless operating beyond their capacity, these "freeways" return at least three types of benefits to those who use them:

(a) By eliminating intersections at grade, vehicle stops at traffic lights and thru-stop signs are eliminated. Also, because traffic flow is better organized on freeways, fewer slowdowns occur, thereby further improving average speeds. Eliminating these kinds of traffic friction reduces unit vehicle operating costs.

Studies conducted in 1960 (13, Table 2 and Fig. 6) show that due to added fuel consumption alone, it costs $0.0025 to slow a passenger car moving at 30 mph, to a stop and then accelerate to 30 mph. Gasoline consumed to keep the engine of a passenger car idling at a traffic light one minute adds $0.0025 to operating costs. Likewise, to slow a passenger car from 40 mph to 30 mph and accelerate to 40 mph again consumes enough gasoline to add $0.00125 to operating costs.

Truck operating costs are proportionately higher. The point is that elimination of vehicle stops, delays and slowdowns results in reduced unit vehicle operating costs.

(b) Stops and slowdowns eliminated by improved highways result in time savings to the drivers of vehicles in the traffic stream to their passengers, to the vehicles themselves, and to goods being carried by trucks.

The extent of delays to traffic caused by traffic control devices, traffic friction and other causes are small when examined on a "per incident" basis. Their cumulative effect, however is large. Benefits from eliminating time delays which come with improved highways have in some cases been measured by assigning average dollar values to users' time (14).

On the other hand, these same benefits can also be measured by simply totaling the number of hours of delay eliminated by an improvement (13, pp. 33-34). Time savings, however, are only "advantages" until business, social and recreational activities are reorganized to benefit from the new conditions.

(c) Highway improvements which eliminate hazards and traffic friction generally increase traffic safety. Motor vehicle accidents constitute a portion of the over-all cost of operating motor vehicles. Some work has been done in relating accident costs to accident rates (15). Reducing congestion cuts down on motor vehicle accidents. Capital invested in freeway-type highways, particularly, has a twofold effect. In the first place, large numbers of vehicles are attracted from lower-standard, congested surface streets or highways to freeways which characteristically have a low accident rate (16). The vehicles diverted to the freeway therefore have fewer accidents. Traffic on existing streets, having been reduced, is less congested and thus the traffic accident rate on these facilities also declines.

2. Reduced Vehicle Operating Costs Lead to Increased Usage. —Savings in time, money, and accident costs lead people, businesses and government to reorganize their activities in a more efficient way. This reorganization gives motor vehicle transportation and the goods and services which are oriented to motor vehicle transportation an economic advantage over other goods and services. This advantage leads to a concomitant increase in motor vehicle use. The goods or services thus displaced become available for use elsewhere.

"Basically, the increase in highway activity associated with lower transportation costs reflects the undertaking of three distinct types of substitution: (a) the substitution of highway for other forms of transportation; (b) the substitution, by consumers, of goods and services which are intensive users of highway transportation for other goods; and (c) the substitution, by producers, of highway transportation intensive means of production for other means." (17)

The net benefit to the economy is derived by taking into account what happens to the goods and services displaced, as well as the gains accruing to highway transportation and goods and services which are highway oriented.

On the average, highway improvements mean slightly less fuel and less motor vehicle consumed per mile of operation. This makes motor travel relatively more attractive than other goods and services, resulting in an increase in motor vehicle travel. This relationship is shown in a generalized way in Figure 3, in which the curve is a simple hyperbola. It can be read as follows: If vehicle operating costs amount to y_1 dollars per vehicle-mile, vehicles will travel an average of x_1 miles annually. If unit vehicle operating costs can be reduced to some lower value (y_2 dollars per vehicle-mile) by improving highway efficiency, vehicles will increase their travel to an average of x_2 miles per year.

One of the features of a simple hyperbola is that the area subtended from any point along the curve to the x and y axes is exactly equal to the area subtended from any other point on the curve. Thus the area $oy_1\ ax_1$ subtended from point a is exactly equal to the area $oy_2\ bx_2$ subtended from point b. These two areas are also a measure of the total outlay for highway transportation by the average vehicle. (Total spending on highway transportation for the average vehicle is computed by multiplying the average operating cost per vehicle-mile of travel by the total number of miles traveled yearly.)

Therefore, a hyperbola identifies a situation where a reduction in unit vehicle operating costs results in a concomitant increase in travel per vehicle, but the total outlay for fuel, repairs and other direct transportation costs is neither greater nor smaller than before.

The hyperbola, therefore, is the breaking point between conditions where the total outlay for transportation decreases or increases with a decline in average unit motor vehicle costs. The new curve (ab' in Figure 4) shows a relationship where a decline in unit motor vehicle costs not only causes an increase in the amount of travel but

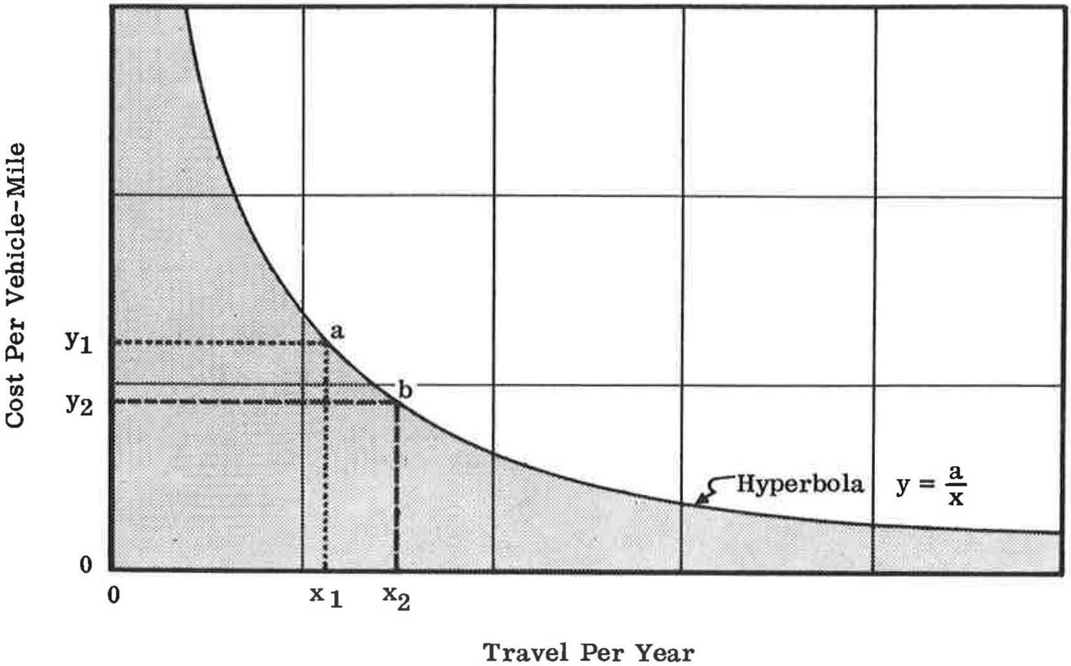

Figure 3. Changes in travel due to changes in unit vehicle cost.

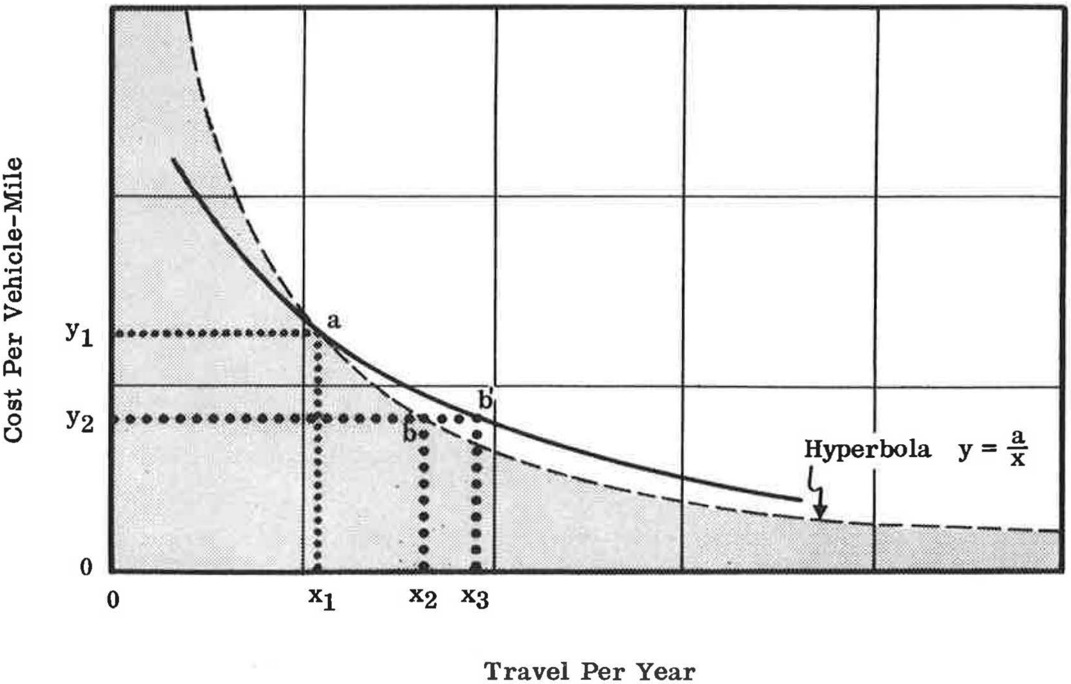

Figure 4. Changes in travel due to changes in unit vehicle cost.

actually results in a larger outlay for motor fuel, oil and motor vehicles and parts. This is known because the area $oy_2b'x_3$ (total outlay per vehicle after unit costs are reduced) is larger than the area oy_1ax_1 (the total outlay per vehicle before unit costs are reduced). The amount of increase in total outlay can be determined from the area $x_2bb'x_3$ since, as in Figure 3, the area oy_2bx_2 is identical to oy_1ax_1. The area $x_2bb'x_3$ is the added amount spent for motor fuel, oil and motor vehicle consumption per year on the average vehicle.

The slope and trend of such curves vary from place to place due to the nature of economic specialization and other characteristics of the area. Reduced highway transportation cost soon results in an increase in highway use. Where the slope and trend of the curve describing these relationships have a "more horizontal" shape (see Fig. 4) than a simple hyperbola passing through one of the points, the total outlay for highway transportation will increase over what it was before. This, of course, directly benefits the petroleum and motor vehicle sectors of the Nation's economy, among others.

3. The Productive Capacity of the Economy.—There are some measures which contribute more than others to growth of the Nation's economy. For example, measures involving improvements to those sectors of the economy which underlie the whole economic structure provide benefits that reverberate throughout the economy.

Transportation, a basic necessity to nearly all other activities, can pass on to others benefits arising from increased efficiency. With particular reference to highway transportation, a 1961 report to the Congress states that the "...nature of highway improvement serves to reorganize local activity. The improvements aid in channeling economic growth into specific locations and, in addition, make it possible through transportation savings to reduce plant production costs." (18, p. 4)

According to a Northwestern University study, "By reducing the resources required to carry goods from place to place and by shortening commuting time, thereby enabling individuals to increase the total time they spend working and/or in leisure activities, highway improvements do, in fact, increase the productive capacity of the economy. They make it possible to produce more services, more consumption and investment goods, and more leisure than would have been possible had they not been made." (19)

The 1961 report to the Congress just cited says: "The remarkable growth in productivity in the United States during the past half century has stimulated a vast exchange of goods and services. The increased emphasis being given to distribution is indicated by the increased position of the work force engaged in this activity. In 1900 about 10 percent of all gainfully occupied workers in the United States were engaged in trade activities compared with about 16 percent in 1940. This commercial progress has been aided by highway transportation in at least two ways: by expanding market areas and by lowering distribution costs." (18, p. 29)

In the light of the foregoing, a decision as to the pace at which highway improvements are to be undertaken or a decision as to which improvements are to be undertaken first becomes a matter of considerable economic consequence to the area or region, not just to those whose property fronts along the highway.

4. Investment Triggering.—In every instance where attention has been given to measuring the economic impact of new highways which materially improve service to users, it has been found that they have a marked influence on land values (18, pp. 5-77). Of particular interest is the ability of metropolitan area freeways to attract investment capital. Where industrial and other business enterprises have been seeking favorable sites, freeways have often "triggered" heavy investment and consumer spending.

In a recent year, for instance, 40 percent of all industrial investment in the Boston metropolitan area was along Massachusetts Route 128, a circumferential freeway serving the area. Between 1951 and 1957, $85 million was invested in land, buildings and equipment along this route which provide employment for 17,000 workers. By autumn of 1958, more than 200 new companies were doing business along Route 128 while still others were under construction (20).

During a recent three-year period, nearly one-half of the 354 new industrial plants built in Indiana located within 25 miles of the Indiana Turnpike (21).

Industrial development along circumferential highways has flourished at Lexington, Ky. (22), the Twin Cities of Minnesota (23), the Capital Belt around Washington, D.C., and the Belt around Baltimore, Md. (24).

The New York Thruway, which links New York City with Albany-Schenectady, Utica, Syracuse, Rochester and Buffalo, has attracted a vast amount of new industrial growth (25).

In Alameda County, Calif., the Eastshore Freeway triggered extensive new industrial developments (26).

A government report (18, p. 29) states that "increased use of highway transportation has been associated with larger and larger trade areas ...." The radius of influence of these areas has increased from "...about 5 or 6 miles in the early part of the century" to as much as 150 miles at the present time. This would have been impossible without the convenience and flexibility of highway transportation. "During this period the number of retail trade establishments increased from about 1.6 to 1.9 million; sales volume increased from approximately $46 billion to $200 billion in 1958 in current dollars; and population increased from 132 million to 173 million."

The report also states that there are now some 4,000 shopping centers, alike in the emphasis they give to easy access by highway and customer parking (18, p. 32).

These studies point up the triggering effect associated with new urban freeways. These economic forces also are at work in other areas, many unreported. In addition, the effect of the original investment is multiplied far beyond what would have occurred had the new and superior highway not been built.

Lack of adequate highways and low-cost highway transportation found in certain depressed areas suggests that the absence of adequate highways may be an important cause for these poor economic conditions (27, 28).

5. Highway Investment.—Capital investment in highway construction has an economic effect quite apart from the use made of highways to accommodate travel. The extent of this impact is in proportion to the size of the investment made. It also depends on the character and extent of interindustry relationships in the highway construction sector of the Nation's economy.

When capital is invested in highways the construction industry spends more money for labor, materials and capital equipment purchased from primary suppliers. Like the waves formed by dropping a stone in a pool, these primary purchases are multiplied into an ever-widening series of purchases from subsidiary suppliers.

Although highway capital operates in the same way as other capital, demands generated by highway capital for labor, materials and capital equipment will be somewhat different. The major impact of highway investment is on the aggregate, petroleum, cement and steel industries.

This highway investment multiplier is of considerable size. For example, material and service requirements generated both directly and indirectly by the $4 billion highway construction program of 1947 totaled approximately two or three times the size of the original investment (29).

The magnitude of benefits earned by highways far outweighs the fictional "imputed interest" proposed by the author. His omission of benefits as earnings accruing to those who directly and indirectly support the highway program is an error of fundamental importance.

Capital Recovery Factors

The formula which the author favors uses capital recovery factors to compute a "uniform annual payment" required to repay construction costs plus interest. The procedure is quite similar to that used to finance a loan on a home. Thus, a uniform periodic payment (monthly in the case of a home loan, annually in the case of the author's procedure) includes repayment of both principal and interest.

The difference, of course, is that in the case of the home loan the interest portion of the payment is in real dollars paid by the homeowner to the bank or savings institution. In the case of the author's proposed procedure the interest is not actually paid out or received by anyone.

In support of his position the author cites a similar procedure used in a 1961 report (1) prepared for the American Petroleum Institute. However, he fails to point out some important practical effects on decision making which are associated with mathematical processes he employs. In this connection reference is made to a report to the Congress from the United States Secretary of Commerce (18, p. 134), which reads in part: "The calculation (of program costs) at 0.0 percent (imputed interest) tends to favor the high-grade, heavy-traffic systems in terms of costs per vehicle-mile and the 5.0 percent calculation to disfavor them, because of the high recovery factor on long-term investments."

This is more fully explained by reference to Tables 1 through 5. Table 1 illustrates the relationships which arise when the service lives of alternatives being compared are assumed to be the same. It shows that for any selected rate of interest the lowest annual cost depends on achieving the lowest initial cost.

Table 2 shows relationships which prevail when the initial capital cost of each alternative is the same as all others, but service lives of the alternatives vary. Under these conditions, at any selected rate of imputed interest, the lowest annual cost is achieved from the longest service life, other things being the same.

Extensive and comprehensive studies of pavement life in the United States show that in the usual or normal condition the highest type of bituminous pavements has a service life about two-thirds that of portland cement concrete pavements. The cost relationships growing out of this condition have an important effect on cost computations.

For example, Table 3 shows the relationship which is found to exist where the initial cost of each alternative is the same and where a two-to-three ratio in service life between alternative prevails. Although the average annual capital cost for the alternative

TABLE 1
AVERAGE ANNUAL CAPITAL COST PER MILE VARIATIONS DUE TO CHANGES IN INITIAL COST AND RATE OF IMPUTED INTEREST (COMPOUNDED ANNUALLY)

Service Life (Yr)	Initial Cost ($/mi)	Average Annual Capital Cost ($/mi)						
		0%	2%	3%	4%	5%	6%	7%
25	25,000	1,000	1,281	1,436	1,600	1,774	1,956	2,145
25	50,000	2,000	2,561	2,871	3,201	3,548	3,911	4,291
25	75,000	3,000	3,842	4,307	4,801	5,321	5,867	6,436
25	100,000	4,000	5,122	5,743	6,401	7,095	7,823	8,581
25	150,000	6,000	7,683	8,614	9,602	10,643	11,734	12,872
25	200,000	8,000	10,244	11,486	12,802	14,191	15,645	17,162

TABLE 2
AVERAGE ANNUAL CAPITAL COST PER MILE VARIATIONS DUE TO CHANGES IN SERVICE LIFE AND RATE OF IMPUTED INTEREST (COMPOUNDED ANNUALLY)

Service Life (Yr)	Initial Cost ($/mi)	Average Annual Capital Cost ($/mi)						
		0%	2%	3%	4%	5%	6%	7%
17	60,000	3,529	4,198	4,557	4,932	5,322	5,727	6,146
25	60,000	2,400	3,073	3,446	3,841	4,257	4,694	5,149
33	60,000	1,818	2,501	2,889	3,306	3,749	4,216	4,704
40	60,000	1,500	2,193	2,596	3,031	3,497	3,988	4,501
50	60,000	1,200	1,909	2,332	2,793	3,287	3,807	4,348
60	60,000	1,000	1,726	2,168	2,652	3,170	3,713	4,274

TABLE 3

EFFECT OF IMPUTED INTEREST (COMPOUNDED ANNUALLY) ON AVERAGE ANNUAL CAPITAL COST PER MILE FOR ALTERNATIVES WITH DIFFERENT SERVICE LIVES BUT THE SAME INITIAL COST

Service Life (Yr)	Initial Cost ($/mi)	Average Annual Capital Cost ($/mi)						
		0%	2%	3%	4%	5%	6%	7%
17	60,000	3,529	4,198	4,557	4,932	5,322	5,727	6,146
Difference in favor of		1,129↓	1,125↓	1,111↓	1,091↓	1,065↓	1,033↓	997↓
25	60,000	2,400	3,073	3,446	3,841	4,257	4,694	5,149

TABLE 4

EFFECT OF IMPUTED INTEREST (COMPOUNDED ANNUALLY) ON AVERAGE ANNUAL CAPITAL COST PER MILE FOR ALTERNATIVES WITH DIFFERENT SERVICE LIVES AND DIFFERENT INITIAL COSTS

Service Life (Yr)	Initial Cost ($/mi)	Average Annual Capital Cost ($/mi)						
		0%	2%	3%	4%	5%	6%	7%
17	50,000	2,941	3,498	3,798	4,110	4,435	4,772	5,121
Difference in favor of		541↓	425↓	352↓	269↓	178↓	78↓	28↑
25	60,000	2,400	3,073	3,446	3,841	4,257	4,694	5,149

TABLE 5

BREAKDOWN OF THE EFFECT OF IMPUTED INTEREST (COMPOUNDED ANNUALLY) ON AVERAGE ANNUAL CAPITAL COST PER MILE FOR ALTERNATIVES WITH DIFFERENT SERVICE LIVES AND DIFFERENT INITIAL COSTS

Service Life (Yr)	Initial Cost ($/mi)	Item	Average Annual Cost ($/mi)						
			0%	2%	3%	4%	5%	6%	7%
17	50,000	Depreciation	2,941	2,941	2,941	2,941	2,941	2,941	2,941
		Imputed interest	0	557	857	1,169	1,494	1,831	2,180
		Total	2,941	3,498	3,798	4,110	4,435	4,772	5,121
Difference in depreciation charge			541	541	541	541	541	541	541
Difference in imputed interest			0	116	189	272	363	463	569
Net difference, in favor of			541↓	425↓	352↓	269↓	178↓	78↓	28↑
25	60,000	Depreciation	2,400	2,400	2,400	2,400	2,400	2,400	2,400
		Imputed interest	0	673	1,046	1,441	1,857	2,294	2,749
		Total	2,400	3,073	3,446	3,841	4,257	4,694	5,149

with the longer life is lower for each of the rates of imputed interest, the difference in favor of the longer-lived alternative gets smaller as the rate of imputed interest increases.

Table 3 demonstrates that introduction of a charge for imputed interest tends to bring shorter-lived facilities into a somewhat more favorable light, even though each alternative has the same initial cost. The margin in favor of the longer-lived alternative decreases as the rate of imputed interest is increased. This favors shorter-lived facilities.

Table 4 shows a situation similar to that in Table 3. The normal two-to-three ratio between service lives is retained, but the shorter-lived facility is now favored by arbitrarily cutting its initial capital cost. Lower initial cost, coupled with a supposition as to a high rate of interest, favors the shorter-lived alternative. In the illustration used, the shorter-lived, lower-initial-cost project would be favored at interest rates of 7 percent and above.

Table 5 is similar to Table 4 except that more detail is provided. The average annual capital cost per mile for each alternative is broken down to show the average annual charge for imputed interest. This table makes it clear that imputed interest is the single factor favorable to the lower-initial-cost, shorter-lived alternative. Other things being equal this alternative is favored at higher rates of interest (7 percent and above in Tables 4 and 5).

This breakdown of "costs" (Table 5) is significant from another viewpoint. It shows that the average annual depreciation charge does not vary with a change in imputed interest. Stated simply, the average annual depreciation charge is the initial capital cost distributed uniformly to each of the years of expected service life. This also is a way of estimating the average contribution of real tax dollars required annually to support each alternative.

For the conditions given in Tables 4 and 5, the longer-lived alternative requires fewer tax dollars over the years even though initial capital cost is somewhat higher.

The longer-lived alternative accrues a heavier assumed penalty in the form of imputed interest. This is true for any rate of interest.

What significance would the foregoing have if these relationships were found to exist over an entire highway system? If an 8,000-mi rural State primary highway system had an average payment service life of 17 years, such a system would on the average require rebuilding 470 mi ($\frac{1}{17}$ of 8,000 mi) of pavement yearly. At an average cost of $50,000 per mi this would total between $23 and $24 million annually for pavement construction.

Another system of equal size with a pavement life of 25 years would require rebuilding an average of only 320 mi each year ($\frac{1}{25}$ of 8,000 mi). At an average cost of $60,000 per mi this would come to between $19 and $20 million annually.

The added $4 million required each year for the shorter-lived, lower-initial-cost pavements is not in the form of imputed interest. These are real tax dollars. Furthermore, they do not result in better service to users. As a matter of fact they result in considerably more interruptions to traffic because of the shorter construction-reconstruction cycle (17 versus 25 years, or about 150 more miles under construction each year). Because the added $4 million annually which would go into the shorter-lived, lower-initial-cost alternative produces no added benefit to users, this expenditure represents a waste of resources and an unwarranted tax burden on those providing support for public highways.

Tables 1 through 5 give average annual capital costs per mile. More complete data are given in Tables 6 and 7, which give for each year (a) the uniform annual payment required to discharge a given debt, (b) the annual charge for imputed interest, and (c) the annual retirement of debt based on 7 percent interest, service lives of 17 and 25 years, and initial capital costs of $50,000 and $60,000 per mile. These tables show how both principal and imputed interest payments vary over the repayment period.

Pavement Life and Analysis Period

The author recognizes that generally some of the money spent for construction of pavements continues to serve beyond the "life" indicated by comprehensive road life mileage studies. To accommodate this phenomenon in his procedures he makes the far-reaching assumption that the money spent for construction must be repaid at interest over a reasonable period of time much like a mortgage on a piece of real estate.

The use of an "analysis period" for comparing the relative economy of several alternatives is an acceptable procedure. However, the author errs when he discards from his procedures information which has a material effect in determining the relative economy of alternatives. He indicates that "... use of the data on service life compiled by the Bureau of Public Roads is not appropriate to this (Baldock's) study ...."

It is important to recall that from the day a highway is built it begins to suffer from all the forces which ultimately bring about its retirement from service. These forces

TABLE 6

AMORTIZATION TABLE[1]; UNIFORM ANNUAL PAYMENT REQUIRED TO DISCHARGE A DEBT OF $50,000 IN 17 YEARS AT 7 PERCENT IMPUTED INTEREST

Year	Unpaid Balance From Previous Year ($)	Uniform Payment January 1 Each Year ($)	Imputed Interest[2] Assumed Due December 31 Each Year ($)	Amount Available As Principal[3] Payment Each Year ($)	Unpaid Balance December 31 Each Year ($)
1	50,000.00	5,121.26	3,500.00	1,621.26	48,378.74
2	48,378.74	5,121.26	3,386.51	1,734.75	46,643.99
3	46,643.99	5,121.26	3,265.08	1,856.18	44,787.81
4	44,787.81	5,121.26	3,135.15	1,986.11	42,801.70
5	42,801.70	5,121.26	2,996.12	2,125.14	40,676.56
6	40,676.56	5,121.26	2,847.36	2,273.90	38,402.66
7	38,402.66	5,121.26	2,688.19	2,433.07	35,969.59
8	35,969.59	5,121.26	2,517.87	2,603.39	33,366.20
9	33,366.20	5,121.26	2,335.63	2,785.63	30,580.57
10	30,580.57	5,121.26	2,140.64	2,980.62	27,599.95
11	27,599.95	5,121.26	1,932.00	3,189.26	24,410.69
12	24,410.69	5,121.26	1,708.75	3,412.51	20,998.18
13	20,998.18	5,121.26	1,469.87	3,651.39	17,346.79
14	17,346.79	5,121.26	1,214.27	3,906.99	13,439.80
15	13,439.80	5,121.26	940.79	4,180.47	9,259.33
16	9,259.33	5,121.26	648.15	4,473.11	4,786.22
17	4,786.22	5,121.26	335.04	4,786.22	0.00
Total	---	87,061.42	37,061.42	50,000.00	---

[1] Refer to Table 5, which shows that revenue demand does not vary with changes in imputed interest.
[2] A hypothetical economic cost to the public; the amounts shown are not actually paid to or received by anyone.
[3] One way of computing an annual depreciation charge. The average annual depreciation charge is the amount of the original debt divided by the life in years.

include wear and tear, decay, inadequacy, obsolescence, action of the elements, changes in the art, changes in demand, and requirements of public policy.

The forces of obsolescence and deterioration are real and, as the author mentioned, have been measured in extensive studies of pavement service life and of the life of funds invested in highway construction. But he fails to recognize that they result in a "cost" to the agency having jurisdiction over the highway. Ultimately this cost is passed along to those who provide tax support for the Nation's highways and streets. Therefore, the rate at which depreciation of streets or roads takes place has an important effect on the total funds required annually for the operation of a street or road system.

The author refers to the highway pavement service lives which have been studied at one time or another by three out of four State highway departments. He also refers to the multi-State analyses which have been made on several occasions. These studies show substantial variations in service life among the several pavement types.

Pavement lives vary from State to State and, further, lives vary depending on structural design features, traffic volume and composition, quality of construction materials, climate, and other factors. Nonetheless, the weighted average data produced in multi-State studies do indicate the prevailing pavement life values which will be encountered throughout most of the United States. These studies indicate that rural State primary highways paved with the highest type bituminious pavement are consistently providing about two-thirds as many years of service as are provided by rural State primary highways paved with portland cement concrete.

All this the author rejects as having no bearing in an economic analysis. He also fails to mention that in addition to pavement life studies one State highway department in four has at one time or another undertaken service life studies of the capital invested in its highways. An underlying difference between "pavement life" and "investment life" studies is that investment studies follow the original construction investment through successive construction operations until zero salvage is reached. This feature causes investment lives for a given highway system to be materially longer than corresponding pavement lives.

TABLE 7

AMORTIZATION TABLE[1]; UNIFORM ANNUAL PAYMENT REQUIRED TO DISCHARGE A DEBT OF $60,000 IN 25 YEARS AT 7 PERCENT IMPUTED INTEREST

Year	Unpaid Balance From Previous Year ($)	Uniform Payment January 1 Each Year ($)	Imputed Interest[2] Assumed Due December 31 Each Year ($)	Amount Available As Principal[3] Payment Each Year ($)	Unpaid Balance December 31 Each Year ($)
1	60,000.00	5,148.63	4,200.00	948.63	59,051.37
2	59,051.37	5,148.63	4,133.59	1,015.04	58,036.33
3	58,036.33	5,148.63	4,062.54	1,086.09	56,950.24
4	56,950.24	5,148.63	3,986.51	1,162.12	55,788.12
5	55,788.12	5,148.63	3,905.17	1,243.46	54,544.66
6	54,544.66	5,148.63	3,818.12	1,330.51	53,214.15
7	53,214.15	5,148.63	3,724.99	1,423.64	51,790.51
8	51,790.51	5,148.63	3,625.33	1,523.30	50,267.21
9	50,267.21	5,148.63	3,518.70	1,629.93	48,637.28
10	48,637.28	5,148.63	3,404.61	1,744.02	46,893.26
11	46,893.26	5,148.63	3,282.53	1,866.10	45,027.16
12	45,027.16	5,148.63	3,151.90	1,996.73	43,030.43
13	43,030.43	5,148.63	3,012.13	2,136.50	40,893.93
14	40,893.93	5,148.63	2,862.58	2,286.05	38,607.88
15	38,607.88	5,148.63	2,702.55	2,446.08	36,161.80
16	36,161.80	5,148.63	2,531.33	2,617.30	33,544.50
17	33,544.50	5,148.63	2,348.12	2,800.51	30,743.99
18	30,743.99	5,148.63	2,152.08	2,996.55	27,747.44
19	27,747.44	5,148.63	1,942.32	3,206.31	24,541.13
20	24,541.13	5,148.63	1,717.88	3,430.75	21,110.38
21	21,110.38	5,148.63	1,477.73	3,670.90	17,439.48
22	17,439.48	5,148.63	1,220.77	3,927.86	13,511.62
23	13,511.62	5,148.63	945.82	4,202.81	9,308.81
24	9,308.81	5,148.63	651.62	4,497.01	4,811.80
25	4,811.80	5,148.63	336.83	4,811.80	0.00
Total	---	128,715.75	68,715.75	60,000.00	---

[1] Refer to Table 5, which shows that revenue demand does not vary with changes in imputed interest.
[2] A hypothetical economic cost to the public; the amounts shown are not actually paid to or received by anyone.
[3] One way of computing an annual depreciation charge. The average annual depreciation charge is the amount of the original debt divided by the life in years.

Unfortunately, there are but few published reports on weighted average investment service lives. Data which have been published consolidate investment lives into somewhat general groupings. However, unpublished data show that the capital invested in the highest type bituminous pavements built on rural State primary highways provide about two-thirds as many years of service as are provided by the capital invested in portland cement concrete on rural State primary highways.

The point of the foregoing is that unless economic analyses procedures take into account differences in investment service lives between alternatives being compared, the procedure is worthless as a definitive tool in judging the relative economic merits of one alternative over any other.

The rate at which pavements deteriorate or become obsolete varies from one type of pavement to another. Pavement life directly influences the level of revenue required to build the renewals needed so the system can render the standard of service required by traffic. Even in those instances where initial cost is higher, longer-lived pavements make less of a demand on highway revenues and provide equal or superior service at lower annual cost.

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R.H. BALDOCK, Closure—Mr. Hansen's interesting discussion in no manner refutes the truth of the statements made in the basic paper for those seeking the economic facts relating to a solution of the problem of the annual cost of highways.